P

Pan American Institute of Geography and History.
See Societies, Cartographic: Latin America

Paper. Paper's importance throughout the twentieth century as a medium for reproducing, disseminating, and storing cartographic information is matched only by its neglect in the literatures of practical cartography and post-Enlightenment map history. Hundreds of articles have addressed the future of the paper map, but its transport medium seems to have eluded scholarly scrutiny, except among archivists and librarians concerned with preservation (McIlwaine 1990). This short entry offers a few general insights about the kinds of paper used in map printing as well as structural changes in the paper industry between 1900 and 2000 that would have affected the papers used to print maps.

By 1900, the paper used for printing maps as well as for map drawing was entirely machine made. The most significant breakthrough occurred around the beginning of the nineteenth century when papermakers in England and France learned to make paper in continuous rolls rather than in individual sheets. The brothers Sealy and Henry Fourdrinier, who ran a stationery business in London, cut the manufacturing time from three months to one day with a multistage machine that converted a slurry of rag or wood fibers into a dry roll of uniformly thick paper, which was then cut into individual sheets (Munsell 1876, 60–61). Machine speed increased progressively throughout the nineteenth and twentieth centuries, and paper manufacturers experimented with numerous improvements to the technical processes for preparing, pressing, chemically modifying, and drying the pulp and for bleaching and coating the paper to meet buyers' requirements for whiteness, opacity, thickness, smoothness, weight, tolerance for folding, and resistance to heat, sunlight, and humidity (Libby 1962).

Although commercial and government mapmakers benefited from ever wider paper-making machines, the market for large sheets of high-grade paper was dominated by book manufacturers, who typically printed signatures of sixteen, thirty-two, or sixty-four pages on the same sheet. The substantial growth in newspaper circulation in the late nineteenth century followed the development of steam-powered rotary web presses that printed directly onto a continuous roll (web) of newsprint, manufactured inexpensively from wood pulp. Until the rise of online cartography in the 1990s, news and weather maps distributed on cheap, acidic newsprint, which readily yellowed, outnumbered all other cartographic images.

Paper for printing maps was typically ordered in comparatively small lots according to specifications that reflected the intended use. Aeronautical and nautical charts, for instance, had to accommodate frequent annotation, and paper for the latter had to resist humidity. Military maps intended for field use were printed on waterproof paper, whereas paper for atlases and double-sided map sheets had to be relatively opaque. Because most sheet maps were printed on only one side of the paper, mapmaking agencies could cope with wartime shortages by printing new maps on the back of obsolete stock.

Salient trends in the pulp and paper industry have affected the quality and durability of the high-grade paper used for map printing. For example, the need for a sizing agent to resist water penetration was a key concern. Maps intended for outdoor use require a highly permanent size, such as melamine formaldehyde, which was common in both 1900 and 2000, but a wider variety of materials was in use at century's end. In 1900 the paper might also have been coated with animal glue, a very robust coating.

Throughout the century, paper for indoor maps was produced using a mixture of hardwoods and softwoods in roughly a 40:60 ratio. Hardwoods provide opacity, smoothness, and resiliency, whereas softwoods provide tensile strength and resistance to tearing along folds. If a folded map were to be opened and closed repeatedly, the paper would typically contain even more softwood and perhaps some long plant fibers. In 1900 most paper manufactured in the United States was made in the

Northeast from species such as black spruce and maple using the sulfite process, which produces bright, hard, and somewhat weaker paper. In 2000 virgin (nonrecycled) paper was made using the kraft process, in which the pulp needs more bleaching but is stronger and less troublesome for the machinery. The major reason for the demise of the sulfite process was the cost and pollution associated with the recovery of the pulping chemicals—problems solved with the modern kraft mill, which is a closed system that can be run with little air or water emissions. With the kraft process, the industry was able to pulp southern pines, but these species were not used in printing grades and found their forte in packaging grades.

Perhaps the most significant difference between 1900 and 2000 is the amount of recycled fiber used in printing. In 1900 little fiber was recycled, but by century's end about 50 percent of the fiber was recycled. Even so, because recycled fiber is weaker than virgin material, higher-quality map papers often contained no recycled fiber.

A second major change concerns the internal sizing and fillers used in the paper. In 1900 the internal size was an alum/rosin system, which required a pH of 4.5 to 5.0 to function properly. Achieving this pH required treating the stock with sulfuric acid, which attacks the glycosidic bond in the cellulose molecule so that these papers eventually become very brittle. In 1900 clay was the principal filler added to the pulp. In the 1970s synthetic sizing agents allowed the use of calcium carbonate as the filler, which produced a stronger paper at a lower cost. In addition, the paper was now buffered at a moderately alkaline pH. Even though the air contains sulfur dioxide, which is detrimental to paper, it is neutralized by the calcium carbonate so that the paper is now permanent.

Although a clay coating could be used together with calcium carbonate to provide a smooth finish, the exact ingredients were usually a trade secret. All maps are not the same, and the papermaker can design a special grade of paper containing a mixture of specific species and additives to meet the product's needs. As with most products, there is always a trade-off between cost and quality.

MARK MONMONIER AND JOHN H. CAMERON

SEE ALSO: Drafting of Maps: Drawing Media; Map: Printed Map; Reproduction of Maps: Reproduction of Maps by Printing

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Paradigms. See Academic Paradigms in Cartography

Paris Peace Conference (1919). The United States entered World War I by declaring war on Germany on 6 April 1917. That month a committee composed of Colonel Edward Mandell House, Sidney Edward Mezes (House's brother-in-law), Walter Lippmann, and David Hunter Miller began peace preparations. Lippmann, as secretary, directed the project, known as the Inquiry, which began at the New York City Public Library. On 10 November 1917, the work was transferred to the third floor of the American Geographical Society, which held a very fine collection of books and maps. The work began to founder, and Lippmann was replaced by Mezes, president of the City College of New York, who also had trouble structuring this newly created intellectual apparatus. Meanwhile, Cyrus C. Adams and John Storck gave time to the acquisition and drafting of maps thought to be needed. Early in June 1918 Storck wrote and released "Guide of the Map Program," indicating that the Inquiry had advanced its mapping program very little.

In August, Isaiah Bowman, who was put in charge of "the running of men, money, and plans," promptly established a Research Committee comprising Charles Homer Haskins, James Thomson Shotwell, Allyn Abbott Young, and himself (Martin 1980, 82). Shortly thereafter, Mark Sylvester William Jefferson returned from his Inquiry investigation of the German populations in Argentina, Brazil, and Chile. Bowman, who had once been an undergraduate at Michigan State Normal School, Ypsilanti, where Jefferson taught, placed his former teacher in charge of the cartographic program. Jefferson had the remarkable ability to simplify complexity, to inspire ingenuity of cartographic expression, and to display such manual dexterity with economy of line that his leadership, long hours, and indefatigable fascination with the enterprise insured success for the mapping effort. Furthermore, Jefferson had both a marked linguistic capacity and an advanced knowledge of the geography of Europe gained through fieldwork, publication of a number of articles, and *Notes on the Geography of Europe* (1917). Historian Charles Seymour described the Bowman-Jefferson relationship as follows: "In the earlier stages of the Inquiry, Bowman turned constantly to Jefferson [whose] influence with Bowman certainly continued at Paris" (letter, Seymour to Geoffrey J. Martin, 14 November 1961). To help with the cartographic undertaking, Jefferson hired one of his former students, Charles G. Stratton, and in November 1918, the still little-known Armin K. Lobeck. Other members to join in this enterprise included Charles Besswerger, William J. Blank, John W. Braback, William A. Briesemeister, Mary Carwood, Stuart Davis, Douglas Wilson Johnson, Charles B. Krisch, W. F. Mathews, Herman Nagel, Howland D. Ralphs, Ellen Churchill Semple, Everett K. Taidor, Russell L. Wiget, and C. Wittenberg. By late November, the cartographic division was the largest sector of the Inquiry. Considerable emphasis was placed on the production of base maps, especially the 1:1,000,000 and 1:3,000,000 base maps of Europe. Block diagrams were prepared in cases where physiography suggested difficulty in delineating a well-defined boundary. Over sixty base maps were constructed, as were more than seventy maps centered on major towns.

In addition to the maps, reports were prepared on most parts of the world—nearly 2000 reports (Rangel 1974). While most of these ranged in length from one to twenty-five pages, the prolific Henryk Arctowski wrote reports on his native Poland of 200, 300, and 500 pages each. Such length was not necessarily helpful. The purpose of the reports was to simplify complex situations and lessen the strain on decision makers. Most of the contributors came from universities. Some were university presidents—Harvard's A. Lawrence Lowell wrote a draft concerning a League of Nations—but others were geographers, historians, political scientists, and legal scholars. Among the participants, Semple wrote largely on Turkey, while Gladys M. Wrigley, Aida A. Heine, and Mrs. Robert W. Jones reported on Africa. The team included consulate officials and such notables as Lord James Bryce and H. G. Wells. Additional briefs requested by Bowman and published in the *Geographical Review* included essays by Eugeniusz Romer (Poland), Jovan Cvijić (Balkans), B. C. Wallis and Alan G. Ogilvie (United Kingdom), Jean Brunhes, Camille Vallaux, Lucien Gallois, Emmanuel de Martonne (France), and Olinto Marinelli (Italy). Government departments and private research agencies contributed other parts of the Inquiry report. Although Bowman paid many geographic experts to prepare reports and maps to his specifications, it is probable that nearly 50 percent of all reports were secured at no cost. Matters perceived as most critical included Alsace-Lorraine, the Balkans, Poland and the Polish Corridor, and the extent to which Germany should be reduced. The cartographic unit in New York played a vital role. As a lasting memento to the Inquiry, Bowman had the commissioners plenipotentiary autograph the wall behind his desk. The last person to do so was Woodrow Wilson, who climbed onto a filing cabinet to append his signature.

On 4 December 1918, the troop transport USS *George Washington* left New York for Brest, France. At this time, the Inquiry ceased existence and was amalgamated with the Division of Territorial, Economic, and Political Intelligence of the American Commission to Negotiate Peace. Of the approximately 150 Inquiry workers in New York, 23 traveled to France on the *George Washington* with President Wilson, who met with 10 of them on 10 December. Of those present, only Bowman took notes (1,200 words), which provided the Wilsonian phrase, "Tell me what's right and I'll fight for it; give me a guaranteed position." These words were later quoted from Bowman's notes by Seymour, Miller, Shotwell, and others (Martin 1980, 87–88).

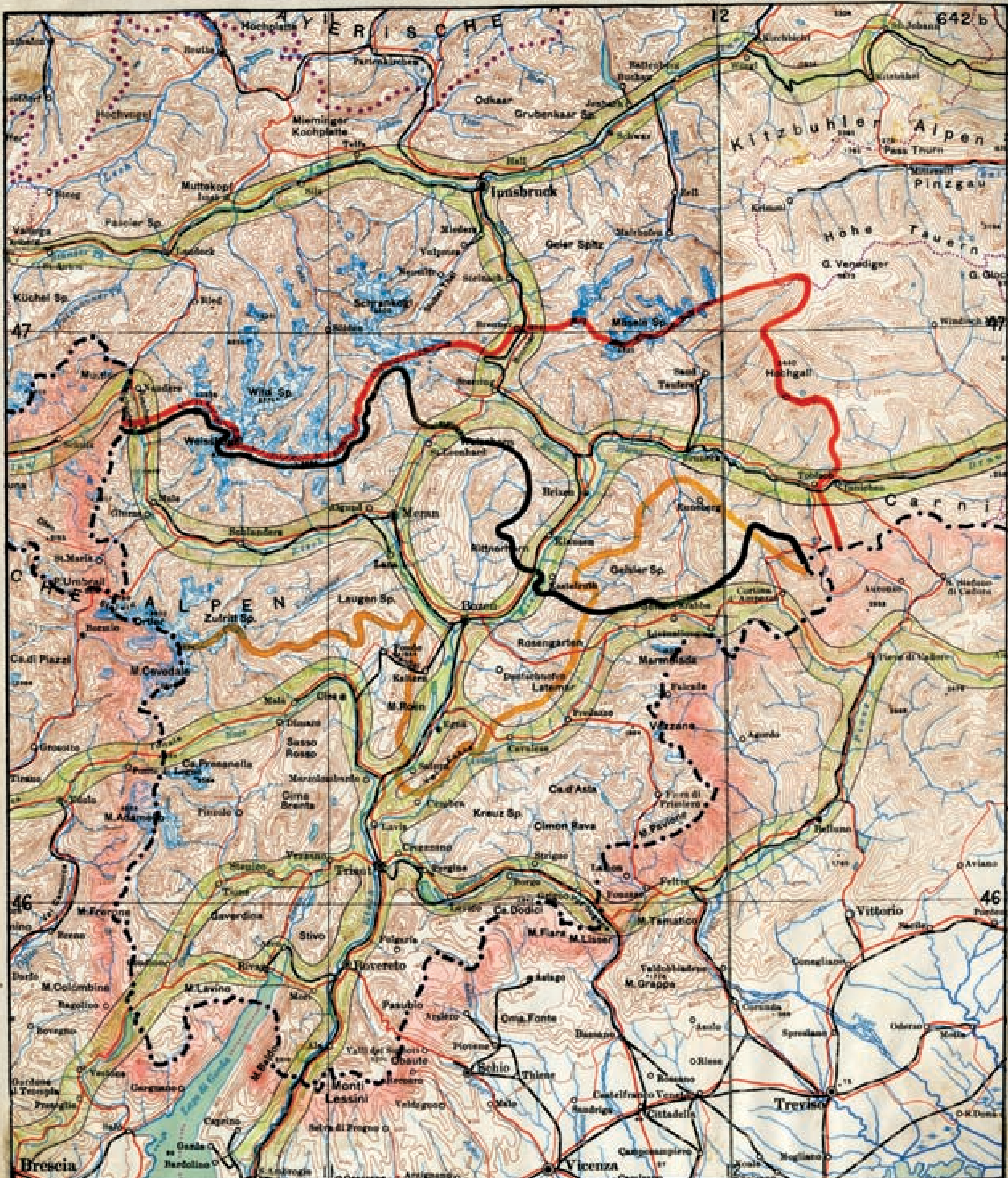
Of the twenty-seven delegations meeting in Paris, France, Italy, and the United States had the largest, while Honduras, Bolivia, Ecuador, and Haiti had the smallest. All came to resolve problems created by the war, and some came with additional agendas. The United States arrived with arguably the best equipped delegation, committed to concluding a just peace. The quest for justice was sought in maps of different size, color, and design—a failure to mete out justice would not reflect a lack of cartographic data.

Work began for Bowman and the American delegation on 15 December 1918, when he appointed eighteen division chiefs, most of them former Inquiry members. He then established the cartographic section, vital to the undertaking, though this meant knocking down bedroom walls in the elegant Hotel Crillon, located close to the Seine in the center of Paris. Personnel had changed from Inquiry days: Jefferson's draftsmen numbered from five to twenty-five, depending on the needs of the delegation. In February 1919, the cartographic unit was expanded to five rooms, an engraving apparatus was provided, and armed guards were posted at the door. Visits from members of the American delegation were commonplace. Bowman would decide on priorities and which foreign delegations to support. Jefferson wrote in his diary for 31 January 1919, "Bowman told me China needed maps—30 copies to defend herself against Japan which

(*Facing page*)

FIG. 646. "IMPORTANT CORRIDORS OF CENTRAL ALPS," FROM THE BLACK BOOK. Plate III, Inquiry 642b, 14a, legend at bottom. Size of the original: ca. 26.6 × 20.1 cm. MS 58, Special Collections, Sheridan Libraries, Johns Hopkins University, Baltimore.

Plate III Important Corridors of Central Alps Inquiry 642b 14a



Note how present Austro-Italian frontier breaches entire system of parallel east-west valley trenches (shaded green) and intervening mountain barriers (unshaded), and controls the north-south connecting trench.

Recommended new frontier. —·—·— Present Austro-Italian frontier.

1915 Treaty of London line (the best strategic frontier).

Linguistic line, separating areas of Latin and Teutonic speech.

PROPOSED BOUNDARIES IN RUSSIA

Inquiry 662

4

——— Linguistic Boundary

was well prepared." And on 11 February 1919, "Seymour asked me to mount 4 Rumanian sheets 1 millionth map for an *English* specialist!" (Jefferson 1966, XIV, XXV). There were many other examples of this help to other delegations provided by the American cartographers. The Americans collected copies of the original maps into the Black Book (European matters) (figs. 646 and 647) and the Red Book (colonial matters), which were made available to selected delegations. These books had their origins in the desire to reduce large maps to smaller versions that were more manageable. At the same time these books "were assemblies of proposed solutions of conference problems" (Bowman quoted in Martin 1968, 187). Jefferson later wrote, "Picture the Big 4 at Paris lying prone in Mr. Wilson's parlor on a 2 millionth of Europe till Mr. Lloyd George jumped up and asked for the little black bible of the Americans containing the same things on the scale allowing each map to be reproduced as a 7″ × 11″ sheet. The large map is too unmanageable" (Jefferson to Alfred H. Meyer, 26 November 1948; Martin 1968, 184). Jefferson sat on the geographers' commission, while Douglas Wilson Johnson, a major in military intelligence, sat on the International Boundary Commission to ensure the legitimacy of topographic line. Johnson also sat on territorial commissions.

The value of maps had been recognized prior to the Paris Peace Conference of 1919, yet at Paris the map suddenly became everything. The American scholars at the conference recognized the map as the common denominator that welded their specialized understanding into an intellectual matrix essential for this undertaking. The map had the capacity to render seamless the variety of contending knowledges. Importantly, all present comprehended this circumstance. The cartographic success was discussed over meals in the Crillon, on walks through local parks and along the Seine, with the French geographers, and in hotel rooms during the evenings, when viewpoints were exchanged. (Later, in 1921, Woodrow Wilson took membership in the American Geographical Society, where he joined with Franklin D. Roosevelt and Frank L. Polk, both members of the American delegation at Paris.)

Diaries maintained at Paris provide fascinating insight. Clearly, some were kept for the historic record, while others were written hurriedly and were incomplete; examples of the former are typified by Miller and of the latter by Bowman. Jefferson maintained a diary brusque and blunt and meant for no one other than himself. Even so, it is probably the most valuable of the diary sources from the geographic and cartographic viewpoints.

And what was to result from this Peace Conference? Three empires were truncated. Germany was reduced by approximately 25,900 square miles (13 percent), decreasing its population by 13 million people. Additionally, Germany suffered losses in China and had her colonies reassigned. Prior to the Treaty of Versailles, the countries of Central Europe were contained with 8,000 miles of boundary. After Versailles, there were 10,000 miles of boundary, and of this some 3,000 miles were newly created, thus lengthening the "zones of friction." Versailles was followed by the treaties of Saint-Germaine-en-Laye (1919), Neuilly-sur-Seine (1919), and Trianon (1920). Later, Jefferson wrote, "the blood of the First World War was not well shed." He who had prepared maps detailing the accomplishment of the Brest-Litovsk Treaty and then put the treaty into some 750 words detailing national boundaries did not consider the treaty just. He did write of the infamy of the "Russian lost lands" and other decisions made at Paris (Martin 1968, 197–98), but, as Bowman noted, "There were ten million dead peering through the windows" (Bowman to his family, 21 May 1945).

GEOFFREY J. MARTIN

SEE ALSO: Boundary Disputes; Cvijić, Jovan; Ethnographic Map; Jefferson, Mark Sylvester William; Linguistic Map; Nation-State Formation and Cartography; World War I; World War II

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FIG. 647. "PROPOSED BOUNDARIES IN RUSSIA," FROM THE BLACK BOOK. Inquiry 662, 4. Size of the original: ca. 26.8 × 20.3 cm. MS 58, Special Collections, Sheridan Libraries, Johns Hopkins University, Baltimore.

Pearsall, Phyllis. Phyllis Pearsall was born Phyllis Isobella Gross in Dulwich, England, on 25 September 1906. An artist and writer, she is most noted for creating the popular London A–Z maps and founding the Geographers' A–Z Map Company.

Accounts of her life differ, and separating truth from fiction is often difficult. Pearsall's early years were chaotic and might be described as riches to rags. Her father, Alexander Gross, a Hungarian immigrant, was the founder of Geographia, a map publishing firm in London that went bankrupt in 1920. Until her father lost his fortune, she attended Rodean School, an exclusive girls school in East Sussex. At age fourteen she went to Paris, where for a time she was homeless, but eventually she found a sales job and attended the Sorbonne. In 1926 she married Richard Pearsall; the pair traveled across Europe, writing and painting, until she left him in 1935. On her return to England, she earned her living as a portrait painter and writer; painting was always her first love. Other activities, including map publishing, were primarily to support her painting.

In the 1930s her father, who had migrated to the United States and established a map publishing firm there, asked her to have one of his former draftsmen create a world map that he would sell in both countries. From this she learned much about map printing and publishing. In 1935 Pearsall got the idea for an up-to-date map of London, supposedly after getting lost on the way to a party while following a 1919 Ordnance Survey map, the most recent available. She conceived of the idea of an easy-to-carry, indexed street atlas and began the fieldwork, which entailed walking London for eighteen hours a day for a total of 3,000 miles to map every street and house number. She had her father's draftsman do the final inking, took it to a printer, and in 1936 began trying to sell the A–Z to bookstores and mapsellers. As a woman she was ignored by many of the sellers, but eventually W. H. Smith & Son agreed to take 1,250 copies, which she delivered personally in a borrowed wheelbarrow. The maps were a great success at railway stations and book stalls throughout London.

During World War II the British government forbade the sale of large-scale maps, and the A–Z maps were put on hold for the duration. The company survived by making maps of the Western Front and European countries involved in the war. Like many others, Phyllis was conscripted into wartime service. Because she spoke five languages and could draw and paint, she worked in two areas: as a censor and as an artist making illustrations for a Ministry of Labor leaflet on the conscription of women. The ministry never used her sketches, but she published them as *Women, 1939–1940* (1985) and *Women at War* (1990).

After the war Pearsall circumvented paper restrictions in England by having her maps printed in Holland, where she made frequent trips to oversee printing and arrange transport. On one of those trips, in 1946, she was badly injured when her plane crashed, and two years later she suffered a stroke. During her recovery, the company was badly mismanaged, but she was able to bring it back to solvency. In 1996, eager to avoid a takeover by outsiders, she converted the Geographers' A–Z Map Company into a trust and made her employees trustees.

Phyllis Pearsall continued to work at the company until shortly before her death, on 28 August 1996, in Shoreham-by-Sea, Sussex. Along the way she was given several honors, including Fellow of the Royal Geographical Society in 1936 and an MBE (Member of the British Empire, a knighthood) in 1989. In 2005 local officials placed a commemorative plaque on the house in Dulwich where she was born.

JUDITH A. TYNER

SEE ALSO: John Bartholomew & Son (U.K.); Labeling of Maps: Typography and Map Design; Ordnance Survey (U.K.); Road Mapping: Europe; Wayfinding and Travel Maps: Indexed Street Map; Women in Cartography

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Pearsall, Phyllis. 1990. *A–Z Maps: The Personal Story from Bedsitter to Household Name*. London: Geographers' A–Z Map Company.

Penck, Albrecht. Albrecht Penck, noted for his research on the Ice Age and its fluctuations, was one of the dominant leaders of the second generation of German geographers, along with Alfred Hettner and Otto Schlüter. Penck also conceived the International Map of the World at a scale of 1:1,000,000, one of the most important map series of the twentieth century. His research extended over a period of about sixty years, from 1877 up to about 1937.

Penck was born on 25 September 1858 in Reudnitz (near Leipzig) and started his studies of the natural sciences at the University of Leipzig in 1875. In 1880 he went to Munich to work under geologist Karl Alfred von Zittel, and in 1883, at the age of twenty-five, he became a private lecturer at the University of Munich. In 1885 he was called to the chair of physical geography at the University of Vienna, where he succeeded Friedrich Simony, the first professor of geography in Austria. There he remained more than twenty years (1885–1906) and, together with Wilhelm Tomaschek, professor of historical geography, built a well-equipped geography department, which became a model for other universities in Central Europe. During that period Penck wrote an important work on the geography of Germany (late 1880s), a classic work on the morphology of the earth's surface (1894), and together with Eduard Brückner, his successor at Vienna, the outstanding *Die Alpen im Eiszeitalter* (1901–9), based on observations of glacial deposits in Alpine valleys.

In 1906 Penck left Vienna to accept the chair of geography at the University of Berlin as the immediate successor to Ferdinand von Richthofen. In Berlin he taught at the university for twenty years (1906–26) and served as rector of the university (1917–18) as well as director of the Museum für Meereskunde. He retired in 1926 and was immediately succeeded by one of his outstanding Austrian students, Norbert Krebs. Penck continued to live and work in Berlin, but in 1943, near the climax of World War II, he was bombed out of his home and moved to Prague, where he died on 7 March 1945 at the age of 87.

Penck was one of geography's leading scholars during the late nineteenth and early twentieth centuries. In *Die Alpen im Eiszeitalter*, the culmination of his personal field research, he and Brückner divided the quaternary Ice Age in the Alps into three interglacial and four glacial periods (named after the Alpine rivers Günz, Mindel, Riss, and Würm). Acclaimed as the foundation of quaternary geology as well as a classic interpretation of human prehistory, this book was Penck's most important contribution to glaciology and quaternary geology.

During the preparation of his seminal *Morphologie der Erdoberfläche* (1894), Penck distinguished between geodesy and geophysics as fields of study and noted the lack of a standard 1:1,000,000-scale international world map series. Motivated by this unmet need, he laid out a systematic plan for this map in a momentous presentation to the Fifth International Geographical Congress in Bern, Switzerland, in 1891. His suggestion was endorsed by the delegates, but little progress occurred until November 1909, when a special conference on the International Map of the World, held in London, passed the first resolutions on the production of the new map series, including decisions on projection, prime meridian, measurement system, sheet lines, relief representation with hypsometric colors, lettering, conventional signs, and geographical names. The project moved forward after a second conference, held in Paris in 1913, passed additional resolutions, and a Central Bureau was established at the British Ordnance Survey in Southampton. As a delegate from Germany, Penck continued to work on the scientific groundwork for the map series, with a focus on its use by scholars, but he lost interest in 1914 when he realized the maps were being used for military purposes.

Penck dealt repeatedly with the topographical map series of several countries and wrote instructive studies on "Neue Alpenkarten" (1899, 1900, 1903), "Neue Karten und Reliefs der Alpen" (1904), "Aegerters Karte der Ankogel-Hochalmspitzgruppe" (1909), and "Zur Vollendung der Karte des Deutschen Reichs" (1910); he also wrote informative reviews on "Oberlerchers Glocknerrelief" (1896) and "Wolfgang Lazius' Karten von Österreich und Ungarn" (1907) (Engelmann 1960, 353, 360, 373, 376). Penck always took an active part in cartography and trained his students to use maps for the study and interpretation of landscape.

INGRID KRETSCHMER

SEE ALSO: International Map of the World; Metric System

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Perception and Cognition of Maps.

Articles in this composite move from vision and low-level tasks to explicitly cartographic studies and the examination of map symbols in psychological research.

Vision and Discrimination. Map symbols, typically graphical, provide information about the earth's surface to human map users. Before map readers can understand the meaning of a symbol, they must first detect the symbol (i.e., tell the difference between the symbol and the background) and discriminate between a particular symbol and others that appear in the map. Only then is it possible for the reader to recognize what the symbol refers to. For this reason, map reading, as an activity that relies on vision, requires cartographers to work within the constraints of the human visual system in order to produce effective maps. Consequently, the study of visual perception, particularly the visual discrimination of symbols, has been an important part of perceptual and cognitive cartography since its initial emergence in the early twentieth century.

Arthur H. Robinson, in his doctoral dissertation at Ohio State University, published as *The Look of Maps* (1952), followed the suggestion by the German cartographer Max Eckert in the early 1920s by calling for the application of psychophysical research to the study of cartographic symbolization, along with more specific experimental and marketing psychology from the early twentieth century on the perception of lettering, color, and graphical structure. Psychophysics, an early branch of experimental psychology that originated in Germany during the nineteenth century, attempted to match the psychological response of human research subjects to the physical magnitude of stimuli, including visual stimuli. The interest was in a person's ability to discriminate both absolute thresholds, such as seeing a dim light or not, and difference thresholds, such as seeing one shade of blue as different from another. Psychophysics provided a highly productive set of methods for scientifically understanding the human discrimination of visual symbols on maps, including color (hue, lightness, saturation), symbol size differences (line widths, circle areas), and textural elements in patterns.

Cartographers acted on Robinson's call by devoting substantial attention to identifying and describing the just noticeable difference (JND) that would ensure that a map reader could discriminate between two symbols. This psychophysical concept refers to the smallest change in stimulus intensity that can be noticed by a human, which may well be smaller than the smallest difference that can be produced and reproduced reliably by the map production process. This research partially echoed the cartographic communication model, prominent from the late 1960s to the early 1990s, in which the function of maps was seen to be the communication to the map reader of a specific message encoded in the map by the cartographer. It would also represent some of the most important map design research carried out in the domain known variously as the human factors of maps or usability research (e.g., Board and Taylor 1977).

This body of research was wide ranging but focused on three types of symbols: grayscale, color hues, and typeface legibility. The goal of early empirical work on grayscale perception was designing symbol schemes that gave a visual impression equivalent to the values they represented (Williams 1958). For example, JNDs for discriminating gray tones are considerably smaller with light tones than dark tones. These studies drew upon earlier research by psychologists investigating the psychophysical properties of graphical stimuli, notably the studies of color hue and value by A. E. O. Munsell and his colleagues (Munsell, Sloan, and Godlove 1933). Several studies undertaken by cartographers had the aim of identifying cartographically appropriate equal-value gray tones (e.g., Williams 1958). However, the recommended scales arising from these studies often differed from one another, and it was typically unclear which scale was best suited for a particular cartographic context.

As map production technologies changed throughout the twentieth century, map perception studies focused on different characteristics of grayscales (fig. 648) (e.g., Jenks and Knos 1961; Kimerling 1975). For example, early studies, conducted when many cartographers made maps using commercially available stick-up patterns, investigated whether texture differences would change map readers' perceptions of symbol lightness. As tint screening became more widely used and cartographers gained greater control over the visual characteristics of their symbols through the use of coarser and finer screens and cross-screening (allowing the production of even-toned symbols), the focus of research shifted to quantifying the effects of perceptual shifts induced by different backgrounds and the relative contributions of symbol design and print production on lightness perception. The more widespread adoption of digital production techniques led to studies investigating laser printing and gray tones for use in classed and unclassed choropleth maps. The conclusion of some of these studies was that particular cartographic contexts demanded the use of different scales.

Changing production technologies over the course of the twentieth century also affected cartographers' use of color hues. Robinson (1952, 77–78) noted that as production technologies multiplied, cartographers became less familiar with how to specify hue most effectively in their maps. This problem was compounded by the variety of conceptual and practical systems available for measuring as well as specifying different aspects of color (e.g., Munsell, Ostwald, CIE, Birren, RGB, and CYMK), which contributed to difficulties in synthesizing the results of different research results into practical guidelines.

One of the greatest difficulties in applying perceptual studies to map design is the problem of graphical context—a single symbol often appears different to map readers when it is surrounded by different tones, hues, and patterns. Visual discrimination researchers often ignored this substantial effect, but when they did incorporate it into their research, they found it very difficult to make widely applicable general statements about symbol design and perception. As a case in point, simultaneous contrast is the perceptual phenomenon in which what

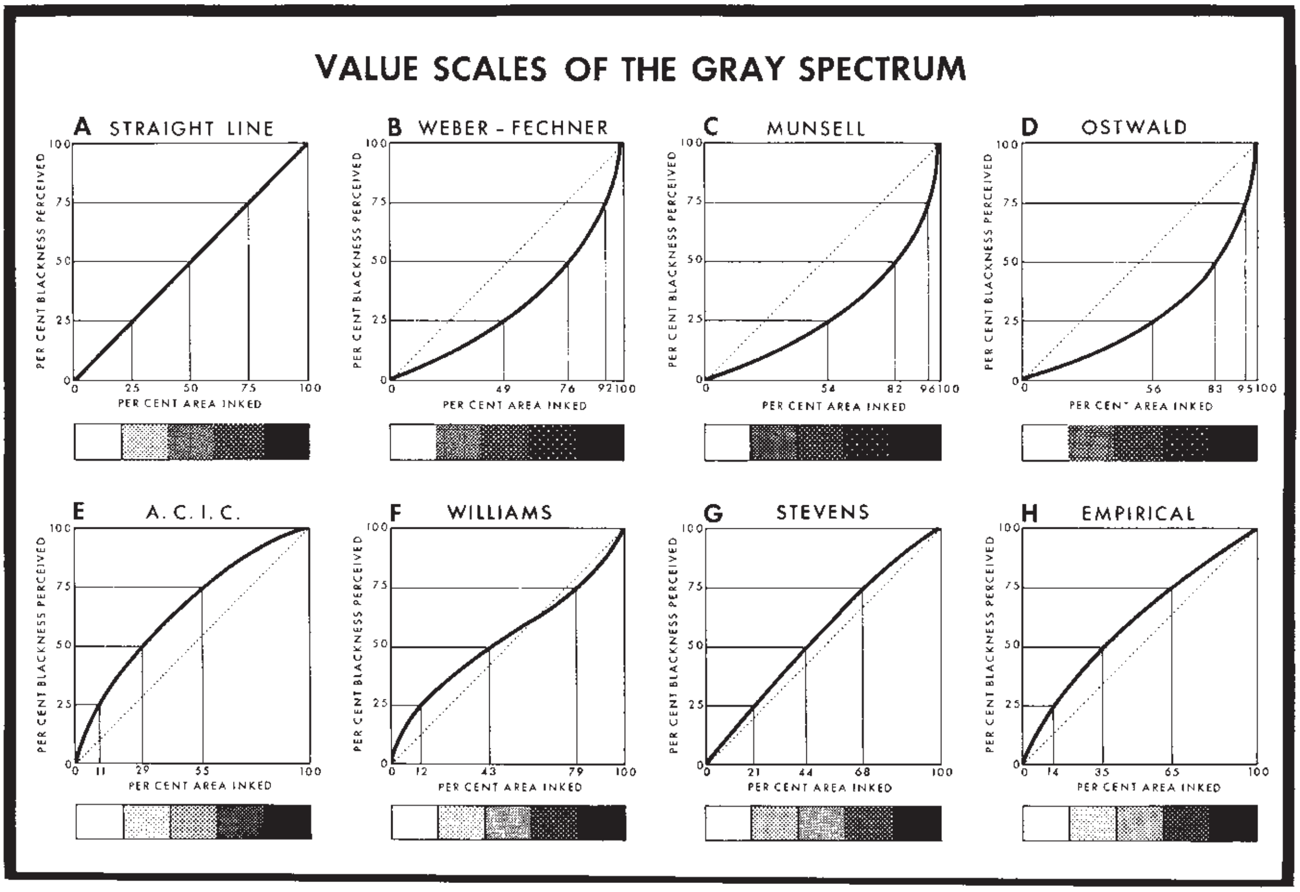

FIG. 648. VALUE SCALES OF THE GRAY SPECTRUM. The scales are from various published theories and are transferred to a common terminological and graphic base, allowing comparison of different theories when applied to self-adhesive shadings. Size of the original: 16.3 × 23.8 cm. From Jenks and Knos 1961, 322 (fig. 2). Reproduced by permission of Taylor & Francis.

surrounds a color can cause a shift in how it appears, thereby increasing the difficulty of reliably discriminating between colors on a map. Toward the end of the twentieth century, cartographic researchers addressed the problem of designing for simultaneous contrast on maps. For example, Cynthia A. Brewer (1997) developed a model that could predict a map reader's inability to discriminate between colors because of simultaneous contrast, thereby allowing the cartographer to create discernible colors by adjusting the color scheme.

Later in the century, cartographers became increasingly sensitive to individual differences among map readers and the need to accommodate these differences when designing maps. In particular, they directed substantial attention to meeting the needs of map readers with visual impairments. Computers made it much more feasible to design multiple versions of a single map. This led Brewer and Judy M. Olson to develop several different color schemes they believed would help readers with impaired color vision to read thematic maps more accurately and efficiently (fig. 649). In testing these schemes with map readers, some with normal vision and some with color-impaired vision, they found the schemes helped map readers with color vision impairment without substantially hindering those with normal color vision.

During the twentieth century, cartographic designers and researchers also focused on the discriminability of typefaces, including the ease of reading different typefaces at different sizes under various illumination conditions. J. G. Withycombe, from the U.K.'s Ordnance Survey, identified several essential requirements for type within maps including "legibility" and "distinction and contrast" (1929, 432). He also urged cartographers to free themselves from the limitations of earlier reproduction technologies, such as copperplate engraving, and embrace the wider possibilities that the new technology of lithography afforded for designing type on maps. Yet

Change in the Number of Jobs by County	Confusing Rendition: Color name	x	y	Y	R	G	B	Accommodating Rendition: Color name	x	y	Y	R	G	B
Gain > 1000	dark green	.175	.756	13	0	145	0	dark blue	.153	.064	9	50	50	250
Gain 500-999	green	.268	.658	30	115	185	0	blue	.205	.164	29	150	150	250
Gain 1-499	yellow-green	.390	.554	61	210	215	0	light blue	.255	.261	65	210	210	250
Loss 1-499	yellow-orange	.480	.484	59	255	190	0	light orange-red	.413	.360	47	255	180	180
Loss 500-999	orange	.603	.385	31	255	110	0	orange-red	.519	.380	28	230	130	130
Loss > 1000	red	.646	.353	13	190	60	0	red	.658	.342	13	200	0	0
No Data	gray	.328	.411	19	150	150	150	dark gray	(not measurable)			90	90	90

D

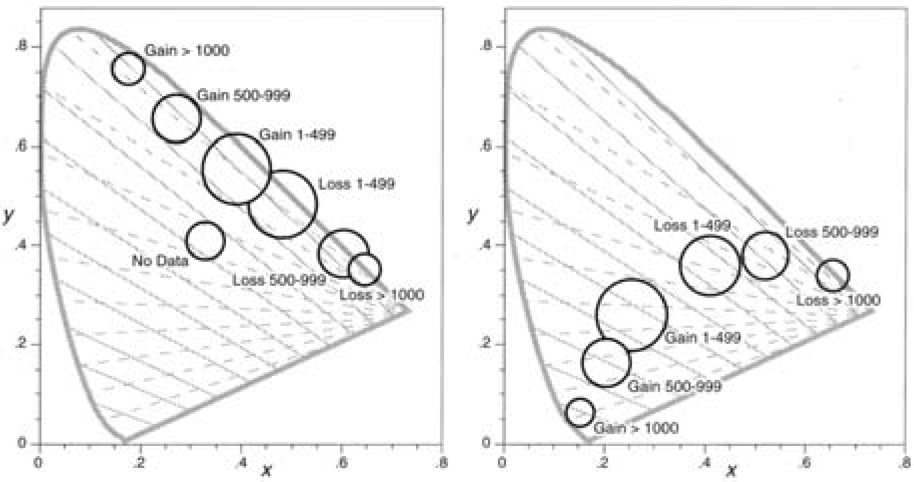

FIG. 649. COLOR HUE CONFUSIONS FOR RESEARCH SUBJECTS WITH COLOR VISION IMPAIRMENT. Map readers with color vision impairments will find it difficult to accurately and efficiently identify colors in schemes whose symbols parallel a color-confusion line (left). Color schemes that are comprised of symbols that cross color-confusion lines will be more easily differentiable for color vision impaired readers (right).
Size of the original: 9.6 × 14.5 cm. From Olson and Brewer 1997, 131 (fig. A6). Reproduced by permission of Taylor & Francis.

for several decades thereafter cartographers relied primarily on guidelines developed by typographers working with other forms of print, such as those found in books, advertisements, and other graphic posters. While Robinson's *The Look of Maps* (1952) devoted several chapters to the problem of type on maps, few of his guidelines were based on research that studied type in a cartographic context.

It was not until cartographer Barbara Bartz Petchenik carried out a series of studies of type on maps as a part of her doctoral dissertation at the University of Wisconsin under Robinson that there was a clear acknowledgment that the function of type is fundamentally different in maps than in other forms of text, such as books. She criticized the lack of an empirical basis for recommending how to design cartographic type, highlighted the importance of searching for particular labels in map reading, and conducted a series of experiments aimed at understanding the extent to which the visual characteristics of type affected this search process (fig. 650). Although her experiments were undermined by a failure to account for interaction among variables, they highlighted the role of type characteristics and map readers' expectations in searching for labels on maps. Petchenik showed that reliable expectations about the labels and certain type characteristics (e.g., size) allowed map readers to filter out irrelevant search targets and find target labels more quickly. A series of experiments by Richard J. Phillips and his colleagues in the United Kingdom, who tracked eye movements to examine where map readers actually looked while searching maps, later reaffirmed more conclusively what Petchenik had found (Phillips, Noyes, and Audley 1978). They also demonstrated that type weight and typeface made little difference to search speed, but that the broader map context in which a label was found could have substantial effects on search efficiency if the target label was positioned close to map symbols that looked like type (e.g., other map labels or unfilled point symbols).

While the search task was useful for developing an understanding of how particular labels could be detected in and among the variety of symbols found on a map, it did not shed light on the difference between any two particular labels. Barbara Gimla Shortridge and Robert B. Welch, at the University of Kansas, used a same-different task, in which map readers judged whether two labels were the same or different in size, to develop guidelines for the minimum size differences (i.e., the JNDs) between

FIG. 650. TEST MATERIAL FOR EVALUATING LEGIBILITY OF TYPEFACES IN A MAP CONTEXT. The map at the top contains labels that differ only in size. The labels in the map at the bottom differ on three dimensions: size, typeface, and type weight.
Size of the original: 11.5 × 8.7 cm. From Bartz 1970, 105 (maps 7 and 8). Copyright © British Cartographic Society. Permission courtesy of Maney Publishing, Leeds.

labels that map readers would be able to discriminate. They demonstrated that map context was critical; the visual noise created by other map symbols hampered map readers' ability to discern differences. However, the map author who used multiple type characteristics (e.g., size and weight) could improve discrimination of differences (Shortridge and Welch 1982).

Much of the research undertaken on the visual discriminability of map symbols was criticized for using testing environments or map reading tasks that were too artificial, for being too narrowly focused on optimizing symbolization for an average map reader, and for producing results that were inconsistent as a function of small changes in instructions, tasks, or test materials. Even so, this body of research did lead to the production of more widely readable maps, particularly for readers with visual impairments. And it also inspired cartographic scholars and researchers to focus more on map users and the perceptual constraints of their visual systems rather than only on the technical aspects of map reproduction, the development of new thematic map symbols, and generalization methods, all of which were major foci of cartographic research in the twentieth century.

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SEE ALSO: Color and Cartography; Perception and Cognition of Maps: Psychophysics; Petchenik, Barbara B(artz); Robinson, Arthur H(oward); Visualization and Maps

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Perceiving, Understanding, and Remembering. Spatial thinking is essential for survival. Life would be difficult if we didn't know how to get home at night or how to bring food to our mouths. Spatial thinking is multimodal, involving all the senses: blind people can be excellent wayfinders, using sound, touch, and even smell as cues instead of visual ones. Spatial knowledge and spatial reasoning are the fundamental basis for abstract thought, from daily parlance—"she's at the top of the heap"—to sophisticated models and diagrams in science. Spatial thinking can be regarded as having two parts: mental representations and mental transformations on those representations. Mental representations of space have often been referred to as mental maps, and the comparison is elucidating.

One of the remarkable achievements of spatial thinking is the making of maps. People learn the world from perceiving and navigating it from the ground: a view from inside the world, surrounded by it. Maps take a view of the world from outside, looking on it. Mapmaking entails shrinking different views and experiences and integrating them onto a small plane viewed from above. Yet maps are among the earliest relics of civilization, predating written language, produced by unschooled people who have never seen maps and by children.

Maps on paper reflect maps in the mind. That is, human perception is from an egocentric or intrinsic or route perspective, but human conception can also take an allocentric or extrinsic or survey perspective. The first conceptual breakthrough was Edward Chace Tolman's work in the 1940s showing that rats could successfully explore mazes from many starting points by forming "cognitive maps," mental representations of the layout of space independent of point of view (Tolman 1948). Tolman's work was aberrant for the times, when the field was dominated by the behaviorist dogma that all that could be known were stimuli and responses external to the mind. A key insight of the "cognitive revolution" of the 1960s (e.g., Neisser 1967) was that mental representations are constructed from experience; they are not copies of experience. The cognitive revolution encouraged researchers to open the "black box" of the mind and gave them methods for doing so. Despite Ulric Neisser's plea to explore ecological psychology, especially spatial cognition, early cognitive research focused on verbal stimuli under the widespread assumption that knowledge of any form could be reduced to propositions. Nevertheless, research progressed in related disciplines. Geographers and environmental psychologists studied wayfinding, including biases in distance and direction estimates (e.g., Downs and Stea 1973; Moore and Golledge 1976). Kevin Lynch (1960) showed that spontaneous sketch maps provided insightful data, distinguishing five graphic elements: paths, edges, districts, nodes, and landmarks. Jacques Bertin (1983) analyzed the schematization and graphical variables used for expressing meaning in maps and diagrams.

The realization that studying propositions overlooked the unique and fundamental character of visual and spatial thinking depended on a convergence of research findings. Allan Paivio (1971) and others showed that words that were easily imaged were remembered better and that instructions to image words improved memory for them; Roger N. Shepard (e.g., Shepard and Cooper 1982), Stephen Michael Kosslyn (1980), and others found a perceptual basis for imagery and mental transformations; still others demonstrated systematic errors of spatial memory (e.g., Stevens and Coupe 1978; Tversky 1981).

Despite the ubiquity, necessity, and facility of spatial knowledge, it is far from perfect, and, in fact, it is the errors of thought that reveal its nature. Spontaneous representations of environments, whether in the mind or in the world, are not mere miniatures. Just as a useful paper map contains distortions and simplifications such as cities represented as circles, roads represented larger than they are, and rugged coastlines straightened, useful mental maps need not rigorously reflect reality. The distortions and errors are not random; they are systematic, the product of the way the mind organizes space and other things as well (Tversky 2005a, 2005b).

Contrary to earlier presuppositions, spatial mental representations are not like a succession of photographs—even fading ones—of experience. Rather, they are constructions of experience. In fact, there is little need to remember exact appearances of specific maps or specific places at specific times. It is more useful to construct and remember a schematic organization of locations of things relative to each other and relative to a reference frame. The living room lies to the left of the entrance; the post office is north of City Hall. Then, if an environment is approached from another point of view, it can still be recognized and navigated. This is key: objects are located and remembered relative both to other objects and to a reference frame.

How does that mental construction happen? Research in perception of objects and scenes provides a framework for understanding the process. Distinguishing figures from backgrounds is an early step, as is assigning orientations and locations to the figures. In the case of maps, figures would typically be landmasses, landmarks, and paths. As noted, these are oriented and located relative to each other and relative to a frame of reference. Those relations are approximate, and the approximations yield systematic errors. The frame of reference error has been called *rotation*. A landmark or landmass—a "figure" according to the Gestalt principle of *figure/ground*—can induce its own frame of reference, typically an axis of elongation or relative symmetry and a second axis perpendicular to it. The mind rotates those axes closer to the axes of the reference frame, reminiscent of the Gestalt perceptual organizing principle of *common fate*. A majority of respondents, for example, upright South America when putting it in a north-south-east-west (NSEW) frame (fig. 651), just as they mistakenly believe that Berkeley is east of Stanford and Stanford east of Santa Cruz. Both South America and the Bay Area are at an angle with respect to a NSEW frame, but the mind rotates their natural axes into closer correspondence to a NSEW framework (Tversky 1981, 415–16). The other figure error has been called *alignment*. In this case, the

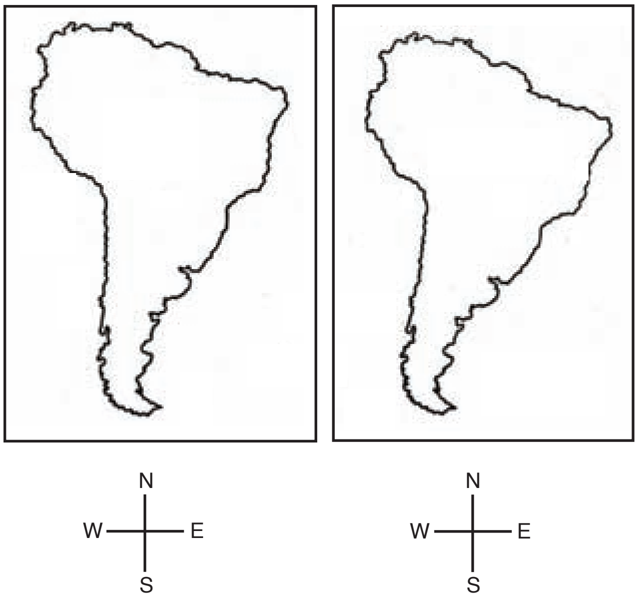

FIG. 651. VISUAL STIMULI USED IN COGNITIVE EXPERIMENT ON THE ROTATION OF MAP FEATURES. On the right is the actual orientation of South America; on the left is the uprighted orientation preferred by most respondents.

FIG. 652. VISUAL STIMULI USED IN COGNITIVE EXPERIMENT ON THE ALIGNMENT OF MAP FEATURES. At the top is an actual world map; at the bottom is the altered world map preferred by most respondents.

mind brings two nearby figures closer to each other, either north-south or east-west, reminiscent of the Gestalt principle of *grouping by proximity*. A majority of respondents mistakenly choose as correct a world map in which the United States and Europe are more aligned (fig. 652) or a Western Hemisphere map in which North and South America are more aligned (Tversky 1981, 410–14). People draw familiar roads as more parallel and perpendicular than they actually are. These errors appear in memory for invented maps and for blobs, as well as in judgments of directions between cities. For example, most people incorrectly believe that Boston is east of Rio and that Philadelphia is north of Rome.

These are not the only systematic errors in people's mental representations. Some derive from the simplification of figures. People mentally straighten borders, such as that between the United States and Canada, and rivers and paths, such as the Seine. They remember figures, such as rivers, as more symmetric than they are. Others derive from organizing principles. Landmarks organize environments, and as a consequence, people estimate the distance from an ordinary building to a landmark to be shorter than the distance from a landmark to an ordinary building, an error that violates any metric model. Distances between cities in the same state or country are judged smaller than comparable distances between cities in different states or countries. Conceptual factors cause distortions as well. People remember related landmarks as closer to each other than they are relative to unrelated landmarks, for example, estimating that certain university buildings are closer to each other than to town buildings even though the selected town buildings are closer. Putting the errors together would not yield a representation that is coherent and consistent; it is unlikely that there is a simple mental topology. Mental representations seem to be constructed on the fly, in response to particular questions or judgments. It's not as if there were ready-made mental maps on file to consult, but rather that the relevant information is collected and integrated on the spot. The relevant information may include more than memories of maps or exploration, but also verbal information, including descriptions of routes and environments. Thus, a better metaphor for people's mental representations than "cognitive map" is "cognitive collage."

If people's mental representations of space are schematic and distorted, how do they manage to get around? One reason is that the environment corrects and fills in missing information. If people believe a turn is 90 degrees, but the road goes 80 or 100 degrees, they will follow the road and not their belief. People do not need to remember exact distances if they know to turn at the landmark or street. The systematic errors are for the most part independent, so when many knowledge elements are combined, the errors may cancel or correct each other. In many situations, exact information isn't necessary; for most purposes, it won't cause trouble to think that Berkeley is northeast of Stanford even though it's northwest.

Notably, many of the errors that occur in mental representations of space also occur in mental representations of abstract concepts, concepts that are metaphorically spatial. Just as people say "we've grown far apart" or "they're in the in-group," people "align" with others regarded as similar to themselves, thinking them even more similar, and people judge sons to resemble their fathers (metaphoric landmarks) more than fathers resemble their sons. Additional evidence suggests that people use their extensive thinking about space as a foundation for thinking about more abstract concepts, applying spatial reasoning to other domains.

Mental representations are one part of spatial thinking. The other part is mental transformations of mental or physical representations. Using a map may require mental rotation to the needed orientation or mental distance and direction estimates. Giving directions without a map may require a variety of mental transformations: imaging one's self in an environment, and then imagining mentally turning at landmarks and mentally progressing on paths. Similarly, estimating directions of unseen landmarks or distances to them requires mental reorientation and mental translation respectively. These mental gymnastics can be difficult but improve with practice. Intriguingly, mental reorientation in space is more accurate when the body physically reorients, even when blindfolded. This kind of knowledge is embodied. Mental translation in space, by contrast, is not facilitated by actual movement. Not only do these mental transformations alter representations in different ways, they also appear to occur in different areas of the brain, and different people are differentially adept at them. Spatial ability is not a single skill, but rather a set of skills.

People also use language to think and communicate about space. Descriptions turn two- or three-dimensional space into narratives that are linear. Language can be a reliable means of describing space and schematizes environments in many of the ways that maps do. Whether described or depicted, environments are conveyed as arrays of landmarks and paths, nodes and edges. Describing space entails taking a perspective on it. One of the prominent perspectives that people's descriptions take reflects the typical way that people experience space, as a *route* perspective (egocentric, intrinsic, relative) embedded in the environment. In a route perspective, people describe landmarks relative to a traveler moving in the environment, using the traveler's left, right, front, and back. Naturally, route directions normally adopt a route perspective, but spatial layouts are also often described that way, for example, in response to the query "Tell me about your apartment." But environments are also described from the *survey* (allocentric, extrinsic, absolute) perspective entailed in mapmaking. A survey perspective takes a view from above and describes landmarks relative to each other in terms of an extrinsic reference frame, typically north, south, east, west. Although languages in most developed countries readily use both systems, a scattering of languages across the world does not use left or right in describing space, relying instead on extrinsic or absolute systems (Levinson 2003). Despite the elegance of the purity of the two reference systems, in actuality, when people are asked to describe learned environments, they mix the perspectives about half the time, switching back and forth, often midsentence, without even signaling. For example, "Go south on Main and turn right at the light." The mixing of perspectives in language may seem less surprising in light of research findings on the neural underpinnings of perspective: research on brain damage, brain activation, and single-cell recording shows that the nervous system encodes information in multiple reference frames, both extrinsic and egocentric. Surprisingly, mixing perspectives causes little cognitive confusion as long as the description is coherent. Early in learning an environment, mixing perspectives in language takes extra time to comprehend, but when environments are well-learned, the cognitive costs disappear. This is further evidence that people's mental representations of environments are perspective free.

Spatial thinking and communication enable exploration, mapmaking, and map use. But spatial thinking is much more. As recently as the 1960s, it was believed that language was the basis for spatial memory and thinking; now it appears that spatial knowledge forms a basis for language. We say we "look" at all sides of a problem to get the proper "perspective" to "see" a solution. From inspection to imagination to insight, thought about thought is spatial. Spatial thinking is a microcosm of how the mind works.

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SEE ALSO: Children and Cartography; Education and Cartography: Teaching with Maps; Navigation; Visualization and Maps

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Perception and Map Design. Perception, critical to communication of any kind, became an area of focus in cartography in the mid-twentieth century. Thinking shifted from what could be logically symbolized on a map to a conscious effort to better understand how the map's design would affect the people using it. Perception was only one focus, largely on the part of academic cartographers, in a much wider mapping milieu. The development, however, penetrated deeply because it shifted attention from the mapmaker and map to the person on the receiving end. Making maps was no longer a matter of following rules and traditions or even developing a clever depiction. Effects on the user became a criterion by which to judge a map.

The term "perception" has multiple definitions. Very commonly it refers to the initial sensing of something, such as a map symbol, before the more complicated brain processes construct information from what is sensed. It also commonly refers to a broader act of processing something from a map as opposed to making the map. In that sense it inherently involves mental processes that go well beyond initial sensing. Sometimes it is distinguished from cognition, the higher processes of transforming what is sensed into something meaningful that is not explicitly symbolized. For example, two series of maps in an atlas may be clearly different in scale, with different background colors, densities of symbols, and symbol sizes. We perceive the differences in these symbols, but cognition transforms what we perceive into the interpretation that one set of maps is different in scale from the other.

Even cognition, however, is not always distinguished from perception (Montello 2002). Certainly the term "perceptive," indicating that someone is especially likely to notice, refers to something beyond sensing the presence of a stimulus or seeing that one thing is different from another.

Despite the inconsistency in terminology, there was a distinctive development of interest in perception in cartography in the mid-twentieth century. The turning point is generally considered to have been Arthur H. Robinson's small 1952 book *The Look of Maps*, developed from his dissertation in cartography and affected by his work as chief of the Map Division in the Office of Strategic Services during World War II. He drew explicitly upon a wide range of literature, including the works of German cartographer Max Eckert and other cartographers and geographers. He also drew from art and graphic arts. His foray into those areas, together with his past experiences, led him to propose that analysis of presentational strength of techniques was necessary, and that methodology needed to be experimental and analytical (5). The book itself is not a report of original cartographic experiments; rather it sets the stage for such efforts. Nor does it describe just what the experimentation should be, but clearly it should be about visual characteristics, i.e., the look of maps.

Meanwhile, another thread in the evolution of perception studies in map design was developing quite separately. Aviation maps were associated with their own peculiar, and highly fateful, issues. Poor design of an aviation map could be a matter of life and death, and the circumstances under which they were used were highly specific. Whereas Robinson was working with maps used under ordinary lighting and with differing content that might be depicted in a variety of ways, aviation maps had to be readable in the red light used at night in cockpits, and standardization was highly desirable. Experiments with aviation maps began in the 1930s with the development of alternative designs, and human testing was part of aviation map evaluation by the early 1950s (Hopkin and Taylor 1979). Those tests fell under the moniker of "human factors," a genre of study that involved ideas of engineering as well as psychology. Aviation map researchers and those working with other types of maps overlapped little.

Robinson's influence on perception studies after *The Look of Maps* was largely through the work of his students. He supervised numerous theses, dissertations, and seminar studies whose authors evaluated visual characteristics of maps. Interestingly enough, those studies generally involved testing with human subjects, whereas Robinson's own contributions to perception in cartography were analytical (size of lettering at twenty feet that matches a certain size viewed at eighteen inches), synthetic (issues to consider in choosing lettering or in using color), and philosophical (the meaning of maps; Robinson and Petchenik 1976).

Just how the transition to studies with human subjects came about is a matter of speculation, but there were at least three influences that likely fed the trend. One is that young cartographers were encouraged to read in psychology, and the highly influential work of S. S. Stevens, a psychologist who preferred to be called a psychophysicist, was gaining wide attention. In particular, his work on the stimulus-response relationship, most clearly explicated in "On the Psychophysical Law" (1957), presented an elegant and simple power equation: the reaction to a stimulus is proportional to size of the stimulus taken to an exponent. It provided a ready tool for analyzing the relationship between stimulus and response, something that at the time was new and fascinating in cartography.

A second influence was the transition of geography from a largely descriptive and interpretive discipline to a quantitative and analytical one. A student of cartography had no problem fitting into that new mode when carefully measuring map stimuli, eliciting human responses to them, and applying statistical regression methods to summarize the relationship. That type of study was not only quantitative but experimental, the epitome of scientific method, in a field (geography) where experiments were largely undoable.

A third influence came from outside of academia. Consumerism was not an area from which cartographers drew references or models directly, but in society at large it became a way of thinking after World War II as producers were looking for customers rather than filling orders for war materials and later as protection of consumers took hold in everyday thinking. Perception studies focused attention on the map consumer.

The earliest cartography dissertation that was based on a test with human subjects was in 1956 by Robinson's first cartography doctoral student at the University of Wisconsin, James John Flannery (fig. 653). Although the results of this study of graduated circles were not published as an article until several years later (Flannery 1971), the scaling exponent for the radius derived from the psychophysical equation (0.57) was included in Robinson's cartography textbook (1960, 163–64). It dominated in the lore of cartographic mapmaking well after other studies derived other exponent values and even after, thanks to computers, mapmaking became versatile enough that any exponent could be used to scale circles, other criteria could be used to select the scaling, and even multiple map versions could be produced.

In the 1960s through 1980s numerous cartographic studies were conducted using human subjects, some psychophysical, others more cognitive in nature. The futility of trying to apply results in map design was a key scholarly criticism of the genre. Barbara Bartz Petchenik (1983), as a commercial map designer, was especially articulate on the issue, although her call for moving on was pointing in much the same direction as those who thought it was an important step toward that future (Olson 1983). Little noticed at the time was the potential effect on computer mapmaking. A number of programs were designed to use a geographic file (e.g., minor civil division boundaries) and an attribute file (e.g., tractors and farms) and create the user's choice of map type (often choropleth, in that case showing the ratio of tractors to farms). Much of the design would be determined by the defaults in the software. The rules by which the map would be created—symbol scaling, size of the map within the neatline, placement of title and legend, etc.—could be (and sometimes was) based at least in part on information from earlier perception studies. Still, applicability of the research results in map design was distinctly limited.

As time went on, perception studies in cartography evolved from psychophysical to cognitive to sometimes qualitative assessments that included open-ended questions asked of human subjects looking at maps. By the early 1990s the attention across many fields to what was being called visualization (McCormick, DeFanti, and Brown 1987) took a firm hold in cartography

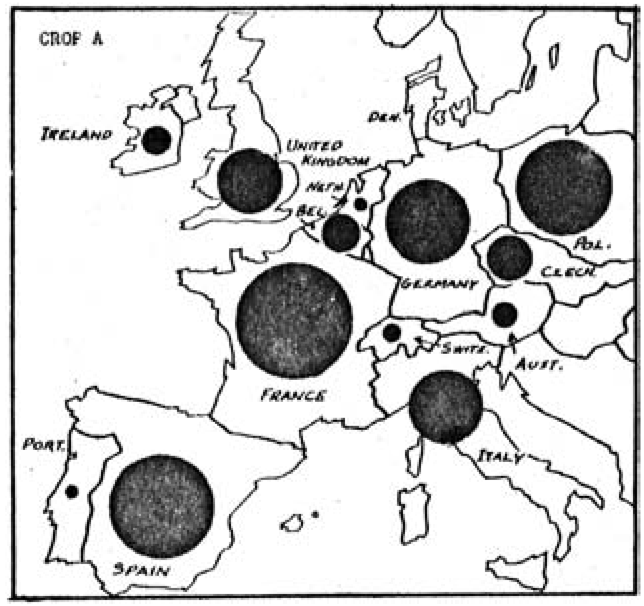

FIG. 653. GRADUATED CIRCLE TEST. Sample graphic from Flannery's test instrument on scaling graduated circles. Students were asked to compare difference in circle size between sixteen pairs of countries. For example, "How much more of Crop A is grown in Austria than Switzerland?"
Size of the original: 8.6 × 9.1 cm. From Flannery 1956, 163 (fig. 27).

(MacEachren and Taylor 1994; MacEachren 1995). The use of the term "visualization" had shifted from predominantly meaning seeing in one's mind to meaning the visual image itself, especially with the use of multimedia—images, video, text, animation, and their interactive arrangements—that was becoming popular through the use of computers. It could be argued that visualization did much to bring back the maker point of view as new media were being tried and ideas beyond those of traditional mapmaking were being put to use in producing logical representations. The new representations, however, raised new questions of perception and visual understanding as well. The experiments testing the effectiveness of those new representations gave renewed life to the study of perception and design.

The new studies that were inspired were often called usability studies, and they were applied to human-computer interfaces and software as well as to the map displays resulting from them. Studies were far more sophisticated than in decades past. Following more general trends in scientific research, they were also more interdisciplinary, with cartographers, information specialists, psychologists, and others not just reading one another's publications but working together in research teams to design and execute studies.

The rise of geographical information systems (GIS) in the 1980s and geographical information science (GISci) in the 1990s focused attention on using large data sets, integrating them, and deriving maps and other spatial information quickly and efficiently from them. The term "cartography" took a backseat until the engineering of the technology reached sufficient maturity for map design, which had now become synonymous with cartography, to have a place in the milieu. The more mature software had options for good design that made them tools of choice even for the most meticulous designers of maps. The software also provided a ready way of constructing products for use in experiments with human subjects. Electronic display made it feasible to deliver the tests. Data capturing capabilities made it possible to perform experiments that measured reaction time as well as accuracy and preferences.

By the end of the century, attention to users and perception in cartography was so integrated into the field that it had become a part of the rhetoric as well as an area of study. Cartographic models had developed as part of the focus on perception, and the main linkages were from mapmaker to map to map user. Models ranged from very simple to highly complex, but the user featured prominently in all. Students saw these models in textbooks and during lectures, and it is hard to imagine a text or class in general cartography that did not attend to the human beings who were on the receiving end of maps.

A quintessential example of applying perception research in design was Cynthia A. Brewer's development of ColorBrewer. Allowing online color selection, ColorBrewer could be employed by map designers (and other users of color in graphics) to select colors likely to fulfill the needs of users (fig. 654). Perception and map design had undergone considerable evolution in half a century.

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SEE ALSO: Art and Map Design; Bertin, Jacques; Color and Cartography; Visualization and Maps

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Cognition and Cartography. Maps and minds have been and always will be inextricably intertwined. There is reciprocity between ideas of the map and of the mind in conceptual and practical terms. Conceptually, the map serves as a metaphor or analytic model for the structure of the contents of the mind while mapping serves as a metaphor or conceptual framework for the process of relating characteristics of the world to the contents of the mind. Multiple modifiers drawn from psychology can precede the term "map": "mental," "cognitive," "perceptual," "mind," and "concept." Practically, apart from the obvious point that maps are the product of the

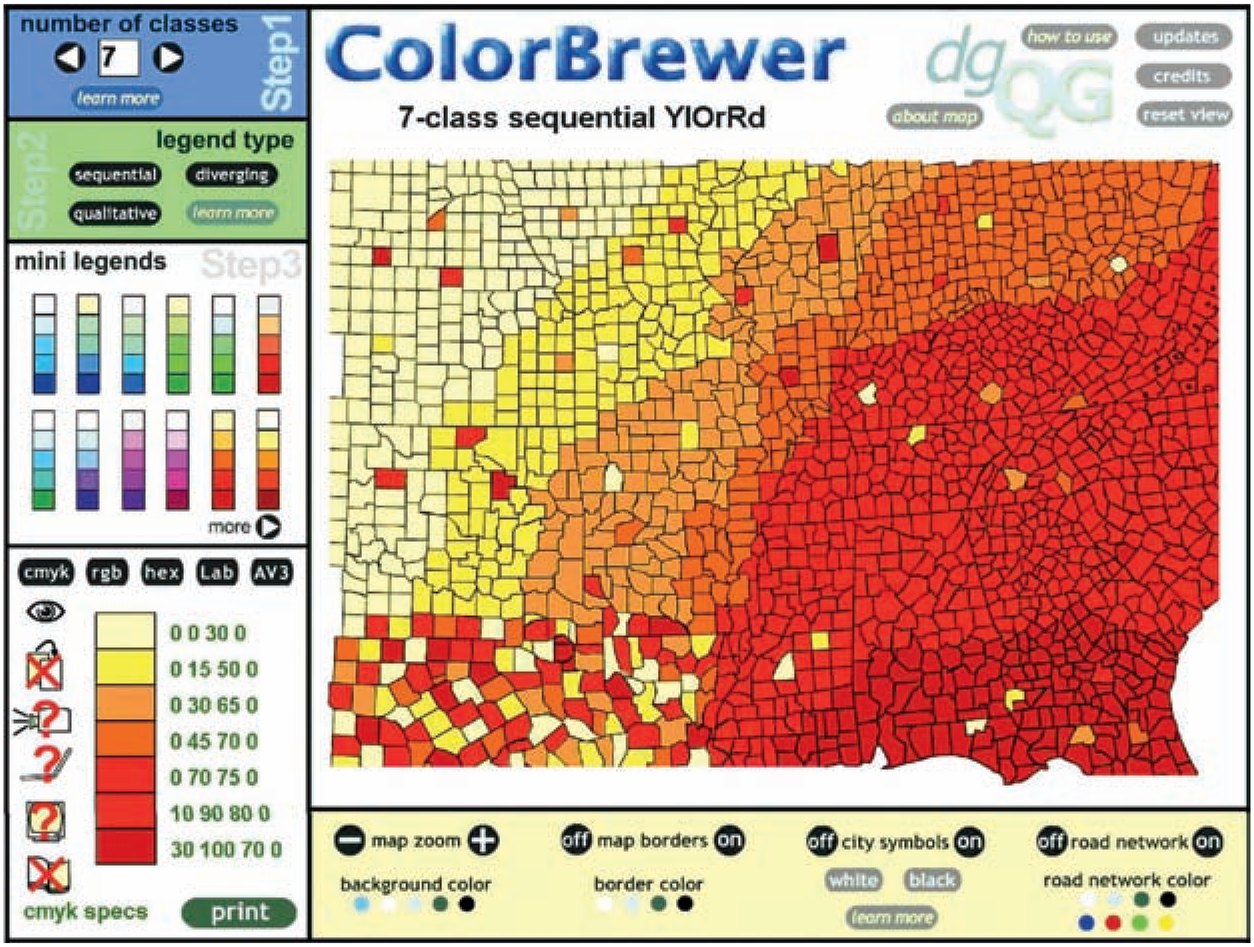

FIG. 654. "COLORBREWER 2.0: COLOR ADVICE FOR CARTOGRAPHY." This is an interactive tool for selecting from a number of color schemes and seeing them in context on a prototype map. It allows the user to restrict the choices to those that are colorblind safe, will print well, and/or will hold up in photocopying. Printed versions of the color schemes are in Cynthia A. Brewer, Geoffrey W. Hatchard, and Mark Harrower, "ColorBrewer in Print: A Catalog of Color Schemes for Maps," *Cartography and Geographic Information Science* 30 (2003): 5–32.
Size of the original: 12.6 × 16.4 cm. From Brewer, Hatchard, and Harrower 2003, 16 (fig. 7). Reproduced by permission of Taylor & Francis.

mind, maps are designed with an awareness of everything from the sensitivities and limitations of color perception (Brewer, Hatchard, and Harrower 2003) to the information needs for wayfinding in you-are-here maps of multidimensional built structures (Passini 1984).

But the pervasive linkages between maps and minds go far deeper. Cartography has been a source of inspiration for scholarship in many disciplines of human behavior. There has been intensive and persistent borrowing and use of the language, concepts, methods, and analytical techniques of cartography. Research traditions within psychology, geography, planning, architecture, landscape architecture, sociology, political science, anthropology, and even ethology have used maps and mapping as inspirations for framing research questions and interpreting results, with maps used as probes to record what people know about the world and the idea of mapping used as a way of describing, analyzing, and representing the structures of knowledge.

Processes of thinking, ranging from the classical method of loci for rhetorical memorization to the modern characterizations of spatial thinking have been built around concepts of maps and mapping. Philosophers such as Stephen Toulmin (1953) captured the structure of knowledge in terms of the structure of the map. Physiologically inclined psychologists postulated that the internal connectivity of cell structures in the hippocampus is literally a map of the world in the rat's brain (O'Keefe and Nadel 1978). Maps have been used to express knowledge of and beliefs about the world in

FIG. 655. SAUL STEINBERG'S *VIEW OF THE WORLD FROM 9TH AVENUE*. Ink, pencil, colored pencil, and watercolor on paper. Drawing for *The New Yorker* cover, 29 March 1976. Private collection.
Size of the original: 71.1 × 48.3 cm.

forms ranging from Kevin Lynch's images of cities such as Boston (1960) to Peter Gould's mental maps of the residential preferences of college students (Gould and White 1974) to Saul Steinberg's iconic representation of the New Yorker's view of the world (fig. 655).

While there is sharing of language, concepts, methods, and techniques in work on maps and minds, the balance of borrowing redounds distinctly to the advantage of the cognition side. The intellectual apparatus of maps and mapping has been central to the development of scholarship on the links between human knowledge and behavior in a wide range of noncartographic contexts.

Given the taijitu-like intertwining of mind and map, there are multiple ways to parse the interconnections among cartography and maps, knowledge or cognition, and space or the world. If we hold the role of the map as central, then we can see five connections. They are (1) from the world to cognition: maps as models of knowledge; (2) from cognition to the world: maps as shapers of spatial artifacts; (3) from maps to cognition: maps as shapers of what we know; (4) from cognition to maps: maps as expressions of knowledge; and (5) the interdependence between space and cognition: maps as shapers of thinking. In all cases, the language of cartography and maps is central to understanding the connection.

In the domain from the world to cognition (maps as models of knowledge), we use cartography in general and mapping in particular as a metaphor and model for the process of cognition. Throughout the twentieth century and across social science disciplines, there were attempts, theoretical and empirical, to explain patterns of human behavior in terms of the underlying knowledge of the world. A key focus was on knowledge of spatial patterns of the physical environment and its translation into wayfinding and navigation strategies. A key debate was the extent to which knowledge was literally copied from as opposed to selectively constructed from the world.

Although the focus has been on humans, the seminal work was Edward Chace Tolman's "Cognitive Maps in Rats and Men." Tolman saw the mind as "far more like a map control room than . . . like an old-fashioned telephone exchange. The stimuli, which are allowed in, are not connected by just simple one-to-one switches to the outgoing responses. Rather, the incoming impulses are usually worked over and elaborated in the central control room into a tentative, cognitive-like map of the environment. And it is this tentative map, indicating routes and paths and environmental relationships, which finally determines what responses, if any, the animal will finally release" (Tolman 1948, 192).

Substituting human for animal, this extended metaphor, based on concepts of many-to-one mapping and schematization, became the motivating force for over sixty years of research on cognition in the human sciences. The range of topics is remarkable. People have studied the geometry of cognitive maps, exploring distance and direction transformations in cognitive spaces using the organizing concepts of map projections and scale transformations and cognitive structures in terms of node edge pairs. Using the rubber sheet metaphor, cartographic maps become the base against which the veridicality and verisimilitude of cognitive maps are assessed. People borrowed concepts of generalization and symbolization to understand the constructive simplification of cognitive maps in relation to the complexity of the world. People used the historical appearance of different cartographic forms to account for developmental changes in types of map forms produced by children. (Golledge [1999] offers an excellent overview of a range of cognitive mapping studies.) The spatial characteristics of the mental worlds of a range of creatures (ants, bees, wasps, pigeons, rats, and chimpanzees) have been captured using many of the ideas derived from the in-

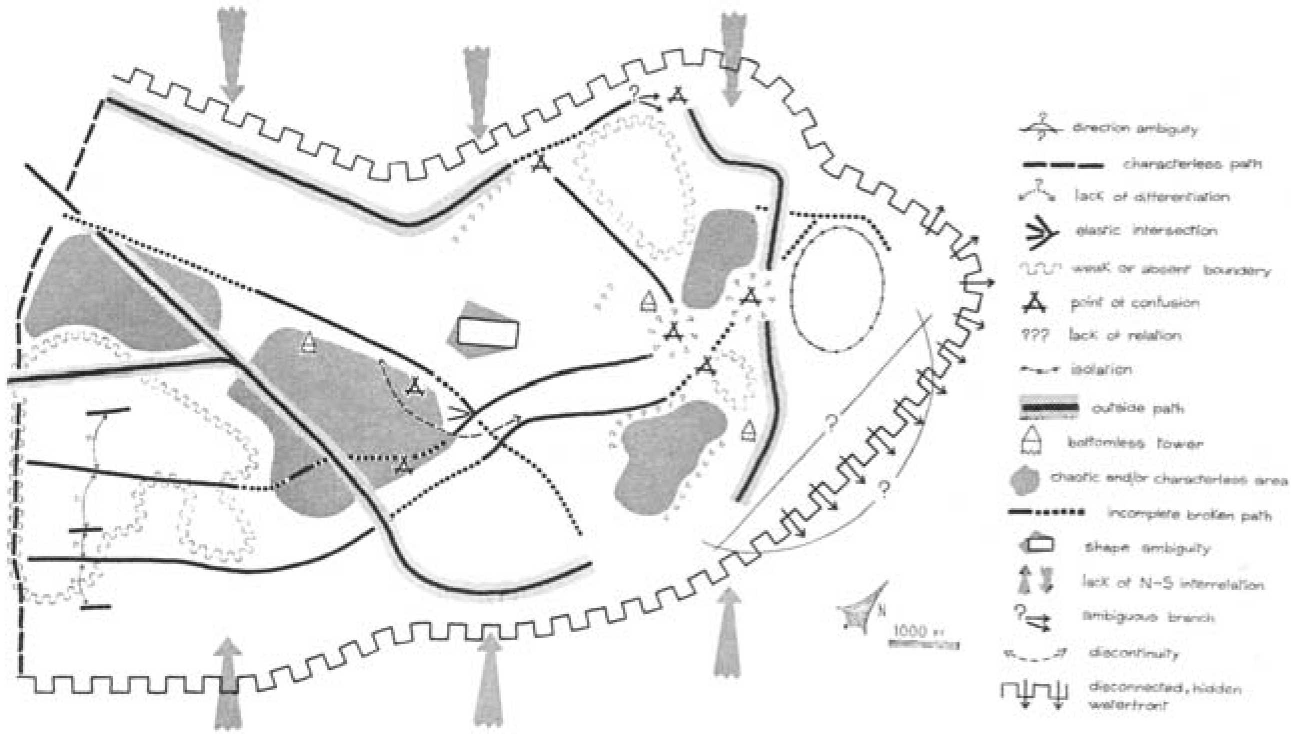

FIG. 656. KEVIN LYNCH'S "PROBLEMS OF THE BOSTON IMAGE."
Size of the original: 6.5 × 11.7 cm. From Lynch 1960, 24 (fig. 8). © 1960 Massachusetts Institute of Technology, by permission of the MIT Press.

tellectual apparatus of cartography (see Healy 1998). Thus, maps and mapping provide intellectual structures and analytic tools for modeling the contents and operations of the mind.

In the domain from cognition to the world (maps as shapers of spatial artifacts), we use knowledge of human cognition to improve the design and use of a range of spatial artifacts such as cities, maps, and mobility systems. Maps and mapping are sources of data, representations of results, and bases for design suggestions.

A classic example is Kevin Lynch's work on livable cities. Based on field studies of Boston, Jersey City, and Los Angeles, Lynch identified two concepts: imageability, or the "quality in a physical object which gives it a high probability of evoking a strong image"; and legibility, or "the apparent clarity . . . of the cityscape" (Lynch 1960, 9, 2). Maps played a central role in gathering data and expressing results (fig. 656). Although an exercise in landscape architecture and planning, Lynch's work was emblematic for a generation of researchers whose work made the link from cognition as understanding the world to ways of designing built environments to be more efficient, aesthetic, and humane. The sensory character of imageability and legibility was not restricted to worlds as seen: using creative map symbols, scholars produced soundscapes and smellscapes in addition to traditional visual landscapes.

In the context of maps, the classic work is that of Arthur H. Robinson in *The Look of Maps* (1952). Daniel R. Montello provides an excellent summary of this tradition, arguing that "map design can be thought of as mind design" and that "the intuition of maps as cognitive devices became a standard part of cartographic training in the twentieth century" (Montello 2002, 283). Even a cursory review of standard cartographic textbooks of the late twentieth century shows the extent to which cartographers are aware of the power of maps to frame an understanding of the world. This approach is an equal mixture of perceptual principles (e.g., drawn from visual discrimination studies of symbol shape and size) and cognitive principles (e.g., Gestalt approaches to good form).

In the context of systems supporting mobility, Reginald G. Golledge's work on the design of a personal navigation system for visually differently abled people exemplifies the multiple conceptual and practical roles of maps and mapping. The system unites a deep and largely map-based understanding of the processes of human spatial cognition and wayfinding with three technologies, those of geographic information systems, global positioning systems, and speech generation systems. The auditory output combines locational information—distance and direction—about places with feature descriptions in a way that supports independent mobility (Golledge et al. 1998). Thus, maps and mapping are powerful tools for channeling, expressing, and enabling human creativity.

In the domain from maps to cognition (maps as shapers of what we know), we explore how the maps that we see shape the nature of cognition. Two map forms are emblematic of the ability of maps to shape understanding of the world. The so-called Mercator effect is captured in the question about the relative size of places such as Saudi Arabia and Greenland on Mercator-based world maps. Failure to understand the properties of map projections leads to misunderstandings about the spatial properties of the world. The shaping power of maps is exemplified by the impact of Henry Charles Beck's 1933 London Underground map on the understanding of spatial relations within London (Garland 1994, and see fig. 483). The highly stylized map became the skeleton by which people organized their understanding of the city, thus distorting distance and direction relationships. In contrast, a simple but brilliant experiment by Barbara Tversky (1981) showed the power of map on mind and vice versa. When given two maps of the Americas, one with the two continents aligned correctly and one with South America moved westward into a vertical alignment with North America, students believed the realigned map to be the correct map. The direction distortions were a product of the interaction of the map and the mind, with the mind simplifying the map. Thus, there is reciprocity between maps and cognition: the experience of maps channels and constrains our knowledge and hence behavior in the world.

In the domain from cognition to maps (maps as expressions of knowledge), we use maps to represent knowledge of the world. The properties of a map—specifically the depiction of spatial relationships—expresses structures and relationships in the nature of human knowledge that may be beyond the conscious awareness of any person. Maps express knowledge.

In a classic set of studies, Gould (Gould and White 1974) asked people, typically college students, to rank order places (states or countries) in terms of residential desirability. After aggregating data, he used principal components analysis to extract the underlying dimensions of residential preference across people and places. Scores for places were mapped, with isopleth maps showing spatial patterns of desirability for states within the United States or choropleth maps showing patterns of desirability for countries within Europe. Gould contrasted the views of people from different parts of a country (e.g., views of the United States from Alabama versus views from Pennsylvania, fig. 657). In his paper "On Mental Maps" (1973), Gould quoted Luigi Giorgio Barzini in an epigraph: "Can geography be mixed up with psychology?" With the intuitively engaging concept of a mental map and the readily adapted method

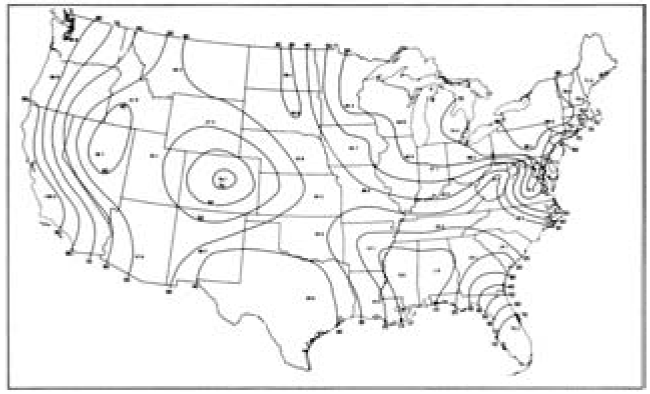

FIG. 657. PETER GOULD'S "THE VIEW FROM PENNSYLVANIA: THE FIRST DIMENSION." Although the values are difficult to read (even in the published version), the isolines show a band along the West Coast as most desirable, a peak of desirability in Colorado and in bands toward the northeast, and lowest desirability in the south (Mississippi and Alabama).
Size of the original: 6.9 × 11.4 cm. From Gould 1973, 191 (fig. 11.4). Copyright © 1973 by Aldine Publishers. Reprinted by permission of Aldine Transaction, a division of Transaction Publishers.

of ranking, analysis, and mapping, Gould answered the question affirmatively for himself and for a generation of behavioral geographers. The concept of a mental map resonated strongly, especially with geographers, although it was eventually superceded by the concept of the cognitive map.

Thomas F. Saarinen (1973) adopted an equally simple yet effective approach. He asked people to draw sketch maps of the world and synthesized individual maps into aggregate cartograms, with area representing the average drawn size of units, most frequently a country, across various groupings based on age or country of residence. The resultant views of the world mixed egocentric and ethnocentric perspectives in revealing ways. For most of the world, continents such as Africa and countries such as Indonesia played disproportionately small roles. Thus, maps become powerful symbolic expressions of everyday knowledge of the world, with the map's technical properties—viewing azimuth, angle, scale, and symbolization—encapsulating the deficiencies of knowledge.

In the domain of the interdependence of space and cognition (maps as shapers of thinking), cognition and maps are intertwined, with maps serving as one of the principal bases for spatial thinking, graphicacy, spatial ability, and concept mapping. At the heart of the domain are two ideas.

The first idea is the pervasive role of the understanding of space and graphics in general thinking processes. This was captured by W. G. V. Balchin and Alice M. Coleman (1966) in their placement of graphicacy alongside the traditional three ways of thinking: literacy (reading and writing), numeracy (mathematical ability), and articulacy (oral communication). Graphicacy, the so-called "fourth ace in the pack," is the capacity to understand and use graphics (especially maps). This focus on graphicacy was matched by the parallel notion of spatial ability, also known as spatial intelligence, that is the ability to generate, retain, retrieve, and transform two- and three-dimensional visual-spatial images. Spatial ability tests are part of the Graduate Record Examination and are used as tests for occupations such as air traffic control because spatial ability is a component of the general concept of intelligence (Carroll 1993). The capacity to think about and to create maps (in particular) is seen as a function of graphicacy and spatial ability. Differences in spatial ability, for example, as a function of age and sex purportedly could account for variations in the capacity to read maps and to use them for wayfinding and other tasks.

The second idea is the fundamental role of space and graphics in a significant mode of thinking, spatial thinking, described by a U.S. National Research Council panel (2006, 3) as being "based on a constructive amalgam of three elements: concepts of space, tools of representation, and processes of reasoning." Maps such as the famous cholera maps of John Snow are used as exemplars of the process of spatial thinking: data are spatialized and the representational forms, especially maps, can structure description, explanation, and prediction. As a learnable skill, spatial thinking underpins everyday activities, the process of scientific thinking, and many job skills. With technological supports through geographic information science (GIScience) and visualization systems, spatial thinking has become more visible and popular. Thus, maps and mapping are simultaneously exemplars of and integral components of fundamental cognitive processes.

By the end of the twentieth century, two technologies—functional magnetic resonance imaging (fMRI) and GIScience—captured the power of the intellectual apparatus of cartography in expressing the nature of human knowledge. The images generated by fMRI systems may localize the physiological roots of human knowledge in the gross and micro structures of the brain, revealing a physiological reality for the development and use of maps and mapping. Thus the classic medical atlas of the physiological structures of the brain may be matched by atlas pages depicting the location of the mapping impulse. In turn, GIScience is revolutionizing the power of the human mind by providing supports for spatial decision making. The supports are becoming tuned to the structures of human knowledge, many of which are spatial in nature. Thus GIScience is enhancing the power of the mapping impulse. In effect, both technologies use the language of maps and mapping to understand and foster the cognitive underpinnings of maps and mapping, reminding us again of the extent to which maps and minds are inextricably intertwined.

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SEE ALSO: Education and Cartography: Teaching with Maps; Visualization and Maps

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Subject Testing in Cartography. During the twentieth century, researchers in the area of perceptual and cognitive cartography asked questions about perception, learning, communication, reasoning, and decision making with maps. These questions were pursued by researchers from different disciplines, including cartography, geography, psychology, and education. Different researchers had different methodological and conceptual training, different research motivations, and different publication and conference outlets. However, all of these cartographic researchers addressed their questions, in part, by applying tools of empirical science—they systematically tested human subjects by observing and measuring their responses during and after map viewing and study. One focus of research was on describing, predicting, and explaining similarities and differences among people in their use and interpretation of maps, analyzing them as individuals or members of subgroups based on gender, age, or cultural background. A second focus, aligned with human factors research, examined viewing conditions that influence the ease and accuracy of using maps—conditions such as lighting, font type and color, and map orientation. A third research focus was on understanding and improving the use of maps in education, as well as education about maps and mapping. Finally, much perceptual and cognitive cartographic research, particularly by cartographers, had the aim of improving the design of maps so they would convey more information more easily and accurately. This final focus on perceptual and cognitive map design research and its testing of human subjects in cartography is reviewed in this essay.

It is likely that some of the earliest cartographers, many centuries ago, recognized that map design would influence how maps were perceived, understood, and used to make decisions. However, this intuition was not pursued systematically as behavioral and cognitive science, nor did it become a formal part of cartographic education, until the twentieth century. The notion that map design could be improved with the help of scientific research on perception and cognition was a twentieth-century phenomenon, and represented a distinct change from the long tradition of a craft approach to cartography, including trial-and-error conventions developed over the centuries about how to design maps, and informal "experiments" carried out by mapmakers on themselves, or their colleagues and assistants (Robinson 1952).

Important nineteenth-century precursors to the twentieth-century emergence of perceptual and cognitive studies in cartography included the emergence of empirical psychology in Europe and the United States, the development of thematic mapping (upon which most perceptual and cognitive cartographic research has been conducted), military efforts in Europe to develop effective methods for portraying relief on maps, and developments in art and art theory. During the twentieth century, the first call to apply psychological research to improving maps as designed objects came from the writings of the German cartographer Max Eckert (later Eckert-Greifendorff). As early as 1908 Eckert explained that "map logic" is one of the most important topics for scientific cartography; by map logic, he meant the principles for creating maps and for cartographic perception (Montello 2002, 287). He thus recognized the subjectivity involved in map communication. These ideas were further developed in his two-volume magnum opus titled *Die Kartenwissenschaft* (1921–25), in which he advocated the application of psychological research to cartography, although he neither reported any such studies with maps nor offered a detailed plan for applying psychology to understanding maps.

The most influential push to apply scientific studies of perception and cognition to improving map design came from Arthur H. Robinson's *The Look of Maps* (1952), which was based on his 1947 dissertation at Ohio State University. This small, mapless book put forth the proposition that the function of maps is to communicate to people. This function depends on the visual appearance of maps, and this appearance in turn depends on explicit and implicit design decisions made by mapmakers. So to understand and improve map function, cartographers need to understand the effects of design decisions on the minds of map users. "The work that makes the data intelligible to the reader . . . . is the essential cartographic technique" (Robinson 1952, 4). Robinson proposed that the best way to understand map communication was the way other mysteries of our world had best been understood—through rational thought and systematic study. This echoed Eckert's early blueprint for cartography as science, in this case behavioral and cognitive science, particularly psychology.

Daniel R. Montello (2002) discussed several other key influences on Robinson's work, including early studies on color and relief representation, map education research, writings on propaganda mapping, and an early address by the president of the Association of American Geographers, John Kirtland Wright, discussing the role of the subjective world of the cartographer in maps. Noncartographic perceptual research, such as work by German psychophysicists, also influenced Robinson in important ways. Clearly, Robinson's experiences as head of the Map Division at the U.S. Office of Strategic Services (OSS) during World War II, as well as his artistic leanings, influenced his ideas about map perception and cognition.

Publications like *The Look of Maps* offered a way to think about cartography as a discipline that attempts to pass along the cartographer's conception of the world to the mind of the map reader via the symbolic medium of the map. This was a seed for the communication model, a broad and comprehensive theoretical framework for describing and explaining cartography. From the perspective of this essay, the communication model provided a theoretical framework within which to justify human subject testing in cartography. In *The Look of Maps*, Robinson called for cartographic researchers to systematically observe and measure—collect data on—how people look at and interpret maps. This led to the application of psychophysical methods to map design research. Soon after initial psychophysical studies in cartography in the 1950s, other tasks and techniques not derived from psychophysics were also applied to the study of map perception and cognition, including tasks wherein the speed and accuracy of searching for particular targets or answering particular questions were recorded (Dobson 1983). As Montello (2002) pointed out, these various methods were used to study the perception of a variety of symbol and map designs, including region areas on conformal projections, dot-area symbols, gray tone scales, type fonts and lettering, and color. The most significant map design research on reference maps, as opposed to thematic maps, was carried out on topographic maps, including those symbolized with isolines (contours), hachures, and shaded relief. A survey for Britain's Royal Society reported many empirical human subject studies of cartographic communication done in Britain, including work done at the Experimental Cartography Unit, or ECU (Board and Buchanan 1974). Perceptual and cognitive research involving subject testing also flourished in German-language cartography (e.g., Koch 1993).

One of the most significant approaches to subject testing in cartography involved recording the eye movements of subjects as they viewed maps (Steinke 1987 provides a historical review). Recording eye movements in cartography is based on the assumption that people will look at places on a map to which they wish to attend; visual attention is the selective focusing of information processing on some parts of the visual field rather than others. So if you know where people are looking on a map, you know where they are attending to on that map—where they are attempting to pick up information visually. More precisely, to "look at" means to "foveate"—to move one's eyes so that the central area of the retina, the fovea, receives input from a place in the visual field. The fovea has the greatest concentration of visual receptor cells (particularly cones), and those cells have the densest connections to postretinal layers of the visual system. Foveated places in the visual field are perceived with greatest resolution. If time-registered locations of foveations are recorded, continuously or very frequently, a record of the temporal and spatial pattern of eye movements, a "scan path," can be diagrammed, providing a record of places to which people were not attending.

Systematic eye movement recording was conducted in psychology and various specialized fields of textual and graphical communication, such as art and advertising, during the first half of the twentieth century (citations in Steinke 1987). Several researchers outside cartography conducted studies throughout the 1950s and 1960s. A watershed event for cartography was the Symposium on the Influence of the Map User on Map Design, held in 1970 at Queen's University in Kingston, Ontario (see Castner and McGrath 1971). The meeting included talks on a variety of cognitive cartographic topics, including eye movement research. L. G. Williams, a psychologist, reported some results from his noncartographic eye movement studies, and papers by Mylon Merriam and Henry Castner cited and discussed eye movement studies and their possible implications for cartography.

George F. Jenks, cartography professor at the University of Kansas, attended the 1970 meeting at Queen's University. Jenks would eventually be recognized as a leader in map design research in the United States, particularly in its empirical manifestations, probably second only to Robinson in influence. At a seminar Jenks held at Kansas during the early 1970s, he and his students drew region boundaries on a dot map showing hog production in North Carolina. The class spent a great deal of time discussing variation in their regionalizations, including possible explanations for it. Armed with the interest in eye movement techniques he had picked up at the Queen's meeting, Jenks and his students conducted seminal recordings of the scan paths of viewers studying the dot map (fig. 658). Although it is safe to conclude that this eye movement study did not particularly illuminate causes for the different regionalizations of his students, it did demonstrate the feasibility (albeit with difficulty) of conducting eye movement research in cartography. In this way, it provided a stimulus for a host of subsequent research projects by several of his students and others using the technique (e.g. Chang, Antes, and Lenzen 1985).

Testing human subjects as a way to study map perception and cognition became very popular during the

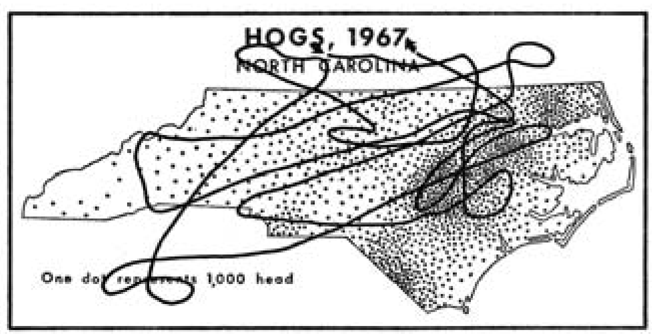

FIG. 658. HOG MAP OF NORTH CAROLINA WITH OVERLAID SCAN PATH RECORDED FROM THE EYE MOVEMENTS OF A PERSON STUDYING THE MAP.
Size of the original: 6.4 × 12.8 cm. From Jenks 1973, 30. Permission courtesy of Bertelsmann AG, Gütersloh.

1970s. Patricia P. Gilmartin (1992) reported a content analysis of research published in major English-language cartographic journals from 1964 to 1989. The period from about 1975 to 1982 had the most "user-oriented" articles (her term for research articles on map perception and cognition), peaking in 1978 and 1979 at over 30 percent of all articles in those journals—the largest single category. Before the late 1970s, historical topics were predominant; the 1980s witnessed the growth of automated cartography (geographic information systems [GIS]) as a topic. American universities where subject testing occurred from the 1960s to the 1980s included the University of Wisconsin, the University of Kansas, the University of Washington, Clark University, and Pennsylvania State University.

However, the reputation of subject testing in cartography, and perceptual and cognitive studies more broadly, suffered somewhat in the 1980s. Empirical studies, including psychophysical and eye movement studies, were criticized as lacking application to actual map production. Many cartographers had recognized the potential value of eye movement studies but came to question what such studies told the mapmaker that was novel. Conclusions such as that subjects look more at areas of the map that contain relevant information or different map designs produce different eye-scan paths were not earthshaking revelations. The most incisive critique came from Barbara Bartz Petchenik (1983), who had studied under Robinson at Wisconsin and was working in production cartography at R. R. Donnelley as map editor for the *World Book Encyclopedia*. She claimed that subject testing with maps was not helpful to map design because it was based on faulty assumptions about the way people use maps (such as that they always have a single, definite question to answer when they look at a map), and because of fundamental differences in the goals of designers and researchers (the first think synthetically, the second analytically).

Petchenik noted that the results of subject testing seemed inconsistent and context dependent; changing the nature of the map task or the precise design of the test materials often led to variability in the results. Other problems included the existence of individual differences—map users are different, and to a certain extent (sometimes great), they look at and think about maps differently. Many of the studies failed to contribute much to an accumulated understanding of map perception and cognition because they were atheoretical, observing humans viewing maps without a strong theoretical framework within which to interpret those observations. Eye movement studies, for example, produce large amounts of data whose signal is buried in considerable noise and irrelevant components. Ultimately, theory should guide our choices among the many options for analyzing these data (fixation locations, fixation durations, scan lengths, number of direction changes, etc.).

So the difficulty of conducting and interpreting subject testing research, and the rise of GIS, led to less perceptual and cognitive research in cartography, at least in the United States and the United Kingdom (it did not decline as much in Germany). However, this decline reversed during the 1990s. The digital computer provided alternative research topics for new researchers—topics that did not involve perception and cognition—but it also made subject testing easier, assisting in the creation and presentation of test stimuli and the collection and analysis of data. Improvements in computer technology also made new information displays possible, including animations, multiscale displays, near-continuous zooming, sonifications, tactilizations, and virtual and augmented realities. Furthermore, digital technologies made geographic information displays increasingly common among laypeople as well as specialists; maps showed up on home computers, in cars, on cell phones, and in public sites from airports to museums. These continuing developments clearly inspired new interest in perceptual and cognitive research to help design more effective and enjoyable geographic information displays, and this has included an increasing application of subject testing in cartographic research.

Alan M. MacEachren's *How Maps Work* (1995), the most comprehensive review ever written of perceptual and cognitive theory in cartography, referenced many studies done after 1990, including work at Penn State and elsewhere. Clifford H. Wood and C. Peter Keller's 1996 *Cartographic Design*, based on the Symposium on Cartographic Design and Research, held at the University of Ottawa in August 1994, aimed to rectify the neglect of map design and map design research with human subjects that resulted from the digital revolution in cartography. In addition to these books, articles reporting the results of subject testing studies in cartography continue to appear in major journals (e.g., see review by Lloyd 2000). These publications suggest that the status of subject testing as an important component of academic cartography has become stronger and that researchers have moved beyond low-level perceptual approaches to the high-level cognitive approaches that involve methods such as protocol analysis and collaborative decision making studies (e.g., Slocum et al. 2001).

Subject testing research influenced the activities of academic cartographers during the twentieth century. Faculty and students spent time thinking about it and doing it. Conferences occurred, articles and books were published, money was spent, and many thousands of research subjects were tested. As a result, many courses in cartography include discussions of map perception and cognition, including subject testing. However, subject testing had much less influence on the production of maps, whether by agencies and private companies in the business of making maps or by mapmakers without professional training (e.g., many media cartographers). This is recognized by many academic cartographers and was a key discussion point in Petchenik's 1983 critique. But this influence has not been completely nil. Petchenik herself conducted subject testing as part of her job in production cartography at R. R. Donnelley. Environmental Systems Research Institute (ESRI) modified its popular GIS software ARC/INFO to let mapmakers rescale their area symbols to accommodate the perceptual effects found in psychophysical research. Cynthia A. Brewer (Brewer and Suchan 2001) did notable work on color for the U.S. Census Bureau and ESRI. In their *Atlas of United States Mortality*, the U.S. Center for Disease Control used the color scheme developed and tested by Judy M. Olson and Brewer (1997) for users with color-vision impairment.

Finally, subject testing in cartography helped focus attention on the idea that map design should be considered in terms of its effectiveness for helping people understand the world. For example, it is fairly widely recognized now that the Mercator projection is inappropriate for most general uses because of the way it distorts areas. The simple notion of "reading" a map has been greatly expanded in appreciation of the fact that there is no single universal way in which maps are "read" (Castner 1983, 97). In sum, empirical map design research with human subjects helped to create a new way of thinking and talking about maps and mapping that continues to affect the entire discipline of cartography. The needs and capacities of map users became understood as central to the design and production of maps and other geographic information displays, and the belief that the mapmaker's intuition will always lead to the best map design is much less widely held.

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SEE ALSO: Color and Cartography; Petchenik, Barbara B(artz); Robinson, Arthur H(oward)

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Map-Use Skills. For much of the twentieth century, skills in using maps (hereafter referred to more simply as map skills) were of major concern in only two restricted contexts. First, in military contexts map skills were viewed as a prerequisite for tactical operations and were taught in a rigidly programmed and rote fashion. Second, in primary and secondary school contexts map (and atlas) skills were viewed as critical for studying geography (fig. 659). Students, too, were taught in a regime of rote learning that covered map reading and interpretation: keys, scales, grids, and types of maps. In neither military nor school context was there any guiding theory or an overarching question to be answered. The instructional goals were simply to teach map skills with efficiency and

FIG. 659. CLASSROOM INSTRUCTION IN GEOGRAPHY. Photographed at the Francis W. Parker School, Chicago. From M. V. O'Shea, ed., *The Child: His Nature and His Needs* (N.p.: Childrens Foundation, 1924), facing 422.

efficacy. In both contexts, maps themselves were seen as uncontroversial, factual statements about the world.

During the same era, map skills were also of some concern in college-level instruction in disciplines in which maps are essential, for example, geography, geology, and astronomy. In addition, map skills were relevant beyond military and educational settings. They were learned as part of hobbies (e.g., orienteering) and family contexts (e.g., navigation during family trips), although there is little systematic data from the twentieth century about how map skills may have been viewed and taught in these informal settings.

During the 1960s and 1970s—as part of the emergence of the behavioral approach within geography and of the cognitive revolution within psychology—there was a major change in how maps and thus map skills were conceptualized. In geography, the foundational premise was that the world in the mind shaped human spatial behavior. This premise led to viewing maps as ways of expressing subjective knowledge about the world, rather than as ways of recording or viewing the world directly as some singular, fixed objective reality.

In psychology, the foundational premise was that human knowledge is a product of a dynamic interaction between a person's cognitive structure (prior knowledge and reasoning skills) and the environment—both physical (e.g., features of the physical world) and representational (e.g., graphic images). This premise led to viewing people's map use as a window into human cognitive processes more generally. Research that used maps as a tool to understanding something else gradually led to questions about the precursors of map understanding itself.

By the late 1970s there was a significant amount of scholarship on the development of map production and comprehension. This turn matched the turn in cartography, led by people such as J. B. Harley (2001), whereby maps were seen as powerful, creative statements about the world that were neither neutral nor objective expressions of preexisting truths.

By the end of the century, there was a vibrant tradition of empirical research and theoretical speculation about map use that centered on three key ideas: first, that maps were not transparent and immediately accessible statements about the world; second, that map use was a complex perceptual and cognitive process; and third, that map skills varied as a function of individual and group factors such as age, gender, and instruction.

At issue were multiple and interlocking questions. Some questions concerned the characterization of maps themselves, for example, how maps fit into the larger context of geospatial representations. Other questions concerned the link between map forms and individuals' use. Do skills vary across different map scales or types? How does the capacity to generate digital maps on demand affect map understanding? How does access to digital maps change map use? Still other questions focused on the processes underlying skilled map use. Are map skills innate or learned? What are the components of map skills, and how is mature performance characterized in each? At what age or under what circumstances are different components mastered, and do all individuals ultimately master them? Are map skills best conceptualized as a separate cognitive domain or are they particular instances of more general cognitive processes? Some questions centered on the research process. How does one ensure ecological validity in map-use tasks? What is the association between performance on laboratory- and field-based tasks? What behaviors should be taken as evidence of full understanding of maps? For example, need users merely decode information, or must they be able to reflect on that information explicitly?

Characterizing Map Skills in a Cognitive Context

Cartographers have long explored map perception, drawing on psychophysical approaches to understand the relations between what was printed on a map and how readers perceived what was printed. The work resulted in guidelines for minimal symbol size and spacing to ensure readability, for symbol shape and shading to ensure discriminability, and for absolute or proportional scaling of the length, area, and volume of symbols to ensure correct judgments of value (Montello 2002).

The cognitive approach to maps blended cognitive psychology with cartographic theory and history to understand the relations between what was represented on the map and the world that was being mapped (MacEachren 1995). The psychophysical approach saw the world-to-map relation as a technical challenge of achieving accuracy and hence veracity, whereas the cognitive approach saw the relation as a mutually creative endeavor in which mapmaker and user struggle to achieve meaning by making sense of the world. Maps were seen as creative realizations, not literal re-presentations (Treib 1980) and as purposeful and selective statements, not neutral and all-encompassing depictions (Harley 2001; Monmonier 1996).

The consequence of the cognitive approach was twofold. First, there was the recognition that maps are not transparent windows on the world that are subject only to fidelity limitations imposed by graphic design, mathematical projections, and printing technologies. Instead they offer differing reflections of the world as intended by the mapmaker and as realized by the map user. Second, far from being a simple perceptual process, map use is a complex cognitive skill that develops over time with instruction and experience.

With the explosion of types and uses of maps in the digital world, therefore, the teaching and learning of map skills became of critical importance not just in specialized domains (e.g., the military) but in everyday life (e.g., using a Global Positioning System [GPS] unit in an automobile).

Map Skills: Cognitive Underpinnings

If maps are conceived of as little more than flattened miniaturizations of the world as it exists, then the challenges of understanding maps would mimic the challenges of perceiving the actual environment. In keeping with this interpretation, some researchers suggested that map understanding comes relatively early and easily because it draws on perceptual processes that are in place early and that are exercised by everyday perception of the physical world.

One influential pillar of this interpretation was formulated by James M. Blaut and David Stea, at Clark University, who combined the disciplinary traditions of geography and psychology. They suggested that because infants perceive the constancy of small objects' size and shape across changes in viewing distance and viewing angle, young children might well be able to interpret maps' spatial transformations of scale and projection (Blaut, McCleary, and Blaut 1970, 339). Consistent with this possibility, they reported that first-grade children (and even younger; see fig. 660) can interpret the meaning of content (e.g., buildings and roads) appearing on aerial photographs of their hometown, create maps from those photographs by tracing roads and buildings on tracing paper, and plan and show travel routes between starting and target locations on that map.

A second variant of the interpretation of early map understanding emerged from the nativist camp of developmental psychology. Nativism is the position that human beings—as part of their evolutionary endowment—have inherent concepts and skills that unfold automatically, assuming that the child develops in a normal environment. In the domain of map use, this position was illustrated by Barbara Landau (1986), who studied a congenitally blind four-year-old child's ability to use a tactile map of a room to find target locations within the room. Based on the child's success in heading in the right direction to the target under varying conditions of map display (e.g., held horizontally or vertically), Landau concluded that "certain fundamental components of map use are accessible without specific prior experience in map reading, and without previous visual experience" (201).

FIG. 660. CHILD INTERPRETING AN AERIAL PHOTOGRAPH. A four-year-old boy responding to an interviewer's request to show "how you would go" from the child's "own" house (indicated by the interviewer as a house on one side of the photograph) to visit a friend's house (indicated by the interviewer as a house on the other side of the photograph).
From Steve Sowden et al., "Mapping Abilities of Four-Year-Old Children in York, England." *Journal of Geography* 95 (1996): 107–11, esp. 109 (fig. 2). Reproduced by permission of Taylor & Francis.

These interpretations of map understanding are consistent with the view that maps are relatively transparent windows on the world. However, as cartographers acknowledged that maps are not merely replicas of the world but instead are graphic expressions offering new and varied insights about that world, developmental and cognitive psychologists likewise began to expand their study of map skills to encompass a more diverse set of component cognitive challenges and skills.

Three cognitive domains—representation, space, and logic—were identified as "central to the comprehension and production of maps" (Downs, Liben, and Daggs 1988, 684). Given well-established differences in each of the domains across ages (developmental differences) and among people of a given age (individual differences), the focus of many investigations evolved from asking how early a given map skill emerged to asking whether progressions or differences in map skills were synchronous with milestones in developing basic representational, spatial, or logical concepts.

Research during this period demonstrated that basic representational skills emerge early but continue to develop with age and experience. Seminal work by Judy S. DeLoache (1987) demonstrated that by three years (but rarely before), children who saw a small object hidden in a scale model or map of a room could retrieve an analogous larger object from the analogous location in the full-sized referent room. However, with more arbitrary symbols or with multiple instances of the same symbol (e.g., several squares representing different tables), preschoolers' success in identifying represented locations is far worse (Blades and Spencer 1994). Performance can be mixed even within a given child and task. For example, the same preschool child who identified a road map as showing "States and stuff" and an aerial photograph of a city as "Lots of buildings" and roads also assumed that a red line on a road map stood for a red-colored road (Liben and Downs 1989, 180, 183). Adults, too, may struggle when resemblance of symbol and referent is low (or deviates from convention): illustrative is the infamous 1972 New York City subway map designed by Massimo Vignelli that had to be recalled and revised, in part because travelers were confused by the use of brown (rather than blue) to symbolize the Hudson and East Rivers.

Map use also draws on spatial concepts. Researchers studied whether users' understanding of scale, viewing angle, and viewing azimuth was linked to users' understanding of the topological, projective, and Euclidean concepts that underpin the major spatial structures identified by Jean Piaget (fig. 661). In general, developmental research showed that when map tasks could be solved by reference to topological concepts, performance was quite good: even young children were generally able to interpret symbols on maps to show that something was "next to" or "on" a landmark. However, map tasks requiring projective concepts are particularly challenging to young children: they have more difficulty understanding nadir than oblique views and are likely to ignore the critical relation between the orientation of a map and the surrounding environment when making location or direction judgments (fig. 662). Even adults have been observed to have difficulty determining navigational direction when they consult you-are-here maps that are misaligned with the environment (fig. 663). Skill in pinpointing locations with metric precision was also shown to develop with age, particularly when locations had to be identified in large, undifferentiated areas of the map or environment (thus devoid of rich local landmark cues that would support topological solutions).

Not only do map skills draw on representational and spatial foundations; they also draw on users' abilities to reason logically and to call upon broader knowledge sets to make sense of the maps they are using. For example, an understanding of class inclusion logical relations (if A is within B and B is within C, A must be within C) underlies understanding of maps' geographic hierarchies (Downs, Liben, and Daggs 1988). Similarly, an understanding of the logic of density is critical for

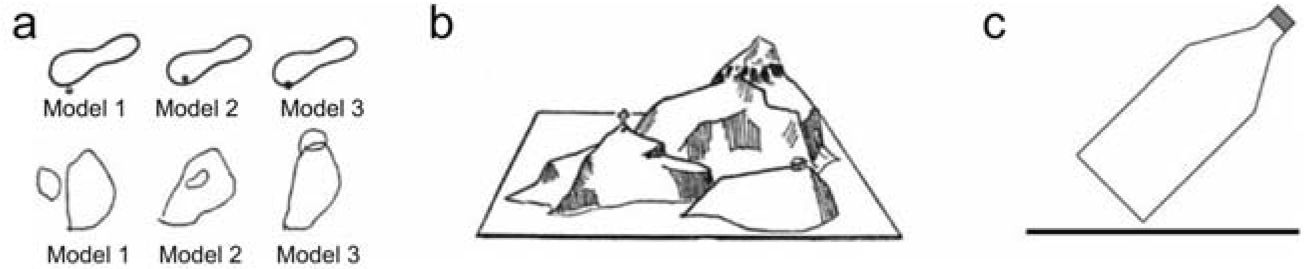

Fig. 1. The triad of spatial concepts identified by Piaget and Inhelder (1948/1956). Topological space encodes spatial qualities and relationships that are retained despite elastic distortion. Children with topological concepts can, for example, appreciate "next to," "in," and "on" relationships but not distance and angle. Thus, asked to copy models shown in row 1 of (a), young children can produce drawings preserving these spatial relations (see row 2), but asked to copy a triangle, circle, and square, they produce equivalent, undifferentiated closed shapes (figure adapted from Piaget & Inhelder, 1948/1956). Projective space relates objects to one another in terms of straight "projected" lines, thereby allowing the coordination among perspectives. Children who understand projective space can determine how appearance changes with vantage point—for example, predicting how an array of mountains (b; from Piaget & Inhelder, 1948/1956) looks to someone seated at a different location from the child. Euclidean space involves the use of an abstract, container-like system such as Cartesian coordinate axes. Children who have constructed Euclidean concepts can, for example, conserve distance across locations, measure angles, and apply their horizontal and vertical coordinate framework to recognize that water in a tilted bottle (c) remains horizontal.

FIG. 661. SPATIAL CONCEPTS IDENTIFIED BY PIAGET AND INHELDER. Explanation of the three spatial concepts and illustrative assessments as proposed in Jean Piaget and Bärbel Inhelder, *La représentation de l'espace chez l'enfant* (1948), translated as *The Child's Conception of Space* (1956). Reproduced from Lynn S. Liben, "The Road to Understanding Maps," *Current Directions in Psychological Science* 18 (2009): 310–15, esp. 312 (fig. 1). Permission courtesy of Sage Publications.

interpreting the meaning of point symbols in relation to area as well as for understanding the ordering of symbol systems used in thematic maps.

Variability in Map Skills

During the last quarter of the century, attention turned to examining the relations among wayfinding, environmental knowledge, and performance on general measures of intellectual skill. Much of this work initially led to the conclusion that standard paper-and-pencil intellectual measures were not good predictors of navigational success. Interestingly, however, most of the research was focused on how individuals navigated by consulting mental maps rather than by consulting physical (largely paper) maps. It was not until the turn of the twenty-first century that cognitive scientists, some working collaboratively with geographers, increased their attention to peoples' skills in interpreting and using maps and other representations rather than on their skills in getting around or thinking about environments (Montello et al. 2004). Given that there is a large research literature showing a male advantage for spatial skills in general, some investigators of navigation skills examined performance in relation to gender. Although gender differences in navigation or map use were rare or small, those that were observed typically revealed a male advantage (Lawton 2010).

By late in the century, geography educators and members of other disciplines in which map skills are essential (e.g., geologists) began to emphasize the need for education and research on map use. Central was *Geography for Life* (Geography Education Standards Project 1994), which was the consensus view of what children of different ages should know and be able to do. Of the eighteen standards, maps (or other kinds of spatial representations) were mentioned explicitly in thirteen, were strongly implied in three, and were arguably entailed in the other two. Many early educational efforts were focused on teaching children about how to link one representation to another (e.g., a photograph to a street map), with later efforts aimed at teaching skills needed to link maps to the surrounding environment and to use geographic information science (GISci) tools (National Research Council 2006).

In sum, with the burgeoning of online mapping technologies, the question of map understanding was no longer of just academic interest. The presentation of geospatial information through media such as Google Earth or in location-based services available on cell phones is simultaneously informed by our knowledge of spatial cognition and map skills and in turn, it drives changes in that knowledge and in the need for and nature of those skills. The nature of map skills will change as the distinction between map creators and map users diminishes as a result of citizen mapping initiatives. The linkage of map skills with traditional map forms and products will disappear as real-time interactive technologies enable collective but ephemeral mapping activities. Over the

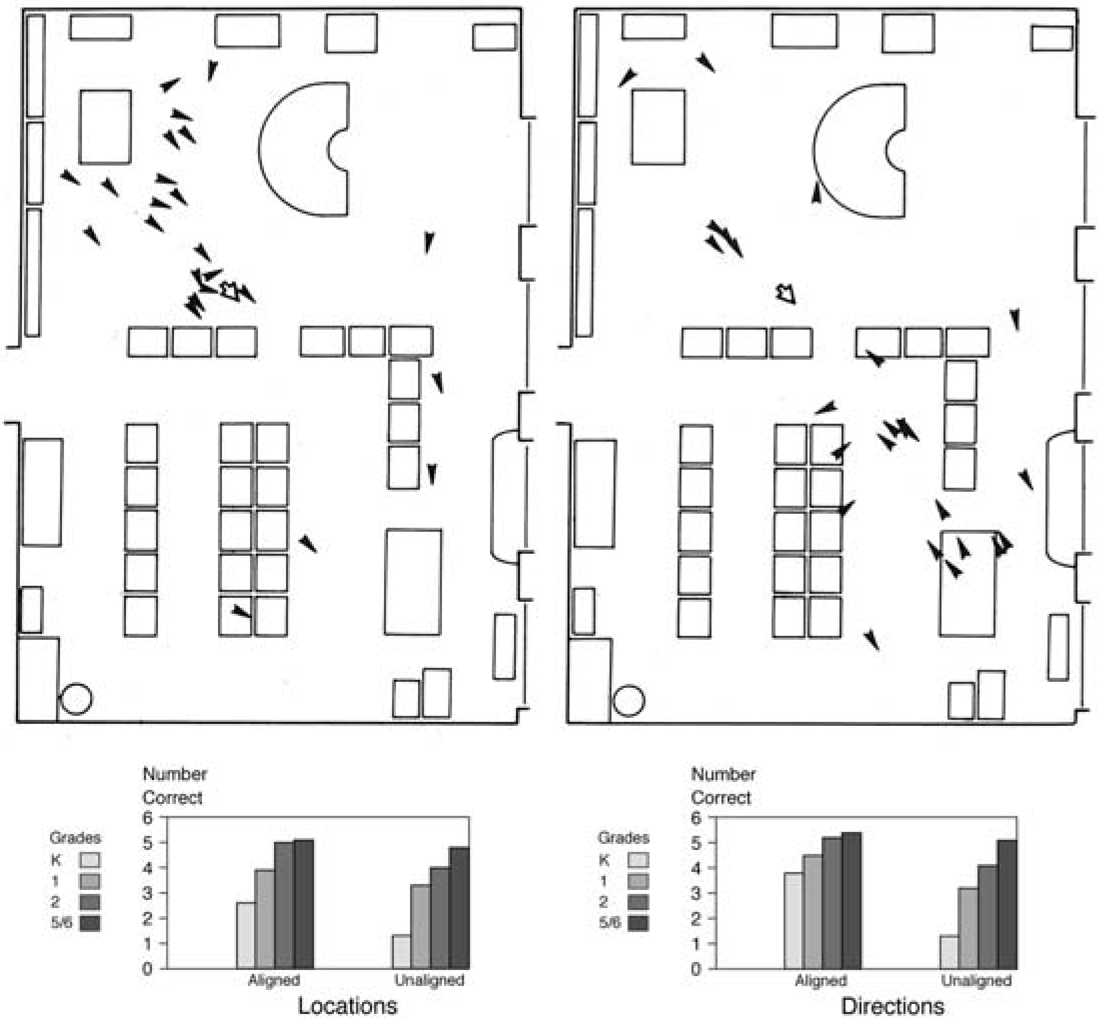

FIG. 662. INFLUENCE OF MAP ALIGNMENT ON CHILDREN'S ABILITY TO JUDGE LOCATION AND DIRECTION. A composite of responses by students in one first-grade class who were asked to put an arrow on their map to show where an adult was standing and the direction he was pointing. At left are responses when the map was aligned with the room; at right are responses when the map was rotated 180° on each student's desk. Correct responses are indicated by the open arrows. The composite of individual children's responses (above) and the graphs of group data (below) reveal the greater difficulty under the unaligned condition, particularly for younger children.

Size of the composite maps: 9.7 × 14.7 cm. Data and composite maps are from Lynn S. Liben and Roger M. Downs, "Understanding Person-Space-Map Relations: Cartographic and Developmental Perspectives," *Developmental Psychology* 29 (1993): 739–52, esp. 745 (table 1) and 746 (fig. 2). Reprinted with permission.

past century, therefore, map skills moved from a position at the periphery in educational, occupational, and daily contexts to a position at the center of human lives.

LYNN S. LIBEN AND ROGER M. DOWNS

SEE ALSO: Education and Cartography: Teaching with Maps; Recreational Map; Scale

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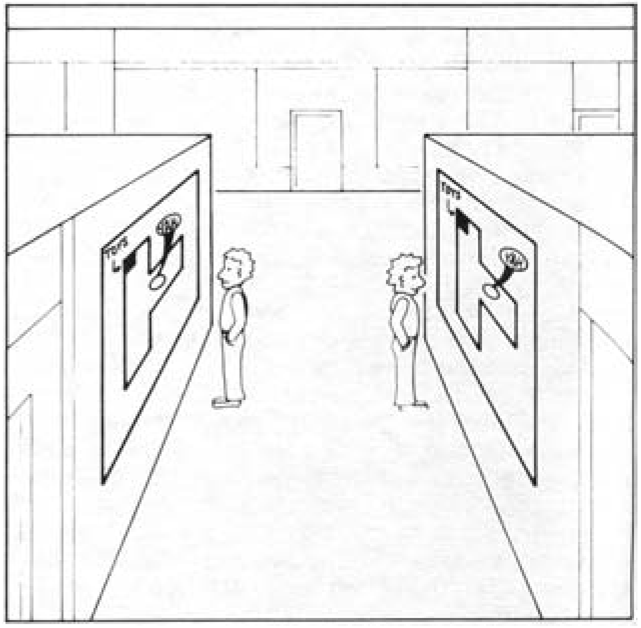

FIG. 663. MISALIGNED YOU-ARE-HERE MAPS. Illustration of how identical you-are-here maps placed on facing walls necessarily place at least one map out of alignment. When maps are misaligned (as on the left), adults commonly walk off in the wrong direction because they fail to take alignment into account.

From Marvin Levine, Iris Marchon, and Gerard Luke Hanley, "The Placement and Misplacement of You-Are-Here Maps." *Environment and Behavior* 16 (1984): 139–57, esp. 144. Permission courtesy of Sage Publications.

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Experimental Studies in Psychology. Maps are symbolic representations that communicate information of varying veracity to people, thereby assisting their reasoning and decision making. Communication, reasoning, and decision making are, in part, psychological acts involving perception, learning, thinking, and memory. During the twentieth century, especially the latter half, a variety of cartographers, geographers, psychologists, and other behavioral and cognitive scientists conducted basic and applied scientific research on perception and cognition with and about maps—an area of research that may be referred to collectively as perceptual and cognitive cartography.

This entry focuses on research that used maps and map-like stimuli to conduct basic scientific research on human mental processes and structures, including perception, thinking, learning, memory, reasoning, decision making, imagery, and language; this can be called experimental map-psychology research to distinguish it from perceptual and cognitive research on map design, human factors, and map education, which are discussed elsewhere in this volume. Experimental studies were conducted mostly by perceptual, cognitive, educational, and developmental psychologists, although geographers James M. Blaut, Roger M. Downs, Robert Lloyd, and Alan M. MacEachren made noteworthy contributions. With very few exceptions, most such research was concerned little, if at all, with improving map design, map use, or map users. Instead, these researchers were mostly interested in basic scientific questions about human spatial and symbolic thinking.

In addition to its relative lack of concern for improving maps or their use, experimental map-psychology research also frequently used exceptionally abstract and simplified "maps" as stimulus materials to show human research subjects. Most academic and professional cartographers would not consider these simple graphics to be maps (fig. 664). Often lacking information about scale, cardinal directions, projection, and map currency, these graphics were not representations of the earth's surface. Furthermore, psychological research often evinced limited conceptions of the design and content of maps and of the variety of tasks for which maps can be used. For these and other reasons, experimental map-psychology research had very little influence on map design or production.

Experimental map-psychology during the twentieth century may be organized into three broad topical areas. The first involved research on the mental knowledge structures and processes involved in map use. Memory tests and protocol analyses (a technique in which map users systematically think aloud while looking at or reasoning with maps) showed that experience with particular classes of maps or particular knowledge domains in-

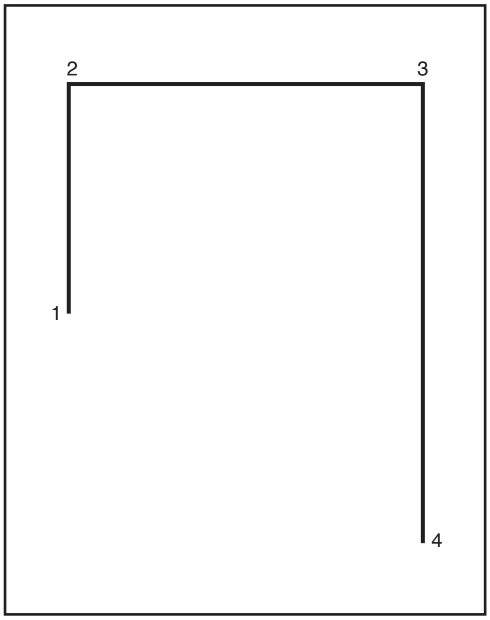

FIG. 664. HIGHLY SIMPLIFIED MAP-LIKE GRAPHIC USED AS A STIMULUS. This example is similar to graphics used in several psychological research programs (including Levine, Jankovic, and Palij 1982; and Presson, Delange, and Hazelrigg 1989).

fluences how people look at and reason with maps, what they remember from maps, and how they organize the knowledge in memory (e.g., Thorndyke and Stasz 1980). Another common method for researching questions on knowledge structures and processes was to analyze patterns of distortion in people's map-based judgments. Such research repeatedly demonstrated that maps are not encoded and stored in memory as unitary "pictures in the head." Nonpictorial cognitive structures—rules or heuristics—organize one's knowledge of map content and layout, presumably because they decrease memory load and typically facilitate map interpretation. For example, just as people mentally regionalize earth surface spaces, they mentally regionalize map spaces and organize them hierarchically (McNamara, Ratcliff, and McKoon 1984). Barbara Tversky (1981) proposed other heuristics to explain patterns of distortions in people's judgments about the relative directions of urban streets and of world cities, learned from maps; these heuristics lead people to assume directional alignment of locations with various local or global reference systems.

A second topical focus of experimental map-psychology concerned the way map orientation when used to navigate in situ influences how it is interpreted (Levine, Jankovic, and Palij 1982; Shepard and Hurwitz 1984). Maps such as road maps and "you-are-here" maps are typically used by people to orient themselves in their immediate surrounds. Research repeatedly confirmed the common observation that most people find maps like these easiest to use in situ when the forward direction of the map viewer is represented toward the top of the map. Maps oriented in any other way, such as with the backward direction of the viewer toward the top of the map, are used more slowly and less accurately when orienting. The extra time required or errors produced in using maps without this forward-top agreement—maps that are misaligned to the surrounds—was dubbed the alignment effect. In order to cope with misaligned maps, viewers must first recognize the misalignment and then mentally or physically transform the map, themselves, or their surrounds.

A third topical focus of experimental map-psychology compared maps as sources of geographic and environmental knowledge to other sources, especially direct experience sensing and moving through the landscape. As sources of information, maps have characteristics that differentiate them from direct experience. They usually provide a survey overview from a vertical or oblique perspective that allows viewers to apprehend the geometric layout of places between which they may never have traveled and may not be able to travel directly. The most influential study on this topic was by Perry W. Thorndyke and Barbara Hayes-Roth (1982). They compared research subjects who learned the layout of an office building from viewing a map for an hour or less to subjects who learned it by working in the building over the course of several months or more. Based on analysis of error patterns in spatial judgments about the building, these researchers developed models for the mental processing of spatial knowledge acquired either from maps or from direct experience, noting that "the obvious advantage of acquiring knowledge from a map is the relative ease with which the global relationships can be perceived and learned" (Thorndyke and Hayes-Roth 1982, 585).

Other researchers produced evidence that knowledge acquired from maps is more tied to a single orientation than that acquired from direct experience. That is, just as maps of the surrounds tend to be used in an orientation-specific way while viewed during navigation, as discussed above, they tend to be recalled from memory in a fixed orientation, requiring time and error-prone mental transformations to use them in any other orientation. Some researchers suggested that knowledge acquired directly might be stored and accessed from memory in a more flexible manner, so that the information could be used in any orientation just about as quickly and accurately as any other. For example, Gary W. Evans and Kathy Pezdek (1980) found that alignment effects occurred more strongly when human research subjects answered questions about the relative locations of U.S. cities—knowledge presumably acquired from maps—but were weaker when subjects answered questions about places on campus, knowledge presumably acquired from direct experience (see also Presson, DeLange, and Hazelrigg 1989). However, subsequent research by others questioned the meaning of the proposed difference between map-acquired and directly acquired knowledge and whether surrounds are even stored in memory in an orientation-flexible manner at all (Roskos-Ewoldsen et al. 1998).

Psychologists came to the study of perceptual and cognitive cartography later in the twentieth century than did cartographers. (Educational psychologists were an exception.) However, perceptual and cognitive map research by psychologists was a busy enterprise in the last two decades of the century, and it actively continued in the early twenty-first century, when ongoing research examined a wide spectrum of maps and newer forms of geographic symbol systems and technologies, including animations, multiscale displays, sonifications, virtual and augmented environments, and more. Psychologists and others continued to apply a variety of methods to study maps, including analyses of errors in spatial judgments, response times, verbal protocols, and eye movements. The advent of new brain imaging techniques in the late twentieth century, notably functional magnetic resonance imaging (fMRI), fostered innovative studies of the neuroscience of map perception and cognition in the early twenty-first century.

DANIEL R. MONTELLO

SEE ALSO: Academic Paradigms in Cartography; Color and Cartography

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Psychophysics. Perceptual and cognitive cartography is an approach to cartographic research and design that emerged during the twentieth century. This approach recognizes that maps provide symbolic representations to people, offering perspectives on the world that must be interpreted by human minds; maps do not simply present the world to people directly and transparently. Thus, perceptual and cognitive cartographers realize that the content of maps—the information they potentially provide to map viewers—depends not just on the graphical marks placed on the page or computer screen but also on the perceptual and cognitive processes of the viewer.

One of the earliest systematic expressions of the perceptual and cognitive approach to cartography was the application of psychophysics in map design research. Psychophysics is a subdiscipline of experimental psychology that studies the relationship of variation in a physical stimulus dimension, such as the amount of energy emitted by a light source or the concentration of sugar in a solution, to variation in a person's subjective responses to that stimulus, such as perceived brightness or sweetness (Boring 1942). The logic of applying psychophysics to map design, particularly the design of thematic maps, was straightforward and sensible in intent. For example, proportional-area symbols represent the values of a quantitative variable (e.g., graduated circles for population size), according to variations in their graphical area. In order to decode such symbols, map viewers must perceive the area of the symbol and then relate this to the corresponding value of the variable being mapped. It is clear that the map viewer will interpret the symbol according to its perceived or apparent size, not its actual size. If the perceived area of the symbol differs much from its actual area, and if it does so in a sufficiently consistent way across time and viewers, then it makes sense to determine the relationship of perceived area to actual area and use this relationship to design the symbols.

The development of psychophysics played a fundamental role in the emergence of psychology as a separate scientific discipline in the nineteenth century. The year 1879, when Wilhelm Max Wundt opened his psychology lab in Leipzig, Germany, is conventionally identified as its start. Along with Ernst Heinrich Weber and Gustav Theodor Fechner, Wundt was a pioneer in the study of psychophysics. These researchers worked on problems including identifying the absolute and difference thresholds for various stimulus continua, such as the brightness of lights or the volume of sounds. The absolute threshold is the weakest stimulus intensity that can be discriminated from no stimulus; the difference threshold is the weakest increment in stimulus intensity that can be discriminated as an increment. Based on many studies, Weber derived a law (a mathematical equation) that related subjective to objective stimulus magnitude as a logarithmic relationship.

In the mid-twentieth century, the American psychologist S. S. Stevens developed and popularized a slightly different mathematical relationship for subjective and objective stimulus magnitude known as the Power Law (Stevens 1957). The Power Law says that the subjective magnitude of a stimulus equals its actual magnitude raised to the power of an exponent and multiplied by a scaling constant. Such power equations have been empirically derived for a wide range of stimulus types in all of the sensory modalities. Scientific interest has typically focused on the size of the exponent, which indicates a linear relationship when it equals 1.0, an accelerating positive relationship (perceived stimulus magnitude grows more quickly than actual magnitude) when it is greater than 1.0, and a decelerating positive relationship (perceived stimulus magnitude grows more slowly than actual magnitude) when it is positive but less than 1.0.

Perhaps the first explicit call to apply psychophysics to the study of cartographic symbolization came from the German cartographer Max Eckert. He presented ideas about the importance of cartographic perception to the development of cartography as a science most prominently in his two-volume *Die Kartenwissenschaft* (1921–25). In this book, Eckert advocated the application of psychological research to cartography, although he did not describe in detail how this should be done, nor did he present any studies of this kind with maps.

Eckert's call for applying psychophysical research to map symbols was picked up and promoted by the American cartographer Arthur H. Robinson, long-time professor at the University of Wisconsin. In 1952, Robinson published a slim book titled *The Look of Maps*, which was based on his 1947 dissertation at Ohio State University. This book has been widely recognized as seminal in cartography, especially in the area of map design research. In *The Look of Maps*, Robinson cited research by both Weber and Fechner, along with more specific experimental and marketing psychology from the early twentieth century on the perception of lettering, color, and graphical structure. He also cited Eckert, describing him as the only person to examine exhaustively the bases of cartographic method. Robinson called for cartographic researchers to systematically observe and measure—collect data on—how people look at and interpret maps. This call led to, among other things, the application of psychophysical methods to map design research.

Most of the earliest empirical map design research was on the psychophysics of area perception in proportional-area symbols, especially graduated circles but also squares, triangles, and other symbols, including three-dimensional symbols. Among the first examples of psychophysical research applied specifically in a cartographic context was reported by Robinson's student at Wisconsin, James John Flannery, whose dissertation (Flannery 1956) derived a formula to describe the psychophysical function for the area of graduated circles (fig. 665). Based primarily on magnitude-estimation tests given to over 1,000 human subjects (students at various colleges), Flannery's work took the median of the results from several parts of the data and offered the following formula as his best estimate of the relationship of apparent circular area Y_c to actual area X, raised to the power of an exponent and multiplied by a scaling constant (p. 112):

$$Y_c = 0.98365\ X^{0.8747}.$$

About the same time Flannery conducted his studies, Robert L. Williams was conducting similar experiments for the U.S. Office of Naval Research (Williams 1956). Williams's work, which in 1957 became his dissertation at Harvard in the Division of Geological Sciences under Erwin Raisz (Geography no longer formally existed at Harvard), compared filled, outlined, and colored squares, triangles, and stars as well as circles. It also included an early study of gray tone scale perception and observations on the perception of volumetric symbols—spheres and cubes. Averaging the results of several tasks in which viewers matched symbols according to their apparent size, Williams produced tables of visually equivalent symbols (fig. 666). He also derived a power

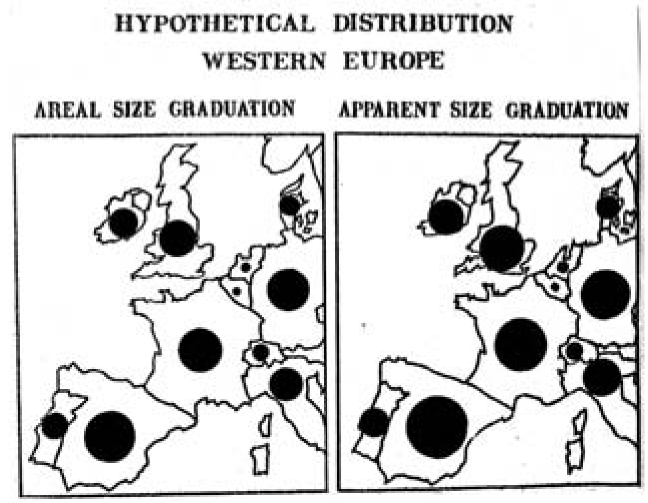

FIG. 665. GRADUATED CIRCLES SCALED ACCORDING TO ACTUAL AREA AND TO APPARENT AREA.
Size of the original: 12 × 15.8 cm. From Flannery 1956, 136 (fig. 20).

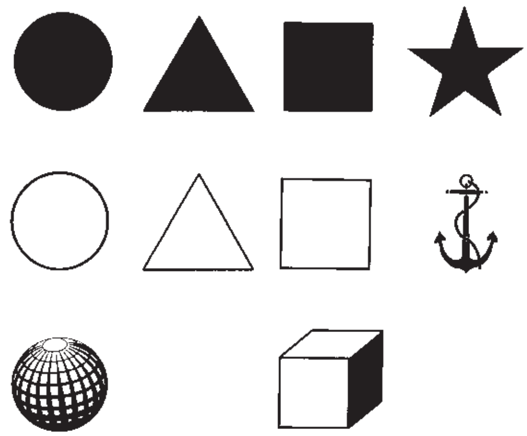

FIG. 666. SYMBOLS FOUND BY WILLIAMS TO BE VISUALLY EQUIVALENT IN SIZE.
Size of the original: 11 × 13.2 cm. From Williams 1956, 38 (fig. 43).

function for symbol size with an average exponent of 0.813. (Williams prudently rounded the exponent to a correction factor of 0.8 [p. 74], in contrast to the spurious precision of Flannery's 0.8747.) This exponent was a little smaller than that reported by Flannery, who commented on Williams's result in his dissertation (p. 134). Flannery was uncertain what the difference in the exponents meant, but he thought that it must have been due in part to the greater variety of stimuli Williams used.

During the next twenty-five years, many additional studies were done on the psychophysics of graduated circles and other proportional-area symbols and on such qualities of cartographic symbols as lightness (value), hue, and dot density (e.g., Castner 1983, 92–98; Ekman, Lindman, and William-Olsson 1963; Kimerling 1989, 692–94; McCleary 1975). However, the value and meaning of psychophysical research in cartography was questioned during the 1970s and 1980s, along with other perceptual and cognitive map design research. Although graduated circles, in particular, were examined in study after study—Kimerling (1989, 692) referred to them as "the 'white rat' of perceptual research"—some writers claimed that work on the Power Law did not add up to conclusions that were very useful to mapmakers. A variety of difficulties were noted with the results of psychophysical studies in cartography. The value of the exponent seemed inconsistent and context dependent. Changing the nature of the map task or the precise design of the test materials often led to variability in the results. Even instructing study participants to estimate apparent size instead of actual size affected the exponent. Other problems included the existence of individual differences—different map viewers produce different exponents. Flannery and Williams both recognized the individual variation in their data but managed to offer single exponents to describe the relationship of apparent to actual circular area by using an average value of some type.

A frequent criticism of psychophysics was that it kept researchers from considering the active thinking mind of the map user (e.g., Petchenik 1975), supposedly because it was part of the paradigm of behaviorism in psychology. Although psychophysics predated behaviorism, and was not particularly closely related to it, there was some validity to criticizing psychophysics for focusing so much on low-level map tasks like feature detection and size perception. In response to some of these critiques, researchers in the 1970s and 1980s began to focus more on higher-level cognitive tasks, like reasoning and inference making; these tasks required a more holistic consideration of relations on maps, not just of isolated symbols. It should be remembered, though, that while a focus on the perception of isolated symbols certainly characterized psychophysical studies, this does not warrant their complete dismissal insofar as such low-level tasks are an essential precondition for seeing anything on a map.

Although psychophysical research in cartography deserved some of the criticism directed at it, its pursuit clearly led to theoretical and practical advances in cartography. For example, perceptual scaling of proportional-area symbols has been shown to work (McCleary 1975, 243), and it has been implemented in the ESRI (Environmental Systems Research Institute) GIS (geographic information system) software ARC/INFO under the label Flannery scaling. As another example, Williams (1956) and others showed conclusively that three-dimensional volumetric symbols do not work; map viewers see spheres as nearly equivalent to circles of the same radius. The logic of such proportional-volume symbols assumes that viewers equate values of thematic variables with perceived volume, rather than perceived area, but this assumption does not hold. Thus, psychophysical research effectively put a stop to the application of what seemed like a clever idea that would have been quite ineffective in practice. Research on color is another success story for psychophysical research. The color scheme developed and tested by Judy M. Olson and Cynthia A. Brewer (1997) for the color vision impaired has been used by the U.S. Center for Disease Control in its *Atlas of United States Mortality* and has been widely applied elsewhere.

DANIEL R. MONTELLO

SEE ALSO: Academic Paradigms in Cartography; Robinson, Arthur H(oward); Visualization and Maps

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Permanent Committee on Geographical Names (U.K.). Geographic (or geographical) names, otherwise known as toponyms, are essentially labels that distinguish one part of the earth's surface from another. As such they must be considered with great care. Because they reflect the human imprint on the global landscape, geographic names provide important information concerning politics and culture. They have long been vital for navigation, communications, trade, census and statistics purposes, planning, the environment, tourism, and a host of other factors necessary for the successful functioning of daily life. In particular, geographic names form a uniquely important part of any map or chart—the part with the most immediately accessible information.

The need to consider the importance of geographic names and avoid the application on official products of carelessly discrepant names and spellings was identified by the British Admiralty as an absolute necessity during World War I. Operations during those hostilities had demonstrated to the British government the dangers involved in using products with discrepant names. As soon as the war ended the Admiralty led an initiative within the British government to form a committee specifically designed to resolve such matters. That initiative led to the establishment in 1919 of the Permanent Committee on Geographical Names (PCGN). The Royal Geographical Society was deemed the natural home for the new committee. Thus the PCGN began life as a committee of that Society, housed in the Society's building and staffed by its personnel, principally Arthur R. Hinks, then secretary of the Society (fig. 667).

Within a short amount of time the volume of work confronting the committee became too great for the Royal Geographical Society's staff to handle on top of their normal duties, and the committee assumed its own independence, though the Society continued to supply the administration for two more decades. Hinks stepped down in favor of the first independently recruited secretary of the PCGN, John H. Reynolds, who assumed the post in 1924. Reynolds was succeeded in 1936 by Marcel Aurousseau, who oversaw a substantial if temporary increase in staff during World War II, when the PCGN was very active in producing gazetteers of areas of operational interest such as Greece (PCGN 1942).

That wartime experience suggested that the administration of the committee ought to be a matter for government rather than the Royal Geographical Society, and in 1949 the Admiralty assumed administrative responsibility for the PCGN. That arrangement continued until 1964, when a widespread reorganization of the civil service in the United Kingdom saw responsibility for the committee pass to the Ministry of Defence and the Foreign and Commonwealth Office, both new creations resulting from a major rationalization and amalgamation of previously existing government departments. Those two weighty ministries jointly financed the committee, the Ministry of Defence providing two thirds of the committee's annual budget and the Foreign and Commonwealth Office providing one third.

Despite the changing administrative and financial circumstances of the PCGN over the years, three essential defining characteristics endured: the interdepartmental nature of the committee, under independent chairmanship; its housing within the Royal Geographical Society, to serve the government's interdepartmental interests without partiality; and the independent recruitment of the committee's own dedicated specialist staff.

The 1940s and 1950s saw work on several glossaries of geographic terms in foreign languages such as Turkish (PCGN 1945) and further gazetteers exemplified by that for Czechoslovakia (PCGN 1958). The same decades saw a revised reprint of the well-received *Alphabets of Foreign Languages* (Gleichen and Reynolds 1956).

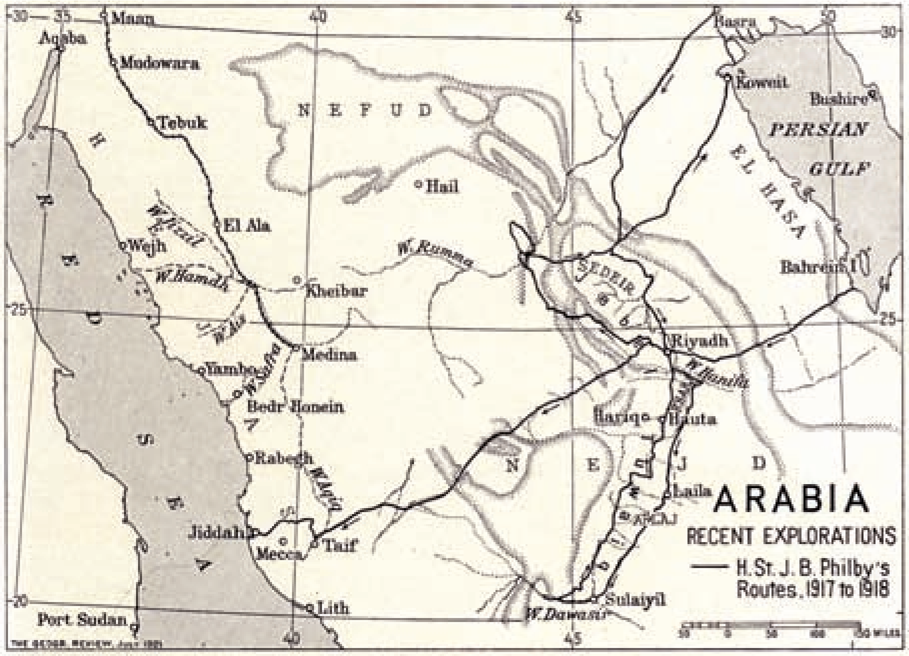

FIG. 1—Sketch map to illustrate recent explorations in Arabia after maps published by the Royal Geographical Society (see footnote 2). Arabic names on the map and in the text of this paper are as spelled by the author. On the vexed question of the transliteration of Arabic names see the note on the Permanent Committee on Geographical Names in the record section of this number of the *Review*.

FIG. 667. MAP OF ARABIA, 1921. The caption of this map, *Arabia: Recent Explorations*, reflects the fact that by 1921, barely two years after its formation, the PCGN had won international respect as a knowledgeable source of information about foreign place-names.

Size of the original: 9.7 × 11.8 cm. From D. G. Hogarth, "Some Recent Arabian Explorations," *Geographical Review* 11 (1921): 321–37, esp. 323 (fig. 1).

In 1955, Aurousseau retired and returned to his native Australia. The secretary from 1955 until 1979 was Patrick Geelan, and upon his retirement Paul Woodman assumed the post. He and two fellow toponymists made up the total staff complement of the PCGN at the beginning of the twenty-first century. The membership of the committee came principally from within government, with various branches of the Ministry of Defence and the Foreign and Commonwealth Office featuring prominently. Valuable representation was also provided by the British Broadcasting Corporation Monitoring Service, the Ordnance Survey of Great Britain, the Royal Geographical Society–Institute of British Geographers, and the Royal Scottish Geographical Society. That last body from 1999 onward provided the chairman of the committee in the person of its director, David Munro.

Much of the committee's work at the end of the twentieth century resembled that of earlier decades. Some techniques had changed, but the nature of geographic names remained constant. Names continued to vary most obviously in a spatial manner, from one location to another. They also changed through time, as demonstrated by name changes such as that from Ciudad Trujillo to Santo Domingo in the Dominican Republic. Equally, the spellings of geographic names altered through changes of political sovereignty; in that way the Kishinev of the Soviet Union mutated into the Chişinău of an independent sovereign Moldova. A change in the orthography of a language could also produce a change of spelling; thus, for example, the traditional spelling Erigavo in Somalia became Ceerigaabo in the relatively new Somali orthography. The name of a feature could also differ across languages; the town in Iraq known as Arbīl in Arabic was known as Hewlêr in Kurdish, while Helsinki in Finland was also officially known by its Swedish-language name Helsingfors. There was also the question of conventional names and their applicability; for instance, the city that in its native Russian form is Moskva is more familiar to Anglophones in the derived form Moscow, either form being appropriate depending on the context.

The role of the committee was to evaluate such geopolitical issues and geographic names developments through the acquisition and analysis of source materials in the world's many diverse scripts and languages. It also established and maintained documents relating to geographic names in areas of interest such as Laos (PCGN 2005) and Kazakhstan (PCGN 2006), and actively supported the work programs of the organizations represented on the committee. Most of the committee's work was in support of mapping programs, database projects, and intelligence requirements within the British government.

The work was all designed to meet the committee's continuing and overriding objective, which was to advise the British government on policies and procedures for the proper writing of geographic names for places and features outside the United Kingdom, excluding those of the Antarctic. One of the principal objectives of the PCGN was to establish and apply the principles by which foreign geographic names should be written. That task involved determination of the written form of a toponym, as established by the official agencies of a foreign country, and romanized to an agreed system where appropriate. The PCGN did not itself create any geographic names, nor did it concern itself with toponymic etymologies. The PCGN sought to develop, maintain, disseminate, and promote policies based on those principles. That work involved advising how British official products could best reflect each foreign country's official national toponymic policies.

Another objective was to ensure interdepartmental service to the British government through the provision of approved geographic names. There could be more than one correct solution to any given toponymic requirement, depending on the context within which the requirement was couched.

The work of the PCGN also involved promoting the international standardization of geographic names by representing the British government within the biennial United Nations Group of Experts on Geographical Names and at the United Nations Conferences on the Standardization of Geographical Names held every five years. Another responsibility was to seek policy harmony with the U.S. Board on Geographic Names (BGN) concerning issues such as romanization system standards, by means of biennial BGN/PCGN conferences and regular ongoing liaison. The final item on the PCGN's list of objectives was to maintain a close relationship with organizations such as the U.K. Antarctic Place-names Committee and the British Standards Institution.

PAUL WOODMAN

SEE ALSO: Board on Geographic Names (U.S.); Geographic Names: (1) Social and Political Significance of Toponyms, (2) Applied Toponymy; Indigenous Peoples and Western Cartography; Royal Geographical Society (U.K.); United Nations

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Perspective Views. See Oblique and Perspective Views

Persuasive Cartography. Although *persuasive map* is a relatively recent term, maps have been used with the intention of influencing the opinions or beliefs of readers for centuries. In the late nineteenth and early twentieth centuries, when cartography was emerging as an academic discipline rather than merely a craft, scholars were troubled by the subjective aspects of mapping, especially generalization and symbolization. Max Eckert's classic 1908 paper examined the ways in which generalization, projection, and color can mislead or introduce bias. Eckert noted that generalization epitomized "the difficulty of scientific map-making, for it no longer allows the cartographer to rely merely on objective facts but requires him to interpret them subjectively. To be sure the selection of the subject matter is controlled by considerations regarding its suitability and value, but the manner in which this material is to be rendered graphically depends on personal and subjective feeling. But the latter must not predominate" (Eckert 1908, 347). In not acknowledging that bias is inherent in map generalization, Eckert endorsed the prevailing scientific view that maps could be objective.

World War II brought about increased interest in maps and power. Both sides created propaganda maps, and a number of often-cited articles addressed the topic, most notably by sociologist Hans Speier (1941) and by geography professor Louis Otto Quam (1943). Both authors dissected several blatant propaganda maps, oddly ignored in books and articles on the use of propaganda in movies, cartoons, fiction, and comic strips. Speier wrote: "Maps are not confined to the representation of a given state of affairs. They can be drawn to symbolize changes, or as blueprints of the future. They may make certain traits and properties of the world they depict more intelligible—or may distort or deny them. Instead of unknown relationships of facts they may reveal policies or illustrate doctrines. They may give information, but they may also plead. Maps can be symbols of conquest or tokens of revenge, instruments for airing grievances or expressions of pride" (1941, 310–11).

Wartime propaganda maps were also examined by Richard Edes Harrison, a cartographic illustrator for *Fortune* magazine, and Walter W. Ristow, at the time assistant chief, U.S. Library of Congress's Geography and Map Division. Harrison (1943) criticized the misuse of the Mercator projection and recommended azimuthal projections as more appropriate for an air-age war. His essay predates by several decades the complaint by German historian Arno Peters that cartographers had blatantly promoted the "Eurocentric" Mercator projection for thematic and reference maps. Ristow (1957) called attention to the wide use of persuasive mapping in the United States in newspapers and news magazines and critiqued several examples. Another prominent wartime critic of persuasive cartography was the U.S. State Department's chief geographer, Samuel Whittemore Boggs, whose cleverly titled essay "Cartohypnosis" (1947) examined ways in which readers might be misled by maps.

Probably the most significant contribution from this period came from John Kirtland Wright, librarian at the American Geographical Society and an authority on the history of geography. Wright looked at all of the subjective elements with an eye to educating readers about the power of maps: "Like bombers and submarines, maps are indispensable instruments of war. In the light of the information they provide, momentous strategic decisions are being made today: ships and planes, men and munitions, are being moved. Maps help to form public opinion and build public morale. When the war is over, they will contribute to shaping the thought and action of those responsible for the reconstruction of a shattered world. Hence it is important in these times that the nature of the information they set forth should be well understood" (Wright 1942, 527).

In the late 1960s and 1970s, when academic cartography embraced the communication paradigm, an eagerness to make maps more effective raised questions about how they communicated ideas. Judith A. Tyner's doctoral dissertation (1974) coined the term *persuasive cartography* to encompass propaganda maps, advertising maps, journalistic maps, and maps for real estate promotions, and by chambers of commerce, political organizations, and environmental organizations. Although these maps share the objective of persuading the reader in some way, to make a point or sell a product, previous cartographic scholars had treated them as separate entities.

Tyner deliberately used *persuasive* to counter the negative connotation of *propaganda*, which originally referred merely to propagating or disseminating information. In the aftermath of World War II and throughout the Cold War, *propaganda* was equated with evil—lies, deliberate distortions, misinformation—whereas *persuasion* implied an appeal based on logic or inducement rather than false assertion. Although this distinction might seem subtle, propaganda maps are persuasive, whereas persuasive maps are not necessarily propaganda. In this vein, Tyner looked at the ways in which the map elements of symbols, projection, text, title, and color could be manipulated to create a persuasive message, which could be subtle or blatant.

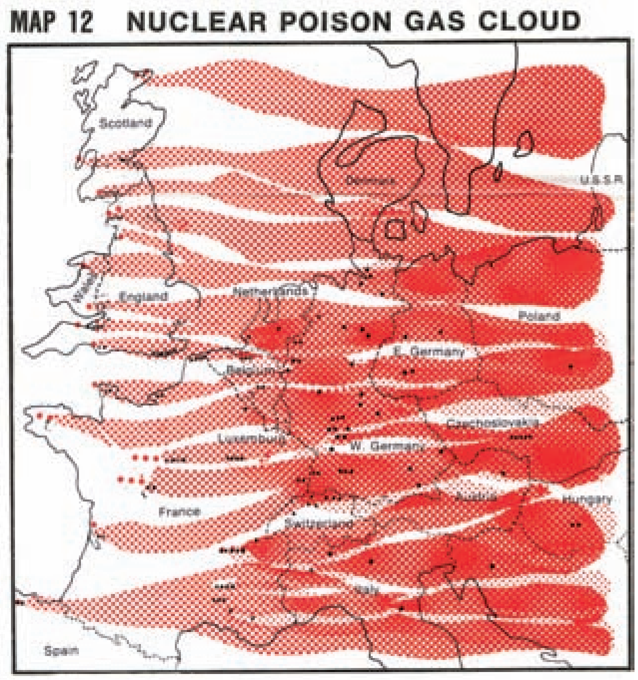

FIG. 668. WILLIAM BUNGE, *NUCLEAR POISON GAS CLOUD*, 1982. Red for danger is the only color used in Bunge's original broadside *Nuclear War Atlas*.
Size of the entire original broadside: 49.7 × 84.5 cm; size of detail: ca. 9.8 x 9.2 cm. From Bunge 1982, map 12.

Tyner's was not the only study of subjective cartography during this period. In 1977 and 1991, Mark Monmonier published books on the topic, and in the late 1960s and early 1970s radical geographer William Bunge advocated the use of "descriptive maps" for propaganda and agitation (1979, 172). In contrast to the more abstract, comparatively sterile maps used to illustrate scientific studies, Bunge's descriptive maps relied on persuasive elements to make their case. An example is a collection of maps illustrating various dangers of nuclear weapons and atomic power (fig. 668). Originally printed on both sides of a large (51 × 87 cm) sheet of paper, folded into a smaller, familiar format of a conventional folded road map, his *Nuclear War Atlas* was self-published in 1982, with the imprint of his Society for Human Exploration. It was commercially released in book format in 1988.

One reason that maps are persuasive is that the general public had long accepted printed maps as truthful and expected them to be accurate. Toward the century's end, even maps on the Internet, notorious for deliberate or inadvertent errors, were widely accepted as true representations of reality—users of MapQuest and other online mapping services often expressed a sense of betrayal whenever the website delivered a customized road map with a needlessly circuitous or erroneous route. In fact, some readers might have been more easily misled because they erroneously assumed that because a computer made a map, it is free from human error or bias.

Tyner's early work on persuasive cartography was problematic in distinguishing objective maps from propaganda maps—a false dichotomy that harks back to Eckert and others who cautioned scientific cartographers to avoid bias. A more reasonable approach recognizes a cartographic rhetoric, similar to the rhetoric of the written word, whereby explanation, description, narration, and persuasion create a continuum from expository cartography to persuasive cartography, or from objective to subjective. Of course, in both cartography and writing, even exposition has bias. Moreover, the spectrum's opposite ends are fictitious insofar as there is no purely persuasive map or text—although some propaganda maps comes close—and many maps combine elements of explanation and persuasion. Tyner (1982) replaced the dichotomy with a continuum.

A second problem involves the map author's intent. Was a given map deliberately created to persuade, or was the apparent attempt at persuasion an accident? After all, a map author can create a persuasive map inadvertently with a poorly worded title, a poor choice of symbol or color, or an inappropriate projection. For example, casting a small-scale world map on the well-known Mercator projection, devised for maritime navigation but also useful on large-scale maps of small areas, easily diminishes the prominence of the Third World while distorting relative area and the shapes of continents. Unless the map author provided notes for the map, which is rarely the case, there is usually no reliable way to determine whether the persuasion was deliberate or accidental. Indeed, seemingly innocent lines or words on a map have caused international incidents, as in 2004, when the words "Arabian Gulf" in parentheses beneath the name "Persian Gulf" in a National Geographic Society atlas so angered Iranians that the government embargoed its magazines and atlases and even refused to let its journalists into the country. J. B. Harley's provocative essay "Deconstructing the Map" (2001, 149–68), originally published in 1989, drew upon literary theory to look at maps as texts that could be deconstructed. In this philosophy the actual intent of the author is of little consequence.

Since the 1980s cartographic scholars, citing both historical and modern maps, have argued that maps are not free of bias, that they can and do tell lies, that they have power, that they hide or distort information, and that they are used to persuade. Notable works include those by Monmonier (1991), Denis Wood (1992), and Jeremy Black (1997). Harley's essays on maps and bias were collected in 2001, and "the power of maps" became a recurrent theme in the history of cartography. Although geopolitical studies involving maps have sometimes used persuasive cartography, the term was often used as a synonym for propaganda maps imbued with evil and lies.

In many cases, though, a clearly persuasive map, its intent readily apparent from its context, reflects a conscious manipulation of map elements. Generalization—the need to reduce and simplify the larger world's geographic complexity—provides a toolbox that includes feature selection, symbolization, text, color, and projection.

Selection for persuasion involves choosing to map facts that support the map author's argument and omitting those that do not. It works because the reader is often unaware that the "whole truth" is not being shown. For example, a developer eager to build in an earthquake-prone area might neglect to show a fault running through the area. The increased use of maps in the twentieth century to advertise development projects and illustrate assessments of environmental impact provided an increased opportunity for persuasive selection of map content, but it's doubtful that deliberate obfuscation was ever successful in overcoming strong local opposition. A more effective strategy was to overwhelm the map reader with details in an effort to obscure crucial relationships or create the impression that an analysis was systematic and thorough.

Map projection can be particularly effective in creating a different perception or point of view by manipulating distances, shapes, and areas. When the menu of recognized mathematical transformations was inadequate, a clever map author might use an ad hoc cartogram. At the turn of the twentieth century, for example, railroad maps commonly distorted rail lines and even the sizes of states, thereby creating the impression of a more direct route. Because these cartograms linked distortion of area and the generalization of shape to provide space for naming many of the numerous places that the rail company served, the obvious distortion was at least as purposeful as it was persuasive—perhaps the reason why travelers and shippers accepted the map's contrived geometry as appropriate while cartographic scholars found it intriguing if not malevolent.

Displacement, another form of map generalization, proved useful for strategic purposes as well as persuasion. During the Cold War, for instance, Soviet maps and atlases shifted some cities away from their actual locations for strategic purposes, to raise doubts about the accuracy of captured maps and geodetic data (Monmonier 1991, 115–18). And a century earlier, during the Australian gold rush, a map that falsely showed Melbourne as closer to the gold fields than Geelong fostered the former city's rapid growth and its selection as the state capital (Tyner 1974, 41).

Individual point symbols are probably the most obvious elements of a persuasive map, and in many cases they are what distinguishes an "objective" map from a persuasive one. Because many persuasive maps use simple symbols that are easy to interpret, a legend is often unnecessary. The symbols are usually pictorial and may have a high emotional impact. Karl Haushofer (1928) called them "suggestive symbols," for example, shadows and encirclement, which implied or suggested threatening situations—the shadow of fascism perhaps, or the encirclement of a country by its enemies. Other suggestive symbols include the octopus (fig. 669), used on maps at least as early as 1870, as well as equally connotative sharks (fig. 670) and tanks. Dynamic symbols, such as arrows and bomb bursts, which give an impression of action or movement, were also used widely during the twentieth century on persuasive maps.

A more subtle form of persuasion involves the manipulation of symbols and categories on choropleth maps, the most common method of portraying census results and similar statistical data. Choropleth maps used uniform color or gray tone symbols within areal units such as countries, states, counties, and census tracts to describe trends in quantitative data. If data are used in raw form, such as population counts, rather than population densities, and if the enumeration areas are not of uniform size, the results are often misleading. For example, the counties in California vary widely in size from tiny San Francisco County with forty-seven square miles to San Bernardino County, the largest county in the United States, with over 20,000 square miles. If both units have the same number of residents of a particular ethnic group and both are filled with the same symbol, San Bernardino county appears to have a far more massive concentration. By contrast, if the data are normalized to population per square mile, the impression is quite different. During the latter part of the twentieth century

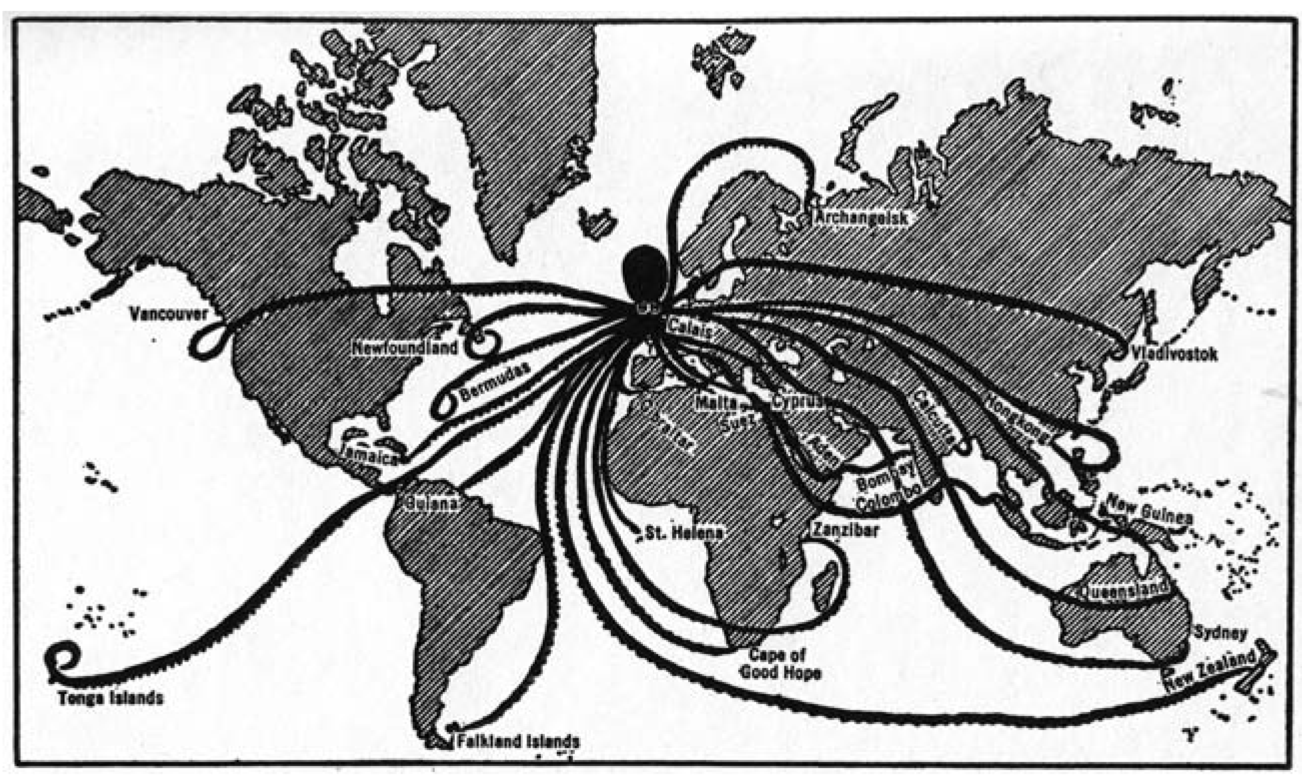

FIG. 669. A SUGGESTIVE SYMBOL—THE OCTOPUS REPRESENTING THE BRITISH EMPIRE. Nazi propaganda map. Size of the original: 9.8 × 16.9 cm. From Andreas Dorpalen, *The World of General Haushofer: Geopolitics in Action* (New York: Farrar and Rinehart, 1942), 15. Permission courtesy of Peter Dorpalen and Bruce Dorpalen.

FIG. 670. ROBERT M. CHAPIN, SUGGESTIVE SYMBOL OF SHARKS SEVERING LINES.
Size of the original: 21.1 × 5.7 cm. From *Time* Magazine, 20 April 1942, 23.

this type of misleading map often arose unintentionally when an inexperienced mapmaker used computer software not designed to distinguish between count and intensity data. When used to map disadvantaged or otherwise anomalous ethnic groups, conceptually erroneous choropleth maps that appear to be objective can foster racist fears. And even when choropleth mapping is used to map intensity data, an innocent or deliberate selection of inappropriate category breaks or map symbols can show misleading trends.

Color is used symbolically on persuasive maps to draw upon existing connotations. Most cultures have color associations. For instance, Americans can "see red," "paint the town red," "feel blue," use "blue language," or label a coward "yellow," while a novelist might write "purple prose" and a newspaper indulge in "yellow journalism." In the Western world, white is the color of weddings and purity, and red symbolizes danger, while in some Asian countries red is the color of weddings, and white is the color of mourning. Ethnic groups may be stereotyped by colors—pejoratives like "yellow peril" (for late nineteenth-century Chinese immigrants) and "redskins" (for Native Americans) were anathema in polite society well before the century's end, while red was used verbally and cartographically through the early 1990s to connote the threat of Communism. These subjective associations were exploited on persuasive and propaganda maps, particularly in the twentieth century, when color printing became less expensive and more common.

The cartographer's intent is most easily identified in the text and title of a map. Following the rules of propaganda, the cartographer will use stereotypes, name calling, selection, lying, repetition, assertion, pinpointing the enemy, and appeals to authority in the text and title of persuasive or propaganda maps (fig. 671). During the 1960s a map displayed prominently at Los Angeles International Airport proclaimed modestly "Los Angeles, Center of the World" (Tyner 1982, 144). This was the epitome of a chamber of commerce map.

Although persuasive maps were used in many ways throughout the twentieth century to illustrate many subjects, maps used during wartime or for postwar political propaganda have received the most attention, partly because they appeared in newspapers and newsmagazines, where they were widely seen (and were readily available to cartographic scholars). During World War II, maps and atlases were produced for distribution in the United States by the German Library of Information, headquartered in New York, where it published the periodical *Facts in Review*. Although maps produced on the home front for popular magazines are generally not considered propaganda, they were hardly free of bias (fig. 672). Robert M. Chapin's maps in *Time* magazine during the 1940s and 1950s were rich in persuasive ele-

FIG. 671. BILLBOARD IN KHABAROVSK, USSR, 1978. The name "Lenin" appears in several languages; the image implies that Leninism is worldwide, and the sign on the left says Leninism is sweeping the planet.
Image courtesy of Gerald E. Tyner.

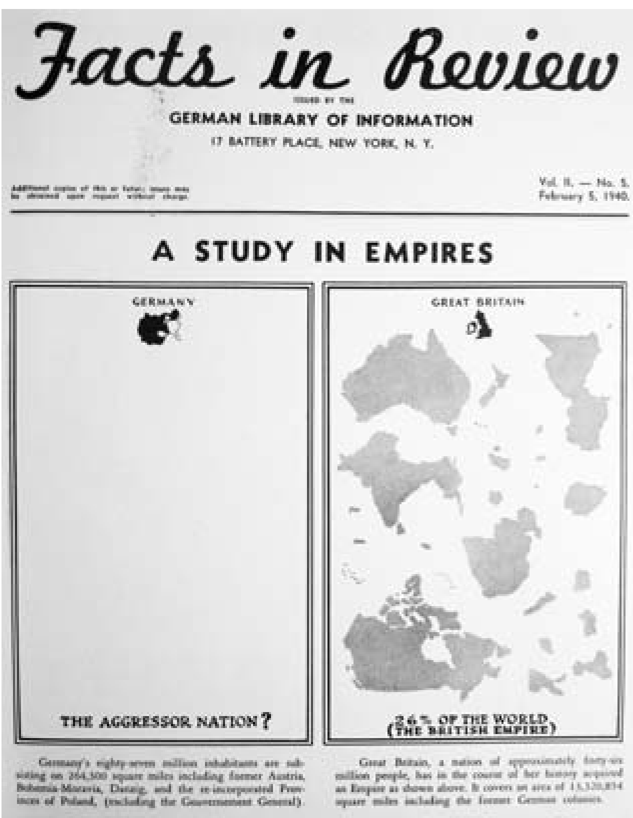

FIG. 672. *A STUDY IN EMPIRES*, 1940. Nazi propaganda map.
Size of the original: 24.2 × 17.8 cm. From *Facts in Review*, vol. 2 (5 February 1940), 33.

ments (see fig. 670 above), as were Charles Hamilton Owens's maps for the *Los Angeles Times* (see figs. 427 and 428) (Cosgrove and della Dora 2005). In addition, persuasive maps have been used on editorial pages and in political cartoons to address issues of international (fig. 673), national, or purely local concern. Designed so that the reader gets the point quickly, cartoon maps typically mixed suggestive symbols with short, pithy, and often humorous titles and text. Politically persuasive maps were also used during the Cold War on billboards and magazine covers in both the United States and the Soviet Union.

Maps have also been used widely in advertising to reinforce a brand's slogan or public image as well as help potential customers find a store. In 1905 the Sherwin-Williams Paint Company adopted a logo that epitomized map-assisted branding by calling attention to its worldwide operations by juxtaposing a paint-covered globe with the words "We Cover the World" (fig. 674). Advertising maps focused on location have been distorted purposely to foster impressions of proximity, pervasiveness, or direct, efficient access.

Maps have been used to sell real estate since the seventeenth century, when John Farrar produced a map of Virginia that described New Albion (California) and the Pacific Ocean as a ten-day journey on foot through rich valleys and "proffitable rivers" (Tyner 1987, 458), but suburban growth and condominium developments attached to resorts led to a marked increase during the twentieth century. In this context, cartographic symbols promising large shade trees, convenient golf courses, and swimming pools were used to suggest an aesthetically pleasing, carefree future. Persuasive maps created by landscape architects and traffic engineers were also used to sell proposed developments to local officials who had to evaluate possible negative impacts.

Political campaigns have also stimulated persuasive cartography, particularly to argue for ballot propositions with geographic overtones. During the women's suffrage movement in the United States, for instance, several maps were made showing the status of women's suffrage in different states. Created by nonprofessionals, the suffrage map of 1913 was particularly effective. The map itself and its legend are straightforward, but the text "The Map Proves It" and "Won't you help us make Texas white?" is an example of persuasive text (fig. 675). "Make Texas white" had a double meaning insofar as making Texas one of the states with full suffrage, which were illustrated in white, would also increase the white vote by giving white women voting rights.

The environmental movement generated numerous maps to help the public understand the plight of endangered species, the decimation of wild lands, and the threat of global warming. At the century's end this type

FIG. 673. A POLITICAL CARTOON MAP BY DOUG JOHNSON. The USSR is symbolized as a bear.
From *Time* magazine, 15 January 1979, cover.

FIG. 674. THE SHERWIN-WILLIAMS LOGO. Adopted in 1905, it is one of the most recognizable logos and persuades the reader that it is the biggest brand of paint on earth. Detail from a two-page advertisement.
Size of the entire original: 34.4 × 51.3 cm; size of detail: 13.6 × 24.4 cm. From the *Saturday Evening Post* 191, no. 13 (28 September 1918), 58–59.

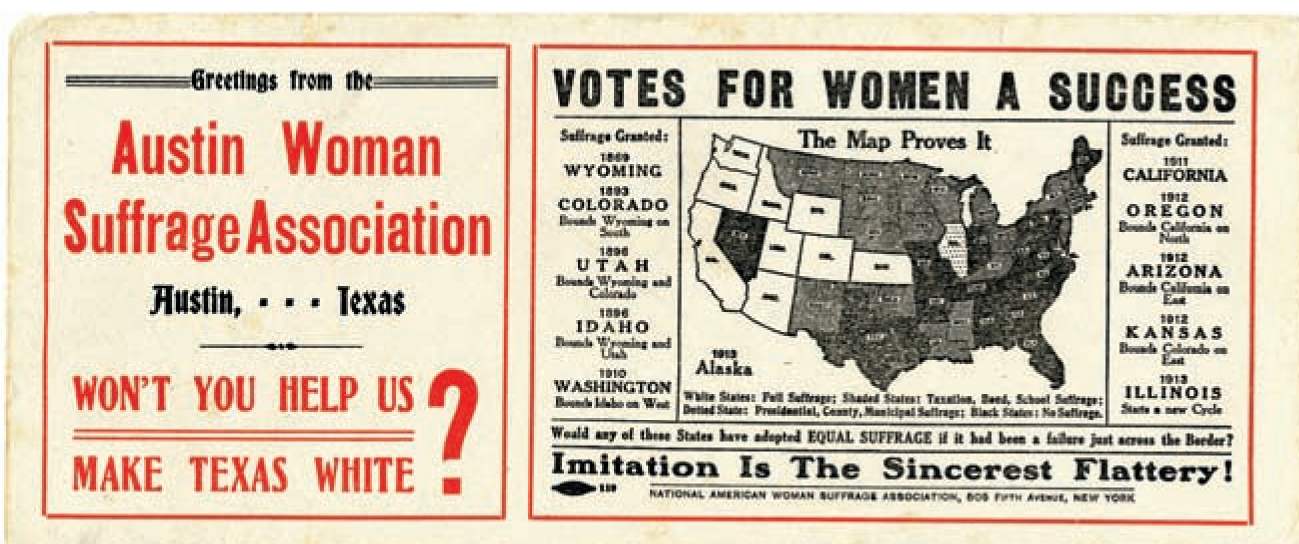

FIG. 675. WOMAN'S SUFFRAGE BROADSIDE, 1913.

Size of the original: 9.5 × 22.7 cm. Image courtesy of the Texas State Library and Archives Commission, Austin.

of intrinsically persuasive mapping was prominent and growing.

Persuasive maps can take many forms. While the most noticeable examples are found in news publications, television, and film or video documentaries, persuasive maps are also noticeable on T-shirts, bandannas, postcards, bumper stickers, paper placemats, and other oddities or decorations. During World War II propaganda maps appeared on Japanese kimonos. Twentieth-century advances in screen printing and other image transfer technologies facilitated this use of maps.

While there is no textbook on making persuasive maps, various books and articles have encouraged their creation. Organizations and individuals with agendas have been instructed on how to make maps to "sell" a subject or to make a point by books like *Boundaries of Home: Mapping for Local Empowerment* (1993), edited by Canadian First Nations advocate Doug Aberley. Although the term *persuasive cartography* is not used, the notion of putting mapmaking in the hands of native peoples and creating empowering images in the process clearly indicates a persuasive intent.

Bunge encouraged making maps for social change and created numerous examples. His Geographical Expeditions in Detroit and Toronto yielded a variety of jarring maps showing, for example, "Potential Regions of Child Loneliness or Overcrowding," "Fly Covered Baby Regions," and the "Region of Rat-Bitten Babies," all geared to reveal the indignity of urban poverty (Bunge and Bordessa 1975, 195, 283, 326). His controversial *Nuclear War Atlas* (see fig. 668 above) exemplifies the ability of provocative persuasive cartography to draw attention to social and political problems.

A series of persuasive atlases published by Penguin Books had their beginnings in the late twentieth century. These include *The State of the World Atlas* (1985), *The State of Women in the World Atlas* (1997), *The State of War and Peace Atlas* (1991), and *The Penguin Atlas of Endangered Species* (2002). All of the atlases in this series utilize persuasive elements, especially selection of subject matter and choice of symbols.

In the 1990s maps on the Internet and the related field of cybercartography emerged as fertile settings for persuasive maps, both deliberate and accidental. After the initial exhilaration of being able to create multimedia and interactive online maps, researchers began to look at the social implications and the subjective elements of these maps, including the related issue of public trust. *Maps and the Internet*, edited by Michael P. Peterson (2003), and *Cybercartography: Theory and Practice*, edited by D. R. F. Taylor (2005), contain chapters on the subjective aspects of mapping, and scholars like Jeremy W. Crampton, John Pickles, and Mark Monmonier have examined various aspects of modern technology and cybercartography. With an increased democratization of cartography likely in the twenty-first century, persuasive cartography is poised to remain a significant force in mapping.

JUDITH A. TYNER

SEE ALSO: Advertising, Maps as; Forensic Cartography; Journalistic Cartography; Narrative and Cartography; Peters Projection; Political Cartoons, Maps as

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Petchenik, Barbara B(artz). Born in Suring, Wisconsin, in 1939, Barbara Petchenik (nee Bartz) received her BS degree from the University of Wisconsin–Milwaukee in 1961. Her MS (1964) and PhD (1969) degrees in geography were from the University of Wisconsin–Madison under the tutelage of Arthur H. Robinson.

During her doctoral studies and immediately thereafter, Petchenik was cartographic editor and staff consultant in research and design for *World Book Encyclopedia*, performing research studies on children's abilities with maps and translating the findings into practical improvements in *World Book* cartography. From 1971 to 1975 she served as cartographic editor of the *Atlas of Early American History: The Revolutionary Era, 1760–1790* (1976). Petchenik became noted for the innovative design of a series of military campaign maps in the atlas as well as for its overall design. The atlas maps were printed by the R. R. Donnelley & Sons Company, and in 1975 she moved to Donnelley Cartographic Services, Mapping Services Division, where she became a senior sales representative. She remained with Donnelley until her death in June 1992, after a short illness.

Among Petchenik's noteworthy achievements was her coauthorship, with Robinson, of *The Nature of Maps* (1976), one of the few books by cartographers to explore the fundamental nature of maps and their place in philosophy. Petchenik served as a member of the Mapping Science Committee, organized under the auspices of the National Academy of Sciences and National Research Council, and she was the principal author of the committee's 1990 report, *Spatial Data Needs: The Future of the National Mapping Program*. Her more than fifty articles, reviews, and essays in the professional literature focus on children's cognition of maps and the theory and practice of map design.

Petchenik was a member of the U.S. National Committee for the International Geographical Union and the original editorial board of the *American Cartographer*. She chaired the U.S. National Committee for the International Cartographic Association (ICA), and in 1991–92 served as a vice president of the ICA, the first woman to hold that position. Upon her death, the ICA established the Barbara Petchenik Children's Map Design Competition, which recognizes outstanding maps drawn by the children of the world.

Throughout her career Petchenik integrated scholarly research on the nature of spatial knowledge and mapping with active participation in commercial cartography. With deeply caring personal concerns for each individual who knew her, she maintained the highest standards of professionalism in her own life and work and expected similar behavior from those with whom she worked. She had an extraordinary intellect and was adept at juggling both the ideal and the practical.

Her early death from cancer deprived twentieth-century cartography of one of its potentially preeminent scholars as well as an articulate spokesperson and a staunch advocate for the increased use and understanding of maps and spatial data by all peoples.

JOEL L. MORRISON

SEE ALSO: Children and Cartography; Robinson, Arthur H(oward); Women in Cartography

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Robinson, Arthur H., and Barbara Bartz Petchenik. 1976. *The Nature of Maps: Essays toward Understanding Maps and Mapping*. Chicago: University of Chicago Press.

Petermanns Geographische Mitteilungen. In 1855, with geography emerging as a scholarly discipline then committed to scientific exploration, the German publishing house Justus Perthes inaugurated a journal that not only balanced scholarly articles for academics with travel accounts for an educated bourgeoisie but also illustrated both with innovative maps. Quickly referred to as "Petermanns Mitteilungen," in honor of its founding editor, August Petermann, the new periodical became a scholarly and commercial success as a leading chronicler of scientific travels and reviewer of geographic-cartographic literature as well as a benchmark for maps on global exploration. In contrast to its rivals—at least until after World War II—it was the only privately managed, profit-oriented, and internationally recognized journal featuring articles and maps prominently that was published without the backing of a professional association such as a geographical society or state institution.

First published in March 1855 as *Mittheilungen aus Justus Perthes' Geographischer Anstalt über wichtige neue Erforschungen auf dem Gesammtgebiete der Geographie von Dr. A. Petermann*, the journal was renamed *Dr. A. Petermann's Mittheilungen aus Justus Perthes' Geographischer Anstalt* in 1879 (vol. 25), and *Petermanns Geographische Mitteilungen* in 1938 (vol. 84) (with a hiatus from April 1945 [vol. 91] to July 1948 [vol. 92]). Published as a monthly until World War I (fig. 676), it then oscillated between a quarterly and a monthly, its frequency and cartographic content fluctuating with Germany's transition through war, depression, and recovery. The final issue appeared in December 2004 (vol. 148).

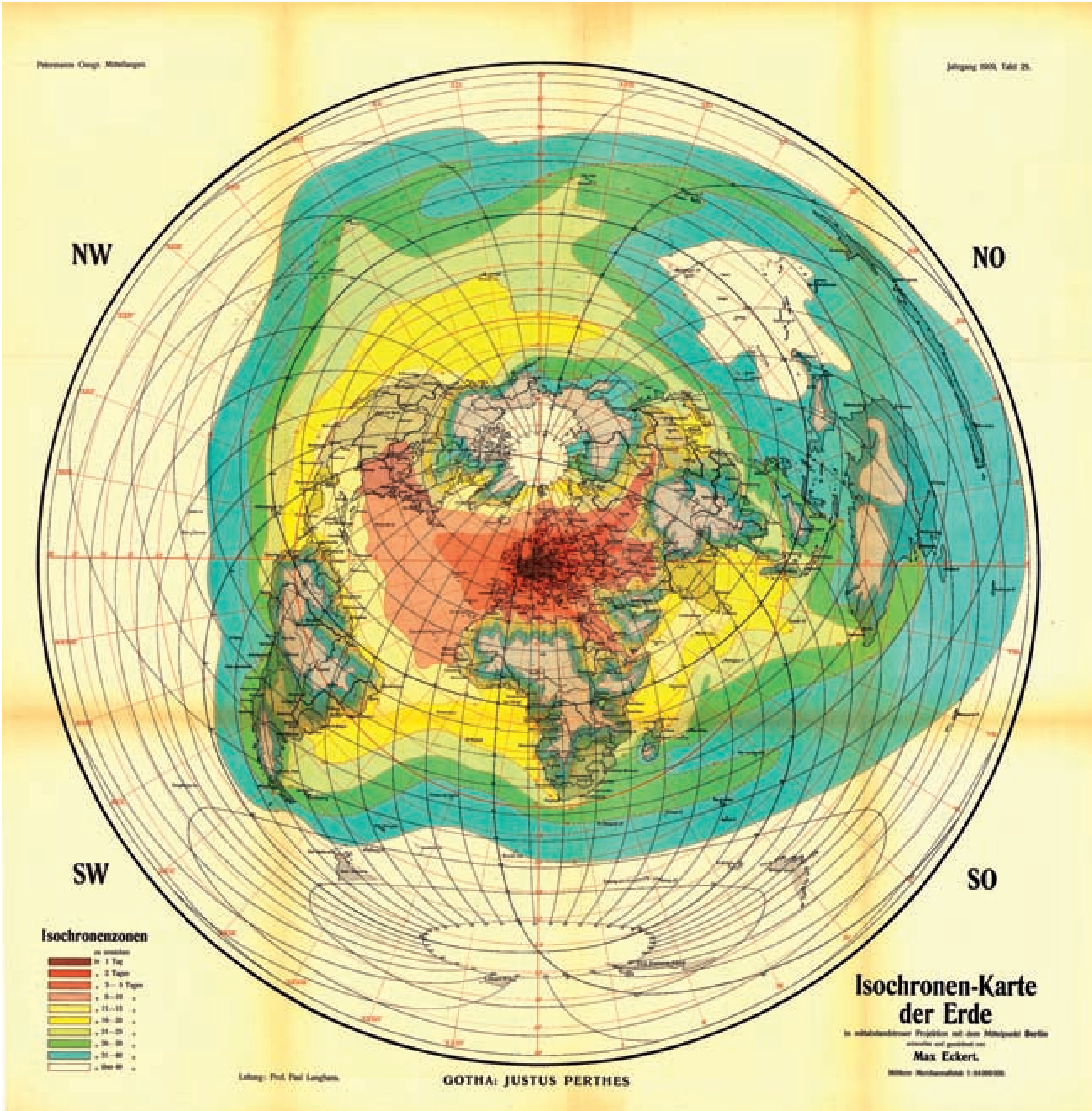

FIG. 676. MAX ECKERT, *ISOCHRONEN-KARTE DER ERDE IN MITTELABSTANDSTREUER PROJEKTION MIT DEM MITTELPUNKT BERLIN*, 1909. Isochronical map of the world in true central distance projection showing the equidistant lines of day travel from Berlin. For a detail, see figure 122.

Size of the original: 65.2 × 64.5 cm. From Max Eckert, "Eine neue Isochronenkarte der Erde," *Petermanns Geographische Mitteilungen* 55 (1909): 209–16, 256–63, pl. 25.

Supplemental volumes (*Ergänzungshefte*), containing a number of articles, were introduced in 1860. By the twentieth century these had become lengthy scholarly monographs (i.e., 1900–1995, nos. 131–289). Especially valuable to map historians are the ninety-one volumes published between 1900 and 1944, which contain 479 maps, mostly topographic or thematic.

Around 1900 *Petermanns* had lost many individual subscribers after Alexander Supan, its third editor (1885–1908)—but the first academic—abandoned the proven formula and refocused the content toward the interests of institutional scholars. The review section, which made up about 40 percent of the journal and assessed up to 3,000 titles annually, provided an internationally comprehensive coverage that became the journal's second trademark, after its maps.

Paul Langhans, a cartographer trained in-house, became the fourth and longest serving editor (1909–37). He changed course by reducing the review section and discontinuing Hermann Haack's unique column, "Kartographischer Monatsbericht" (1909–11). In their place, he added the supplement on military geography (1909–14), and in 1911 absorbed the popular geography journal *Globus* (founded in 1862). Langhans refocused *Petermanns* toward human geography and travel accounts and added halftone photographs. The increased content necessitated a division into two annual volumes (*Halbbände*) between 1910 and 1914. The first volume for 1912, in some respect a peak for the journal, ran to 368 pages, included twenty-nine larger articles, and was illustrated with twenty-six colored and sixteen black-and-white maps and fifty-one photographs.

Although the journal was drastically reduced in size, thematic scope, cartographic artwork, and overall internationality after World War I (fig. 677), still a tenth of the articles covered cartography. By the 1930s physical

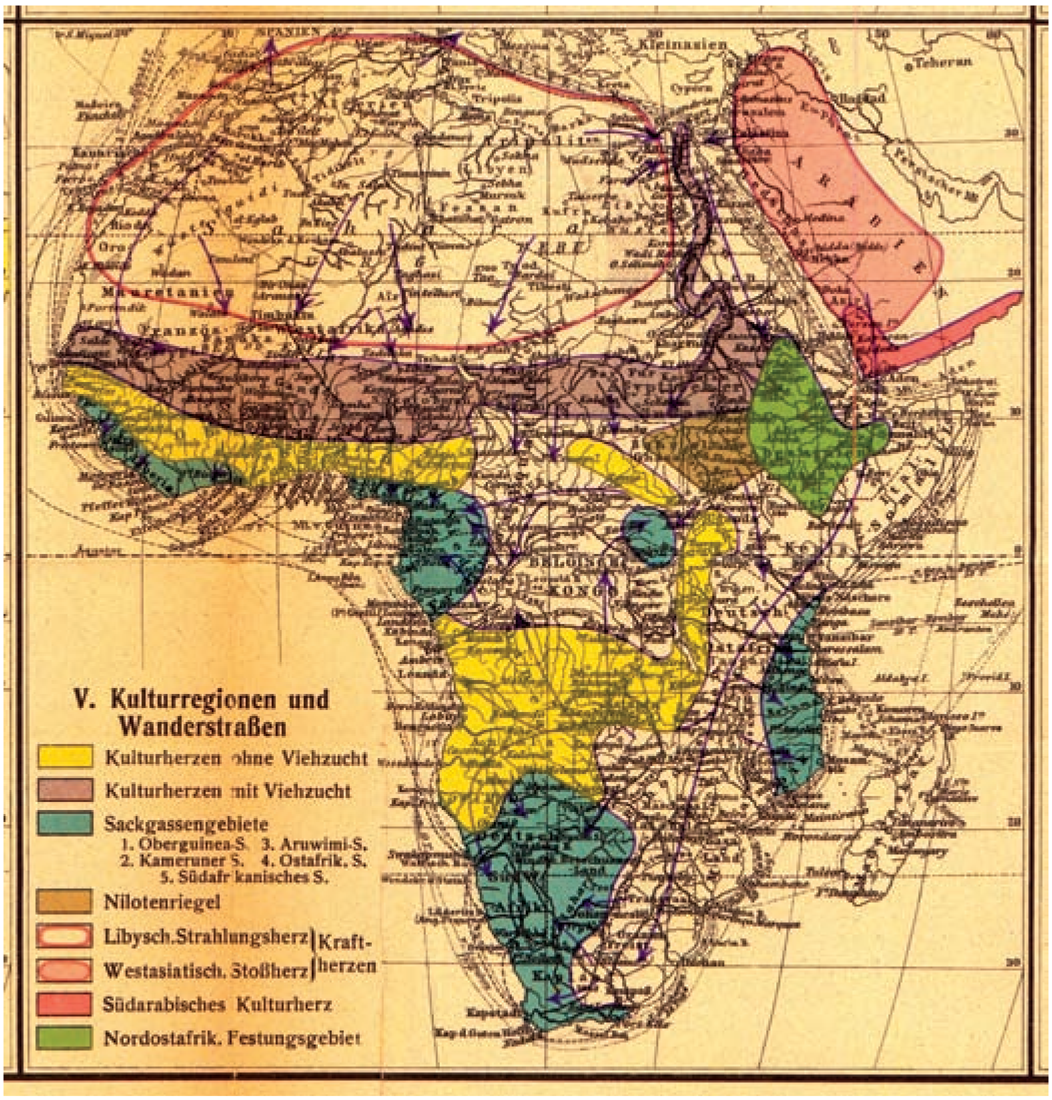

FIG. 677. SIEGFRIED PASSARGE, *KULTURREGIONEN UND WANDERSTRAßEN*, 1924. Part V of *Politische-geographische Karten von Afrika für die Zeit vor dem Eingreifen der Europäer*. Early geopolitical map of precolonial Africa postulating zones of activity (*Kraftherzen*), barriers (*Nilotenriegel*), and dead end regions (*Sackgassengebiete*).

Size of the entire original: 30.2 × 41.6 cm; size of this map: 14.3 × 13.8 cm. From Siegfried Passarge, "Die politische Erdkunde Afrikas vor dem Eingreifen der europäischen Kolonisation," *Petermanns Geographische Mitteilungen* 70 (1924): 252–61, pl. 18, map V. © Ernst Klett Verlag GmbH, Zweigniederlassung Gotha.

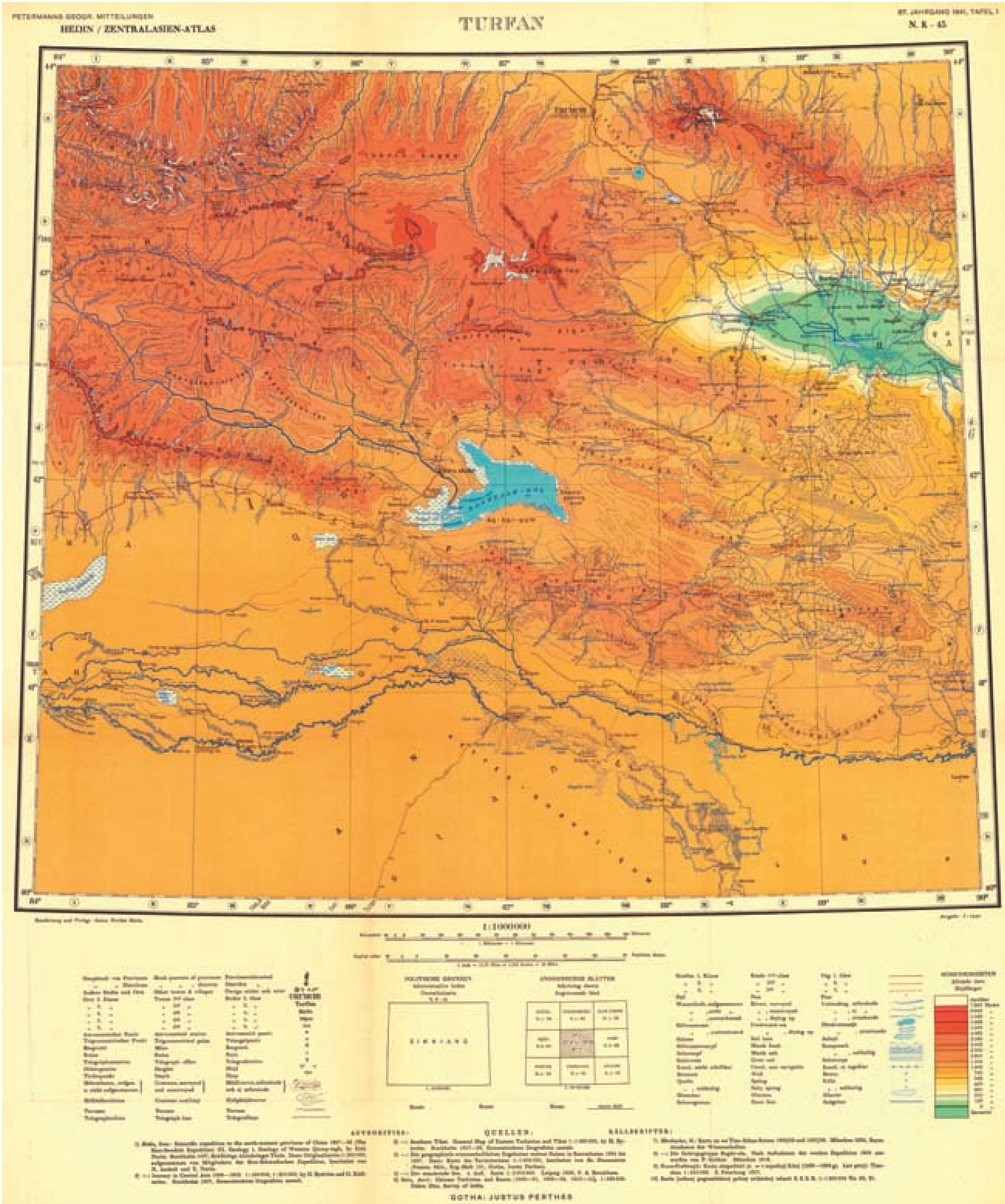

FIG. 678. *TURFAN*, ZENTRALASIEN-ATLAS, 1941. Part of Sven Hedin's Central Asia atlas following loosely the 1:1,000,000 map of the world regulations. This topographic sheet (N.K-45) based on Hedin's explorations in Sinkiang appeared in the first quarterly issue in 1941 totally devoted to the project, but only one of the three sheets was ever published. Size of the original: 63.5 × 53.3 cm. From Hermann Haack, "Sven Hedins Zentralasien-atlas," *Petermanns Geographische Mitteilungen* 87 (1941): 2–7, pl. 1. © Ernst Klett Verlag GmbH, Zweigniederlassung Gotha.

geography maintained its dominance, while travel accounts and regional geographies gave way to general and human geography. After 1933 *Petermanns* experienced less pressure than its German competitors to conform to Nazi ideology, except for occasional articles and maps on *Geopolitik*. This situation reflects both its stature as an internationally recognized journal and the recognition of Langhans, a prominent nationalist cartographer and longtime party member. Between 1900 and 1945 the journal published 1,490 maps, an average of thirty-two maps annually (fig. 678).

After World War II, Haack, whom Langhans had sidelined, became the sixth editor (1948–54), mainly because of his strong reputation in the Soviet Union. Situated in East Germany (1949–90), *Petermanns* was nationalized and enjoyed a monopoly as the German Democratic Republic's sole geographic periodical. Brought in line with Communist ideology in the early 1960s, it provided an outlet for East German geographers, who favored nonpolitical topics in physical geography. Continued as a quarterly from the 1950s to the 1990s, *Petermanns* was a far cry from its once opulent and groundbreaking cartographic prominence.

Following German reunification in 1990 *Petermanns* was reprivatized to the Perthes family in March 1992. Unable to compete in a unified German market against such well-positioned scholarly competitors as *Geographische Rundschau*, *Erdkunde*, and *Erde*, and lacking the resources needed to upgrade its operations, the journal was sold a month later to Ernst Klett, a major publishing group in education. The new owner launched a revamped version in 2000 as a full-color bimonthly with themed issues and an expanded scope that included ecology and the geosciences. When subscription numbers failed to rise significantly, Klett lost patience and in December 2004 abruptly ended what had been the world's oldest geographical journal.

IMRE JOSEF DEMHARDT

SEE ALSO: Journals, Cartographic; Justus Perthes (Germany); Societies, Cartographic: Western Europe

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Peters Projection. Named for Arno Peters, the German historian who devised it, the Peters projection is a rectangular equal-area map projection with standard parallels at 45°. Intended for world maps, it was introduced in Budapest in 1967, at a meeting of the Hungarian academy of science, Magyar Tudományos Akadémia, and formally published in Germany in 1972. Peters presented his map to the public in Bonn in May 1973 at a press conference attended by television reporters and about 350 journalists from the German- and English-language media. In October 1974 he lectured on his projection at a meeting of the Deutsche Gesellschaft für Kartographie in Berlin; that first presentation to professional cartographers triggered a hostile reaction among academics to the projection's proposed use in atlases and for wall maps. Even so, the Peters map had its defenders, and the ensuing controversy in the German, American, and British cartographic literature, which lasted from the mid-1970s well into the 1990s and focused attention on the relationship between cartographic techniques and society, is one of the twentieth century's best examples of the intersection of cartography and ideology. Enthusiastically accepted by development advocates who questioned cartography's social agenda and its focus on geometric accuracy, the Peters projection had become a value-laden symbol for a "fair" representation of the less-developed world—ironic because it severely distorts the shapes of Africa and South America.

Peters was born on 22 May 1916 in Berlin-Charlottenburg and graduated in 1945 from Berlin University, where he studied journalism, history, and art and wrote a doctoral dissertation titled "Der Film als Mittel öffentlicher Führung." In 1952 Peters and his first wife Anneliese produced their universal world history, *Synchronoptische Weltgeschichte*, a massive annotated time line that was revised and republished several times (1970, 1999, 2000) despite criticism of its authors' leftist leanings (Crampton 1994, 22–23).

Peters recognized the importance of maps for visualizing spatial information, and in 1967 he first talked about a "new" projection for world maps. He named the projection after himself, filed for copyright protection, and presented it with great fanfare in 1973. Although his early presentations ignored issues of map scale, mathematical equations, and the location of standard parallels, Peters claimed that his projection possessed fidelity of area, and thus was vastly superior to the projection that Gerardus Mercator had introduced in 1569 for use in navigation—a projection cartographic experts had long considered inappropriate for atlases or school wall maps. Unlike the Mercator projection, which severely distorts area toward the poles, the Peters projection preserves area relationships throughout. But its rectangular-cylindrical framework and standard parallels, originally

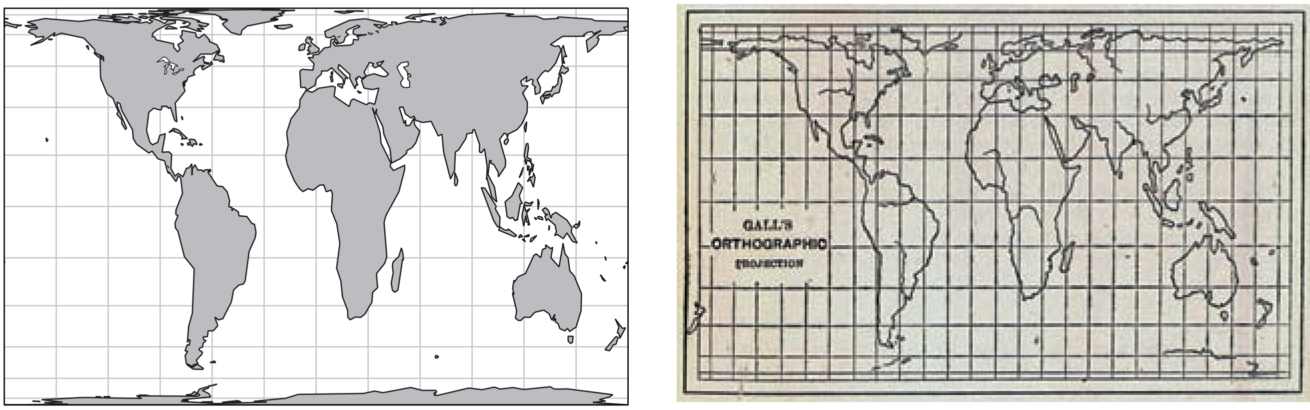

FIG. 679. PETERS PROJECTION (LEFT) AND GALL PROJECTION (RIGHT). The Peters projection, a cylindrical equal-area projection secant at 45°, is sometimes called the Gall-Peters projection because James Gall introduced an identical framework in a paper presented to the British Association in 1855 (published in 1885).
Size of the original (right): 6.7 × 10.8 cm. From James Gall, "Use of Cylindrical Projections for Geographical, Astronomical, and Scientific Purposes," *Scottish Geographical Magazine* 1 (1885): 119–23, fig. on 121.

at roughly 46° (Maling 1974, 155), produce significant north-south stretching along the equator and marked east-west stretching toward the poles.

Peters was challenged by several prominent German and Austrian cartographers, most notably Karlheinz Wagner, Herbert Hufnagel, and Ingrid Kretschmer, as well as by Britain's D. H. Maling, an expert on cartometry. After carefully measuring Peters' published map, Maling (1974) claimed that the Peters projection was not precisely equal-area. Maling and American cartographers John Parr Snyder and Arthur H. Robinson questioned Peters' originality—the German historian, they argued, had merely added to the well-known gallery of cylindrical equal-area projections presented by innovators like Johann Heinrich Lambert (late eighteenth century), James Gall (mid-nineteenth century), and Walter Behrmann (early twentieth century) (Snyder 1993, 164–66). Indeed, Behrmann had described a whole series of cylindrical equal-area projections with standard parallels at a 10° interval from the equator poleward to 60°. And more than a century before Peters, Gall had presented an ostensibly identical projection with standard parallels at 45° (fig. 679). Nonetheless, Peters convinced many socially and politically conscious organizations and individuals that his projection was superior to all previous maps, and that it provided a correct image of the world for the late twentieth century. In largely ignoring other developments in cartography, he framed the question of a correct map projection as a choice between his map and the Mercator map's old Eurocentric view of the world.

In Central Europe and in the German-speaking countries no leading map publishing house adopted the Peters projection for its world maps, but in the early 1980s there was a serious discussion of whether a rectangular world map might be useful in the mass media, including television. However, the Deutsche Gesellschaft für Kartographie (1982) formally condemned the Peters map, and in the following years several German- and English-language journals reprinted the society's statement.

In 1983 Peters struck back with *Die neue Kartographie = The New Cartography*. The book introduced an array of "New Cartographic Categories" labeled "Fidelity of Area," "Fidelity of Axis," "Fidelity of Position," "Fidelity of Scale," "Proportionality," "Universality," "Totality," " Supplementability," "Clarity," and "Adaptability." Academic cartographers denounced these principles as nonsense, but development education institutions and many individuals not trained in cartography embraced them as useful insights.

In the 1980s three events led to increased public awareness of the Peters projection (Crampton 1994, 25). In 1980, the Independent Commission on International Development Issues, chaired by Willy Brandt, used the Peters world map on the cover of its report and hailed the projection as a move away from Eurocentrism. In 1983, UNICEF (United Nations Children's Fund) issued a Peters world map a few weeks before Christmas and gave the projection wider prominence in the United Kingdom, where Christian Aid had published the first English-language edition of the map in 1977. At the same time other agencies within the United Nations began distributing a full-color version of the Peters map (Vujakovic 1989), and many major national aid agencies used the map to describe locations of their overseas projects. Because of its distinctive appearance, the Peters projection had become an emblem of solidarity with the less developed world. And in 1989, the Peters projection was featured in the *Peters Atlas of the World*, which was divided into two parts: a topographic section ("The World in 43 Maps at the Same Scale") and a thematic section ("Nature, Man and Society in 246 Thematic World Maps"). All of the world thematic maps were cast on the Peters projection, and all of the topographic maps were cast on a rectangular projection with a nearby standard parallel—rather than 45°—to avoid severely distorted shapes. As a novel feature, each two-page topographic map was framed to show exactly 1/60 of the earth's surface.

While the Peters projection and the Peters world map received great support from development education services, academic cartographers severely criticized the extreme distortion of shapes. Even so, the projection's instantly recognizable coastline was embraced by development educators, who used its distinctively gaunt Africa and South America to draw attention to the plight of the less developed world.

Arno Peters died on 2 December 2002. His legacy, which includes a heightened awareness of map projection and the emblematic role of cartography, might well spawn further innovation in world maps for development education.

INGRID KRETSCHMER

SEE ALSO: Eurocentric Bias; Mercator Projection; Persuasive Cartography; Projection: (1) World Map Projections, (2) Cultural and Social Significance of Map Projections

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Peucker, Karl. Karl Peucker, an Austrian geographer and cartographer who provided a theoretical foundation for relief representation with hypsometric colors, was born on 15 June 1859 in Bojanowo, Poland. Homeschooled by his grandparents, he later attended the gymnasium in Breslau (Wrocław), then part of Prussia. Continuing his education at the universities in Breslau and Berlin, he studied history, philosophy, German studies, and, with growing interest, geography under Joseph Partsch and Heinrich Kiepert. In 1890, after writing a dissertation on the methodology of orometrics, "Beiträge zur orometrischen Methodenlehre," he received his doctorate at the University of Breslau. In 1891 he moved to Vienna, where he succeeded Anton Steinhauser as scientific director of the cartographic department at the publishing house Artaria & Co. Peucker filled that post until his retirement in 1922.

In 1892 Artaria & Co. inaugurated a line of school atlases (*Atlas für commercielle Lehranstalten*) designed and edited by Peucker, who introduced a new sequence of color tints for relief representation in 1899. His work on the atlas led him to question the scientific basis for relief representation on medium- and small-scale maps in papers presented at German cartographic meetings in Stuttgart (1893) and Jena (1897) and at an international conference in Bern (1891). Peucker's influential monograph *Schattenplastik und Farbenplastik* (1898) stimulated international discussion among scholars interested in the history and theory of terrain representation. He had developed principles of the adaptive-perspective perception of colors based on their position in the visible spectrum and their lightness and saturation. Applying his ideas about the three-dimensional visual effects of colors to map design, he created a new sequence of hypsometric tints (fig. 680). Despite severe criticism of his approach by Eduard Imhof in the 1920s, Peucker is acclaimed for decisive methodological contributions to cartographic relief representation.

Prior to World War I, Peucker published numerous contributions to scientific cartography, notably "Drei Thesen zum Ausbau der theoretischen Kartographie" (1902), "Neue Beiträge zur Systematik der Geotechnologie" (1904), "Physiographik" (1907), and several articles on layer tint maps (*Höhenschichtenkarten*) (1910/1911) (Bernleithner 1983). His interest then turned to aeronautical charts and to mapping landforms for the International Map of the World at a scale of 1:1,000,000, a massive endeavor initiated in 1891 by Austrian geographer Albrecht Penck. Peucker also advised the government of Bavaria on its hypsometric map series (1:250,000) and consulted for the governments of Egypt, Great Britain, India, Italy, and Romania on the design of their topographic map series.

Peucker became the first lecturer in cartography at an Austrian university in 1910, when he began teaching at the Exportakademie (founded in Vienna in 1898, later the Wirtschaftsuniversität), where he was appointed docent in 1913. He continued those activities until 1931.

In 1920 the map publishing department of Artaria &

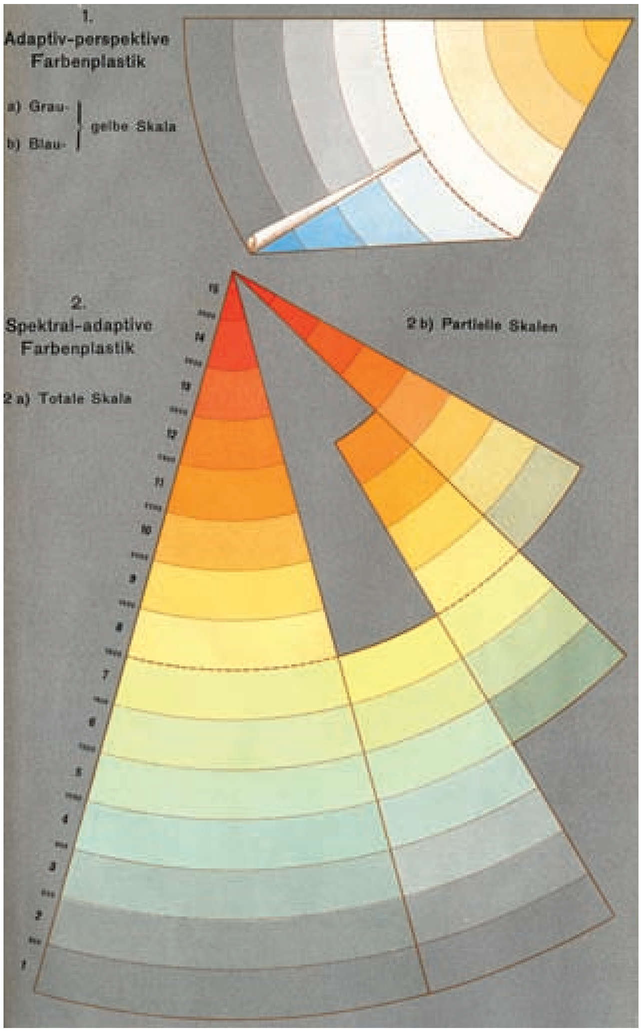

FIG. 680. KARL PEUCKER'S COLOR SEQUENCE, PATENTED 1909.
Size of the original: 20.4 × 12.7 cm. From Karl Peucker, *Höhenschichtenkarten: Studien und Kritiken zur Lösung des Flugkartenproblems*, special impression from *Zeitschrift für Vermessungswesen* (Stuttgart: Konrad Wittwer, 1910), pl. 1.

Co. was consolidated with the cartographic establishment G. Freytag & Berndt. In 1921 and 1922 Peucker edited two volumes of *Kartographische und Schulgeographische Zeitschrift* (founded in 1912 by Johann Georg Rothaug and suspended in 1922 after ten volumes).

Within the Österreichische Geographische Gesellschaft in Vienna Peucker founded the study group Landkarte in 1922 with a special cartographic program that evolved into the serial *Die Landkarte*, which published five volumes between 1925 and 1927, with Peucker as editor. He was concerned with issues of copyright in cartography and the use of aerial photographs for constructing topographic maps. In 1907 he became a founding member of the Österreichischen Gesellschaft für Photogrammetrie, the world's first photogrammetric society.

Peucker produced more than eighty books and articles between 1888 and his death on 23 July 1940. His most important atlases and maps include the *Atlas für Handelsschulen* (1897; 3d enl. ed. 1902; 8th rev. ed. 1929), the sheet *Floridsdorf* in an administrative map series of Lower Austria (1914), hiking maps at a scale of 1:100,000 (1917), and the hypsometric map in the atlas *Burgenland* by Fritz Bodo and Hugo Hassinger (1941). He also edited railway maps and ethnographic maps of Austria-Hungary and Central Europe, various town plans, and road maps of Russia, southeast Europe, and much of the Balkan Peninsula.

INGRID KRETSCHMER

SEE ALSO: Academic Paradigms in Cartography: Europe

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Photogrammetric and Remote Sensing Societies. See Societies, Photogrammetric and Remote Sensing

Photogrammetric Mapping.

Aerial Photogrammetry and Cartography. Among the many technical innovations in cartography in the course of the century, the one that arguably had the greatest impact on the volume of maps produced was the introduction of aerial photogrammetry as a major method of data collection. Aerial photogrammetry offered a number of advantages over traditional land survey methods of data collection, especially the ability to map areas that were inaccessible using those traditional methods. But in the early years of the twentieth century it was by no means obvious that aerial photogrammetry would be more cost-effective than traditional methods. The costs of land survey were known, and recent innovations in technology, such as tacheometry, seemed to indicate that costs would be even lower in future.

Throughout the twentieth century, aerial photogrammetry had much higher capital costs than land survey, and little could be done about the cost of airplanes, cameras, and plotting instruments. As a result, many organizations began to explore the use of labor-intensive but low-capital-cost techniques, including graphical and optical transfer methods. So successful were some of these cheaper techniques that they remained in widespread use until the 1970s and were abandoned only when the inflation of labor costs led to the loss of their economic advantage over instrumental methods.

Once the aerial photographs had been taken, individual points of detail or height could be collected very rapidly by experienced photogrammetrists. While detail surveyed on the ground required each point to be measured by the survey party, and subsequently plotted, each stage taking several minutes, individual points could be plotted in seconds from aerial photography. The advantage of aerial photogrammetry was even greater for height measurement. Ground surveys for contouring relied either on grid leveling of an area to be contoured, with the contour lines interpolated between the measured heights, or on pegging out the contours on the ground by leveling, followed by surveying to determine the plan position of the contour. Photogrammetric contours could be plotted directly by the operator putting a measuring mark on the surface of the photogrammetric model and then moving the floating mark around the model, keeping the mark on the surface. This meant that the contour was plotted continuously, offering greater speed and higher overall accuracy. The relative efficiency of photogrammetry, relative to land survey, made it more cost-effective for all but the surveys of small areas.

Another advantage of aerial photogrammetry, and one that was to have a major impact on the extension of topographic mapping, was that the land surveyor did not have to visit an area on the ground for it to be mapped. This meant that areas such as marshlands, intertidal areas, or contaminated land could be accurately mapped, frequently for the first time. As a noncontact method of mapping, photogrammetry did not disturb the area that was being mapped, an important factor in environmentally sensitive areas.

Aerial photography also provided a permanent record of the terrain at the moment the photograph was taken. It provided a historical record of past landscapes, allowing the areas to be mapped with little loss of accuracy compared with contemporary mapping. This was essential when attempting to map and model environmental change over time.

The possibility of making maps from aerial photography had been explored from the middle of the nineteenth century, but the lack of a convenient photographic medium and a suitable platform meant that progress had been very slow. Tethered balloons, free balloons, kites, and even pigeons had been used to carry cameras before the first airplanes became available. The ability to position an aircraft over the area to be photographed was the key to producing photography for mapmaking. Initial attempts at photography simply involved pointing a camera between the struts of the wings, but it was soon recognized that the best photographs for mapping were those taken vertically. By the outbreak of World War I the basic principles were understood, even if the airplanes and cameras were still fairly primitive.

Even before the first photographs had been taken from an airplane, stereophotogrammetry was being employed using terrestrial photography. Terrestrial photogrammetry involved taking an overlapping pair of photographs of an area to be mapped from a suitable vantage point, such as a hill or a mountain. If the photographs were coplanar (taken in the same vertical plane), it was possible to make measurements on the photographs and from those measurements to derive coordinate values for the measured points. Initially, this involved manual measurement of the two photographs separately, but in 1901 and 1902 two instruments that were developed independently allowed accurate measurements to be made while viewing the photographs stereoscopically. Henry Georges Fourcade's measuring stereoscope and Carl Pulfrich's stereocomparator laid the foundation of stereophotogrammetry (Collier 2002), but both only permitted the measurement of individual points, whose coordinates still needed to be computed. Once computed, the points could then be used to interpolate planimetric and height information. The comparator approach was to be successful in the longer term, when digital computers became available to compute the coordinates of points in real time, but for stereophotogrammetry to be able to compete with land survey, it was necessary to develop an instrument that allowed direct plotting of heights and detail.

In 1908 two instruments were introduced that permitted direct plotting from terrestrial photography. Eduard von Orel produced his autostereograph while working in the Militärgeographisches Institut in Vienna (Anonymous 1910; Kretschmer 1991), and F. Vivian Thompson produced his stereoplotter while working in the School of Military Engineering in Chatham, England (Thompson 1908). To simplify the design of the instruments, both relied on the photographs being taken in the same vertical plane. The value of von Orel's instrument was realized by the Austrian survey and was soon employed on mapping in the Alps and subsequently taken up by surveys in other countries, particularly Germany. Good contoured maps existed for the whole of the United Kingdom, and so Thompson's stereoplotter was of little interest to the Ordnance Survey. It was adopted only by the Survey of India, where it was used for mapping in the Karakorum, and in Fiji, where difficulties with photography meant that no good results could be obtained.

In some ways, the initial success of von Orel's instrument led photogrammetrists to believe that simple modification of the basic design would result in an instrument suitable for use with aerial photography. Unfortunately, this was not the case, as aerial photography is never taken in exactly the same plane. In order to reconstruct the geometry that existed at the moments of exposure, it was necessary to rotate the two images about two horizontal axes and one vertical axis. Both the von Orel and the Thompson instruments were incapable of being modified to permit this.

In parallel with the attempts to develop instruments capable of making measurements from aerial photography, other researchers were trying to develop simpler and less expensive methods. Mapping from terrestrial photography using graphical methods had already become practical. Édouard Deville's use of perspective grids in association with panoramic photography was developed further by James Warren Bagley at the U.S. Geological Survey (USGS) (Collier 2002). Bagley was to adapt the method still further to cope with aerial photography.

Following the outbreak of World War I, all the major combatant nations attempted to develop simple techniques to allow the revision of existing maps. The range of techniques used during World War I can be grouped into optical and graphical. The optical types usually relied upon projecting the image and attempting to match points on the photograph to the appropriate points on a preexisting map. Once matched to the appropriate points on the map, any required detail could be traced directly onto the map. The simpler projectors did not allow for the correction of any tilts in the photography, while the more sophisticated projectors could be tilted to remove some of the tilt displacements in the original aerial photograph. Although Theodor Scheimpflug (1898) had already defined the conditions necessary to correct a tilted image, none of the early instruments allowed for the so-called Scheimpflug condition and cannot, therefore, be regarded as true rectifiers. The optical projection systems used by the Germans and French mostly involved projecting light through a photographic diapositive, while the British generally preferred to use epidiascopes, which could project opaque images onto a screen and thus allow the mapmaker to work with paper prints.

A number of graphical methods were used on both sides in the conflict. The Germans tended to favor the use of the perspective grid method, in which perspective grids were drawn on both the map and the aerial photograph using the same points of detail. Once a grid had been constructed, it was relatively easy to transfer detail from the aerial photograph to the map, although its accuracy was not particularly good. Proportional dividers could be use to improve the accuracy, but only at the cost of reduced speed. The "paper strip" method (Altenhofen 1952, 451–52) was used by most combatant nations when the equipment for anything more sophisticated was lacking. This method gave reasonable results but was time-consuming and tedious. All the graphical techniques only allowed the transfer of individual points. The plotting of any continuous line features involved interpolation between transferred points, leading to a lower overall accuracy than possible with optical transfer techniques.

Some experiments were carried out during World War I on the use of radial line plotting (Collier 2002), and while reasonably successful, there was no theoretical underpinning for the technique. In 1920 the British War Office established the Air Survey Committee, which was specifically charged with investigating the use of air survey for mapmaking (Great Britain, War Office 1923, 4). After initial studies of aerial photography, including the definition of specifications for a camera for aerial photogrammetry, the work of the committee focused on the development of simple, low-cost plotting methods. Martin Hotine, working for the Air Survey Committee in the 1920s, was able to provide the necessary theoretical underpinning of radial line techniques (Hotine 1927) leading to their widespread adoption in English-speaking countries (Collier 2006). Hotine's use of radial line techniques relied on the use of minor control plots for the artificial intensification of ground control, a process usually called control extension. However, minor control plots were time-consuming to produce and only allowed control extension within individual strips of photography. This meant that surveyed ground control points were needed at both ends of every strip of photography. It was also a two-stage process, involving graphical-strip formation and then a graphical-strip adjustment to bring the control to a known scale. In 1936, Charles Wood Collier, working at the U.S. Soil Conservation Service, developed the slotted-templet method of control extension (Kelsh 1940) (figs. 681 and 682). As the technique could be used to provide control for blocks of photography, performing block formation and adjustment as a single process, it significantly reduced

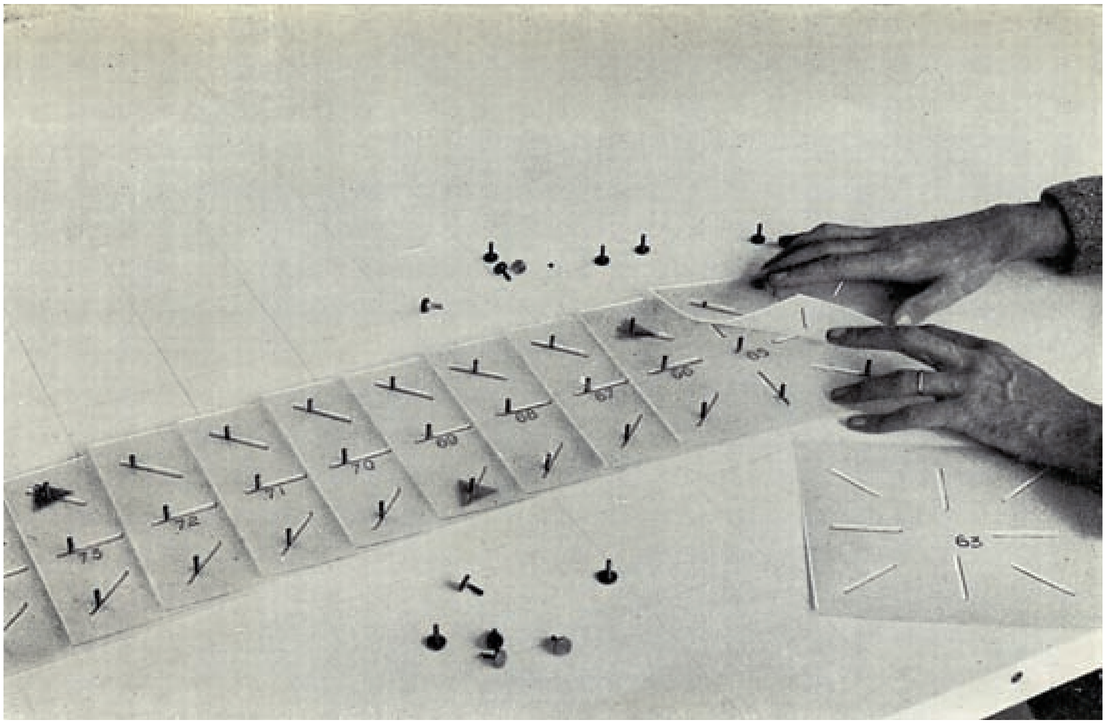

FIG. 681. FRENCH SLOTTED-TEMPLET ADJUSTMENT STRIP. A strip of slotted templets is laid between control points to provide intermediate planimetric control for mapping at the IGN in Paris.

From Hurault n.d., pl. IX (top). Permission courtesy of the Cartothèque, Institut géographique national.

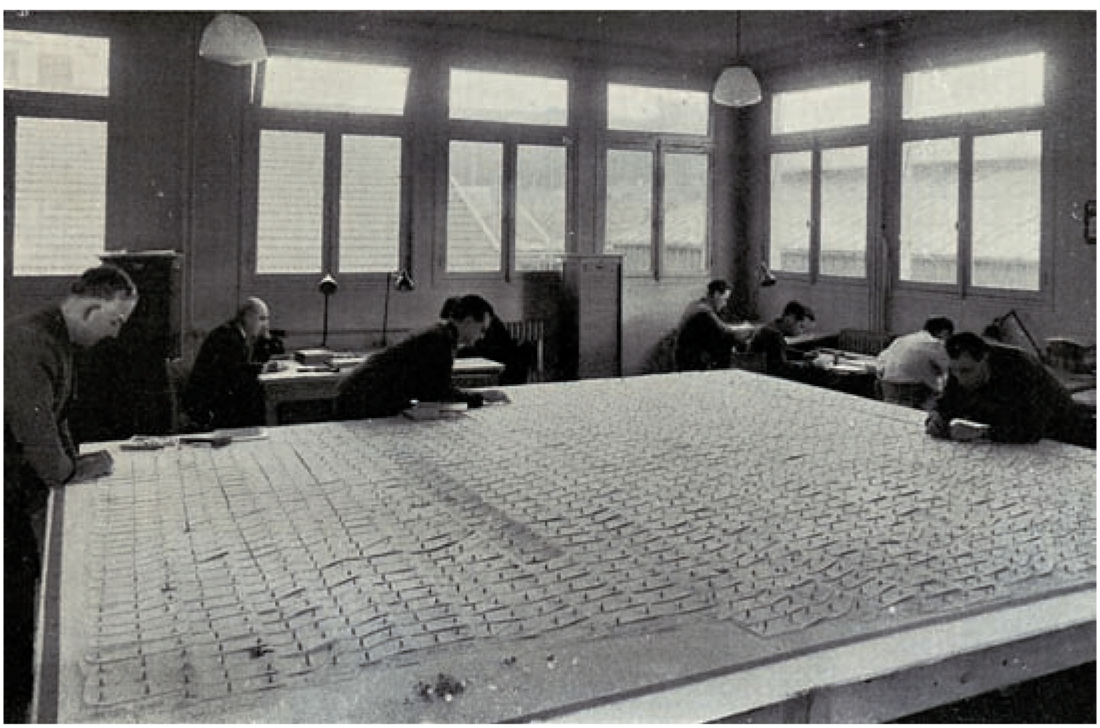

FIG. 682. FRENCH SLOTTED-TEMPLET ADJUSTMENT. A block of templets is laid to carry out an adjustment and to provide planimetric control for a block of mapping at the IGN in Paris.

From Hurault n.d., pl. IX (bottom). Permission courtesy of the Cartothèque, Institut géographique national.

the time taken as well as the need for surveyed ground control points. As David Landen (1952, 884) noted, this was "one of the most important inventions in photogrammetry" and made possible "mass-production of photogrammetric maps at low cost and great speed." The technique was adopted rapidly by the various agencies carrying out mapping in the United States but was not adopted in Europe until World War II, when it was introduced by U.S. forces.

After World War II, radial line methods were used in most mapmaking countries, only finally being phased out in the 1970s. During that time they were largely responsible for the huge increase in world coverage by topographic mapping. The British Directorate of Overseas Surveys was able to map some 2,500,000 square miles in a period of twenty-five years through the use of radial line methods. However, graphical plotting using radial line techniques was very labor intensive. The cartographer was required to identify points to be fixed by intersection, drawing rays through them on two aerial photographs. The plotted points were then joined up by interpolation. The number of points fixed by intersection and the subsequent reliance on interpolation were very much at the discretion of the cartographer. Attempts were made to simplify and automate the process through the use of radial line plotters. These plotting instruments were little more than a mirror stereoscope with a plotting system linked to cursors that pivoted around the principal points of the aerial photographs. The operator plotted detail continuously, by viewing the photographs through the stereoscope and keeping the intersection of two cursors on the detail to be plotted. Plotting detail with the radial line plotter was much quicker than with manual graphical plotting but required intense concentration by operators if errors were to be avoided.

In Europe the main emphasis was on the use of restitution instruments, which could be used to create a theoretically correct model of the surface to be mapped. Initially, instrument designers tried to develop a working instrument by modifying the existing designs for terrestrial instruments. These attempts were fundamentally flawed, as the terrestrial plotters used coplanar photography, a condition never found in aerial survey. The instruments became more and more complicated in their design and required a very time-consuming orientation process before plotting could be started. H. S. L. Winterbotham (1928) was able to use the inefficiency of these early instruments to justify the British focus on graphical methods.

The conceptual breakthrough that enabled the development of cost-effective instruments was the recognition that it was necessary to reproduce the orientation of the camera at the two air stations at the moments that the aerial photographs were taken. This could be achieved through the use of goniometers, projectors capable of being rotated around the *x, y*, and *z* axes. Once goniometers had been introduced into plotting instruments, it was possible to re-create a theoretically correct model of the ground on which accurate measurements in *x, y*, and *z* directions could be made. However, creating a model was still problematic due to the lack of a rigorous orientation procedure. This problem was solved by Otto von Gruber, who devised an empirical orientation procedure based on viewing the stereo model at six points, and carrying out appropriate orientations around the *x, y*, and *z* axes. The combination of goniometers and an efficient orientation procedure meant that by the late 1920s aerial photogrammetry had become a cost-effective option for routine large-scale mapping work. The first instrument that incorporated the new design features was the Zeiss C4 (1930), a photogrammetric plotter that used direct projection of the photographic images for both model formation and viewing (Burnside 1993). Wild introduced a rival instrument, the A5, in 1937. Through the introduction of mechanical analogs of the camera lens and the rays of light that formed the photographic image, this instrument separated model formation and viewing. The basic design of the A5 was applied to a series of instruments that remained in use until the end of the century.

French instrument design and manufacture developed independently. Starting in the 1920s Georges Poivilliers, the major figure in French photogrammetry, designed a range of instruments for the Service géographique de l'armée. Although these instruments were used for many years within the Service and its successor organization, the Institut géographique national (IGN), they were not widely adopted. The optical-mechanical design used by Poivilliers was only used for one other major instrument, the Thompson-Watts plotter, designed by E. H. Thompson for governmental survey organizations in Britain. Like the Poivillier instruments, the Thompson-Watts plotter was not adopted outside of its country of origin. Apart from the wish not to infringe existing patents, another important factor was the desire to have an independent design and manufacturing capacity (Collier and Inkpen 2003).

In addition to the Poivilliers instruments, another instrument was designed and used very briefly in the 1930s, the Gallus-Ferber plotter. As far as is known, only one example of this instrument was made. It was used by a private survey company in France and experimentally on behalf of the British Ordnance Survey, but the results were generally disappointing.

While cost-effective for large-scale mapping, the relatively slow orientation procedure of the early Zeiss, Wild, or Poivilliers instruments and the need for two-man operation meant that they were not cost-effective

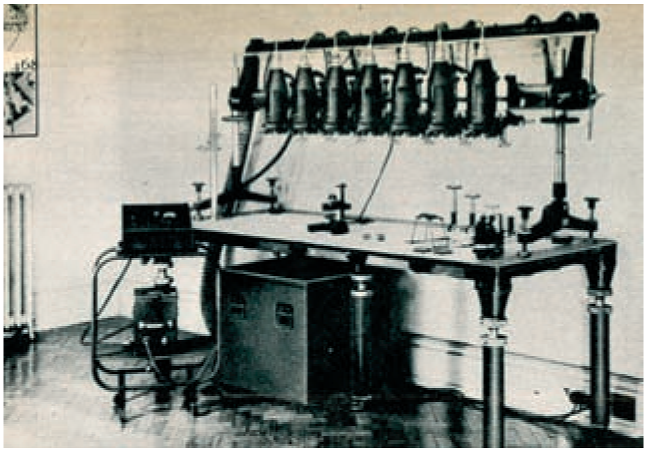

FIG. 683. WILLIAM-ROSS SEVEN-PROJECTOR MULTIPLEX LONG BAR. A long bar multiplex instrument provided additional control by the so-called classical, or bridging, method of aerial triangulation. This method could provide both planimetric and height control.
From "The World in Camera," *Flight and Aircraft Engineer* 57 (April 1950):463–70, esp. 468.

FIG. 684. WILLIAM-ROSS MULTIPLEX MARK 1 WITH THREE PROJECTORS. The development of the multiplex plotter permitted low-cost photogrammetry and was widely used between the 1930s and 1970s. This particular instrument was made by the Williamson Company in Britain.
Image courtesy of the Defence Surveyors' Association, U.K.

for medium- and small-scale topographic mapping (Hopkins et al. 1966). The introduction in 1930 of multiplex instruments by Zeiss in Germany and Nistri in Italy meant that at last photogrammetrists had instruments that were cost-effective for the smaller-scale mapping (fig. 683). Multiplex was much cheaper than earlier instruments, could be oriented very quickly, and was easily used by a single operator. The Zeiss version was adopted by the USGS in 1930 and was soon being widely used in North America. In Britain, there was little interest in the instrument before World War II, the first instruments being introduced in Britain by Canadian and U.S. forces. The delay in the introduction in Britain was due to the Ordnance Survey only carrying out original survey work at scales of 1:2,500 and 1:10,560, which were too large for multiplex techniques. However, the development of a major military survey capability during the war, and the creation of the Directorate of Colonial Surveys after World War II, led to a demand for a medium-scale photogrammetric capability. At the time, this need could be met only by multiplex. By this time, Zeiss and Nistri were no longer the only manufacturers of multiplex equipment—the Bausch & Lomb Optical Company, in the United States, and Williamson and Ross, in Britain, had become major manufacturers (fig. 684).

The global scale of the fighting in World War II created an unprecedented demand for mapping at topographic scales to support ground operations on all sides and strategic bombing campaigns waged by the U.S. and British air forces. Prior to the outbreak of war, the major combatant nations in Europe had systematically collected the topographic maps of any countries where their forces might be engaged. In general terms, these maps provided the source material for most of the military mapping produced by Germany, Italy, and the Soviet Union. All three carried out some additional mapping, but it was rarely extensive. Where maps were required at scales larger than those available, the most frequent response was to enlarge an existing map to the required scale. The Western allies used existing maps wherever possible but found it necessary to carry out either a major map revision or extensive new mapping for particular campaigns.

As A. B. Clough, former director of survey, Supreme Headquarters Allied Expeditionary Force (1952, 373) had noted, "Continued progress and development in artillery technique, radar and other modern devices made it essential to ensure that all probable operational areas in western Europe should be covered by good, accurate maps on 1/25,000 scale." The British Army sent to France at the outbreak of war in 1939 was provided with 1:25,000 mapping of northeastern France and Belgium, and the British had attempted to provide their troops with mapping at this scale wherever they were likely to be involved in set-piece battles. However, the kinds of operations in which they were involved in the early years of the war meant that this scale of mapping was rarely available. The first time they were able to use 1:25,000 mapping in an offensive operation was during the fighting around Matruh (Mersa Matruh) in 1941, when they used maps compiled from aerial photography (Clough 1952, 73–84). The most intensive use of aerial photogrammetry during the war in Europe was to provide the 1:25,000 mapping for the invasion of France in 1944. Preparations for the invasion started in mid-1942 but gathered steam with the arrival in Britain of American survey units. The original intention was to compile conventional line maps from aerial photography, but due to worries that the maps would not be ready in time, photomaps were produced of Brittany by the U.S. Army, with the coverage later extended into Normandy by producing 1,600 10 × 10 kilometer map sheets. As it turned out, the line mapping was completed in time for the invasion.

U.S. forces fighting their way across the Pacific could rarely rely on existing mapping to supply their needs. However, because of the expansion of the domestic aerial survey capacity during the New Deal and the need to map the island bases acquired from the British in 1940, they entered the war with a large body of trained photogrammetrists. These trained photogrammetrists allowed a very rapid expansion in mapping activities, with the Solomon Islands campaign among the first to benefit. The most significant photogrammetric project of the war was the systematic photographing and mapping of the Japanese home islands. As this could be carried out only after the home islands were in range of the B29 airplanes used to capture the photography, work could not start until late 1944. Even so, the mapping would have been ready in time for the intended invasion of Japan in November 1945. One of the novel features of this mapping was the printing of a conventional line map on one side of the sheet and a photomap on the reverse.

Following the end of World War II there was an urgent need to reconstruct the devastated European cities and infrastructure, which could not proceed without a systematic survey of the damage. Existing maps could be used as a basis for the survey where a city had not been too heavily damaged, but new mapping was needed where the destruction had been widespread. In Britain, the whole country was flown with aerial photography by the Royal Air Force using the aircraft and cameras no longer needed for military purposes. The Ordnance Survey recognized that the scale of destruction in many cities was such that conventional line mapping would take too long to produce and would thus impede the work of planning and reconstruction. It was therefore decided to produce photomaps of the badly damaged cities at the new urban scale of 1:1,250. Outside the neatline, sheets were the same as regular map series, and the photomaps also had the rectangular framework and coordinates of the National Grid, which had been introduced in 1936. These photomaps were produced using rectified photographs, which meant that the technique was really suitable only for cities on flat sites; nonetheless, the demand for maps was so great that the technique was extended to most cities, and then to lowland rural areas, for which photomaps were published at 1:2,500 (Board 1995).

In France, the Service géographique de l'armée had been moved to the civilian sector as the Institut géographique national in 1940 but retained most of its military staff, and, more importantly, its large photogrammetric capability. It continued to carry out mapping work throughout the war, even covert work of use to the Allies, and was therefore well-placed to produce mapping for reconstruction at the end of the war.

In Germany, the scale of devastation was far greater than elsewhere in Western or Central Europe, and the means to carry out the necessary mapping were almost completely lacking. Many of the trained personnel were in prison camps, and much of the equipment that had not been lost through bombing had been seized by the Allies as reparations (Macdonald 1996, 33). When Germany was divided at the end of the war, responsibility for mapping devolved to the individual states of what became West Germany, reversing the centralization that had taken place under the Nazi regime. However, as the Allies were responsible for the administration of their respective zones, they soon became active in the reconstruction of German mapping. By 1948 the new survey departments had become largely self-sufficient. A major factor in this development was the decision by the U.S. authorities to relocate much of the manufacturing capacity and staff of the Carl Zeiss Company from Jena in the Soviet zone to Oberkochen in the American zone. The Communist regime in East Germany also reestablished a Carl Zeiss Jena to manufacture equipment for the Soviet Bloc and subsequently for export to earn hard currencies.

The two most noteworthy photogrammetrically based mapping programs were those of Canada and the Soviet Union. Prior to World War II Canada was one of the most poorly mapped of all Western industrialized nations. At four inches to one mile (later 1:250,000), only three of the 918 sheets needed for full coverage had been completed, and at one inch to one mile (later 1:50,000), there were fewer than 200 sheets of the nearly 13,000 needed for full coverage. That Canada was able to transform this situation, completing coverage at 1:250,000 in 1970, and achieving complete coverage of all provinces, the Yukon Territory, the mainland portion of the Northwest Territory, and many of the Arctic islands by the end of the 1990s, was due almost entirely to the extensive adoption of photogrammetric techniques (O'Brien and Sebert 1999). In 1947, the Canadian government adopted a plan that called for the completion of the Four-Mile Series within twenty years by the newly formed Surveys and Mapping Bureau. In addition, work would continue on the One-Mile Series, with some contribution from provincial mapping departments. The availability of the technology would not, on its own, have led to the adoption of such an ambitious plan. It was the political context of the Cold War, in which Canada was perceived to be in the front line, that led to resources being directed into the mapping program.

A range of photogrammetric techniques were used during the course of the Canadian mapping programs. Slotted templets were used for aerial triangulation from the mid-1940s until the mid-1960s, supplemented and then replaced by Gerhardus H. Schut's strip adjustment (Schut 1964). The Schut strip adjustment computed the coordinates of the principal points and pass points in a strip of photography, providing the coordinate values needed for absolute orientation of the models being used in stereo compilation. From the mid-1970s computational methods were adopted, notably Friedrich E. (Fritz) Ackermann's PAT-M aerial triangulation block adjustment software, of which Canada was one of the earliest champions (Ackermann 1973). Block adjustment required fewer ground coordinated points than strip adjustment to compute the coordinates of the points needed for stereo compilation, leading to a significant reduction in the cost of ground control surveys. Compilation of 1:50,000 mapping was largely carried out using multiplex until the 1960s, with Kelsh and Gamble plotters being introduced in the 1950s, and the Kelsh remaining in use until the late 1970s. In the 1960s the Wild B8 and Kern PG2 instruments were also acquired. These instruments were used for the 1:50,000 program until the mid-1990s (O'Brien and Sebert 1999, 88–89, 97). The instruments and methods used on the 1:50,000 program were very similar to those in use at that time in many other Western mapping programs, for example, the Directorate of Overseas Surveys. It is the vast territory covered by the program that made the Canadian effort almost unique.

The only mapping program comparable to Canada's in terms of size was that of the Soviet Union, which by the late 1980s had completed coverage of the country at a scale of 1:25,000, with more than 300,000 sheets. In 1923 Feodosiy Nikolayevich Krasovskiy had stated that even the mapping of the central part of Russia would require 100 to 150 years to complete (Yashchenko 1990, 3). Although some mapping at 1:25,000 had been carried out prior to World War II, it only covered some 600,000 square kilometers of economically developing areas (a little over 2.5 percent of the total surface area). This meant that after the war, a huge effort and tremendous resources were necessary to achieve total coverage. As with Canada, a major factor driving the program was the Cold War but with the added imperative provided by the recent invasion of the Soviet Union by Germany and the need for reconstruction. Without the widespread adoption of photogrammetry, based almost exclusively on Soviet-designed and -produced equipment, the program could not have been completed within such a short time span.

To meet the increasing need for mapping, a number of companies produced a series of so-called approximate instruments. These instruments used nonrigorous solutions to provide the stereo model for plotting. In general, these instruments were used to revise existing large-scale maps and some original survey work at topographic scales. While these approximate instruments were much cheaper than the instruments capable of creating a theoretically correct model, they were frequently unpopular with operators. With a theoretically correct solution the operator could concentrate first on putting the floating mark on the ground in the model and then on plotting any detail or contours. But with most approximate instruments it was also necessary for the operator to remove *y*-parallax during the plotting process by a constant adjustment of the photographs. Louis Hurault (n.d., 106), director of the IGN in Paris, argued that such instruments were inefficient in the long run because of their inferior productivity, the indifferent quality of the output, and the greater need for fieldwork. However, many survey organizations invested in them as a way to reduce costs.

By the late 1950s photogrammetry was the dominant technology for data collection in large- and medium-scale topographic mapping programs. Instrument manufacturers of land survey equipment tried to keep ground survey competitive through the introduction of self-reducing tacheometers and improved telescopic alidades, but for all but the smallest areas, photogrammetry had become the most cost-effective approach. Improved survey cameras, and particularly better lenses, meant that the photography was improving in quality, and the increasing use of aerial photography was driving down the unit cost in real terms. The overwhelming majority of the photography being flown used black-and-white panchromatic film, but black-and-white infrared film was being widely used for mapping tide lines, and color and color infrared film was starting to be used on a wider scale, particularly in the United States. In the English-speaking world graphical techniques were still the most common form of photogrammetry. This situation was destined to last as long as labor costs were low and plotting instruments were relatively expensive. The change in the balance of costs occurred first in the United States around 1960 and in the rest of the English-speaking world by about 1970. The last major use of slotted templets was in the early 1970s to control photomosaics as part of a photomapping program in Gambia.

As it was necessary to have the coordinates of three plan points and four height points to carry out the absolute orientation of any stereo model, one of the biggest problems for photogrammetry was the acquisition of ground control. Accurate aerial triangulation techniques had to be developed if costly ground surveys were to be avoided or minimized. In aerial triangulation the photogrammetrist derives the true ground coordinate values of a series of points measured on the aerial photographs using a sparse network of ground-surveyed points to control the process. These additional derived points are selected in the corners of the stereo model, using either the ground features identified on the photographs or entirely artificial points created by marking the emulsion of the photograph. Depending on the method being used, the artificial points are referred to as minor control points, pass points, or wing points.

Planimetric control for medium-scale topographic mapping was not problematic insofar as slotted-templet adjustments were sufficiently accurate to meet that need. However, height control was still a problem. Long bar multiplex instruments could be used to provide height control for short strips of photography as long as a platform of ground-surveyed points existed at both ends of the strip and there were a few additional height points in between, a technique known as bridging. Nonetheless, long bar multiplex instruments could normally only control strips of about ten models, which meant that clusters of control were needed at that frequency. It would be possible to reduce the need for ground control if longer strips could be bridged in the same way.

Some of the more sophisticated and expensive technology—the so-called universal photogrammetric instruments, such as the Zeiss C5 and Wild A5—could be used to carry out classical aerial triangulation using a facility called "'base-in'–'base-out'" (Born 1966, 379). In this technique a model would be established in the usual way, with the first photograph in strip in the left projector and the second photograph in the right projector—photogrammetrists called this the base-in condition (fig. 685). Once that model had been established and the *x, y*, and *z* coordinates of any ground-surveyed and pass points had been measured, the left photograph was replaced by the third photograph, and the instrument was changed to base-out mode. In this mode the instrument would behave as if the left projector were on the right, and the right projector were on the left. The model was then established with a single projector orientation procedure using just the left projector. Once the model was established and the pass points measured, the instrument was changed back to base-out and the second photograph was replaced by the fourth. A single projector orientation was then carried out on the right projector. This process could be continued for the entire length of the strip, and, in theory, strips of almost any length could be used. In practice, the accumulation of small errors in carrying out orientation would become problematic if the strips were too long. Once all the points in the strip had been measured, the whole strip was adjusted and the true ground coordinates of the

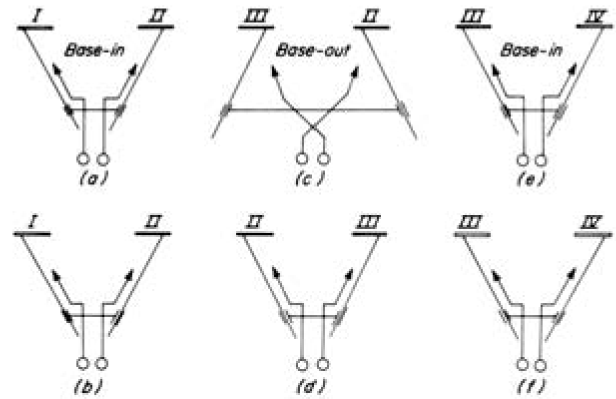

FIG. 685. BASE-IN, BASE-OUT. Some photogrammetric instruments, normally referred to as universal instruments, could be used to carry out strip formation within the instrument using a facility called base-in, base-out. The instrument is put into the base-in condition (*a*), whereby the two space rods converge and the left eye sees the left photograph and the right eye sees the right photograph (*b*). The first photograph in the strip is placed in the left projector and the second in the right projector. The model is then formed by carrying out a normal two-projector relative orientation followed by absolute orientation. The pass points and any control points then have their coordinates measured and recorded. The first photograph is then replaced by the third photograph, and the instrument changed to the base-out condition (*c*), where the space rods diverge and the eyes view the opposite photographs, however through an optical switch, the observer still sees what should be the right image with the right eye, and the left image with the left eye (*d*). The second model is then created using a single-projector orientation on the left projector and pass-point coordinates are recorded. The instrument is then returned to the base-in mode (*e*), and the right photograph is replaced by the fourth photograph. The left and right eyes see the appropriate images as the optical switch is also changed back (*f*). This process is then continued to the end of the strip.
Size of the original: 5.4 × 8.5 cm. From Francis H. Moffitt and Edward M. Mikhail, *Photogrammetry*, 3d ed. (New York: Harper & Row, 1980), 426 (fig. 13–7). © 1980. Reprinted by permission of Pearson Education, Inc., Upper Saddle River.

pass points could be derived. When not being used for aerial triangulation, the universal instrument could be employed on normal plotting work.

An alternative to the classical method was analytical aerial triangulation. In this approach a stereocomparator or monocomparator was used to measure the *x* and *y* coordinates of ground-surveyed and pass points on the photographic images. These precisely measured coordinates were then used to calculate the true *x*, *y*, and *z* ground coordinates of the pass points. Before analytical aerial triangulation was first introduced, the computation of the true ground coordinates was an extremely labor-intensive and time-consuming operation, and all calculations needed to be carried out manually using mechanical calculators. Introduction of electronic computers in the 1950s speeded up the process and made analytical aerial triangulation popular with large survey organizations, which had a sufficient demand for aerial triangulation to keep the comparators fully employed. Smaller organizations found the approach less cost-effective insofar as the comparator could not be used for plotting when not employed on aerial triangulation.

In the late 1960s Ackermann developed aerial triangulation by independent models (AIM), a cost-effective approach to aerial triangulation that could be carried out on almost any precise instrument (fig. 686). In this approach the operator performed a relative orientation in the normal manner but did not carry out an absolute orientation of the model. The instrumental coordinates of any control points were then recorded. The next model was then inserted, and the procedure continued until all the models had been observed. The processes of strip formation and adjustment were carried out computationally. In addition, the strips could be joined together to form blocks, which could then be adjusted. The observation process was simple, though repetitive, and required a great deal of care on the part of the operator, but the strip and block formations and adjustments were very rigorous, leading to a major reduction in the number of ground-surveyed points required. AIM also enabled mapping control for inaccessible areas, as it was possible to use peripheral control around the inaccessible area without loss of accuracy (Ackermann 1973).

Despite significant advances in the design of instruments and improved methods of providing control for the mapping process, the actual plotting of plan and height information from the stereo models still relied on skilled photogrammetric operators. From the late 1950s there were attempts to develop automated ways of capturing information from aerial photographs, but the cost of computers and the lack of available computing power meant that the developments were of little practical value for mapping at the time. Gilbert L. Hobrough (1959) of the Photographic Survey Corporation, a Canadian firm, described the first attempt to use image correlation as a way of deriving height information automatically. The process was incorporated in the Wild B8 Stereomat (Löscher 1964), and later in the Wild-Raytheon A2000, but neither was commercially successful. The only significant use of image correlation was in the U.S. Army's Universal Automatic Map Compilation Equipment (UNAMACE), which produced orthophotographs, contour plots, and digital terrain models (Dowman 1977). While proven as a technique, image correlation was not widely adopted until the 1990s, when the cost of computing had declined significantly.

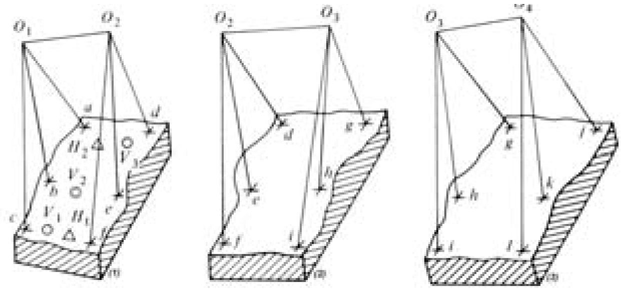

FIG. 686. AERIAL TRIANGULATION BY INDEPENDENT MODELS (AIM). In the AIM approach the photogrammetrist puts the photographs for the first model in the strip into the instrument and creates a stereo model using a normal two-projector orientation to carry out relative orientation. No attempt is made to scale the model or make it horizontal. The photogrammetrist then records in machine coordinates the pass points and any control points. In addition, the coordinates of the projectors O_1 and O_2 are recorded. The photogrammetrist then places the photographs forming the next model in the instrument, and repeats the same orientation and coordinate-recording process. This procedure is then repeated for every model in the strip. The strip is then formed computationally by first scaling model 2 to match model 1, which is achieved by matching the distances between the pass points. Next, the software translates the coordinates of O_2 in model 2 to the coordinates of O_2 in model 1. Finally, the end triangle formed by the projector and the two wing points of model 2 is made coplanar with the end triangle of model 1 by a rotation around O_2. This process is then repeated to join together all the photographs in the strip. Once the strip has been created, it is adjusted to ground control using any control points in the strip. The adjustment process generates ground-control values for all the pass points. *V* and *H* represent vertical and horizontal ground control points.
Size of the original: 4.6 × 9.7 cm. From Paul R. Wolf, *Elements of Photogrammetry (with Air Photo Interpretation and Remote Sensing)* (New York: McGraw-Hill, 1974), 436 (portion of fig. 18–6).

The relative success of the UNAMACE system was due in part to its ability to produce orthophotomaps. The utility of photomaps had been recognized as early as World War I (Collier 1994), but there had been little attempt to build on that initial work until the 1950s, when Russell K. Bean developed the first successful photogrammetric instrument capable of producing orthophotographs. Earlier photomaps had always been regarded as interim editions, to be replaced by conventional line maps when time and resources permitted. The idea that a photomap or orthophotomap could be the definitive product was accepted only very slowly in many countries. In general, well-mapped countries were reluctant to adopt this new type of map, frequently arguing that there would be great user resistance to the innovation. However, the decision by the USGS to initiate a photomapping program encouraged other developed countries, notably West Germany and Sweden, to adopt the new maps. In military circles there was much less resistance to photomapping, especially for areas that would be poorly represented by conventional line maps. In particular, the U.S. Army Map Service (AMS) initiated a massive program of photomapping in Southeast Asia to supplement existing line maps. The value of orthophoto mapping was also demonstrated by the speed with which the USGS was able to provide maps of the Mount St. Helens areas within a few days of the volcanic eruption in 1980.

There were significant changes in conventional photogrammetry during the 1970s, largely as a consequence of changes in the cost and power of computer systems, which made analytical systems a viable alternative to analog instruments. At the start of the decade there was really only the Bendix OMI AP-1, which had been developed from Helava's first analytical plotter of 1957. By 1980 all major instrument manufacturers had introduced analytical instruments, which had been adopted by most large national mapping agencies. For routine stereocompilation there were few advantages in the new analytical instruments, with the exception of the speed of model establishment and the wider range of photographic focal lengths. Conventional plotting of detail or contours could be carried out almost as quickly with the old analog instruments. Because most mapping organizations had large numbers of still serviceable analog instruments, these continued in use for many years, sometimes being converted to analytical operation.

The move to digital photogrammetry was initially quite slow, mainly due to the cost of creating and storing large image files, the expense of first-generation software, and the powerful workstations required to operate them. Although all the technology was in place by 1990, few nonmilitary mapping agencies seemed interested in going the digital route. Most had invested heavily in analytical instruments, which still had many years of working life. An additional factor that may have delayed adoption of the new technology was the lack of any clear advantage in planimetric mapping. The new systems had been developed to take advantage of image correlation for digital terrain model extraction. As this was an automated process, it did not require much user interaction with the system. However, if the systems were used for planimetry, the operator was required to wear special glasses for viewing the stereo model, and it was significantly less clear than on an analytical instrument.

The use of aerial photogrammetry was not limited to topographic mapping, although that was by far its most important use in the century. Geologists, foresters, soil scientists, and archaeologists were among the most common users of aerial photogrammetry. Most disciplines did not require the standards of accuracy considered normal in topographic mapping. This led them to use a wide range of approximate methods, such as the Bausch & Lomb Zoom Transfer Scope, the Hilger & Watts Stereosketch, or the Zeiss Stereopret (Pennington et al. 1966). The common feature of these instruments was that they could be used only to provide planimetric information. The need for this kind of instrument declined with the more ready availability of orthophoto products, and they were largely redundant by the end of the century, when scientists could use geocorrected scanned aerial photographs to derive their thematic boundaries.

PETER COLLIER

SEE ALSO: Coastal Mapping; Lidar; Map: Images as Maps

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Air Photos and Geographic Analysis. The idea of using air photos for geographic analysis can be traced back to Aimé Laussedat's work in the mid-nineteenth century. Experiments to collect air photos were carried out from then on, but early efforts were hampered by the lack of a suitable platform from which to take the photos. Tethered and free balloons, kites, and even pigeons were employed without a great deal of success. Air photography became a practical proposition only with the development of airplanes.

The earliest practical use of air photos taken from airplanes is usually considered the reconnaissance photos taken by Captain Carlo Piazza of the Italian army in 1912, during the Italo-Turkish War. During World War I all major combatant nations made extensive use of air photos for both reconnaissance and mapping purposes. Most of this work was limited to the detection of militarily important objects, such as trench systems, artillery positions, communications systems, and stores. A direct consequence of this work was the development of camouflage to inhibit detection from the air. Partly as a consequence of the enemy's attempts to conceal potential targets, but mainly due to the difficulty of interpreting images taken from an unfamiliar perspective, the new discipline of air photo interpretation was developed.

While most interpretation activity was directed toward warfare, a number of users of air photos recognized that, in addition to military information, there was considerable geographic information on the photos. In the United States, the Geological Survey initiated experiments using air photos for civil mapping. After the war, a number of important published papers drew attention to the benefits of air photos. Using air photos of the Jordan Valley, H. Hamshaw Thomas (1920) showed how vegetation patterns, which were difficult to see on the ground, could be easily detected on air photos. G. A. Beazeley (1919), while surveying in Mesopotamia, noticed that previously unrecorded archaeological remains could be clearly seen on air photos. This led directly to the pioneering work in aerial archaeology of Osbert Guy Stanhope Crawford at Britain's Ordnance Survey (Crawford and Keiller 1928).

In the United States a number of papers advocated the use of air photos for studying urban areas, most notably Willis T. Lee (1920) and W. L. G. Joerg (1923), but the first serious attempts to use air photos for urban analysis did not take place until the 1930s (Hudson 1936). A number of projects initiated in the United States under the New Deal made extensive use of air photos. These included the analysis of agricultural land carried out by the Agricultural Adjustment Administration (Monmonier 2002) and the work of the Tennessee Valley Authority (TVA). Such federal projects encouraged the development of the air photo industry and the adoption air photo methods by other organizations, including local governments.

There were significant developments in photographic technology in the 1930s that impacted the way air photos were used for geographic analysis. The first came in 1931, when black-and-white infrared film was used for the first time during transcontinental stratospheric balloon flights. In 1936 Kodak produced its first color film stock, a negative film that had a slow emulsion that limited its application in air photography. However, this led to the development of Ektachrome reversal film in 1942 and its derivative, color infrared (CIR) film.

The German armed forces made considerable use of air photos for military geographic analysis in the period leading up World War II and during the early years of the war. The photos helped assess terrain conditions prior to military operations and identified infrastructure and industrial targets for bombing missions. For reasons that have never been adequately explained, German efforts in this area declined during the war, while those of the Allied powers developed very rapidly to the point that an operation launched in the absence of up-to-date air photo coverage was almost inconceivable.

During World War II air photos had a wide range of geographic applications, from determining beach gradients, terrain trafficability, and water depth over coral reefs to the productive capacity of factories and the volume of traffic railroads were capable of carrying (Babington Smith 1957). In the same way that World War I gave an impetus to the early uses of air photos, World War II led to a rapid acceleration in civilian air photo application in the physical sciences and in such fields as planning. Unlike the aftermath of World War I, the Cold War following so quickly after the end of World War II meant investment in the technical development of air photos continued.

As had happened after World War I, at the end of World War II people trained in the interpretation and use of air photos went back to their civilian occupations convinced of their usefulness. Geographers such as David L. Linton returned to their academic departments determined to make air photo interpretation a key component of the curriculum. In addition, in Europe the scale of destruction was such that existing maps were of little or no use for planning reconstruction. Air photos seemed the most cost-effective way to supplement or replace existing maps and to provide information on current land use and the scale of the destruction. A number of countries initiated systematic air photo programs. In Britain the whole country was flown in the late 1940s using aircrew, airplanes, and cameras no longer needed for military purposes. This early systematic coverage has subsequently provided a useful baseline for monitoring changes in human and natural environments.

One of the most important conceptual breakthroughs in the use of air photos following World War II was the development of land systems analysis by C. S. Christian and G. A. Stewart of the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO). The recognition that a close relationship exists among geology, land forming processes, and the resultant landforms, and that these, in turn, closely relate to soil and vegetation distribution, led to the development of methodologies for the rapid inventory and mapping of natural resources. The CSIRO carried out a large number of studies in Australia and Papua New Guinea using this approach. In the United Kingdom, land systems analysis was widely used by the Land Resource Development Centre in carrying out development planning in sub-Saharan Africa, the Pacific, and Central America.

Growth in the use of air photos for civilian applications led to an increase in textbooks on the subject. A key early work was Melville Campbell Branch's *Aerial Photography in Urban Planning and Research*, published in 1948 as part of the Harvard City Planning Series. Frank Walker's *Geography from the Air*, first published in 1953, demonstrated to a wider geographical community the value of air photos for research, especially in physical geography and geomorphology. The most important body of work on the use of air photos was that of Robert N. Colwell, culminating in his editorship of the *Manual of Photographic Interpretation*, published by the American Society of Photogrammetry in 1960. Although never reprinted, it remains a key work. In Europe the teaching of air photo interpretation was aided by the publication of *Photo Interpretation*, a trilingual series of guides to interpretation by Éditions Technip in Paris. Publication of this practical series of interpretation guides started in 1961 and took the form of stereo triplets (designed to be viewed under a hand stereoscope), a transparent overlay showing interpreted features, and written descriptions in French, English, and Spanish. In addition to covering almost the entire spectrum of applications, the series frequently included regional or thematic bibliographies.

For nearly twenty years after World War II panchromatic black-and-white photography remained dominant (fig. 687). Black-and-white infrared film had become the standard emulsion for mapping tide lines in coastal environments and was used occasionally for mapping disease in crops. Color and CIR remained too expensive for general use, even though the superior qualities of CIR for vegetation analysis had been clearly demonstrated (figs. 688 and 689). Some confusion about what in the plant was responsible for the reflection of infrared light cast some doubt on the technology's utility. This ambiguity was resolved, however, and Edward B. Knipling's paper (1970) laid any remaining doubts to rest.

In the 1960s there was rapid growth in the use of both color and CIR photography, initially in the United States but increasingly throughout the Western world. Research in Canada and Great Britain showed significantly higher correct interpretation rates when color photos were used, even though interpretation times tended to be longer. Work at the United Nation's Food and Agriculture Organization had also clearly demonstrated the superiority of CIR for high-altitude photography, particularly in the tropics.

By the early 1960s air photos had become standard tools of foresters, soil scientists, geologists, ecologists, archaeologists, and other professionals interested in

FIG. 687. BLACK-AND-WHITE AIR PHOTO OF TANGA, TANZANIA, USED FOR MAPPING MANGROVES, 1954.

Image courtesy of Peter Collier.

mapping spatial data. Ambitious mapping programs were initiated, such as the land use/land cover mapping of the United States, where the larger-scale mapping used aerial photography. Its use was also starting to become widespread in carrying out censuses of both human and animal populations. This use was to continue largely undiminished for the rest of the century. However, the launch in 1972 of the first environmental satellite resulted in academics and researchers paying increasing attention to satellite imagery and less to air

FIG. 688. COLOR AIR PHOTO OF A BALANCING LAKE NEAR MOUNT FARM LAKE IN MILTON KEYNES (U.K.), 26 NOVEMBER 1980. The balancing lake, which is used to control water levels in a river during periods of high rainfall, is important for environmental assessment and mapping.
Copyright reserved Cambridge University Collection of Aerial Photography.

FIG. 689. COLOR INFRARED AIR PHOTO OF TONGWELL LAKE IN MILTON KEYNES (U.K.), 28 JULY 1983.
Copyright reserved Cambridge University Collection of Aerial Photography.

photos. In consequence, the number of papers reporting air photo research declined, even though professionals in many fields continued to rely on them. There was also a significant decrease in the teaching of air photo interpretation to students. This led, in some countries, to a shortage of skilled interpreters at a time when the availability of high-resolution satellite data was renewing a need for those with interpretation skills.

In the late 1990s the development of digital cameras for photogrammetric applications signaled that the long-term future of film cameras looked insecure. While well suited to the needs of digital photogrammetric systems, especially for the automated compilation of digital terrain models, imagery collected by early digital cameras was not suitable for conventional air photo interpretation since it did not permit stereo viewing. Throughout the twentieth century the same imagery was used for photogrammetry and geographic analysis and effectively cross-subsidized the use of the imagery. The developments at the end of the century threatened this relationship at the expense of geographic analysis.

At the same time that advances in digital technology started to threaten the long-term future of air photos, there was the realization that historic air photos were an increasingly valuable data source. Concern about environmental change led environmental scientists to use historic air photos to establish baseline studies against which recent changes could be compared. Maps had been used for this purpose for many years, but it was now recognized that maps record what was considered to be important at the time of their creation, whereas air photos preserved information whose significance had only been realized later. This led to ambitious plans to create digital archives of millions of air photos to make them readily accessible to scientists.

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SEE ALSO: Agricultural Adjustment Administration (U.S.); Forestry and Cartography; Land Systems Analysis; Land Use Map; Map: Images as Maps

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Feature Extraction and Photointerpretation. Aerial photography from balloons, kites, and pigeons predated the twentieth century, but it was not until the advent of airplanes that the systematic use of aerial photographs became practicable. Although some aerial photography had been taken in the years before World War I, these images were little more than a curiosity. At the outbreak of the war all the major combatant nations were poorly equipped to exploit the new technology. Airplanes were deployed like cavalry, with the observer making written notes, and cameras were carried only to confirm written observations. It was soon realized, however, that photographs were more useful than written notes, and photography was placed on a regular footing.

It is not clear who took the first aerial photograph during World War I. Robert S. Quackenbush et al. (1960, 15) credited Frederick Charles Victor Laws of the British Royal Flying Corps (RFC) as being the first to take an aerial photograph, but Laws was not a lieutenant at the time, as Quackenbush et al. claim. Rather than serving above the fray as an aerial observer, Laws was on the ground with an early antiaircraft unit, acting to ensure that it did not fire on British aircraft (Conyers Nesbit 1996, 14). The first aerial photograph taken during World War I was probably taken by Lieutenant George F. Pretyman, a pilot of No. 3 Squadron who took five photographs of the Aisne battlefield on 15 September 1914 (Finnegan 2011, 43).

In the early days of aerial photography no great skill was required to extract information. Enemy forces were deployed in open view of reconnaissance airplanes, which allowed the interpreter to count the troops and equipment and to map the location of field fortifications. Once the trench lines had hardened on the Western Front, the armies became very aware of each other's use of reconnaissance photography and started to make efforts to conceal their positions, equipment, and movements. It was at this stage that photographic interpretation started to develop.

Much of the photointerpretation in World War I was for tactical use. Any new offensive operation by the enemy would require the buildup of artillery and stores close to the front before it could take place. Penetration deep over enemy territory was not necessary to detect these preparations, and the limited range of the airplanes restricted what could be achieved. A race began between photographic interpreters and camouflage specialists and continued throughout the rest of the century. Frontline fortifications could not be disguised, but attempts were made to hide mining operations, artillery positions, ammunition dumps, and other rear area activities. Interpreters soon learned that such activities could often be detected by looking for changes on repeated photography of the same areas. For example, evidence of traffic across fields could lead to the identification of camouflaged positions. As complete concealment by camouflage was difficult, it was common to construct dummy positions that could attract artillery fire away from real positions. The interpreter's skill lay in detecting the real from the false.

Armies started to produce interpretation guides, which were often little more than a series of interpreted photographs illustrating the kinds of features that needed to be identified. In 1916 the British General Staff issued *Notes on the Interpretation of Aeroplane Photographs*. The notes were subsequently revised in March 1917 and edited for use by the U.S. Army War College in September 1917. The guide contained no photographs but was accompanied by a separate booklet, *Illustrations to Accompany Notes on the Interpretation of Aeroplane Photographs, Series A*. The *Notes* began with general instructions that stressed the importance of what came to be called ground truth and cautioned that "every opportunity should be taken of studying on the ground objects similar to those which may require to be identified on a photograph. Thus, captured hostile trenches and positions should be visited until the different types of German works become thoroughly familiar" (U.S. Army War College 1917, 7). Interpreters were advised to study the best map and to have it available during interpretation, to ascertain the direction of light, to focus on the object to be interpreted, to use the photograph as independent evidence for comparison with evidence from other sources, to compare the photograph with earlier photographs of the same locality, and to be aware of the effects of changing seasons. It also stressed the importance of shadows in determining depths and heights of objects. The *Notes* then discussed in detail the features associated with different enemy positions and ended with a discussion of the benefits of stereoscopic viewing.

By 1917, when the United States entered the war, all the combatant nations had developed systems for the systematic use of aerial photography. These systems were largely a matter of trial and error. The allies recognized the importance of stereoscopic viewing of aerial photographs (U.S. Army War College 1917, 19). Even so, Roy M. Stanley (1981, 55, 270) noted that even in World War II the Germans relied heavily on monoscopic viewing of aerial photography.

Strategic use of aerial photography was still in its infancy at the end of the war. The British had started to construct a bomber force, the Independent Air Force, to be used against targets in Germany. It started operations in June 1918, but at the time of the armistice in November 1918 it still lacked the heavy bombers needed for a significant impact, and little is known about the photointerpretation work associated with the bombing campaign. However, as Stanley (1981, 29) noted, by 1919 "all of the major aspects of World War II aerial photoreconnaissance had begun to take shape . . . photomosaics, target graphics, photo interpretation using stereo viewing, comparative and strip coverage—all existed in some form." He further noted that there was "no clear distinction between intelligence and mapping" (32).

By the end of the war many soldiers had become familiar with the use of aerial photography and some had come to appreciate it as a tool for nonmilitary work. With demobilization some of these soldiers started to use aerial photography in their civilian work. However, there were no guides to help them as they attempted to use photography in archaeology, geology, forestry, and a range of other disciplines. They also needed to convince others of the merits of working with aerial photography.

Willis T. Lee (1920) was one of the first to publish a work on the use of aerial photography and photointerpretation, and other geographers quickly followed. In the 1930s many agencies of the United States government started to use photointerpretation on a routine basis. The Agricultural Adjustment Administration systematically photographed farms and rangeland as part of the New Deal (Monmonier 2002). Photointerpretation became part of the normal work of the U.S. Geological Survey, as well as of the U.S. Forest Service and agencies such as the Tennessee Valley Authority (Quackenbush et al. 1960, 7) in 1934 by the American Society of Photogrammetry, became a major outlet for papers on photointerpretation. In Europe, Germany took the lead in the development of photointerpretation, with Carl Troll becoming one of the leading figures in the interwar period. *Luftbild und Luftbildmessung* became the leading European journal dedicated to photogrammetry and photointerpretation, but other journals, such as *Zeitschrift der Gesellschaft für Erdkunde zu Berlin*, also regularly published papers on photointerpretation.

Panchromatic black-and-white film emulsions were the only ones available for aerial photography before the early 1930s. While some early types of color film could be used for terrestrial work, their emulsions were too slow for use from airplanes. Black-and-white infrared film was the earliest type that extended film sensitivity beyond the visible part of the spectrum. Pan K film was sensitized to near-infrared light by exposing it to ammonia vapor prior to its use on stratospheric balloon flights across the United States. It demonstrated both the enhanced haze penetration of infrared photography and the potential of the film for vegetation studies. In 1935 Kodak introduced Kodacolor, a negative film that was sufficiently fast to allow its use from airplanes. The cost of the film, however, restricted its use until the outbreak of World War II, when it was widely used during the Pacific campaign for estimating the depth of water over coral reefs. In 1942 Kodak introduced Ektachrome, a color reversal film that was widely used after the war. Kodak's 2443 color infrared (CIR) film was subsequently reworked from Ektachrome for use in camouflage detection.

At the outbreak of World War II Germany enjoyed a considerable lead in photointerpretation over Britain and France. In 1938 Werner von Fritsch, the German chief of staff, had predicted that "the nation with the best photo reconnaissance will win the next war" (Quackenbush et al. 1960, 8). The Luftwaffe repeatedly photographed northern France, and the photographs were subjected to intensive analysis as a prelude to the invasion of France and Belgium in May 1940. The fall of France in June 1940 meant that Britain, and later the Western Allies, were almost entirely dependent on aerial photography for much of the intelligence needed for military operations. Britain rapidly developed a sophisticated capability (Stanley 1981, 57–60), which recognized the need for three stages of interpretation: an initial assessment of the photographs followed by a more detailed analysis by specialist interpreters and a comparison of the most recent photography with earlier imagery to detect changes. Even before the United States joined the war in December 1941, U.S. military personnel spent time in Britain learning the latest techniques.

An important development was the recognition that photointerpretation could be used for strategic analysis. Specialists were trained to carry out analysis of industrial plants, oil refineries, and power stations to determine their level of production. Allied bombing compelled the Germans to disperse their production of vital war materials throughout the country as well as to local facilities underground. In Britain efforts were made to camouflage factories and to disguise military buildups, particular before D-day. Both sides also created fake targets designed to make the enemy drop their bombs in the wrong places. An arms race of sort emerged between the photointerpreters and those attempting to hide potential targets. These methods were further refined during the Cold War.

Because of these huge investments in photointerpretation, by the end of the war large numbers of people had been trained in the use and analysis of aerial photography. Although many of the more specialist skills had little application in civilian life, the more generic skills could be readily applied in a broad range of fields, including geology, forestry, archaeology, soil science, ecology, planning, and geography. University degree programs in these areas incorporated training in the use of aerial photography, thereby ensuring some continuity of expertise. Papers on the use of photointerpretation became increasingly frequent in academic and professional journals, and the ready availability of war surplus airplanes and cameras made aerial photography much cheaper in real terms than before the war.

In Australia, C. S. Christian and G. A. Stewart used aerial photography in their pioneering land systems analysis work in the Katherine-Darwin region (Christian and Stewart 1953). Their approach involved the identification on aerial photography of small landscape units called land facets, which together make up larger landscape units called land systems. Because of reliable relationships among parent geology, weathering regimes, hydrology, soil types, and natural vegetation, land facets can be used to map these factors in a cost-effective way, thereby providing a limited ground truthing for photointerpretation. This efficiency made land systems analysis attractive for resource inventory work in developing countries, and the military in a number of countries adopted this approach for terrain analysis.

Although CIR film was too expensive initially for widespread civilian use, University of California, Berkeley, forestry professor Robert N. Colwell did much to make it popular for vegetation analysis, and by the 1970s it had become the film of choice for vegetation studies. Initially, CIR film had been used by the military because healthy vegetation appears on the film in magenta while camouflage netting appears blue, making it easy to identify enemy positions. Healthy vegetation could also be differentiated from diseased or stressed vegetation by its much brighter color. Early post–World War II texts mistakenly related light-induced changes in the infrared-sensitive layer of the film to differences in leaf chlorophyll, caused by a breakdown of the chloroplasts as the plant became stressed, leading some scientists to question the results of vegetation analysis using the film (Benson and Sims 1967). Edward B. Knipling of the U.S. Department of Agriculture drew on practical work in biology to discuss the interactions between near-infrared light and leaves and removed any uncertainties regarding the use of the film (Knipling 1970).

By the end of World War I most of the basic elements of interpretation had been identified and discussed in training materials and textbooks. The list was further developed and refined during World War II. Six initial elements—size, shape, shadow, color or tone, texture, and pattern—have been identified (Rabben et al. 1960, 100–105), and stereoscopic view, association, and resolution have been added to the list.

Size could be determined either by direct measurement of an object on the aerial photograph or by comparison with the size of a well-known object on the same photograph. The shape on an aerial photograph is the shape as seen from above. While many people can recognize the differences between tree types based on their profiles, specialist training is needed to recognize them from their plan view. The same is true for many other familiar objects. The shadow of an object can reveal something of its profile, its height relative to other objects, or even its actual height if the time of photography and latitude are known. The color or tone of an object will be affected by a number of factors, such as atmospheric haze, illumination conditions, and film type. The identical soil type in two fields could appear different on a photograph due to difference in moisture level or surface roughness. While both of these factors could be taken into account by an observer on the ground, they might not be readily apparent on an aerial photograph. Because the normal human eye can discriminate between about 2.25 million different colors but between only about 40 grayscale values, color is a much more powerful tool in interpretation than gray tone. Texture is usually a function of factors such as surface roughness, allowing the discrimination between, for example, the managed grass of parks or playing fields, and the grass in pastures. Pattern relates to the distinctive arrangement of features within an object. It could be the ways in which streets are laid out in urban areas of different ages, the tillage and harvesting marks in fields, or the differences between different roof types. Stereoscopic viewing is useful in determining heights of objects or the steepness of slopes as well as in acquiring a general sense of an object's structure. Association concerns the relationship between an object that cannot be directly interpreted on the aerial photograph and an object that can be interpreted. For example, it may not be possible to interpret the function of a building simply from its shape and size, but features around it, such as parking for vehicles and storage for materials, could indicate whether it has a retailing or a manufacturing function. Resolution relates to the smallest size of object that can be identified as separate on the photograph. For example, a geologist could use resolution to estimate the size range of rocks and other materials on the surface.

Although interpretation guides had been in use since World War I, they were further refined by the end of World War II to help photointerpreters in their work. Two distinct types of interpretation keys were developed: the selective key, which allowed the interpreter to select the key item that most closely matched the object on the photographs being examined, and the elimination (or dichotomous) key, which ruled out interpretations that were unlikely if not impossible (Rabben et al. 1960, 112–13). When no suitable examples of object images existed for the area being studied, it was common to use an analogous-area key, which contained examples from an area believed to be very similar to that being studied.

Although a number of books published after World War II discussed the use of photointerpretation in particular disciplines, there was no general text that laid out the principles of photointerpretation and then provided exemplification within particular disciplines. This gap was filled in 1960, when the American Society of Photogrammetry published *Manual of Photographic Interpretation*. Edited by Colwell, a leading advocate of photointerpretation, the *Manual* provided a comprehensive overview of the state of photointerpretation and its role in the physical and human sciences. However, it could not have been produced in that form a decade later as newer image types, such as radar and thermal imaging, were already starting to have an impact, and *remote sensing* would come to supplement and then replace *photointerpretation* as the general term for the collection and analysis of imagery.

Photointerpretation methods continued to be used during the early years of satellite remote sensing because much of the imagery was supplied in hard copy form to users who lacked computer-based image processing (Curran 1985, 4–5). Landsat imagery could be obtained from ground stations directly or from vendors as either individual bands printed in monochrome or as false-color composites. These would then be interpreted as if they were conventional photographs, and viewing was normally monoscopic because of limited overlap between adjacent images. There was a decline in the use of photointerpretation techniques once microcomputer-based image processing became widely available in the mid-1980s. Early image processing software could use only the spectral response of an object as a basis for interpretation or classification. Despite the obvious limitations imposed by this constraint, users of remotely sensed data who enthusiastically adopted image processing typically argued that the cost-effectiveness of image processing outweighed the disadvantages resulting from the misidentification of objects or surfaces. Widespread adoption of image-processing software for the analysis of scanned airborne or satellite data precipitated a rapid decline in the teaching of photointerpretation in universities and colleges.

In parallel with the development of imagery based on spectral response, considerable research was focused on the problems of automatic feature extraction, particularly as an aid in the rapid revision of maps from aerial imagery. Some algorithms were developed to identify and delineate particular features or objects of military significance, such as airplanes. Toward the end of the century there were also some advances in the automatic extraction of well-defined structures, such as standardized apartment blocks. Despite major technological advances in pattern-recognition tasks such as face recognition, the complexity of most features in aerial images thwarted significant breakthroughs in automated feature extraction. Most military analysts recognized that the human eye-brain system was still the best tool for interpreting images and, consequently, showed little interest in using the classification tools available within the software. Their use of image processing was largely restricted to enhancing the image to facilitate visual interpretation.

At the end of the century the successful launch of the commercial satellite IKONOS-1 in September 1999 signaled a revival of interest in the use of photointerpretation techniques for civil applications. Early users of the first high-resolution satellite data—IKONOS offered a spatial resolution of one meter, and QuickBird, launched two years later, raised the resolution to sixty centimeters—quickly became aware that familiar image processing techniques failed to deliver satisfactory results.

PETER COLLIER

SEE ALSO: Lidar; Remote Sensing: Data Handling and Information Extraction from Remotely Sensed Imagery; Terrain Analysis and Cartography

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Military Photogrammetry as a Precursor of Remote Sensing. Armies had shown an interest in the possibilities of photogrammetry from the middle of the nineteenth century, but the need to use terrestrial methods or rely on balloons or kites when overhead imagery was required was a severe limitation on its application. Two soldiers, F. Vivian Thompson, in Great Britain, and Eduard von Orel, in Austria, developed instruments for plotting information from terrestrial photography in the first decade of the twentieth century. Both instruments were subsequently used for civilian topographic mapping. The development of airplanes provided the stable and flexible platform needed for aerial photogrammetry to become a practical proposition.

Aerial photographs were taken by a number of armies prior to the outbreak of World War I, but they were regarded as an aid to military reconnaissance rather than a mapping tool. The outbreak of World War I was a major stimulus to the development of aerial photogrammetry and led to the first applications of what would subsequently be called remote sensing. The static warfare that developed on the Western Front as well as in Gallipoli, Palestine, and Mesopotamia led the combatant nations to seek additional ways to acquire positional information for artillery targeting and military planning. Aerial photography became the only workable data source, and primitive photogrammetric methods were developed to create maps from the aerial photography (MacLeod 1919; Collier 2002). The task of acquiring aerial photography became more difficult with the development of fighter planes and antiaircraft guns. This resulted in a drive to produce better cameras with longer focal length lenses, allowing airplanes to fly higher while still obtaining high-quality large-scale photographs. At the start of the war the only cameras available used glass plates, but by the end of the war film cameras were becoming common. By 1918 cameras with focal lengths of up to forty inches were being used, and the Germans had introduced electrical heating to cope with the cold temperatures (Stanley 1981, 26).

Many scientists and technologists were recruited into the armed forces as a consequence of the unprecedented scope of the war. Their exposure to aerial photography led to an interest in photography for mapping in the postwar period. H. Hamshaw Thomas, a biologist working with the Royal Air Force, noted that vegetation patterns not readily discernable on the ground were clearly visible on air photos (Thomas 1920), and in Mesopotamia, another soldier, Lieutenant-Colonel G. A. Beazeley, was able to see previously unmapped archaeological remains on air photos (Beazeley 1920, 118–19). The focus of all these early studies was on what could be derived from an inventory of single-date photography and related mapping (fig. 690).

FIG. 690. DETAIL FROM THE 1:10,560 MAP *SAMARRAH*. The map sheet (T.C. 109) is dated 15-7-17 and shows part of the archaeological remains. Size of the entire original: 46.5 × 54.6 cm; size of detail: 10.8 × 18 cm. Image courtesy of Peter Collier.

Military interest in photogrammetry declined at the end of World War I, although in a number of countries, such as France and Italy, national mapping remained a military function. In these countries there was active participation by the military in the development of photogrammetry. Specialist equipment, such as analog photogrammetric plotters, were developed either within the military survey, as with the equipment developed by Georges Poivilliers in France, or for the military survey, as with the plotters developed by Ermenegildo Santoni in Italy (Blachut and Burkhardt 1989, 117, 126). In the United Kingdom the Air Survey Committee was established to develop equipment and methods (Great Britain, War Office 1936). Although the Ordnance Survey was also represented on the committee, most of the members were active army or air force officers. The committee published two general reports as well as a number of professional papers, dealing with issues such as camera design, camera calibration, and plotting techniques. Although the committee sponsored the design of a plotter, the instrument was never used operationally.

While photogrammetry was advancing during the interwar period, air photo interpretation was largely neglected. Although most armies produced instructional material on air photo interpretation, these resources demonstrated no significant developments in methodology and did not reflect any changes in the kinds of objects to be interpreted. For example, the training guide issued by the U.S. Army in 1926 still focused on the interpretation of trenches and communications (United States, War Department 1926). There was no attempt to discuss the interpretation of strategic targets.

Extensive improvements in camera technology were made during the interwar period. The change from glass plate to film cameras was completed, and cameras were being fitted with electrical drives to advance the film through the camera. Simple intervalometers were also being introduced to control the time between exposures. In the United States, cameras were designed with interchangeable lenses, with long focal lengths as well as wider angles so that larger areas could be covered without loss of detail. Film formats were also becoming standardized with the U.S. cameras being either 7-inch or 9.5-inch format (Stanley 1981, 147). The 9.5-inch film gave a 9 × 9 inch image (230 × 230 mm), the standard format of air survey cameras in the postwar era.

At the start of World War II the Germans enjoyed a technical and operational advantage over the Allies, but Britain started to commit large resources in equipment and personnel in an attempt to redress the balance. By the time the United States entered the war, the British had gained a significant advantage over the Germans and had been sharing their expertise with the Americans since mid-1941. The main advantage gained by the Western Allies was through their design and production of large numbers of relatively light-weight cameras, suitable for use in fast single- or twin-engine fighters, whereas the Germans were forced to use larger and slower airplanes. As Roy M. Stanley (1981, 172–81) noted, the German Rb 50/30 manufactured by Zeiss weighed 160 pounds, whereas the British F.24 manufactured by Williamson weighed only 42.25 pounds and could provide higher-quality images capable of greater magnification. British and U.S. cameras were of much simpler design than their German equivalents, making them cheaper and easier to manufacture and maintain.

It was recognized that a single photograph of a site revealed little about enemy activities or intentions, but repetitive coverage could yield valuable information about both. The ability to mount cameras in fighter planes meant that, at their peak, the British were flying 100 sorties per day and capturing 50,000 images, and that repetitive coverage of important sites was possible. Improvements in air defenses also forced reconnaissance airplanes to fly ever higher. The best airplane, the De Havilland Mosquito PR 34, had a top speed of 425 miles per hour, a service ceiling of 44,000 feet, and a range of 3,500 miles, making it relatively invulnerable to German air defenses. The ability of the Western Allies to obtain reconnaissance and mapping photography almost at will was seen as a major factor in Allied success in the war (fig. 691). It ensured that image intelligence, as it became known, continued to be seen as important in the postwar period. One of the important lessons learned during the war was that a single image revealed very little about enemy intentions, while multidate imagery could reveal much. From this, earth scientists who worked in photo intelligence came to appreciate that multitemporal photography could also reveal much about natural processes. In turn this was to underpin later thinking on monitoring environmental change and the development of systems that would make this possible.

A number of technical innovations made during the war were to have a significant impact on postwar activities. Color aerial photography had been introduced in the mid-1930s, but the film was slow and unsuitable for use in fast airplanes. The development in 1942 of Ektachrome reversal film by Kodak led to a much wider use of color film. Perhaps more importantly, it led to the development of color infrared (CIR) film. The ability to distinguish between camouflage and natural vegetation using CIR film made it a great asset in detecting enemy installations. Subsequently, CIR photography was to become a major tool in vegetation mapping and monitoring (see fig. 689). The speed of reconnaissance airplanes meant low-altitude photography was extremely difficult with conventional cameras and shutters. An early form of image motion compensation (Thompson 1966, 143)

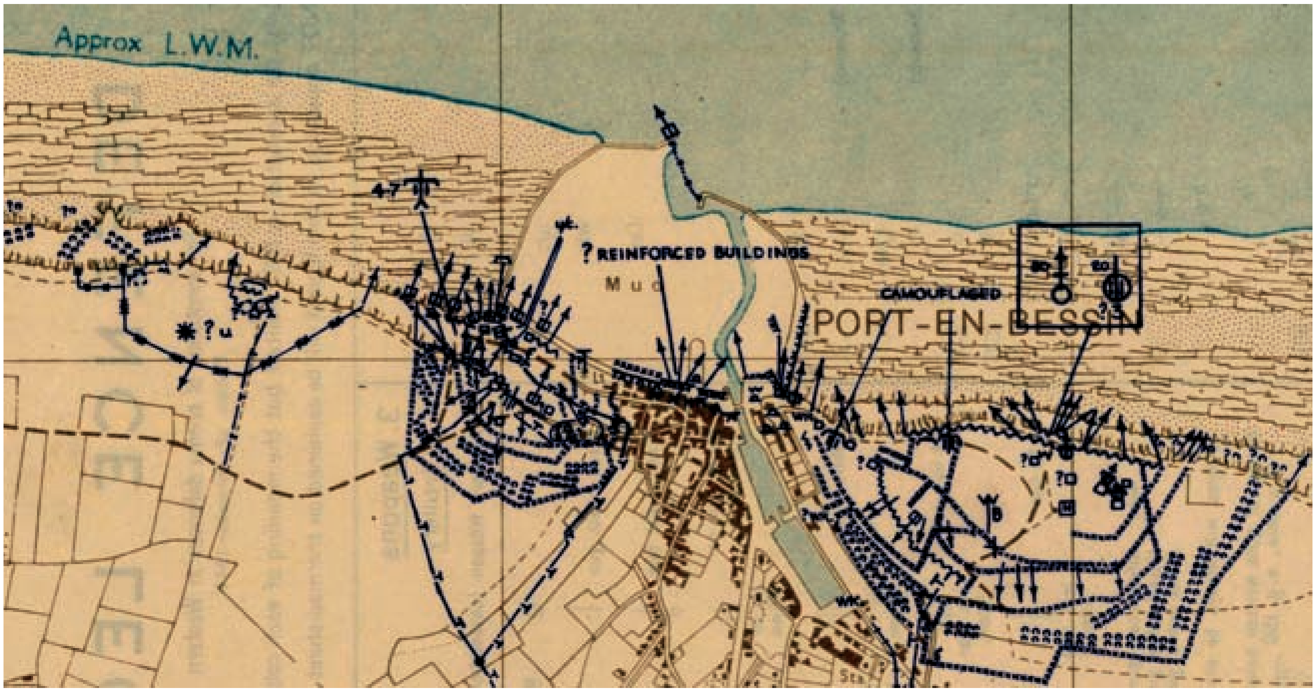

FIG. 691. DETAIL OF A BABY BENSON. Map shows the beach defenses at Port-en-Bessin on the Normandy coast. The information on this map (*Defences*, GSGS 4490, sheet no. 81, May 1944) is nearly all derived from aerial photography. Benson was the name given to the secret 1:25,000-scale maps prepared for the D-day landings in Normandy. The 1:12,500-scale maps, which covered a smaller area, were called Baby Bensons.
Size of the entire original: 49.3 × 61.0 cm; size of detail: 9.6 × 18.4 cm. Image courtesy of Peter Collier.

and the Sonne camera were two developments designed to overcome this problem. The original Sonne camera, developed for the U.S Army Air Force, was based on the same principle as the cameras used for recording photo finishes in horse races. Instead of a conventional shutter, a Sonne camera had a slit at right angles to the line of flight. Film was passed through the camera continuously at a rate that could be varied according to the ground speed of the airplane. The result was a continuous-strip image of the area overflown. Physicist Amrom H. Katz went on to develop the photogrammetric application of Sonne cameras by using forward- and rear-oriented lenses on the camera (Katz 1952). While the means by which this solution is achieved changed with the shift from film to digital technology, the principle was used in some later imaging systems.

The Cold War following so closely after World War II meant that the experience and importance of aerial reconnaissance were still fresh in the minds of military planners. Many different types of airplanes were used in reconnaissance and mapping missions in the decades after World War II, from the new generations of jet fighters and bombers to the B-29s used on mapping missions during the Korean War. However, it was recognized that for missions deep into the airspace of hostile powers, new types of airplanes would be needed. In the United States, the establishment of the Central Intelligence Agency (CIA) led to a number of major innovations including the development of the Lockheed U-2. Among the advances in camera technology was the introduction in the late-1940s of panoramic cameras to obtain maximum coverage from each overflight. Due to their geometry, panoramic cameras posed a particular problem, and as their use was extended from airplanes to other platforms the issue of data reduction became increasingly important (Cloud 2002). The solutions to the problem of data reduction were to have a significant impact on future developments in remote sensing, not just for terrestrial applications but for mapping missions to other planets and their moons.

Overflights of the Soviet Union by the CIA using U-2s continued until U.S. reconnaissance pilot Francis Gary Powers was shot down in 1960. However, the limitations and potential vulnerability of such flights had been apparent for a number of years, and the United States had started to take an interest in the potential use of satellite-derived images by the mid-1950s. The launch of the Soviet Union's Sputnik in October 1957 gave added impetus to these efforts. The first successful launch of a reconnaissance satellite was SAMOS (Satellite and

Missile Observation System) on 31 January 1961. The Soviet Union had started its development of a reconnaissance satellite, Zenit, in 1956, culminating in a first successful launch on 28 July 1962. High-altitude reconnaissance flights continued to be important, in particular during the Cuban missile crisis, and even though more exotic airplanes were developed, including the Lockheed SR-71, it was clear that the immediate future lay with satellite technologies.

The early reconnaissance satellites used film technology to record images. This meant that the film had to be returned to the ground for processing and subsequent analysis. The U.S. Corona program used a system whereby a capsule containing the film magazine was ejected from the satellite. Its descent slowed by a parachute, the capsule was captured by an airplane using a hook. By contrast, the Soviet system involved the return of the whole satellite, which permitted reuse of the cameras. The first Corona satellites produced images with wide area coverage and a resolution of between ten and fifteen meters, but this was quickly improved to between one and two meters. In 1963 the U.S. Gambit satellite produced images with a resolution of fifty centimeters but a limited field of view. The United States continued to use two satellite systems until the early 1970s, when satellites were introduced that could produce both narrow-angle and wide-angle coverage. The Soviet satellites had been able to produce both types of image much earlier, with the wide-angle images permitting the precise positioning of the narrow-angle images (Norris 2008, 68–69).

Little is known about the Soviet mapping programs that used Zenit imagery, but the sale of Soviet military maps following the end of the Cold War revealed what they were able to achieve. As the Soviet Union could openly acquire topographic mapping of Western countries, the main purpose of its satellite missions was to map details not shown on published maps (fig. 692). This would have included military installations, such as missile bases, airfields, and communications infrastructure. As all Soviet topographic mapping was classified, the task faced by the United States was much greater. Instead of carrying out map revision, which the Soviet Union perfected, the United States needed to create new mapping. This involved the development of new technologies to enable them to create maps from the geometrically unconventional images produced by the satellites. Some work had been carried out earlier to exploit images from the U-2 missions, but it became more intense once satellite images were available on a regular basis (Cloud 2002).

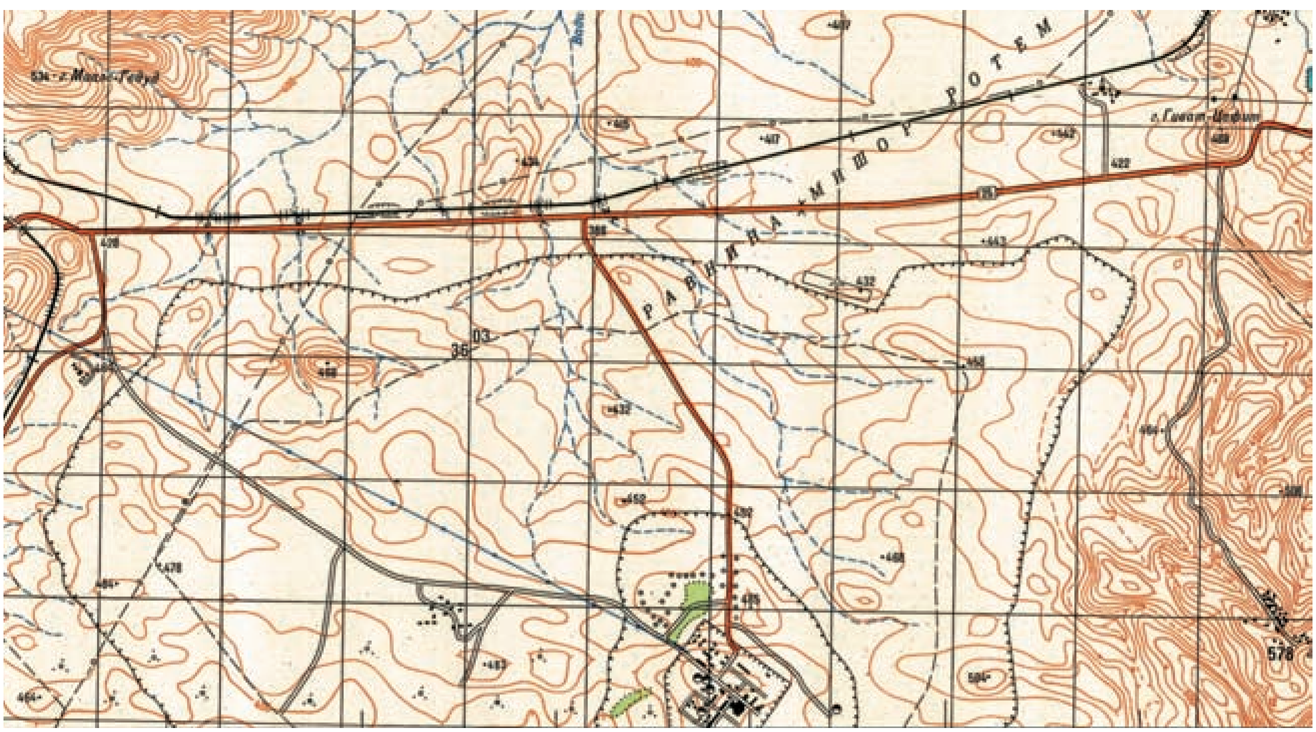

FIG. 692. DETAIL FROM *DIMONA*, SOVIET 1:50,000 MAP OF THE NORTHERN NEGEV, 1993. The map (sheet H-36-35-B) shows the Dimona nuclear facility; the site and its surrounding fences appear on no publicly available Israeli map. Size of the entire original: 42.9 × 51.2 cm; size of detail: 11.8 × 21.4 cm. Image courtesy of the Earth Sciences and Map Library, University of California, Berkeley.

While the existence of reconnaissance satellites was widely known, outside of military circles their capabilities were unknown. Before the first manned space missions the potential use of satellite images for nonmilitary applications had been demonstrated only by a few sounding rocket images (Lowman 1964). The Ranger missions to map the moon prior to the first landing allowed earth scientists an insight into what could be achieved if satellite imagery of the earth became available. The launch of the Earth Resources Technology Satellite (ERTS, later renamed Landsat) in 1972 was a major step forward in the development of satellite remote sensing, but the 79 × 57 meter pixel size of its multispectral scanner gave far poorer resolution than the contemporary military satellites. It was only in 1999, with the launch of IKONOS, that civilian satellites were to come close to matching the resolution available from military satellites since the mid-1960s.

Not all military reconnaissance activity had been directed toward the use of satellites. A number of systems that had their origins in World War II were developed during the Cold War and were subsequently of great use in civilian applications (fig. 693). The two most important of these were ground-imaging radar and thermal imaging. Both technologies experienced accelerated development by the United States during the Vietnam War, as its military needed all-weather systems to cope with adverse weather conditions as well as the ability to detect enemy movements at night and under forest cover. By the late-1960s side-looking airborne radar was being deployed on civilian mapping programs where cloud cover had previously made aerial imaging difficult.

In the 1990s interest in pilotless vehicles or drones grew because they gave a real-time capability offered by neither conventional airplanes nor satellites. Interest in the use of drones started after the Yom Kippur War of 1973, between the Israeli Army and the armies of Egypt and Syria. At that time the Israelis had no satellites and their air force relied on fast jets for reconnaissance and ground support. The antiaircraft missile batteries deployed by the Egyptians and Syrians meant that the Israeli air force had to suppress the missiles before they could support the ground forces. Senior officers in the Israeli armed forces started to question the use of manned airplanes, and to campaign for the development of drones to replace manned airplanes in roles such as reconnaissance. However, the cost of drones meant that their use in civilian applications was rare.

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SEE ALSO: Cold War; Remote Sensing: (1) Earth Observation and the Emergence of Remote Sensing, (2) Satellite Imagery and Map Revision; U.S. Intelligence Community, Mapping by the

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United States. War Department. 1926. *Military Intelligence: Tactical Interpretation of Aerial Photographs*. Washington, D.C.: War Department.

Analytical Photogrammetry and Control Surveying. During the first fifty years of photogrammetry, from 1850 to 1900, the reconstruction of three-dimensional objects from two-dimensional photographs and images was achieved by graphical means in two dimensions. By the turn of the century photogrammetry had become a mathematically oriented tool, and stereo viewing and stereo measurement permitted the extraction of 3-D object information from overlapping images taken from different exposure stations.

In essence, the process of measurement involved reconstructing the geometry that existed at the time of photography between two camera positions and the surface being photographed. To do this the x, y, and z coordinates (or eastings, northings, and height) of each camera position need to be known, together with the orientations of the cameras at the moment of exposure relative to the two horizontal and one vertical axes, the focal length of the camera, and position of the photographic material in the camera. The photogrammetric process therefore entails achieving a solution for nine unknowns for each camera position. The solution of these unknowns is broken down into three stages: inner (or interior) orientation, which solves for the focal length and position of the photographic medium in the camera; relative orientation, which solves for the rotations around the camera axes; and absolute orientation, which solves for the camera positions.

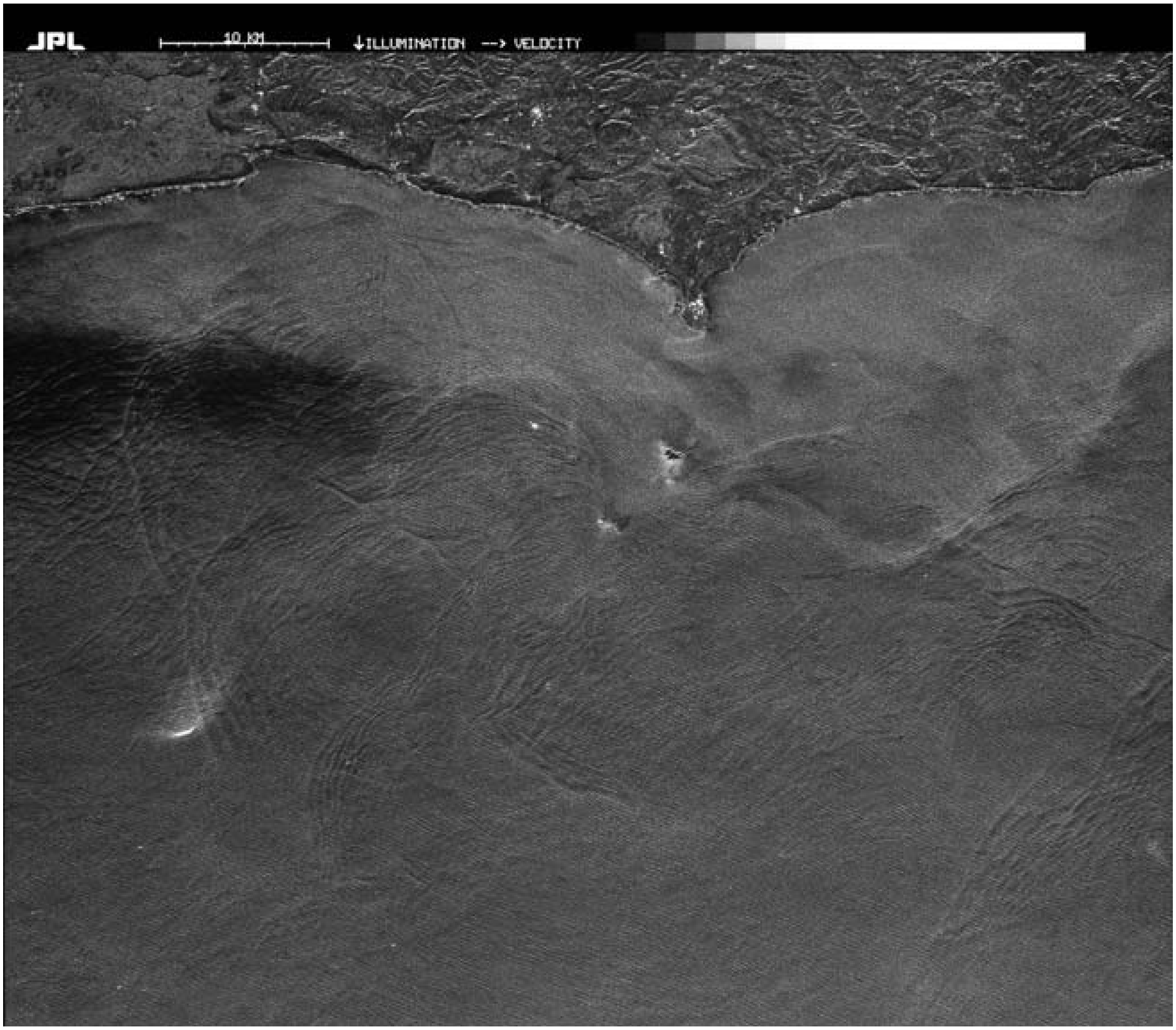

FIG. 693. SATELLITE RADAR IMAGE OFF PORTUGUESE COAST SHOWING PATTERNS OF WAVE DIFFRACTION. Ground imaging radars were a major spin-off from military developments.

Image courtesy of NASA/JPL-Caltech.

Three-dimensional information extraction had become a simple matter if the photographic exposure conditions were simplified. This was possible in terrestrial photogrammetry, for which overlapping images were taken by phototheodolites normal to the base created by the two exposure stations, making the two images coplanar. In effect, this solved for the unknowns of relative and absolute orientation. By measuring the differences between the positions of the same point in the *x* direction (the direction of a line joining the two camera positions) on both photographs it was possible to calculate the distances of the points from the camera positions using parallax equations.

Instrumentation was developed to measure the image coordinates of corresponding points in the left and the right photographs and the differential change between both images in *x* and *y* direction, the so-called parallax. The first instrument of this type was the Zeiss stereocomparator developed by Carl Pulfrich in 1901 in Germany. Independently, Henry Georges Fourcade in South Africa designed a similar prototype, the measuring stereoscope, also in 1901 (Blachut and Burkhardt 1989, 29–33).

The simple geometric relations are:

$$x = y/f \cdot x'$$

$$z = y/f \cdot y', \text{ and}$$

$$y = -(1/b \cdot f) \cdot px; \; px = x' - x''$$

with x' and y' designating the measured image coordinates from the center of the left image and x'' from the center of the right image; f is the focal length (principal distance) of the camera; and b the base length between the two exposure stations. x, y, and z denote the 3-D object coordinates in the stereo model (fig. 694).

However, even these simple calculations were rather tedious to make by hand or hand calculators for the many points measured. In addition, if contour lines were required they would have to be drawn by interpolation between measured height points. For his 1904 map of Devil's Peak near Cape Town, Fourcade measured 266 points with the measurement, computation, and plotting taking more than twenty-five hours. Soon mechanical devices were designed that were able to translate the mathematical relations into mechanical movements of a plotting pencil, as in F. Vivian Thompson's stereoplotter of 1907 or the Zeiss-Orel stereoautograph of 1908 (Blachut and Burkhardt 1989, 92–101).

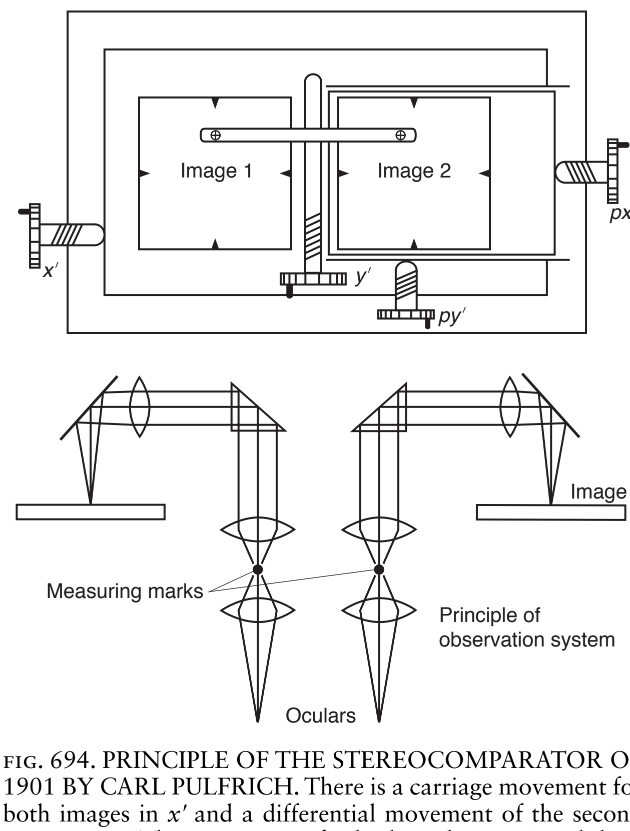

FIG. 694. PRINCIPLE OF THE STEREOCOMPARATOR OF 1901 BY CARL PULFRICH. There is a carriage movement for both images in x' and a differential movement of the second image in px'. The optics move for both oculars in y', and there is a differential movement in py'.
After Konecny 2003, 110 (fig. 3.3).

Terrestrial photogrammetry was applicable for topographic mapping in mountainous areas but was not suited for mapping of flat regions. Around the turn of the century, however, a new platform for photography became available. In the nineteenth century, tethered gas balloons were used as platforms, but these were static and not suitable for mapping extensive areas. Free balloons were also used, but there was little control over the area photographed. With the Wright brothers' development of the motor-driven airplane in 1903, the real potential of aerial photography was opening up. In Germany in 1915, Oskar Messter provided a mechanism for taking overlapping images along a flight strip of near-vertical aerial images for use in World War I. Other countries quickly developed mechanisms for obtaining stereoscopic coverage.

The fact that the images could not be taken in the true nadir direction (vertically down), but were subject to slight tilts, up to a few degrees, due to atmospheric influences, created complications for the geometric restitution of photographs as the photographs were not coplanar. At that time there was no possibility to measure directly the camera tilts. An indirect method of deriving the inclination of a photograph had to be found by the measurement of imaged control points and computations.

The first to offer a solution was Sebastian Finsterwalder, a mathematics professor from Munich, Germany. He succeeded in deriving object coordinates from the image coordinates of two overlapping balloon photographs over the town of Gars am Inn. However, it took him about three years of calculations to present the result in the form of a published map. At that time computing devices were not yet available to calculate the complex transformations from image coordinates to object coordinates in real time. The only aids available were mechanical calculating machines, such as the Brunsviga that Fourcade had used in South Africa.

The solution was to reconstruct the geometry that existed between the two camera positions and the ground at the moment of exposure by the optical projection of the overlapping pair of aerial photographs. This first became possible in an optical analog system, called the Gasser Projector, for which Max Gasser received a German war patent in 1915. The instrument consisted of two projectors, which projected reduced-sized diapositives of the two properly centered images. When the projectors were oriented in the same way that the photographs were taken, the projected images could be viewed as a stereoscopic model if anaglyph filters in complementary colors were used in the projectors and the operator viewed with appropriately filtered specta-

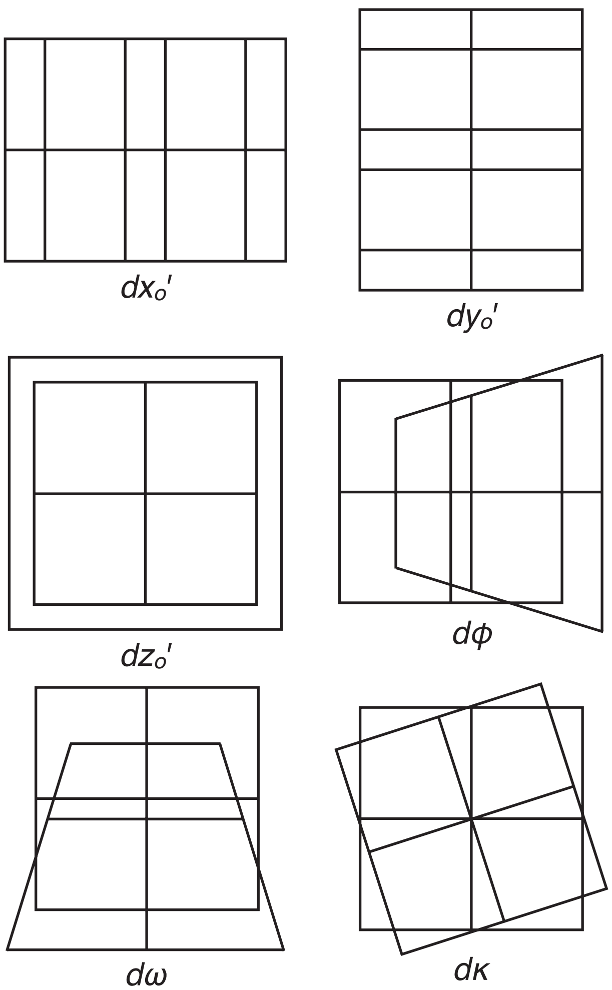

FIG. 695. EFFECTS OF TRANSLATIONS AND ROTATIONS OF THE MULTIPLEX PROJECTOR ON THE PROJECTION TABLE BY THE SIX ELEMENTS OF ORIENTATION.
After Konecny 2003, 117 (fig. 3.10).

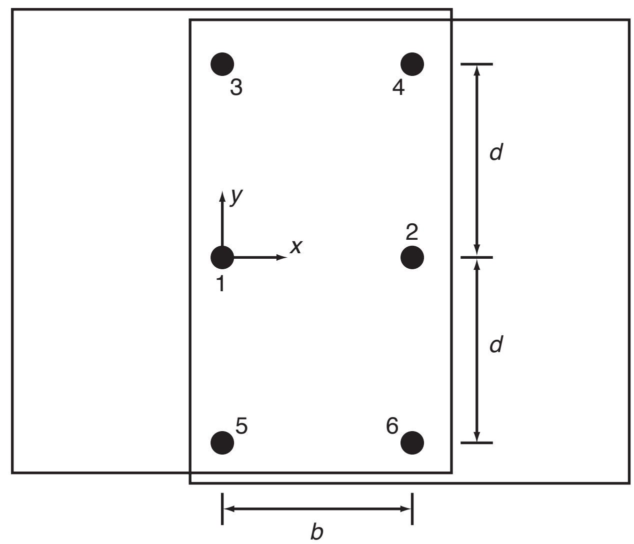

FIG. 696. THE SIX VON GRUBER POINTS. Used for relative orientation in the stereo model, *b* is the base between the two exposure stations, and *d* is the distance determined by the overlap between strips so that *d* in both strips, due to symmetry, is about equal.
After Konecny 2003, 118 (fig. 3.11).

cles. Once a model had been formed the operator was able to plot planimetric and height information.

Gasser not only designed the system but also suggested possible ways in which the orientation of the two projectors could best be achieved (fig. 695 shows displacements of an image grid when projected with tilts and shifts). Around 1930 this led to a relative orientation procedure used to eliminate the *y*-parallaxes at the six characteristic von Gruber points (after Otto von Gruber) with five degrees of freedom. The procedure was normally referred to as an empirical relative orientation (fig. 696).

With their relative orientation established, the two projectors could then be related to the earth's reference system using control points with seven degrees of freedom in the process of absolute orientation (fig. 697). This process is now called geocoding. Initial attempts to relate the stereoscopic model and the earth's reference system using ancillary devices were made at the end of World War I, when the Survey of Egypt attempted to fix the plan positions of camera stations by resection using simultaneous readings to three radio transmitters. While this approach was unsuccessful at the time, the principle was used successfully at the end of World War II.

The Gasser Projector was later rebuilt in modified form by other manufacturers—for example, by Carl Zeiss in 1933 under the name Multiplex. Gasser never obtained full patent rights for his invention. Subsequently, other producers in Italy (Nistri), the United States (Bausch & Lomb), and Britain (Williamson & Ross) followed with designs of this type.

During the 1920s and later, other designers circumvented possible patent rights by the construction of other optical, mechanical, or opto-mechanical devices for the analog calculation of object coordinates from image coordinates (Hugershoff-Heyde's stereoautograph, Zeiss's stereoplanigraph, Wild's autograph, the Thompson-Watts plotter, Santoni's solar periscope, and instruments by Georges Poivilliers). In most of these instruments it was possible to make measurements that permitted the calculation of solutions for relative and absolute orientation. However, the calculations were very slow, and most instrument operators preferred using empirical solutions.

During the first half of the century the problem of geocoding without the existence of global navigation

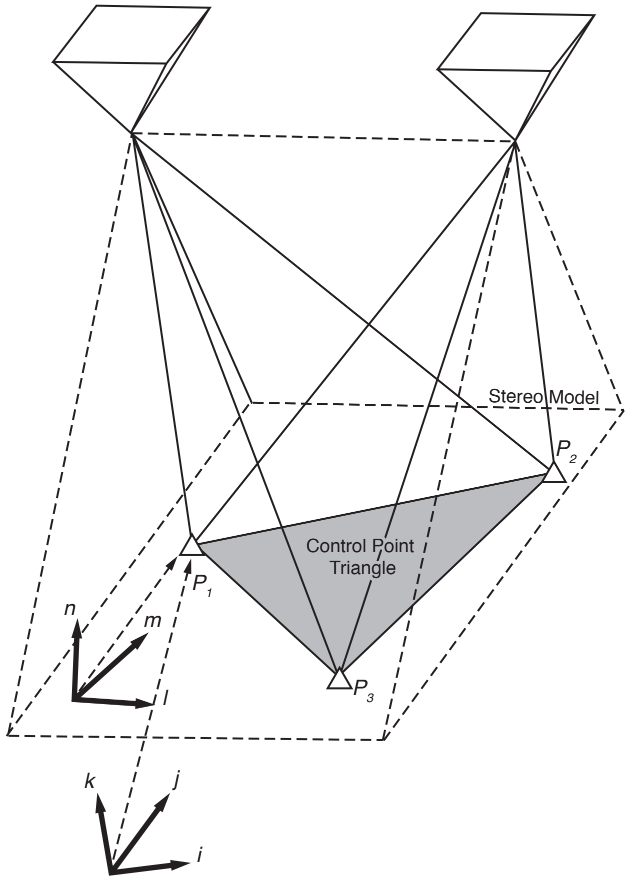

FIG. 697. ABSOLUTE ORIENTATION OF THE STEREO MODEL AFTER RELATIVE ORIENTATION. The two projectors have to be spatially rotated together so that the projection fits the required spatial distance between control points P_1 and P_2 and the elevations of all three points P_1, P_2, and P_3.
After Konecny 2003, 122 (fig. 3.15).

satellite systems or global positioning systems (GNSS-GPS) was not that easy. Geocoding had to be related to ground control and measured by tedious and costly ground surveys. While relative orientation of two images was possible without ground control, absolute orientation required a minimum of two plan positions and three height values. The two plan positions were used to control the model for scale and orientation, while the three height values were used to control the model relative to the datum surface, or to "level" the model. In practice it was normal for each model to be controlled by three plan points and four height points to provide independent checks on the accuracy of the result.

The requirement to orient each stereo model separately soon led to the idea that it would be possible to minimize the control effort within a flight strip and within a flight block by utilizing the scale and rotation dependencies between adjacent stereo models. The idea had already proven useful in two dimensions, when radial triangulation procedures had been developed to fit images of a flight strip or block to a geometrical map base. After World War II maps of vast flat areas in northern Canada and Alaska were compiled after a mechanical radial triangulation by slotted templates had been carried out, fitting it to control points established by Shoran trilateration. The Institut géographique national and the Directorate of Overseas Surveys both made extensive use of slotted templates to control mapping in Africa.

In the 1930s there had already been attempts to carry out aerial triangulation in three dimensions. The simplest form of this involved the use of multiplex plotters. It was possible with a multiplex plotter to orient a third projector to an existing model formed by the first two projectors, which had already been absolutely oriented.

This was carried out using a single projector relative routine, using the three rotations around the *x*, *y*, and *z* axes and translations of the third projector in the *y* and *z* directions. The third translation in the direction of the base (the *x* direction) was then carried out by a scale transfer, by matching the height of a transfer point in the new model to the height of the same point in the existing model. Long bar multiplex instruments could have up to twelve projectors, each additional model being joined to the existing ones using the same single projector orientation procedure.

A series of so-called first-order or universal optical and mechanical plotters were produced by major instrument manufacturers that could be used to carry out this operation by switching the base alternately between "base-in" and "base-out" settings. In this operation the instrument would go through the orientation procedure in the base-in condition, having the left photograph of a stereo-pair in the left projector, and the right photograph in the right projector. Once the model had been established and the heights of transfer points recorded, the left photograph was replaced by the next one in the strip and the instrument changed to the base-out condition. A single projector orientation was then carried out using the left projector. It was then possible to replace the right photograph with the next one in the strip, change the instrument to base-in, and carry out a single projector orientation on the right projector. This routine, alternating base-in and base-out, could be carried out for strips of photography containing up to about twelve models (see fig. 685).

This strip aerial triangulation (sometimes called "classical" aerial triangulation or "bridging") suffered from error propagation from model to model. Therefore, the discrepancies had to be diminished using control points at the beginning, in the middle, and at the end of the strip. The discrepancies were corrected by interpolation using polynomials. Even block discrepancies between adjacent strips could be corrected by interpolation in that way. The interpolation solution was far from satisfactory but continued in use until the widespread adoption of computers made it redundant. The method was used extensively in large-scale mapping of the U.S. interstate highway corridors in the mid-1950s.

Interest in analytical photogrammetry and analytical aerial triangulation started in the 1930s, and instruments such as the Cambridge Stereocomparator were developed to explore its potential in national mapping. However, it was in the 1950s and 1960s that it became the preoccupation of mathematically inclined photogrammetrists. Very comprehensive analytical solutions for orientation problems, such as those of Karl Rinner of Austria and E. H. Thompson of the United Kingdom, were developed within the academic community. However, the scholars who had access to the best computer facilities, such as those offered by the U.S. government—for example, Hellmut H. Schmid and his collaborator Duane C. Brown—had the most comprehensive solutions. They used the network of collinearity equations between image points, exposure stations, and object points in a block for a complete solution, which offered the opportunity for accuracy analysis, statistical testing, and self-calibration using least squares adjustments (fig. 698).

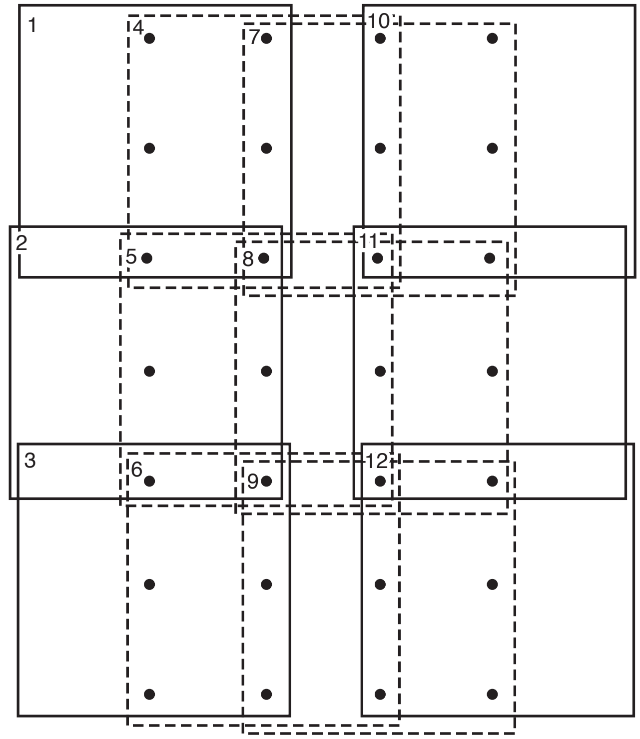

FIG. 698. CONFIGURATION OF A BLOCK OF AERIAL PHOTOS FLOWN WITH 60 PERCENT LONGITUDINAL AND 20 PERCENT LATERAL OVERLAP. Shown are the von Gruber points at which measurements of image coordinates are required to spatially orient all photos of the block together.
After Konecny 2003, 147 (fig. 3.31).

Another approach was developed in which stereo models could be connected in a block adjustment. The so-called Anblock aerial triangulation or aerial triangulation by independent models (AIM) was initially propagated by Friedrich E. (Fritz) Ackermann in the 1960s and 1970s (fig. 699). The software developed by Ackermann was very popular with national mapping agencies since it was well suited to adjusting large blocks of approximately vertical photography. However, AIM was not well suited for dealing with convergent or highly tilted photography, for which the bundle adjustment is considered a more versatile solution. A bundle adjustment is also expandable to other sensors and platforms. Aerial triangulation permits a reduction in the number of surveyed ground control points necessary to control the mapping process. To achieve model accuracy a control point is required every five models of the block, if no additional sensor data are available (fig. 700).

A number of attempts were made to provide additional information to help control mapping. V. P. Nenonen in Finland invented the statoscope to determine differential changes in the flying height, one of the six orientation components of a camera. This was later combined with horizon cameras, which permitted the determination of tilt in the x and y directions. Ermenegildo Santoni in Italy invented the solar periscope, which allowed the determination of tilts from solar images exposed simultaneously with those of the aerial camera pointing to the approximate nadir. These methodologies have led to the development of star sensors, which were able to deduce orientation angles in the National Aeronautics and Space Administration's extraterrestrial exploration efforts.

A fundamental breakthrough occurred with the invention of the digital computer (the Zuse Z3, introduced in 1941, and Howard H. Aiken's Automatic Sequence Controlled Calculator [the Mark I], completed in 1944). The first uses of digital computers in photogrammetry occurred when the originally graphical corrections of strip aerial triangulation were replaced by corrections calculated on the digital computer. Such polynomial interpolation programs were programmed by Gerhardus H. Schut at the National Research Council of Canada in the mid-1950s.

Uno Vilho Helava, who invented the analytical plotter, was the first designer to apply digital computation principles to the 2-D/3-D photogrammetric transformation problem (Helava 1957) (fig. 701). Digitally computed solutions to the problem of model formation had dis-

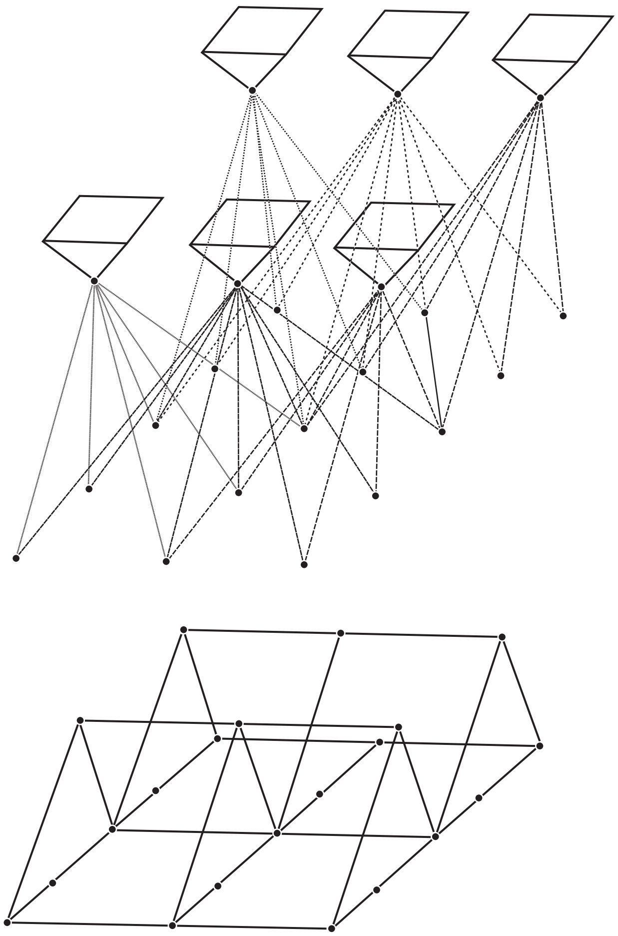

FIG. 699. BUNDLE BLOCK ADJUSTMENT. This method uses the collinearity equations between exposure stations, photo points, and von Gruber points for orienting all images of the block. The same can be reached by Anblock adjustment fitting the stereo models of the block together.
After Konecny 2003, 146 (fig. 3.30).

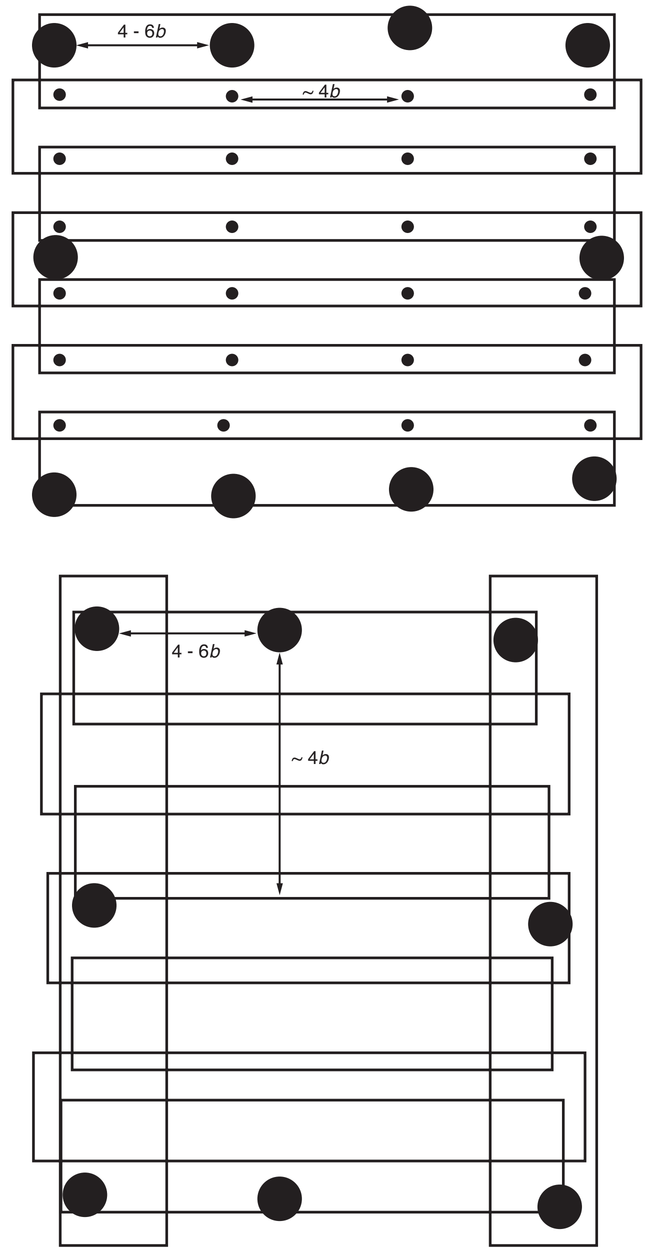

FIG. 700. SPATIAL ORIENTATION OF AERIAL PHOTOGRAPHS. To spatially orient a block of aerial photos reliably a limited number of ground control points distributed over the block are required. The top figure shows the needed location of elevation control points and the bottom figure the required position of horizontal control points. Large dots are horizontal control points, small dots are vertical control points, and *b* is the base distance between the two exposure stations.
After Konecny 2003, 148 (fig. 3.32).

tinct advantages over analog solutions. Most analog instruments were severely constrained in terms of the focal length of the photography that could be used. No such constraints applied to analytical solutions. Many analog instruments were also constrained to use photography taken within a few degrees of vertical, whereas analytical solutions could use tilted photography, including convergent and terrestrial images. The main limitation on the adoption of the analytical plotter was the cost of the computer needed to control it. The development of relative cheap minicomputers in the 1970s made the use of analytical plotters cost-effective for large mapping agencies and led to the development of analytical plotters by all major photogrammetric instrument manufacturers. By the end of the 1980s the manufacture of analog instruments had been phased out.

The more independent solution of a digital workstation was introduced by John Sharp of IBM in 1964, who attempted to realize a fully automated digital image processing solution. However, the technology available at the time and the cost of computing meant that there was little interest in such solutions beyond the

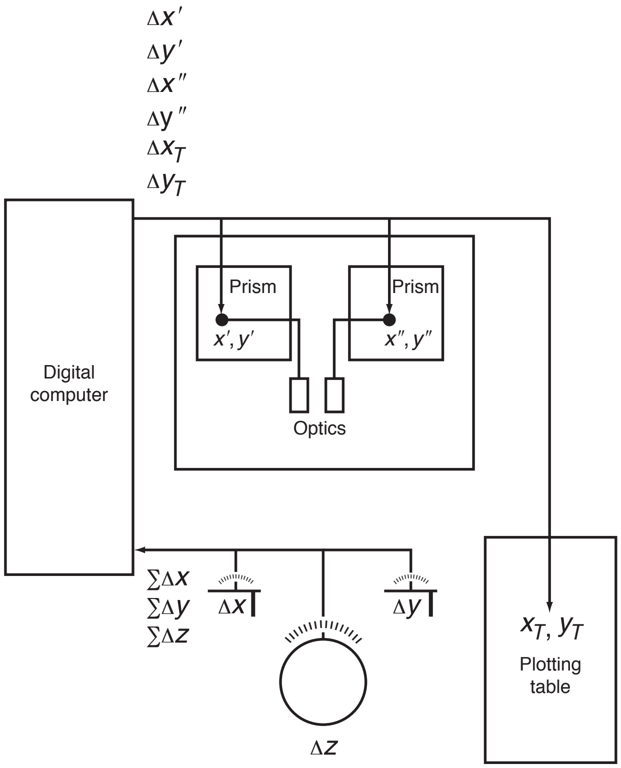

FIG. 701. DIAGRAM OF ANALYTICAL PLOTTER. In the analytical plotter the hand wheel movements of *x, y*, and *z* are accumulated as digital values in the computer. The analytical relation between object coordinates *x, y, z* and the image coordinates of the left image *x′, y′* and the right image *x″, y″* are calculated according to the orientation matrixes for the left and the right image and set by servo systems; *x* and *y* may be connected to a plotting table.
After Konecny 2003, 124 (fig. 3.16).

U.S. military. There had to be substantial reductions in the cost of computing, together with major advances in scanning technologies, before digital solutions could be economically viable, and that did not happen until the 1990s.

The major breakthroughs in providing in-flight control data that allowed the geolocation of exposure stations were the introduction of GNSS-GPS and inertial measurement units (IMUs). Differential GPS measurements could determine the location of the exposure stations with an accuracy of a few centimeters, while the IMUs provided the angles of rotation around the *x, y*, and *z* axes. By century's end, aerial triangulation was still being used to verify the correctness of the positional and rotational accuracies. Even so, it seemed plausible that GNSS-GPS and IMUs could be used to improve the attainable accuracy. Indeed, if properly calibrated, they are capable of replacing the old geopositioning and orientation methodologies for remote sensing systems, as already shown for high-resolution satellite imaging systems. Georeferencing then becomes an issue of calibrating the satellite orbit with respect to a global reference and supplying correction data in form of RPCs (rational polynomial coefficients).

Aerial photogrammetry has been the tool used to provide topographic map coverage of the countries of the world during the twentieth century. By 1980 about two-thirds of the land areas of the world were covered by maps at 1:50,000 scale. However, the revision rate was between fifteen and fifty years. Except in Europe and the developed world, including China and the Russian Federation, which always considered mapping to be important for development, larger-scale maps required for settlements were much less common.

GOTTFRIED KONECNY

SEE ALSO: Property Mapping Practices; Topographic Map; Topographic Mapping: Overview

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Geodesy and Photogrammetric Mapping. Geodesy is the science of measuring the size, shape, and gravity field of the earth. It dates back to ancient times. Photogrammetry is the science or art of obtaining reliable measurements by means of photography. The word "photogrammetry" came into general usage about 1934, when the American Society of Photogrammetry was founded, although the term had been widely used in Europe since 1893. It is derived from three Greek words: *photos* meaning light, *gramma* meaning that which is drawn or written, and *metron* meaning to measure. During the twentieth century a critical interaction between the two sciences enabled substantial progress in modern mapping technologies to be made. The necessary linkage consisted of photogrammetrists identifying on their images geodetically determined horizontal and vertical control points on the ground where these points are referenced to a national coordinate system, commonly called a datum. Geodesists have defined both a horizontal datum and a vertical datum. Once such points are identified, photogrammetrists can accurately position objects identified on their images to precise positions on a model of the earth.

The two main categories of photogrammetric mapping are terrestrial photogrammetry and aerial photogrammetry. Terrestrial photogrammetry, in which the camera is mounted on a tripod, with the camera axis horizontal, is very specialized. It will not be discussed here as its use in twentieth-century cartography was negligible.

Aerial photogrammetry uses images taken from an air- or space-borne camera. Most useful are vertical photographs, those taken with the optical axis of the lens pointed vertically downward at the time of the exposure. In reality, each vertical photograph is tilted to some degree from true vertical.

The developments that led to the twentieth-century photogrammetric mapping date back to 1849. Aimé Laussedat, an officer in the engineer corps of the French army, embarked on a determined effort to prove that photography could be used to prepare topographic maps. In 1858 he experimented with a glass plate camera in the air; he also made a few maps with the aid of balloon photography. Laussedat developed a mathematical analysis for converting overlapping perspective views into orthographic projections in any plane. In a three-volume work he described his research on methods and instruments for the compilation of topographic maps (Laussedat 1898–1901).

Around 1900, Captain Theodor Scheimpflug of the Austrian army provided a solution for the problem in aerial photogrammetry that had been a stumbling block to Laussedat—obtaining complete coverage of the area visible from a camera station in the air. Scheimpflug used an eight-lens camera attached to the basket of a balloon. This camera consisted of seven oblique lenses grouped around a central vertical lens, providing one vertical and seven oblique views that could be transformed into an extremely wide-angle composite photograph.

The development of instrumentation for taking accurate measurements and for compiling maps from photographs proceeded concurrently with the development of the methods for securing photographs. With the discovery in 1892 by Franz Stolze of the principle of the floating mark and the subsequent development by Carl Pulfrich of a practical method of measuring with floating marks, stereophotogrammetry came into use. Near the turn of the century two members of the Militärgeographisches Institut in Vienna, Arthur von Hübl and Eduard von Orel, developed the stereocomparator and the stereoautograph. Even today the majority of all photogrammetric mapping instruments apply the principle of stereophotogrammetry and use some type of floating mark.

The development of the airplane brought about major developments in aerial photogrammetry surveying and mapping. The first known photograph to have been obtained from an airplane was a motion picture taken in 1909 by Wilbur Wright in a flight over Centocelle, Italy. The earliest known use of photographs taken from an airplane for mapping was described in 1913 by Captain Cesare Tardivo in a paper presented at a meeting of an International Society of Photogrammetry held in Vienna.

Since aerial mapping could be accomplished only if every part of the area being mapped were visible on two or more photographs, aerial cameras were developed that fit into a port in the body of an airplane, and photographs were taken with at least a 60 percent overlap in the direction of flight. The area to be mapped usually required more than one flight line, and in most cases the flight lines were parallel and flown so that photographs from the second flight line overlapped the first flight line by about 20 percent. With 60 percent forward overlap and 20 percent side lap, parts of the area to be mapped were visible on six different photographs.

The first single-lens mapping cameras were the type T-5 developed in 1938. This camera had a six-inch lens, which had an angular field of 93 degrees with good resolution. The format was nine by nine inches. It had an inner cone made from a special aluminum alloy having a low coefficient of expansion. The lens, focal plane, and fiducial marks, which are used to determine film distortion, were rigidly attached to the inner cone. There were usually four or eight fiducial marks. If four, they were located in the middle of the sides of the focal plane or in its corners. If eight, four were in each location. These marks were exposed onto the photo when the picture was taken. The lines joining opposite pairs of fiducial marks intersect at the center of collimation. Cameras are manufactured so that this occurs close to the principal point of the optical system.

The prime requisite of a mapping camera is a constant relationship between the lens, the focal plane, and the fiducial marks, so that once the camera has been calibrated the calibration data will remain valid for normal use of the camera. With few exceptions, all commercial cameras built since 1938 have a six-inch focal length and a nine-by-nine-inch format. These are referred to as standard wide-angle mapping cameras. They have a between-the-lens shutter and a means for recording auxiliary data. For low-altitude photogrammetry, the requirement for better ground resolution has resulted in the development of improved lenses and shutters, a moving platen that compensates for image motion, automatic exposure control, and gyro-controlled camera mounts. In response to the demand for close control of film distortion, some camera manufacturers have incorporated a reseau plate (a calibrated grid), into the camera. The reseau grid is imaged onto the film at the instant of exposure.

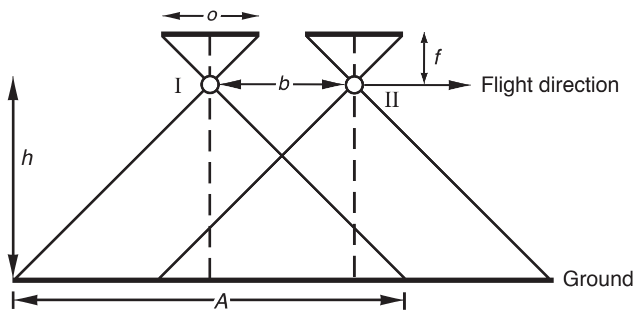

FIG. 702. THE GEOMETRY OF TWO SEQUENTIAL AERIAL PHOTOGRAPHS. The distance between photos, the base distance, is denoted *b*, the flying height above the ground is *h*, the camera focal length is *f*, the size of one photograph is *o*, and the corresponding ground coverage is *A*. For most wide-angle mapping cameras, the base/height ratio is 0.6.

After the development of the aerial camera, stereoscopic plotting instruments (stereoplotters) were manufactured to complete the mapping process. Figure 702 shows two sequential photographs taken with an aerial camera. Stereoplotters were designed to simulate the situation of figure 702 and create a map of the area overlapped in the two photographs. All stereoplotters have four main components: the projection system, the viewing system, the measuring system, and the tracing system. The aerial photo negatives are copied onto glass plates, called diapositives, and these are placed into projectors. Different manufacturers use different techniques to create the stereomodel. A Balplex stereoplotter (fig. 703) has controls that allow the operator to rotate and translate the projectors to create the same geometry that existed when the photographs were exposed; only one stereomodel can be traced at a time. Other instruments, such as the Multiplex (see fig. 683 and 684), have a series of projectors that allow the operator to work with multiple stereomodels. The Multiplex and Balplex use diapositives smaller than the nine by nine inches, requiring a reduction from the original negatives. The first stereoplotter to use the nine-by-nine-inch diapositives was the Kelsh plotter.

The stereoplotter operator performs what is called relative orientation to simulate the actual geometry of the stereomodel. After relative orientation is completed, it is necessary to scale and level the model to existing ground control. This is called absolute orientation. Absolute orientation requires two horizontal control points visible for scaling the model, and three vertical control points to level the model. These control points have to be established by a surveyor and, with few exceptions, have to be in existing coordinate systems. The survey points are established before the photographic mission is flown. For them to be visible on the photographs, the surveyed points must be surrounded with a photo-identifiable material. If the surveyed point is along a paved surface, a white cross is painted around the point. (Only the legs of the cross are painted so that the unpainted center of the cross is directly over the surveyed point.) The size of the cross varies with the altitude of the photographic mission. If the surveyed point is on bare ground, panels are laid out to resemble a cross using inexpensive materials such as plastic. There are also special targets available from surveying supply houses.

The ground control, both horizontal and vertical, must be available for every stereo model and must be plotted on the manuscript map before map compilation. For small mapping projects, the surveyor provides all control. For large projects there are stereoplotters available, such as the Wild A7, that produce the base manuscript with all control plotted. The Wild A7 is called a bridging instrument. The surveyor establishes photo-identifiable control for both the first model and the last model of a strip of photography. The A7, with only two projectors, has the capability of scaling and leveling the first model, then reversing the base and replacing the first diapositive with the third, then orienting this diapositive to the already scaled and leveled first model. This process is continued until the last model is reached. The existing ground control visible in this last model is compared to the control carried through the bridging process, and any differences are adjusted. In the end the base manuscript has all the necessary control plotted, and the manuscript is taken to other stereoplotters to trace the map.

With the introduction of the digital computer, manufacturers switched from analog stereoplotters to analytical plotters. Analytical plotters are a combination of a stereoscopic viewing system, a digital computer, and state-of-the-art photogrammetric software. When the operator places the floating mark on the ground, *x* and *y* coordinates of the point from both photographs are measured by encoders and sent directly to the computer. The computer uses these photo coordinates along with camera calibration data and ground coordinates of marked geodetic control points to calculate geodetic coordinates of the point in real time.

Softcopy stereoplotters are the latest development in stereoplotters. The system uses digital images that can be acquired from a digital camera or, more often, by scanning the negatives of aerial photos taken with conventional film cameras. The operation is identical to that of the analytical plotter. Rather than generating a line and symbol planimetric map, softcopy uses a procedure called digital image processing that generates an orthophotomap.

The expression *ground control* means geodetic control. The horizontal control needed for scaling a photogrammetric model and the vertical control for leveling a model are based on two different geodetic datums.

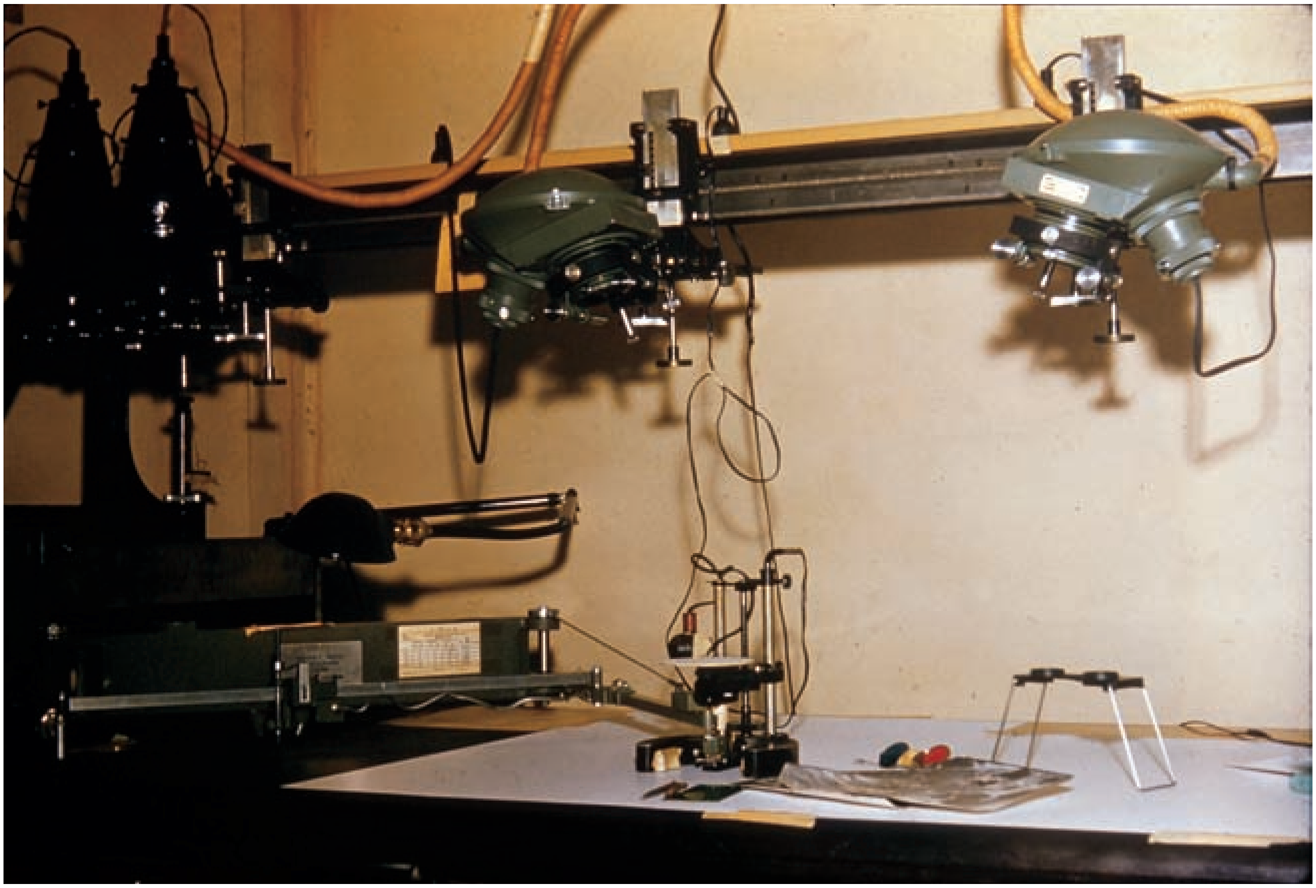

FIG. 703. ER-55 MULTIPLEX STEREOPLOTTER USING BALPLEX PROJECTORS. Designed by Russell K. Bean of the U.S. Geological Survey in the early 1950s.

Image courtesy of the U.S. Geological Survey, Rolla.

Examples of horizontal control coordinates are latitude and longitude and State Plane Coordinates. Vertical control coordinates are the orthometric heights, commonly called elevations or heights above sea level. During the twentieth century, in the United States and Canada, four different horizontal datums and three different vertical datums were used.

The first horizontal datum was the New England Datum, used from 1879 to 1901; the second was the U.S Standard Datum of 1901, which became the North American Datum in 1913. Neither played a role in aerial mapping. The third datum, the North American Datum of 1927 (NAD27), was in use from 1927 to 1986, and the fourth, the North American Datum of 1983 (NAD83), was the horizontal datum in use at the end of the twentieth century.

The first vertical datum, initiated in 1912, was the Fourth General Adjustment, also called the Sandy Hook Datum. In use until 1929, it played no part in aerial mapping. The second datum was the National Geodetic Vertical Datum of 1929 (NGVD29); it was in use until 1988. The third datum, the North American Vertical Datum of 1988 (NAVD88), was the vertical datum in use at the end of the twentieth century.

Up until the late 1980s, horizontal control for aerial photogrammetry had to be established using conventional geodetic surveying procedures. The base control network for most of the world was established by triangulation. The highway departments in every U.S. state established horizontal control for highway construction and maintenance. Before the electronic era, surveyors used transits and steel tapes and ran traverses for establishing control. With the invention of the electronic distance meter in the 1940s, followed by the electronic total station, establishing geodetic control by traversing became less labor intensive.

Vertical control could be established only by differential leveling. Vertical control networks are abundant because orthometric heights are needed for all civil works. From an established vertical control point, a surveyor could use trigonometric leveling for extending control accurate enough for aerial mapping.

With the development of the Global Positioning System (GPS), geodetic control could be established in a fraction of the time required for conventional techniques. GPS receivers are installed in airplanes alongside the aerial cameras. At the instant each exposure is made, the GPS receiver determines the position of the camera. Both horizontal and vertical coordinates of the camera position are recorded. With the camera station position determined, the amount of ground control needed is decreased significantly. GPS is also used to establish horizontal control points that are paneled.

A laser mapping system, called lidar (light detection and ranging), was developed in the latter part of the twentieth century. The system, carried in an airplane, consists of a laser imaging device, an inertial navigation system, a GPS receiver, and a computer. Laser pulses are transmitted toward the terrain below the aircraft, reflected from the ground itself and objects on the ground, and detected by the system in the aircraft. By accurately measuring the time delay between transmission and detection, the distance from the ground or object on the ground can be determined. The inertial navigation system determines the attitude (roll, pitch, yaw) of the aircraft, and the GPS receiver determines the position of the detector. The computer processes all observed data and is able to compute the positions of all ground points. Not only are positions of ground points determined, but an image of the ground is also generated. The data can be used to produce digital elevation models (DEMs), which are then used to produce contour maps and other topographic products.

Basic photogrammetric mapping has not changed in concept since the late nineteenth century. Despite various refinements, the stereoplotter using the floating mark remains the backbone of aerial mapping. Softcopy stereoplotters have replaced analog stereoplotters. Orthophotomaps can now be produced in addition to line and symbol maps. Even with the advent of digital aerial cameras, scanning film negatives remains cost-effective. And lidar systems obviate the necessity of establishing photoidentifiable ground control. Given these technological advancements and the array of those on the horizon, the future of twenty-first century mapping is hard to imagine.

JAMES REILLY

SEE ALSO: Figure of the Earth; Geodesy; Hotine, Martin; Property Mapping Practices; Tidal Measurement; Topographic Mapping: Overview

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Instrumental Photogrammetry and Stereocompilation. At the start of the twentieth century, little detailed, systematic topographic mapping existed outside of Western Europe, India, and small portions of the United States (Collier 2002, 155–56). While it could be argued that military requirements drove the production of topographic mapping, it was largely due to one technology, instrumental photogrammetry, and one process, stereocompilation, that topographic mapping covered so much of the world by the end of the century.

Instrumental photogrammetry is the technology of making measurements from an overlapping pair of photographs using a device that permits a stereoscopic view of them and incorporates a measuring mark (called the floating mark) to make measurements in the x, y, and z (easting, northing, and height) directions. If the measurement system is linked to a plotting system, it is possible to carry out stereocompilation—the plotting of planimetric and height information—directly from the overlapping pair of photographs. The techniques of what has been called "classical instrumental photogrammetry" were developed and used and became obsolete entirely within the twentieth century (Petrie, Bethel, and Walker 2004, 758–59). Classical instrumental photogrammetry can be subdivided into two methods: analog photogrammetry, which involves the creation of a theoretically correct model of the surface using either optical or mechanical reconstruction, and analytical photogrammetry, where the camera geometry and its restitution are modeled mathematically (Konecny 2003, 106–82). This discussion will be exclusively concerned with analog photogrammetry.

To be able to make accurate measurements from stereo photography it is necessary to reconstruct the geometry that existed at the moments the two photographs were taken. This includes the internal geometry of the camera, the relationship between the two camera positions, and the relationship between the camera stations and the object (usually the ground) being photographed. Once the original geometry has been reconstructed, the photogrammetrist can make accurate measurements in the x, y, and z directions as well as plot information in the horizontal plane, including contours, on a reduced-scale model of the object photographed. This process is called stereocompilation.

Although the basic theoretical underpinnings were laid in the late nineteenth century by, among others, Theodor Scheimpflug, Ignazio Porro, and Carl Koppe, the earliest practical instruments were only developed in the first decade of the twentieth century (Blachut and Burkhardt 1989). By the 1980s the last new analog instruments were being introduced as analytical instruments were replacing them in most major national mapping agencies (Petrie, Bethel, and Walker 2004). By 2000, digital techniques had replaced classical instrumental methods at most large mapping agencies, but the robust design of analog instruments and their ease of use in the hands of experienced photogrammetrists ensured that they remained in use with smaller organizations into the early twenty-first century.

A photogrammetric instrument must be able to do three things: create a theoretically correct model, use a viewing system so that the photogrammetrist can view the model, and enable the photogrammetrist to make measurements and plot features. There were three possible approaches to the restitution (also called reconstruction) of the stereo pair: direct optical projection (sometimes referred to as the Porro-Koppe principle), mechanical restitution, and optical-mechanical restitution (Blachut and Burkhardt 1989, 53 ff.; Konecny 2003, 111 ff.). Optical and mechanical restitution instruments were the most widely used, with the optical-mechanical solution employed by only a few instrument manufacturers, chiefly in France and Great Britain (France, Service géographique de l'armée 1938; Blachut and Burkhardt 1989).

There is debate over who produced the first instrument designed to make accurate measurements from a pair of overlapping photographs. It is probable that Henry Georges Fourcade, in South Africa, and Carl Pulfrich, in Germany, came up with broadly similar solutions quite independently (Collier 2002, 158). In both cases, the instrument was designed to make accurate measurements of conjugate points on the two photographs, from which the coordinates of the points could then be calculated. To create line features, the coordinates of individual points along the feature had to be determined and then joined together. To plot contours, a scatter of height points was measured and the required contours manually interpolated. What was needed to make photogrammetry cost-effective was some way of automating the process of plotting detailed lines and contours. F. Vivian Thompson, in Britain, and Eduard von Orel, in Austria, made this technical advance more or less simultaneously (Collier 2002, 158). Both instruments were designed to work with an overlapping pair of terrestrial photographs that were coplanar, that is, taken in the same vertical plane. While this posed no significant problem working with terrestrial photographs, it made the instruments unsuitable for dealing with aerial photography, which was rarely, if ever, coplanar. This meant that the early use of instrumental photogrammetry was restricted to mapping in upland or mountain environments, in which an adequate field of view could be obtained. Important early uses of the technique included the topographic mapping of parts of the Tyrol by the Austrian Militärgeographisches Institut (Kretschmer 1991) and the Taghdumbash Pamir by the Survey of India (Atkinson 1980).

Once aerial photography had become an established technology, photogrammetrists made numerous attempts to design an instrument that could be used to plot plan information and contours directly. A number of these early efforts were directed at modifying the existing terrestrial plotters to cope with noncoplanar photography. This approach was a blind alley because the resultant instruments became increasingly complex in their design and operation. In particular, setting up a model from which measurements could be made might consume an entire workday—at the expense of time that could be spent plotting. Not cost-effective, these early instruments were ultimately abandoned.

Scheimpflug had proposed a solution to the problem of the projection of noncoplanar photographs with the goniometer, a projector capable of being rotated about three mutually orthogonal axes. The first successful design, the Zeiss C4 (1930), came from the recognition that the goniometer was the solution to the problem of reconstructing the orientation of the cameras at the moment of exposure (Burnside 1993). The successful Zeiss instrument, which used optical projection of the photographs for model formation and viewing, was followed in 1937 by a design from Wild, the A5, which separated model formation from model viewing (fig. 704). The model was created using two mechanical analogs: space rods to represent the optical rays and cardan joints to

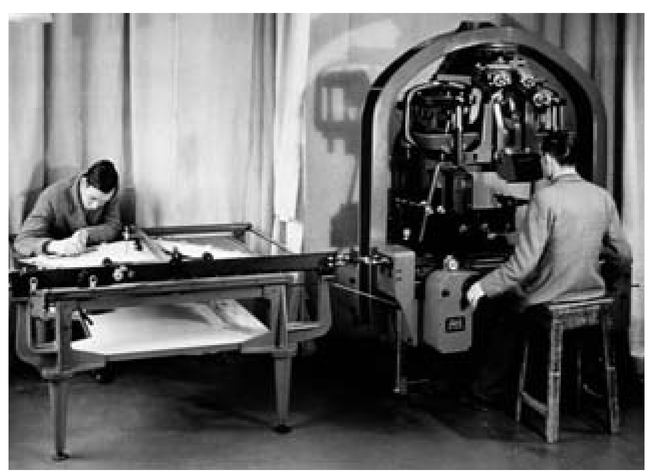

FIG. 704. THE WILD A5 AUTOGRAPH, CA. 1937. In use at the Ordnance Survey.

represent the lenses used to create the original photographs. Despite the added mechanical complexity, this solution resulted in an instrument with a very good viewing system, which made it easy to use.

With the introduction of the Zeiss C4 and the Wild A5, photogrammetry based on aerial photography had, at last, become cost-effective for large-scale mapping. Even so, such instruments were still complex and not well suited to medium- or small-scale topographic mapping (Collier 2002, 167–70). It was another instrument, introduced in 1933, that was to provide the solution. This instrument, the multiplex plotter, was designed by Zeiss, in Germany, and independently by OMI-Nistri, in Italy, in 1933. Simplicity and low cost led to the design's rapid adoption by other instrument manufacturers. The multiplex approach opened up the era of mass production of topographic mapping using photogrammetric methods. Along with the introduction of better designed instruments, a major breakthrough came when Otto von Gruber developed an orientation routine. Photogrammetric models could be created much more quickly, making the whole photogrammetric process more cost-effective.

Von Gruber recognized that to reconstruct the geometry and to create the model, the photogrammetrist must go through three stages: inner orientation, relative orientation, and absolute orientation. This procedure is broadly similar for all analog instruments, but the process described here is based on the two-projector orientation technique used in multiplex-type instruments. Although they became obsolete by the early 1970s, the multiplex was still used as an example when describing the orientation process in textbooks as late as Gottfried Konecny's (2003). A comprehensive account is given by B. Thomas Hopkins, S. J. Friedman, and J. W. Halbrook (1966), who also provide detailed descriptions of most major multiplex instruments.

The multiplex instrument has two or more projectors suspended from a horizontal bar. Images from a pair of projectors are projected down toward a plotting table and the images are viewed on the platen of a tracing table. To see a stereo model, the photogrammetrist must see only one image with each eye. This is achieved by using anaglyph filters—one red, the other blue/green—on the two projectors. The photogrammetrist wears a pair of glasses with corresponding filters and sees only the right image with the right eye and the left image with the left eye. The brain then creates a three-dimensional model by combining the two images. In the middle of the platen is a small dot of light, the floating mark. The platen can be raised or lowered to intercept the model at different heights such that the floating mark appears to sit on the ground. On the platen is a glass height scale, which is used to make height measurements. Models can be at a range of scales, and the instrument is supplied with a range of interchangeable height scales. Once a model has been correctly oriented, the floating mark is used as a measuring mark to plot detail and heights.

In the process of inner orientation the photogrammetrist reconstructs the relationship between the lens and the film at the moment of exposure. This involves accurately locating the principal point of the photograph over the optical axis of the projector of the photogrammetric plotter. The principal point is the point on the photograph that was on the optical axis of the camera at the moment of exposure, and its position is defined by fiducial marks, a series of marks around the edge of the photograph that were also created during exposure. In addition, the focal length of the camera is set on the plotter to ensure that the geometry of the bundle of light rays creating the model will have the same geometry as those that created the photograph. In the case of multiplex instruments, which use reduced-size diapositives, the focal length of the camera is set on the reduction printer used to make the diapositives (Hopkins, Friedman, and Halbrook 1966).

The next stage, relative orientation, involves the reconstruction of the relative positions of the two camera stations and the orientation of the camera at the moment of exposure. The orientations of the individual camera stations can be thought of as rotations about three orthogonal axes passing through the lens. In the case of air survey, the x axis, which passes through the lens in the direction of the line of flight, is a horizontal axis defined by the nose and tail of the airplane. The y axis is a horizontal axis orthogonal to the x axis, while the z axis, which is the optical axis of the camera, is a vertical axis passing through the lens. In a correctly oriented model, the photogrammetrist can see the surface clearly and use the floating mark to measure heights and plan positions. If the model is not correctly oriented, the photogrammetrist will see the same point of detail on the left photograph displaced in the y direction relative to its position on the right photograph. This displacement, called y-parallax, prevents accurate measurements.

To remove y-parallax, the photogrammetrist observed the model at each of the six von Gruber points (see fig. 696), and at each point corrected for y-parallax in the model by rotating the left or right projector around the appropriate axis until the floating mark was no longer split (fig. 705). When there is y-parallax in the model, each eye sees the single floating mark against slightly different parts of the image; in fusing the two slightly displaced images into a single model, the brain is forced to resolve the floating mark as two separate objects. The photogrammetrist can now see the presence of y-parallax, and correct for it by rotating the appropriate projector until the floating mark is no longer split.

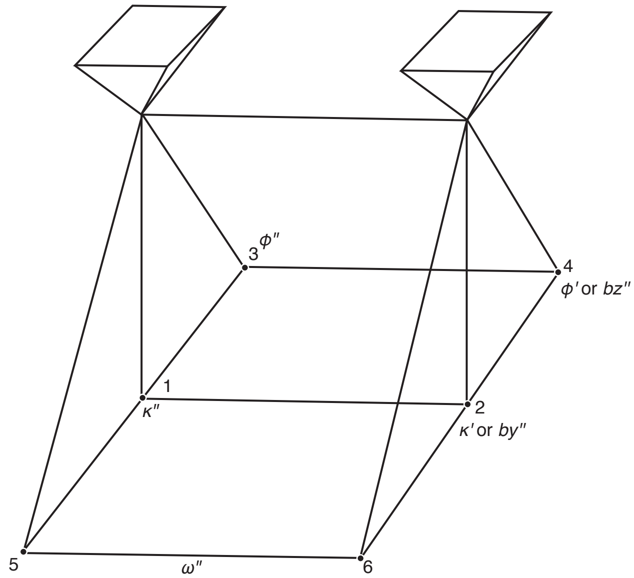

FIG. 705. DIAGRAM ILLUSTRATING THE ORIENTATIONS OF THE PROJECTORS USED AT EACH POINT. κ is a rotation about the z axis, φ is a rotation about the y axis, and ω is a rotation about the x axis.

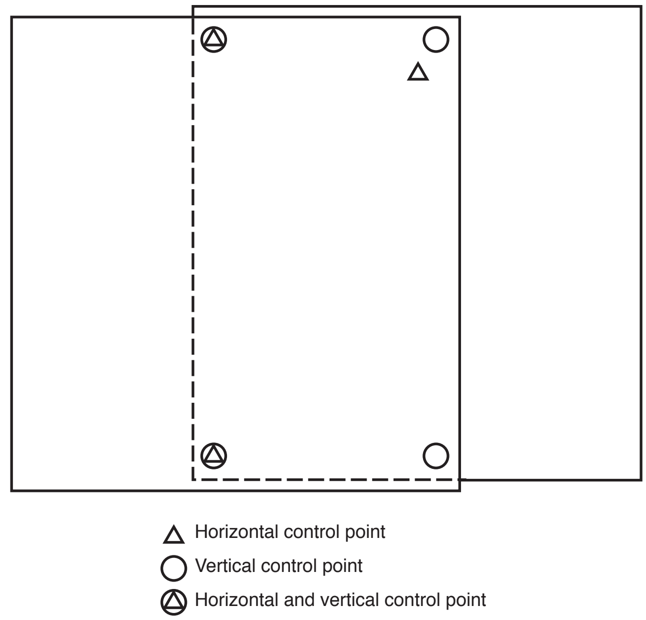

FIG. 706. THE LOCATION OF CONTROL POINTS USED TO SCALE AND LEVEL THE PHOTOGRAMMETRIC MODEL.

This procedure for relative orientation was one of von Gruber's (1924) most important contributions to photogrammetry. Once the *y*-parallax was removed, the photogrammetrist could commence absolute orientation.

In absolute orientation the photogrammetrist brought the stereo model to a known scale and leveled the model relative to the datum surface. This operation required three plan points with known *x* and *y* coordinates and four points with known heights. The photogrammetrist scaled the model by first plotting the positions of two of the three plan points. These plotted positions were then compared with the correct positions, normally plotted on a gridded sheet of plastic, and the scale error determined. The scale was adjusted by altering the separation of the two projectors. Moving the two projectors closer together reduced the scale of the model; moving them farther apart increased the scale. This is known as changing the base setting, or the Bx distance. The third coordinated point was used to check the accuracy of scaling.

In leveling the model, that is, aligning it with the horizontal plane, the photogrammetrist selected one height, usually the bottom left point, to act as datum (fig. 706); placed the floating mark on the correct point and adjusted the height scale to read the correct height; and then moved the floating mark to a second point, usually the top left point, and read the height on the height scale. The difference between the height reading and the correct height for the point was used to calculate the adjustment needed to correct the height reading, which was done by rotating both projectors by an equal amount around the common *x* axis. Once the second point had the correct height, a reading was taken at the bottom right point, and the process was repeated to calculate the adjustment needed. To make this adjustment, both projectors were rotated around a common *y* axis and used the fourth height point to check on the accuracy of the leveling. Once the leveling was completed, the accuracy of the scaling was checked and adjusted if necessary. The operator then had a theoretically correct model of the scene, which could be used to make accurate measurements of *x*, *y*, and *z* or to plot contour lines and map features in the horizontal plane.

The demanding process of creating the theoretically correct model could be time-consuming and required skilled and experienced photogrammetrists if stereocompilation was to be cost-effective. To plot features in a cartographically correct horizontal plane, the operator put the floating mark on a particular detail in the model, adjusted the platen to the correct height, and followed the feature with the floating mark, readjusting the height of the mark as needed to accommodate any height changes in the model. A pencil lead beneath the floating mark traced off the line onto the plotting medium, either paper or plastic. If the photogrammetrist wanted to plot contour lines, the floating mark was set to the appropriate height and the platen locked so that it could not accidentally be raised or lowered. Then the platen was moved across the model until the floating mark appeared to be on the surface. To plot the contour line, the photogrammetrist moved the floating mark around the model, keeping it on the surface.

Introduction of multiplex-type instruments not only made medium- and small-scale photogrammetric mapping cost-effective but also brought the recognition that different kinds of photogrammetric instruments could fulfill different tasks (Schermerhorn and Makarovic 1966). For original mapping at large scales, most mapping agencies used sophisticated and expensive instruments, such as the various models of the Zeiss Stereoplanigraph, or the Wild Autograph. These instruments were usually supplied with a plotting table driven by *x* and *y* handwheels, which were also used to move the floating mark around the model. A foot disk controlled *z* movements of the floating mark. The photogrammetrist's ability to control the floating mark using a combination of two handwheels and a foot disk was acquired only through a lengthy period of intensive training, which meant that plotting with the instruments could be a slow, laborious process. Even so, the precise measurement made possible by the handwheel-controlled movements allowed the instrument to be used for very precise measurements of plan positions. In the United States, the highly skilled nature of the photogrammetrists' work led the U.S. Geological Survey to regard it as a task for graduate engineers, whereas in Great Britain, the Ordnance Survey only employed experienced land surveyors to do the work. Other organizations found that any reasonably bright high school graduate could be trained as a photogrammetrist.

The soundness of the design of these instruments and their mode of operation meant that they changed very little over a period of more than forty years. Some models, called universal instruments, could also be used in classical aerial triangulation, but all later models were capable of being used for aerial triangulation by independent models. The main problems with the instruments were the slowness of operation and the high capital cost. The latter was a consequence of the need for the mechanical parts to be manufactured to very high standards. In particular, the space rods needed to be manufactured with a tolerance of a few microns.

Manufacturers recognized the need for cheaper, if less precise or flexible, instruments that could be used for plotting only. The A6 Autograph from Wild was designed to meet this requirement, but it was still relatively expensive. In 1952 Wild introduced the A8 Autograph, which became one of the most commercially successful precise instruments, and two years later they introduced the B8, of which more than 1,500 units were sold (Petrie, Bethel, and Walker 2004, 732), making it one of the most commercially successful analog instruments. In 1960 the Swiss company Kern introduced the PG2, another very widely used instrument. Both the B8 and the PG2 were of relatively simple construction and very easy to use. They lacked the handwheels and foot disks of the more precise instruments, but they were far quicker to operate, especially when contouring or plotting irregular detail such as rivers and coastlines. The instruments were sufficiently precise to be used for all but the largest mapping scales; their ease and speed of operation made them well suited for medium- and small-scale mapping. They became the mainstay of many mapping organizations through the 1960s and 1970s, and many remained in use with smaller organizations until the end of the century.

Following its introduction in 1933, the multiplex was widely adopted around the world. Versions of the instrument were manufactured by companies such as Bausch & Lomb in the United States and Williamson in Great Britain. While very easy to use, and in the long bar version (see fig. 683) capable of being used for aerial triangulation, multiplex suffered from a number of drawbacks. The use of reduced-size diapositives, which had simplified the design and manufacture of the projection system, reduced the accuracy of the measurements taken from the resulting model. In addition, use of the anaglyph approach, coupled with relatively poor illumination, meant that the instrument could be used only in a darkened room.

While standard multiplex equipment remained in use until the mid-1970s, some forty years after its first introduction, efforts were already afoot in the 1930s to produce instruments designed to use full-size diapositives and with better illumination. Most of the development work was carried out by U.S. government agencies such as the Department of Agriculture, the Geological Survey, and the Army Map Service (Thompson 1952). This research resulted in a number of successful designs, such as the Army Map Service M-2, the Kelsh KPP-3, and the Bausch & Lomb Balplex ER-55. These instruments became the mainstay of government mapping agencies and of the rapidly developing commercial photogrammetric mapping industry in the United States. Similar attempts in Europe to develop direct projection plotters with full-size diapositives resulted in a number of designs, notably, the Nistri Photocartograph, the Williamson Large Scale Plotter (LSP), and the Kern PG1, but only the Nistri instrument had any commercial success.

The adoption of full-size diapositive instruments in the United States, which was not replicated outside of the Americas, was rooted in the very different mapping needs of the continents. While much of Europe was covered by medium-scale mapping, by the beginning of the century such mapping was quite rare elsewhere. In Europe, demand was mostly for large-scale mapping (1:10,000 and larger), which was best produced using precise instruments. In the United States demand for both medium-scale (1:24,000 and smaller) and large-scale mapping led to a demand for both precise instruments and the more general-purpose Kelsh type instruments. In South America, Africa, and much of Asia the demand was overwhelmingly for medium-scale (1:50,000 to 1:100,000) mapping, which was best produced using multiplex-type instruments. By the 1970s, the need for photogrammetric instruments to carry out medium-scale mapping declined with the gradual completion of worldwide map coverage. Demand shifted overwhelmingly to instruments designed for large-scale mapping, and by the 1980s this need was being met by new analytical instruments.

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SEE ALSO: Hotine, Martin; Property Mapping Practices; Topographic Map; Topographic Mapping: Overview

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Orthophotography and Orthophoto Mapping. The orthophotograph (or orthophoto) is a vertical aerial photograph from which the image displacements caused by camera tilt and ground relief variation have been removed. Within certain limits, normally imposed by photogrammetric plotting, the orthophotograph is a scale-correct, orthogonal projection of the terrain photographed. An orthophotomap is a map in which the linework and symbols of a conventional map are replaced by or combined with the orthophotographic image. The resultant map has the positional accuracy of a conventional line map, together with the information content of the original air photo. This is an important advantage of the orthophotomap—the photogrammetrically produced line map has only 10 percent of the information content of the original air photos.

In the theory underlying orthophoto production, image displacements can be separated into those due to the attitude (tilt) of the air camera at the moment of exposure and those due to relief. Since only rotations about the horizontal x and y axes are involved, displacements due to attitude can all be removed by the process of rectification. Hence, any rectifier that satisfies the Lens law, the Scheimpflug condition, and the Vanishing point condition will enable the correction of these displacements. The rectifier can also be used to bring the photograph to a known scale. Therefore, if the terrain photographed was approximately flat, with local relief less than 25 meters on 1:50,000-scale photography, the resulting rectified photo could be considered an orthophoto.

A number of civilian mapping agencies used this method to produce photomaps; adopters include the Ordnance Survey in Great Britain in the immediate aftermath of World War II and the Directorate of Overseas Surveys in mapping the Okavango Swamp in Botswana. However, military mapping agencies made the most extensive use of this approach, usually as a rapid solution to a mapping requirement prior to the production of conventional line maps (fig. 707). The U.S. Army's photomaps of Jamaica in 1942 and Brittany in 1943 are good examples of this use of photomapping. The U.S. Army continued to make extensive use of what it called "map substitute products" until orthophotography replaced them. As part of its work, the U.S. Army also experimented with a range of reproduction techniques designed to enhance the interpretability of the resultant photomap. These included the use of pictomapping and pictoline mapping processes, which produced higher-contrast images than conventional half-tone screening (United States, Army Corps of Engineers 1963). The U.S. Geological Survey (USGS) carried out similar experimental work for orthophoto mapping (Pumpelly 1967).

The second type of image displacements, those due to ground relief variations, cannot be removed by normal rectification. Relief variations mean that every image element of an object that was not in the datum plane will be at a different scale and will be displaced away from the center of the photographs on which they appear. To remove these displacements, each image element needs to be brought to the correct scale and then projected to

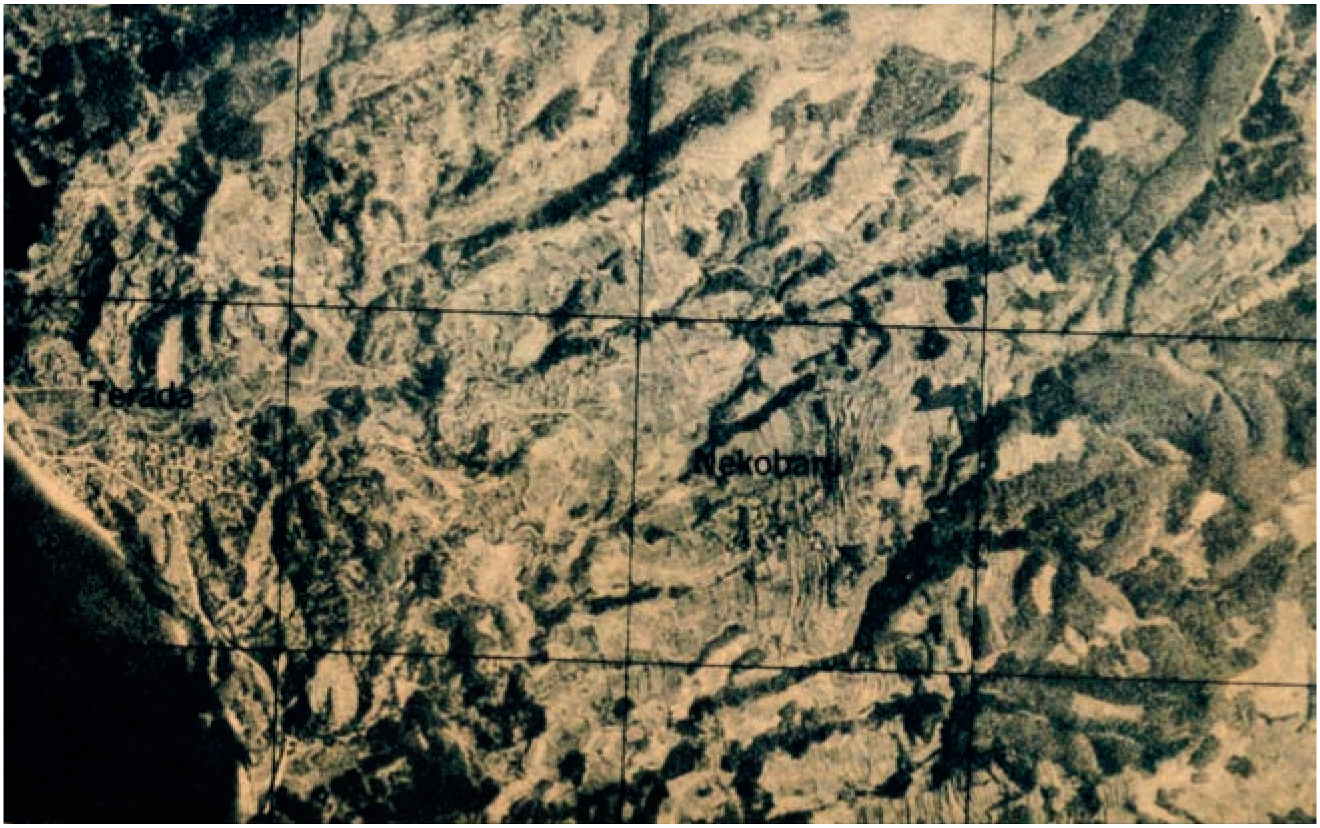

FIG. 707. DETAIL FROM *KANOYA NW*, 1945, AN EARLY 1:25,000 PHOTOMAP OF JAPAN. Produced by the Army Map Service, sheet 4241 II NW, first edition. Size of the entire original: 47.2 × 52.3 cm; size of detail: 8.7 × 13.9 cm. Image courtesy of Peter Collier.

its correct plan position. The method of carrying out this procedure was originally called differential rectification, but Russell K. Bean, who designed the first practical instrument for carrying out this process, introduced the term "orthophotography," the name by which the process has been known ever since (Bean 1955).

Theodor Scheimpflug is usually credited with proposing the use of orthophotographs and orthophotomaps, but it was not until 1926 that his ideas could be put into use, and then only on flat terrain. In 1929 Otto Lacmann designed a "rectifier for uneven terrain" that used a Zeiss Stereoplanigraph, wooden profile templates, and pneumatic system for vertical movements. This idea was taken up again in 1960 by Erwin Gigas, resulting in the Gigas-Zeiss I Orthoprojector, introduced in 1964, with series production starting in 1966 (Blachut and Burkhardt 1989, 76–80).

In 1933 Robert Ferber also produced a solution to the problem of rectifying uneven terrain. This led to the Gallus-Ferber instrument, which was used briefly in the 1930s (Collier and Inkpen 2003, 238). However, it was Bean's instrument, based on the widely used Kelsh plotter, that provided the first truly practical solution to the problem (fig. 708). Following development at the USGS Research and Development Facility in Reston, Virginia, Kelsh Instrument Company undertook series production, with the U-60 being marketed from 1958. The operator produced an orthophotograph by systematically scanning across the photogrammetric model, keeping a floating mark, in the form of a slit, on the ground. Light from the projected original image passed through the slit and created a new, geometrically transformed image on a sheet of photographic film immediately beneath the slit. As the height of the slit was varied during the scanning process, all relief and scale variations were removed. The production process was very exacting and laborious for the operators, but the photomaps created from the images were much cheaper and quicker to produce than the line maps derived from conventional photogrammetry. As the instrument used direct optical projection and anaglyph viewing, the film could be sensitive to only one color of light or there would be a double exposure from the two projectors. This meant that only black-and-white negatives could be produced.

During the 1960s most of the major photogrammetric instrument manufacturers produced orthophotoscopes

FIG. 708. KELSH T-64 ORTHOPHOTO EQUIPMENT, CA. 1964. The T-64 orthophotoscope was designed and built in 1964 by Russell K. Bean at USGS. Shown here is the first orthophotoscope in Menlo Park, California, used to produce orthophotoquads.
Image courtesy of the U.S. Geological Survey.

(or orthophotoprojectors) based on existing analog instruments. The most successful of these instruments was the Topocart B, manufactured by Carl Zeiss, in Jena. This instrument was widely used within the former Soviet Bloc, but was also widely exported. The 1:100,000 orthophoto mapping of large areas of central Australia was produced using the Topocart B. All of these instruments relied upon the operator scanning across a stereo model to produce the orthophotograph. In most instruments this was a real-time operation, with the operator creating a photographic negative as the model was scanned. The size of the slit through which the negative was exposed could be varied to cope with different kinds of terrain. For example, a longer slit, and hence wider scan line, was used for flat terrain. The speed of scanning could also be varied for different terrain, with faster speeds being used on flat terrain. If a model contained both flat and irregular ground, one slit length and scan speed was adopted to cope with the most difficult terrain because if either were changed during the scanning process, it would lead to variations in the density of the negative. The need for flexibility in scanning speed led some manufactures to include a gray wedge in the optical path between the projected image and the negative. This could be automatically adjusted for changes in scanning speed to ensure even exposure of the negative.

In addition to producing the orthophotograph, some instruments were fitted with a device called an orograph, which produced a series of lines corresponding to the individual scan lines on the orthophotograph. The lines produced by the orograph varied in thickness as the height of scanning changed, normally changing as the scan went through a contour height. The output from the orograph could then be manually interpreted to produce a contour plot of the area scanned. However, the orograph output, usually called drop-lines, could be difficult to interpret, leading many survey companies to produce contour plots as a completely separate process using conventional photogrammetric instruments.

In an effort to overcome some of the shortcomings of existing instruments, Kelsh introduced the K-320 Orthoscan in the early 1970s. In this instrument the photographic negative was not created as the operator scanned the model. Instead, the profiles defined by the scanning process were recorded on a computer. The scan line could be overwritten by rescanning if the operator made a mistake. The operator could also vary the speed of scanning to cope with irregular terrain. Once all the profile lines had been recorded, the instrument was used to create the negative by scanning across the model space following the recorded profile lines at a constant scan speed. As only one projector was used during the exposure process, at this stage it was possible to replace the black-and-white image used to create the stereo model by a color diapositive made from the same negative. In the K-320 and the Matra-SFOM 693 orthoprojector instruments a triplet of overlapping air photos were projected, with three projectors used to create two connected stereo models. This arrangement allowed the production of an orthophotograph from a complete air photo by using the middle projector during the exposure phase.

In 1959 Gilbert L. Hobrough designed an instrument, the Stereomat, that allowed the automatic scanning and measurement of a stereomodel using hardware correlators (Hobrough 1965, 599–601). Essentially a modified Wild B8 Aviograph analog instrument only manufactured in small numbers, the Stereomat was used by the U.S. Army Map Service, the Division of National Mapping in Australia, and the Institut géographique national in France for orthophoto production in the late 1960s and early 1970s.

In the early 1970s Hobrough introduced an analytical instrument, the Gestalt Photo Mapper (GPM), which used image correlation to create a digital elevation model (DEM). This DEM was then used to produce an orthophotograph. Unlike earlier instruments, which used a scanning approach, the GPM used an area matching approach to create the DEM. In working in this way, the GPM can be seen as a precursor of the digital systems introduced in the late 1980s. The GPM was manufactured only in small numbers, and its use was originally offered only as a bureau-based service. Subsequently, instruments were acquired by the Surveys and Mapping Branch in Canada and by the USGS, which used them on a round-the-clock basis for orthophoto production. The GPM was not the first analytical instrument to use image correlation; it was preceded by the UNAMACE (or UAMCE; Universal Automatic Map Compilation Equipment) produced by Bunker-Ramo Corporation. However, this highly complex system was used only by the U.S. Defense Mapping Agency, and relatively little has been published about it (Bertram 1965; Petrie 1977, 58).

A number of "bolt-on" correlators were designed and fitted to existing analytical plotters from the mid 1980s (Petrie, Bethel, and Walker 2004, 757), but these were rapidly superceded by the introduction of the digital photogrammetric workstation (DPW). By the end of the century the bulk of orthophoto production was being carried out using DPWs, often using inexpensive standard desktop computers to obtain solutions that, at the beginning of the 1990s, would have required expensive specialist hardware and software. For the purposes of orthophoto production, the important feature of a DPW solution is the automatic generation of a DTM (digital terrain model) through area-based image correlation. This DTM can then be used to carry out orthorectification on the scanned air photos or on the scanner data used to generate the DTM.

Some of the first DPWs to be introduced, such as Helava SOCET SET, were intended to produce DTMs for military programs, with orthophoto production seen as little more than a by-product. The potential of the digital systems to provide orthophotos quickly and cheaply was quickly appreciated by the users of geographic information systems (GIS), who needed up-to-date backdrops for GIS applications. To meet this demand, a number of companies introduced entry-level systems, which required little or no knowledge of photogrammetry. OrthoBASE, marketed as part of the ERDAS (Earth Resources Data Analysis Systems) IMAGINE software suite, and Leica Photogrammetry Suite (LPS), which replaced OrthoBASE, are examples of this approach.

The technical capability to produce orthophotos was not sufficient to ensure that orthophoto mapping would also be produced. In some countries, such as the United States, orthophoto mapping was produced for areas deemed unsuited to conventional line mapping. An example of this was the mapping of swamplands, such as the Okefenokee Swamp on the Georgia-Florida border, by the USGS (Radlinski 1968; Pumpelly 1967) (fig. 709). Orthophotomaps were also produced as an immediate response to disasters, such as the volcanic eruption of Mount St. Helens. In other countries, such as Germany, 1:5,000-scale orthophotomaps were produced in parallel with conventional line maps of the same scale. In Sweden, whole series at a particular scale were produced only as orthophotomaps (Johansson 1968), and, following the decentralization of mapping in Spain, the new Institut Cartogràfic de Catalunya initiated a program of orthophoto mapping.

In some countries, the national mapping agency did not believe there would be consumer demand for orthophotomaps. In Great Britain, for example, the Ordnance Survey used orthophotos only as revision tools in conventional line mapping programs. The Ordnance Survey was not always so resistant to the use of photomaps, as it had used rectified photos to make interim editions of its large-scale series (1:1,250 and 1:2,500) in the period immediately after World War II. However, it was always intended that these photomaps would be replaced once up-to-date line maps had been produced.

In the United States, the development of the orthophotoscope by Bean in the 1950s meant that the USGS was able to embark on an ambitious program of orthophoto mapping. Demonstration sheets were produced for a wide range of environments, including urban areas. These first demonstration sheets were to have a major impact, encouraging other national mapping agencies to investigate orthophoto mapping. Most of the orthophotomaps produced by the USGS were at 1:24,000, a standard mapping scale in the United States.

Through the 1990s, the development of GIS led to an unprecedented demand for orthophotographs. This demand was generated by the need of GIS users for up-to-date image backdrops while performing GIS operations (Vandegraft 2003). In many countries GIS users found that much of the existing line mapping was not up-to-date, even where it was available in digital form. A number of companies entered the market to meet the demand for up-to-date digital image layers. These included the Longman Geoinformation publishing group, whose Cities Revealed data sets played a significant role in developing a European market for digital orthophotography. Longman was able to exploit the large underused capacity for orthophoto production that existed in Eastern Europe following the end of the Cold War. When production costs rose in Eastern Europe, much of the work was moved out of Europe to South or East Asia, where labor costs were significantly lower. As a result, it has been far easier to outsource orthophoto production than has been the case with conventional line mapping, where a familiarity with the environment being mapped is usually necessary. By the end of the century, the demand for digital orthophotos from the GIS community led even a traditionally reluctant Ordnance Survey to offer an orthophoto layer as part of its MasterMap product.

Most GIS users lack the competence to carry out their own conventional photogrammetric mapping but can carry out orthorectification using simple digital photogrammetric systems, which started coming onto the

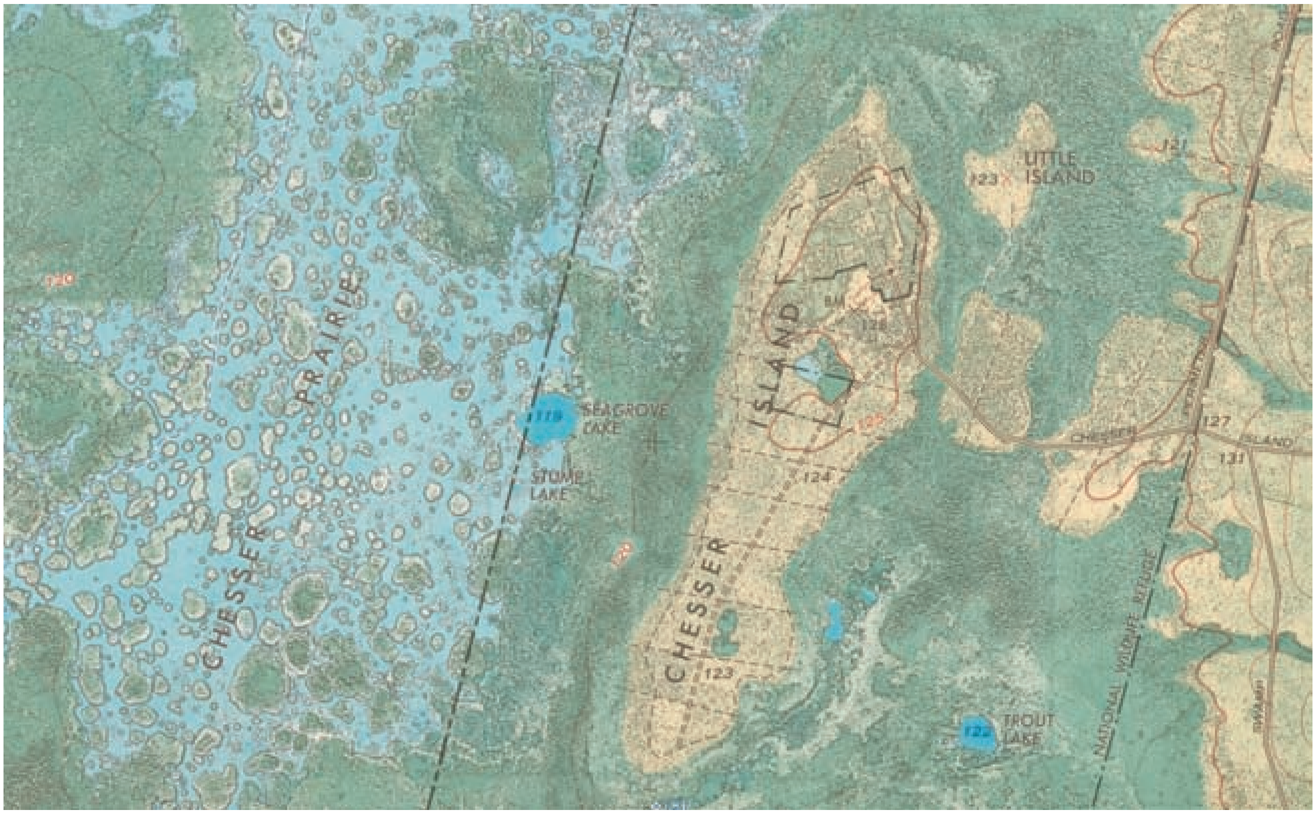

FIG. 709. DETAIL FROM *CHESSER ISLAND QUADRANGLE*, 1:24,000, EXPERIMENTAL EDITION, 1965. Okefenokee Swamp orthophotomap produced by the USGS. Size of the entire original: 67.6 × 55.7 cm; size of detail: 14.9 × 24.3 cm. Image courtesy of Peter Collier.

market in the 1990s. The high cost of scanners designed to provide distortion-free scans of air photos for orthophoto production meant that most GIS users needed to pay a service bureau to carry out the scanning for them. By the end of the century, however, the introduction of digital photogrammetric cameras opened up the prospect of a fully digital workflow, from camera to orthophoto.

During the course of the twentieth century orthophoto production progressed from being just an ambition of early photogrammetrists to a routine and relatively simple procedure. Over the same period, the use of orthophotos has changed from being a low-cost and quickly produced substitute for a conventional line map into a widely used digital product considered superior to line mapping for many applications. While printed orthophoto mapping never became as widespread as some of its early advocates anticipated (Petrie 1977), this might have been as much a consequence of the decline of printed maps as it was a consequence of any perceived shortcomings of orthophotomaps.

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SEE ALSO: Lidar; Map: Images as Maps; Topographic Map; Topographic Mapping: Overview

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Photographic Engraving. See Reproduction of Maps: Photomechanical Processes

Photography in Map Design and Production. Invented in Europe during the 1830s, photography, the new process for creating images automatically by the action of light on a sensitized emulsion, developed and spread rapidly. In map design and production, it was used from the 1860s onward in making the printing images from which maps could be reproduced in multiple copies. The discussion here is a condensation of a longer exploratory essay (Cook 2002).

Since the advent of printing in the fifteenth century the design and production of the printed map had been based in the printshop, where a skilled craftsman followed lettering and symbolization traditions in translating the mapmaker's hand-drawn compilation into a printable image, whether incised on a copperplate, engraved in relief on a woodblock, or drawn as a greasy image on a lithographic stone. After 1860 photomechanical techniques could create printing images directly from pen-and-ink drawings, but eliminating the skilled middleman led to graphic problems when authors' amateurishly drawn sketch maps were photographed and published as illustrations (Mayer 1930, 1664, 1666). Excessive photographic reduction could make even the best original illegible.

The development of map design as a separate activity preceding map production was a response to such problems. In 1874, for example, Henry Blackburn formed a professional Illustration Studio in Britain to produce maps and other illustrations for photomechanical reproduction. He must have been drawing upon that experience when he wrote in his textbook, *The Art of Illustration*, that:

> The artist who draws for reproduction by chemical and mechanical means is thrown upon his own resources . . . . [W]e cannot often have good wood engraving, as it is not always cheap enough or rapid enough for our needs—we draw on paper what we want reproduced, and resort to one of the photographic processes described in this book.
>
> I do not think the modern illustrator realises how much depends upon him in taking the place, so to speak, of the wood engraver. The interpretation of tone into line fitted for the type press, to which the wood engraver gave a lifetime, will devolve more and more upon him. (Blackburn 1894, 67, 70–71)

Soon methods of designing and drafting for photography became formalized. Instruction books for professional illustrators and draftsmen appeared, emphasizing the need to draw well-spaced, solid black lines for photography (Blackburn 1894, 95, 99). After the Survey of India adopted photography for map production in 1862, wash shading and colored inks unsuitable for photography were replaced by black pen-and-ink lines (Waterhouse 1878, 10). A new design strategy, drafting for photographic reduction, soon became standard. Reducing pen drawings to 75 or even 50 percent of original size made lines finer and imperfections less noticeable.

A reducing glass was often used to visualize the final effect and check the design. Other methods of reducing guesswork in designing for photographic reduction were developed. Specimen sheets of lettering and symbols in different sizes were introduced (fig. 710). Ruling pens, used earlier for map drafting, had seldom been marked with settings for line widths, but around 1930 Graphos and other technical pens in standard widths came into use (Hambly 1988, 58–64) (fig. 711).

The development of standard styles and sizes of lettering templates and preprinted adhesive-backed sheets for lettering and symbols also occurred from the 1920s onward. Standard colors of printing inks (cyan, magenta, yellow, and black), adopted for process work using halftone photographic screens and filters to color-separate a multicolored original for printing, also helped the map designer to plan ahead. As the overprinting of flat, photographic tint screens in set percentages to create different colors became common, charts of sample color combinations became standard equipment for the graphic designer (fig. 712). Such innovations were intended for graphic illustration in general, but cartographers quickly took them up. Using such design aids, geographers compiling maps during World War II could select and specify lettering symbols and colors for draftsmen working in another building (Raisz 1948, 229). Later, cartographic manuals began instructing the map designer how to outline systematically and specify the steps in the map production and reproduction process (Keates 1973).

At first maps intended for photography had been drafted entirely in ink, but a new collage approach to map production emerged in the 1920s. The creation of the image by applying to a supporting surface different materials, shiny or matte, thick or thin, made it hard to visualize the final effect of the printed map. Previewing the final product became crucial when the practice of working on registered overlays or separations came into use. When artwork for a complicated map consisted of numerous pieces, some negative and some positive, the combined effect remained guesswork until the final map

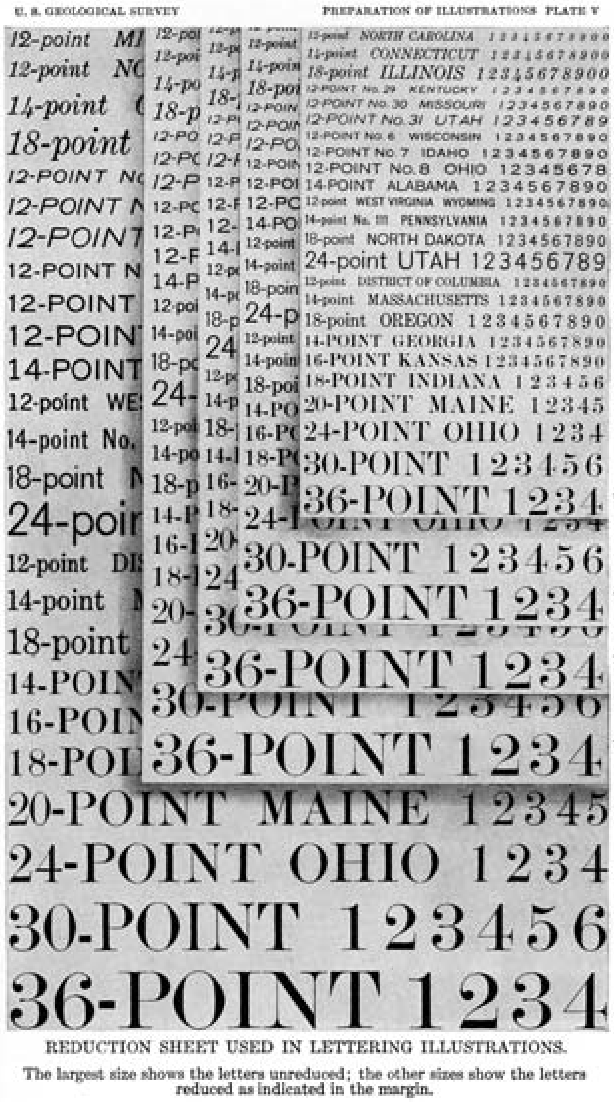

FIG. 710. TYPE REDUCTION SHEET USED FOR DESIGNING U.S. GEOLOGICAL SURVEY ILLUSTRATIONS.
Size of the original: 18.7 × 11.3 cm. From John L. Ridgway, *The Preparation of Illustrations for Reports of the United States Geological Survey with Brief Descriptions of Processes of Reproduction* (Washington, D.C.: Government Printing Office, 1920), facing 54.

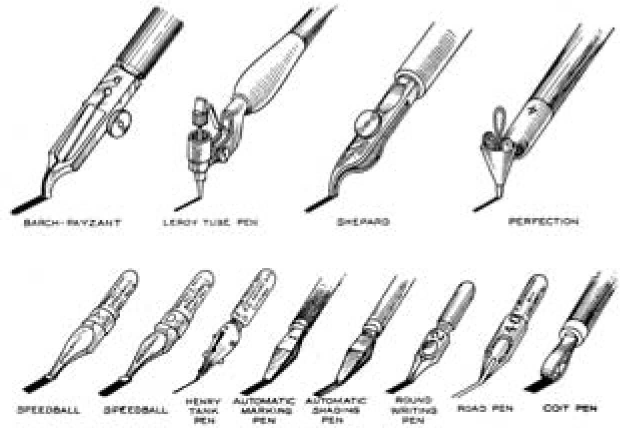

FIG. 711. LETTERING PENS. Pens were manufactured in a range of shapes and standard sizes.
Size of the original: 7 × 10.1 cm. From Frederick E. Giesecke, Alva Mitchell, and Henry Cecil Spencer, *Technical Drawing*, 5th ed. (Austin: Technical Book, 1933), 57 (fig. 79).

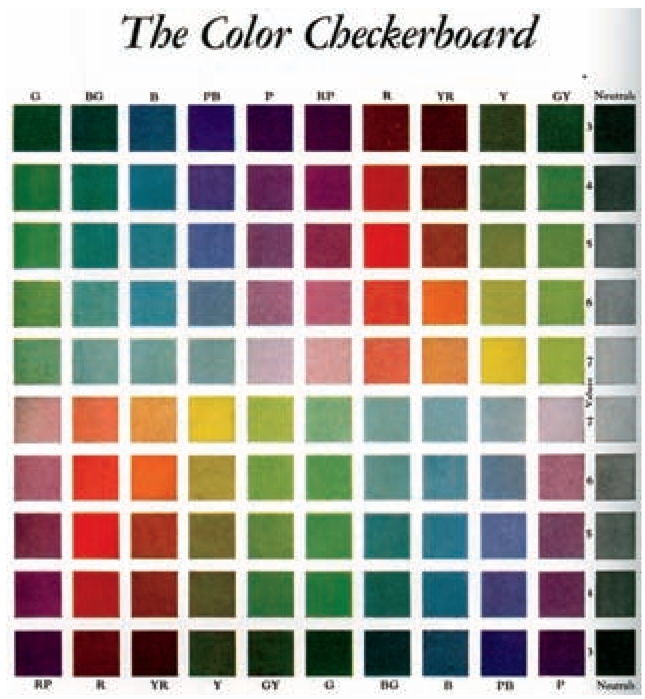

FIG. 712. "THE COLOR CHECKERBOARD." A color chart based on the Munsell System of color and intended for use by graphic designers.
Size of the original: 17 × 15.8 cm. From Louis Flader, comp. and ed., *Achievement in Photo-Engraving and Letter-Press Printing* (Chicago: American Photo-Engravers Association, 1927), unnumbered insert before 257.

was printed. Press proofing, standard practice for text pages, was expensive for complex graphics. During the 1930s articles appearing in printing journals about advances in photomechanical color separation complained that color-proofing methods badly needed improvement (Gamble 1932). Subsequently developed photographic proofing methods ranged from basic single-color materials used for checking content to expensive multicolor systems simulating the look of the final map (Nadeau 1989–90, 1:75–76; Robinson and Sale 1969, 327–35).

Cost-effective design required an understanding of the relative advantages, requirements, and costs of both production and reproduction techniques. In 1924 the English map publisher George Philip & Son used the following approach: "Before work is commenced upon an atlas or a single map the Editorial Department exercises its selective and critical faculties, so that the best sources of information can be drawn upon, the most suitable methods of production employed, the question of the colour scheme and style of lettering settled etc.; work, which, like the foundations of a bridge, is never seen, but upon which the superstructure is built" (Anonymous 1924, 37).

After the mid-nineteenth century, general advances in reproduction technology greatly expanded the available graphic options. Until then the printed map had been primarily a black line image on white paper, sometimes enhanced by hand coloring. However, the development of lithography, a printing process invented just before 1800 in Germany, soon led to mechanical innovations in image production and reproduction (tonal techniques, image transfer, and color printing). Cartography, along with other types of graphic illustration, was profoundly affected. As a result, flat and varying tones, area patterns, and colored symbols became increasingly common on maps.

Soon photomechanical techniques began to play a part. Mapmakers in Australia and England led in developing successful photolithographic transfer techniques by 1860. At first photolithography could reproduce only line images satisfactorily. The invention of the halftone photographic screen during the 1890s and its combination with color printing after 1900 occurred in general graphic reproduction but were soon adopted for mapmaking. The designer's choices expanded as halftones, flat tints, and color became common on both topographic and thematic maps.

Map production is the stage of mapmaking that turns the map compilation into a print-ready image. Production by and for photography generated one or more preprinting images leading up to the print-ready image. At first the photographic preprinting image was a guide image for hand copying. By 1857 photographic negatives printed onto sensitized woodblocks formed guide images for the wood engraver (Nadeau 1989–90, 2:384–85). Some pictorial wood engravers altered their techniques to imitate the tonal effects of photographs. Although cartographers also used photographic guide images, maps remained primarily line images. Photographic guide images were used for wax-engraved maps (see fig. 1094), a relief printing process popular in the United States from the 1840s until the 1930s.

Another early use of photography in both map and pictorial illustration was to create a guide image that a draftsman could draw over in black ink. That use continued into the twentieth century. Sometimes the guide image was a photographic print that could be bleached away after drafting, but it could also be printed in blue or another color that would drop out during high-contrast photography (Nadeau 1989–90, 1:47; Waterhouse 1878, 8). Additional copies of the same guide image were used to draft separations for color printing, a practice increasingly common after 1900.

Successful transfer of photographic line images for lithographic map reproduction was achieved separately in Australia and England by 1860. Thereafter, such transfers were also used to create preprinting images for relief and intaglio reproduction processes.

The best photographed line image was inferior to hand engraving, but the lower cost of drafting maps in pen and ink (compared to copper or wood engraving) was compelling. Maps not originally intended for photography often needed touching up, as some early drafting instructions recognized (Waterhouse 1878, 12). Cartographer Erwin Raisz (1938, 70) observed philosophically, "Maps can now be made by geographers and not necessarily by highly skilled engravers. The resulting maps may be less perfect technically, but they will more informally express geographic ideas."

Before 1920 maps were usually drafted as inked line images. Mechanical area patterns were usually added to the printing plate after photographing the line image. The Ben Day tint frame, invented in the United States by Benjamin Henry Day in 1878, held celluloid sheets with raised patterns (fine patterns were called tints) that could be inked and pressed onto printing plates (fig. 713). The cartographer marked in nonphoto blue on the drawing to show the printer where to add the Ben Day tints (fig. 714). Working indirectly through the printer made it hard for the cartographer to visualize or control the final effect and also raised production costs (Anonymous 1931, 221).

During the 1920s new collage techniques inspired by photography came into use in both fine and commercial art. The European Cubist and Dada schools of art adopted collage and photomontage for expressing avant-garde views about society, politics, and war. Map production, like commercial art, combined collage techniques (called stick-up by mapmakers) with pen-and-ink drafting for photography for practical reasons—to enable cheaper, faster production by less skilled personnel. The collage look did not carry over into the printed map because of the leveling effect of high-contrast photography and printing.

Pasting type printed on paper onto maps intended for photography did not become common until around 1920. The various adhesive backings included wax (burnished down), rubber cement (when dry, it would stick to a patch of dry rubber cement on the support), and Duco cement (brushed with acetone just before application) (fig. 715). Float lettering (printed on thin paper and positioned before brushing with adhesive that passed through the paper) could be drafted over, but patent restrictions prevented its wider use.

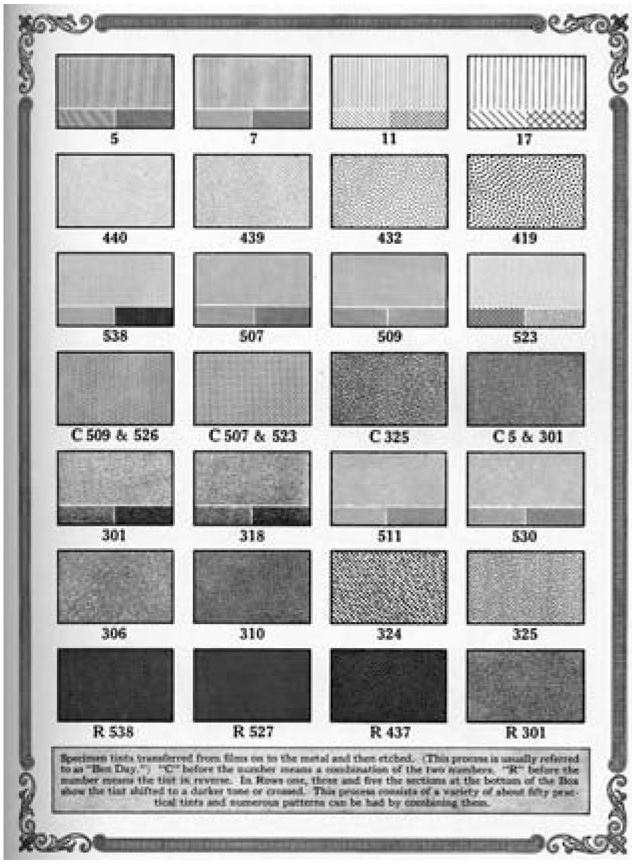

FIG. 713. SAMPLE BEN DAY SCREEN TINTS AND COMBINATIONS.
Size of the original: 21.5 × 15.7 cm. From Flader 1927, 129.

FIG. 714. STEPS IN ADDING BEN DAY TINTS TO A PHOTOENGRAVING.
Size of the original: 21.5 × 15.7 cm. From Flader 1927, 126.

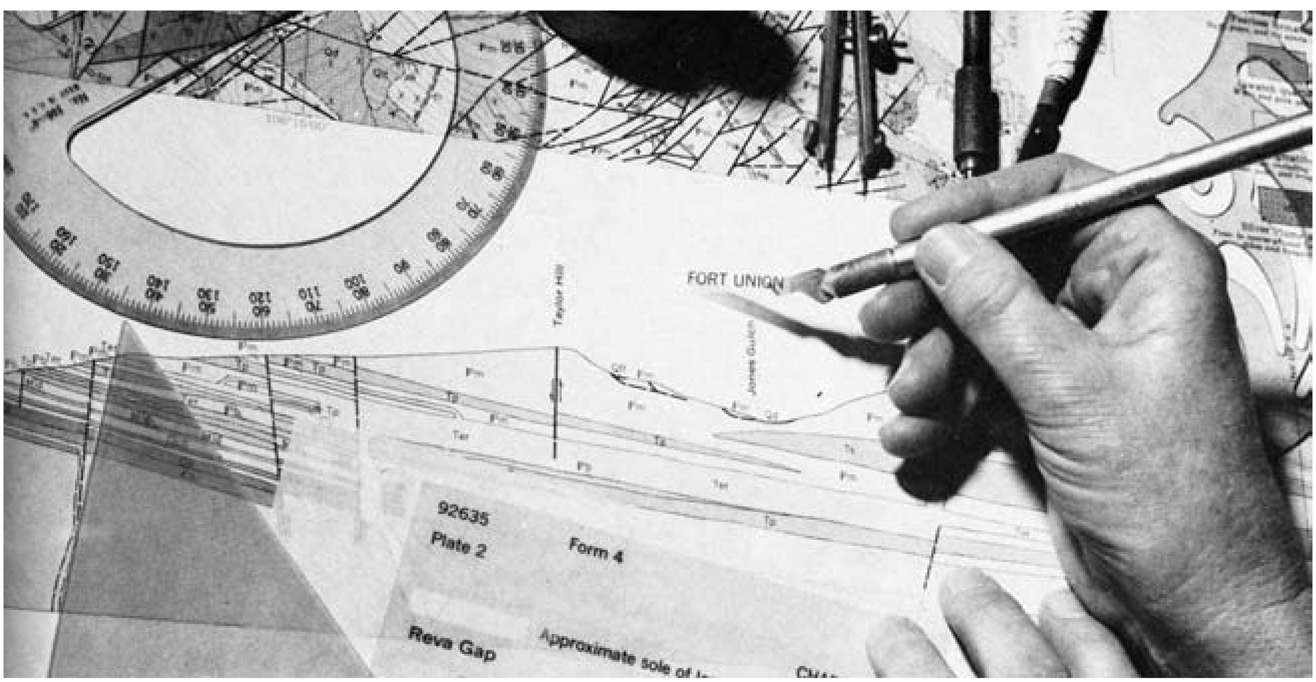

FIG. 715. APPLICATION OF STICK-UP LETTERING. The lettering on adhesive-backed film adheres to the tip of an X-Acto knife as the draftsman maneuvers it into position on the artwork.

From U.S. Geological Survey, *United States Geological Survey Yearbook, Fiscal Year 1977* ([Washington, D.C.]: United States Department of the Interior, Geological Survey, 1977), 69.

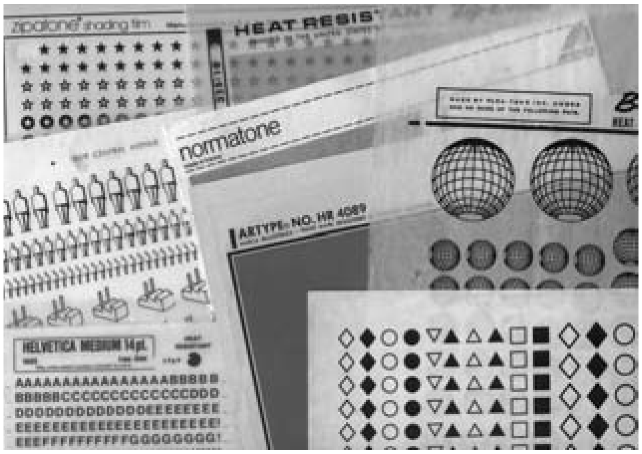

FIG. 716. DIFFERENT BRANDS OF RUB-DOWN AND STICK-UP LETTERING AND SYMBOLS. These were staples of map production for photography from the 1920s through the 1970s, after which their use declined.
Image and permission courtesy of George F. McCleary, Jr.

Area patterns and point symbols printed on adhesive-backed cellophane sheets began to be manufactured commercially in the 1920s (fig. 716). After a time, more heat-resistant adhesives replaced wax. Rub-down wax lettering and symbols that could be burnished off a backing sheet were also introduced then (Anonymous 1930a). Some drafting paper bore invisible area patterns that could be revealed after inking by brushing developer over selected areas. Adhesive line-symbol tapes also came into use. Most preprinted symbols and area patterns were intended for general use, but some were specifically for mapmaking.

Preprinted sheets of letters in various forms could be combined to form words, although job-specific type orders, produced in-house or by commercial firms, allowed faster placement of entire words and blocks of text. The incorporation of photographic techniques reduced typesetting costs and enabled offset lithography to replace letterpress for printing newspapers, magazines, and books by the 1950s. Following initial experiments by the Monotype firm in England during the 1930s, phototypesetting equipment was in commercial production in Europe and the United States by the 1950s (Boag 2000, 58). Thereafter the technology advanced from the exposure of individual stationary characters on a negative to the stroboscopic flash exposure through negative images on a constantly moving disk. Another 1960s innovation used electronically stored characters displayed and projected by cathode ray tube (CRT) onto light-sensitive paper or film. Large cartographic organizations led in adopting top-quality equipment, such as the Monotype Photo-lettering machine. Cheaper models, such as the Varityper Headliner, which smaller cartographic operations could afford, yielded good results while offering greater flexibility in sizing, styling, and positioning of letters (Hodgkiss 1970, 104–6).

At the same time, pen-and-ink drafting for photography was becoming easier. Although ruling and dip pens, such as the crow quill, remained in use, technical pens producing lines of standard width, both ruled and freehand, gained popularity. The Rapidograph, introduced in the 1950s, and other brands of tubular reservoir pens improved in design and supplanted pens that needed cleaning after each use.

Some pens worked for dotting distribution maps (such as Barch-Payzant pens), while others intended for use with mechanical lettering devices also worked well for ruled lines and freehand drawing (such as Leroy pens). Lettering templates decreased the use of freehand lettering, although their mechanical look was often criticized. Type lettering and symbols set in imprinters (special holders for hand stamping) retained a role in map production until the mid-twentieth century. Stamped type would not dislodge as stick-up lettering was prone to do.

Other twentieth-century innovations included special papers, tracing cloths, celluloid, vinyl, and polyester for drafting supports (Raisz 1938, 172–74). Dimensional stability and transparency were provided from the 1920s onward by new synthetic materials, for example in Germany by Zellon and Astralon. They improved upon celluloid, which was highly flammable. Because traditional India ink did not adhere well to new synthetic surfaces, special inks, such as etching ink for drafting on plastic, were developed.

There was also general interest in the graphic arts in rendering photographs and other tonal images printable. One such method, collotype, had been perfected in France by Alphonse Poitevin by 1867. Collotype's reticulated gelatine emulsion produced superior tonal effects, but the fine-grained plates were too delicate for reworking the image or large press runs (Nadeau 1989–90, 1:73–75). Sometimes used to reproduce relief models or early maps, it was otherwise seldom used in cartography.

Printable area images created with photographic screens proved more viable technically. William Henry Fox Talbot, who used gauze fabric to break up tonal photographs, was followed by other innovators (Kainen 1952; Nadeau 1989–90, 1:121–23). An experimenter in New York City, Frederick W. von Egloffstein, used wavy-line screens in 1865 to create printable intaglio images (including maps with halftone terrain shading), but his secretive methods prevented the spread of his process. Frederic Eugene Ives and brothers Louis Edward Levy and Max Levy in Philadelphia perfected glass halftone screens during the 1890s (Kainen 1952, 419–20). The Levy screen was formed by cementing together two sheets of glass with black lines set at right angles. Ex-

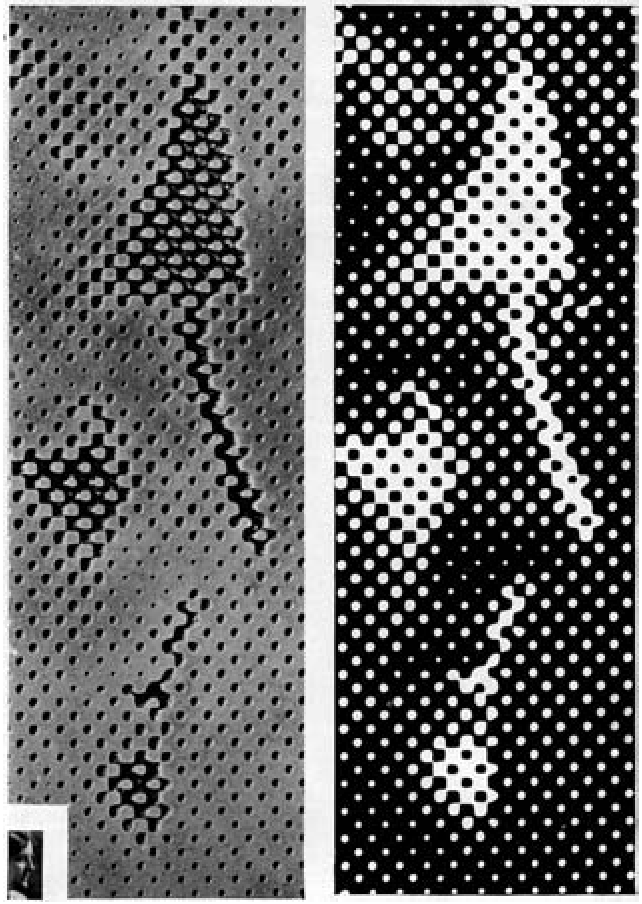

FIG. 717. THE HALFTONING PROCESS. Dark and light portions of the images are reversed on the enlarged detail of a negative (left) and positive (right) of a photograph halftoned for relief printing.
From Hackleman 1924, 245 (figs. 678 and 679).

posing the image through the screen broke up the tonal image into printable dots of graduated sizes, a process called halftoning (fig. 717).

A disadvantage of halftoning was its reduction of the entire image to shades of gray. Manually touching up the negative or the printing plate to add shadows and remove highlights was an early solution; by the 1920s it became possible to add highlights photographically.

In the late nineteenth century halftoned photographs of relief models began appearing in atlases and on wall maps (Aitoff 1929, 552). More sophisticated designs used the halftoned relief image as a gray middle ground setting off added darker, lighter, or brighter lettering and symbols. Terrain relief shading executed in media such as pencil, wash, airbrush, and oil or acrylic colors was also in use by the early twentieth century. Halftoned photographs of relief models were common during World War II. At first halftoned relief maps were manually separated for color printing, but photomechanical process color became common for bird's-eye views after the early 1900s. Other types of maps began to be halftoned, too. A 1917 graphics handbook recommended halftone reproduction of dot distribution maps composed of colored beads on pins. Historic early maps and other maps not originally intended for printing could be turned into printable facsimiles by halftoning, although screening altered their graphic character by softening edges and lowering contrast. In the 1970s, the U.S. Geological Survey began using rectified aerial photomosaics, called orthophotographs, as halftoned backgrounds for topographic, soils, and geological maps. Movie-studio techniques for painting cartoon cels with acrylic colors were also borrowed to create map overlays for photomechanical separation and printing in process colors.

Sometimes photographic screens were used to create graded sequences of flat tints, such as layer tints. As early as 1870, a technique using masks to selectively expose areas and create a series of graduated photographic tints was patented in England, although the patent does not mention maps. The Eckstein lithographic engraving process (used for map reproduction in the Netherlands from 1864–1910) started with a wet collodion photographic guide image on three lithographic color stones, subsequently machine ruled and selectively etched to create twenty to forty colored tints (Koeman 1975, 146–49). A photographic technique for producing halftone layer tints for maps was patented in the United States by O. M. Miller in 1929. The employment of photographic tint screens at set percentages became more common after the mid-twentieth century (fig. 718). Fine-textured screens contact-exposed on the printing plate produced better quality images than photographed stick-up area patterns (Robinson and Sale 1969, 327). Pattern screens could also be made by photographing area patterns, while bold patterns could be subdued by tint screening.

Photographic techniques could also be used to create effects such as vignetted shading, outlines for solid symbols, and double lines for road symbols. At first specialist photographic firms were employed, but after World War II more cartographic establishments acquired their own photographic equipment.

Scribing, a new technique for producing the line image, also grew out of photography. In scribing, pointed tools selectively removed portions of an opaque coating from a transparent support material to create photographic negatives directly. Originally called *cliché-verre* in France, negative engraving on glass was used intermittently by artists in England and France after 1839 (Nadeau 1989–90, 1:69–70, 2:381). Scribing on glass found use in map reproduction after the mid-nineteenth century, but the fragility of glass was a drawback. In 1913 Charles Henry Little, manager of a drafting machine company in East Cleveland, Ohio, suggested scribing on a flexible supporting material, but suitable transparent

FIG. 718. STAGES OF MAP PRODUCTION. Shown here (clockwise from upper left): pen-and-ink drafting with stick-up lettering on mylar film; film negatives for making block-out positives; punch-registered film negatives and positives with photographic tint screen percentages and angles marked on orange masking paper; photographic composites on paper and film; and the printed map illustration in the book. Original map is illustrated in William Y. Chalfant, *Cheyennes and Horse Soldiers* (Norman: University of Oklahoma Press, 1989), 117. Image courtesy of Kansas University Map Associates.

materials were not available at that time (Little 1920). New synthetic base materials and concerted efforts by cartographers to develop scribing techniques led to the rise of scribing after 1940 (fig. 719). Improved tools and materials, such as gem-tipped scribers and film strippable into open-window negatives, became commercially available. Register punches facilitated registration of overlays.

Point symbols and lettering could be scribed but were often added on separate positive overlays as stick-up. Scribing could produce lines closer in quality to copper engraving than any pen-drawn image and more cheaply because it eliminated some photographic steps. By the 1960s, scribing was regarded by many as state-of-the-art production.

Because the map was created as multiple overlays, proofing content and final appearance were critical. Color proofing with the requisitioned German Ansco Printon process was introduced at the U.S. Army Map Service during World War II (Nadeau 1989–90, 1:75–76). The subsequent development of other photographic proofing materials, including more expensive ones closely simulating the look of the final map, helped the cartographer visualize the map product and afforded an opportunity to make design changes and remedy errors before the map reached the printing press.

Without the engraver as an intermediary between the cartographer and the printer, the mid- to late twentieth-century cartographer designing and drafting or scribing the map for photomechanical transformation into the printing image had to possess technical understanding of the printing process. Both collage-style drafting and scribing on overlays had made it harder, rather than easier, to predict the appearance of the final product. Cartographers had to rely on charts of standardized lettering, symbols, patterns, and colors when designing maps. Charting the steps in map production and reproduction were also invaluable. The need for communication and coordination between cartographer and printer through the bidding process, instructions, and exchanges of proofs and corrections increased rather than lessened as printing became more automated. Continuing innovations enhanced the graphic capabilities and cost-effectiveness of photographic techniques until their use in mapmaking peaked in the 1970s. Thereafter the focus of innovation shifted toward computer technology, which had almost entirely replaced photographic technology in mapmaking by the end of the century.

KAREN SEVERUD COOK

SEE ALSO: Color and Cartography; Map: Images as Maps; Reproduction of Maps: (1) Photomechanical Processes, (2) Reproduction, Design, and Aesthetics

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FIG. 719. MAP SCRIBING. Contour lines for a topographic map are being scribed by following a photographic guide image printed on scribecoat with a handheld pen-style scribing tool, while a rigid graver rests nearby on its side, ready to be picked up and pushed across the scribecoat removing lines of coating with its conical point held vertical by its two supporting feet as they slide across the surface.
From U.S. Geological Survey, *United States Geological Survey Yearbook, Fiscal Year 1978* ([Washington, D.C.]: United States Department of the Interior, Geological Survey, 1978), 67.

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Physiographic Diagram. The physiographic diagram, together with its derivative the landform map, is "one of the more distinctive contributions of American cartography" (Robinson and Sale 1969, 187). Essentially, it presents landforms as symbols in an oblique rather than vertical perspective. These symbols are then combined with a planimetrically correct two-dimensional map.

The semi-arid terrain of the western United States was particularly conducive to the detailed physiographic study of rock structures, providing ample opportunity for the creation of visually pleasing maps and diagrams of landforms during the latter stages of the nineteenth century as exemplified by the eminent geographer William Morris Davis. His pupils such as Douglas Wilson Johnson were strongly influenced by his teaching methods. In turn, Johnson was highly influential in promoting Armin K. Lobeck's interest in the representation of landforms at Columbia University (Smith 1959). Lobeck's first notable production of physiographic diagrams began as a member of the American Commission to Negotiate Peace at the Paris Peace Conference, 1918–19. He was responsible for the production of physiographic maps of Europe's problem areas, most notably the Balkans. By 1921, Lobeck had published his first physiographic map of scientific and educational importance, the *Physiographic Diagram of the United States*. Physiographic diagrams of Europe and Allegany State Park followed, in 1923 and 1927 respectively. During World War II, Lobeck served in the Military Intelligence Service of the U.S. Army and prepared physiographic maps for the invasion of North Africa. Physiographic diagrams of many parts of the world, including Asia and Africa, followed shortly after the war (fig. 720). Similar work for the U.S. Army was carried out by another exponent of the physiographic diagram, Guy-Harold Smith, who considered his physiographic map of Japan his finest physiographic drawing (Brown 1978, 115).

The landform map, a close derivative of the physiographic diagram that placed greater emphasis on the character of the surface form rather than its origin, is most closely identified with the work of Erwin Raisz. Like Lobeck, Raisz worked with Johnson at Columbia University from 1923 to 1930. His first map publication was the *Physiographic Diagram of the New York Region* (1930). At Harvard, Raisz set about developing his method of landform mapping by systematizing the

FIG. 720. DETAIL FROM THE *PHYSIOGRAPHIC DIAGRAM OF AFRICA*, 1:14,000,000, 1946, BY ARMIN K. LOBECK. Lobeck's diagrams were accompanied by cross-sections and detailed descriptions, which in this case stretched to approximately 15,000 words. Note the schematic nature of the depiction.

Size of the entire original: 69.7 × 56.7 cm; size of detail: 13.4 × 15.6 cm. Image courtesy of the American Geographical Society Library, University of Wisconsin–Milwaukee Libraries.

diagrams of Lobeck and others into forty morphologic types (Raisz 1931). His landform maps were characterized by his acute attention to detail and an apparent desire for realism in the depiction of the earth's surface. During the early 1950s, Raisz took advantage of the availability of aerial photography for those areas lacking sufficiently detailed topographic maps. Landform maps based primarily on trimetrogon aerial photography of Alaska, Canada, Arabia, Turkey and Iraq, and North Africa were published during the early 1950s (fig. 721).

Ubiquitous in the classroom, physiographic diagrams remained the benchmark against which computer-generated visualizations of the earth's surface were measured. As a map type, the physiographic diagram epitomizes twentieth-century cartographic innovations motivated by scientific research and encouraged by political and military necessity only to be superseded by more cost-effective, less labor-intensive computer-based techniques. Many would argue that subsequent methods failed to improve on their predecessors.

ALASTAIR W. PEARSON

SEE ALSO: Alpine Cartography; Lobeck, Armin K(ohl); Raisz, Erwin (Josephus); Relief Depiction: Relief Map; Terrain Analysis and Cartography

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Plane Table. The plane table is a drawing board that is mounted on a tripod and leveled so that it can be rotated about a vertical through the center of the board. From the sixteenth century until the middle of the twentieth century it was used widely to supply topographic detail for maps using visual or graphical methods (fig. 722). The chief advantage of plane tabling over other methods

FIG. 721. DETAIL FROM THE *LANDFORM MAP OF NORTH AFRICA*, 1952, BY ERWIN RAISZ. Trimetrogon photography provided the chief source for this map, enabling Raisz to portray Saharan dune systems and desert landforms in intricate detail. Note the use of descriptive terms and the systematic application of symbols that portray the characteristics of the surface forms.

Size of the entire original: 52.3 × 118 cm; size of detail: 13 × 21.7 cm. Image courtesy of the American Geographical Society Library, University of Wisconsin–Milwaukee Libraries.

FIG. 722. SURVEYOR FROM THE U.S. GEOLOGICAL SURVEY. Herbert "Shortie" Clark using a plane table with telescopic alidade in the Rockies.
Image courtesy of the U.S. Geological Survey.

of land surveying is that when a map is created in the field, the surveyor can check for any errors or omissions before returning to the drawing office. It also helped surveyors become adept at observing the terrain they were mapping. Although used for teaching basic principles of surveying and for field mapping by archaeologists and geologists (Elfick et al. 1994, 246–47), the plane table has not been widely used for topographic mapping since the 1950s, when it was largely replaced for detail survey work by graphic photogrammetric methods. The heyday of plane tabling was the late nineteenth and early twentieth centuries, when the U.S. Geological Survey and the Survey of India produced some of the most skilled topographic surveyors in the history of cartography.

The plane table is normally used to map detail by intersection or by direction and distance (Close 1905, 57–62; United States, War Department, 1940, 327–50). In the intersection method, a sheet of graph paper on which the surveyor has plotted the positions of known points is fixed to the plane table board. The plane table is located over one of the known points and oriented to another known point using a sighting device called an alidade. The alidade is aligned on the plane table between the plotted positions of the occupied and unoccupied known points. The alidade is then sighted on the unoccupied point by rotating the plane table. When correctly oriented, the table is locked, so that it cannot be moved. Rays are then drawn on the plane table to the objects to be mapped using the alidade, which is pivoted around the plotted position of the occupied point. Once rays have been drawn to all the required objects, the plane table is then positioned over another known point, and rays are drawn to the same objects. The intersections of the rays define the correct positions of the objects.

In the direction and distance method, the plane table is oriented in the same way as in the intersection method. Details are then plotted by drawing rays to the required objects and by measuring the distances to these objects. The scaled distances are then plotted on the plane table. A tape can be used to measure the distances for objects close to the plane table position. For longer distances, a telescopic alidade can be used in conjunction with a calibrated staff to measure the distance using a technique called tacheometry (fig. 723). Telescopic alidades are also used to ensure accurate pointing over long distances. In conjunction with the plane table, the Survey of India measured height differences with an instrument called the Indian Clinometer (fig. 724).

PETER COLLIER

SEE ALSO: Coastal Mapping; Property Mapping Practices: Triangulation, Trilateration, and Traverse; Topographic Mapping

FIG. 723. WILD PLANE TABLE WITH TELESCOPIC ALIDADE.
Image courtesy of Peter Collier.

FIG. 724. WILD PLANE TABLE WITH SIMPLE ALIDADE AND INDIAN CLINOMETER.
Image courtesy of Peter Collier.

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Planetary Mapping. See Lunar and Planetary Mapping

Planning, Urban and Regional. The use of maps in city planning and urban design is an often-overlooked theme in the history of cartography. When historians of cartography or city planning have written about this topic, it has usually been with a decided focus on the relationship between maps and urban design during the Renaissance or early modern Europe. The reason for this historical bias may be that before the Industrial Revolution, urban mapping techniques were less scientifically accurate and more openly subjective. Moreover, cities were smaller, often contained within defined walls, and thus easier to represent as a single, iconic image. Indeed, as art historian John A. Pinto (1976) has suggested, the dual function of the Renaissance city map as a representation both of physical reality and of an idealized image resulted in a strong overlap between the genres of map and plan.

As cartographic genres, maps and plans have drifted further apart since the nineteenth century. Where city maps portray features that are not a physical reality, such portrayals are usually explicitly accompanied by the term "projected." When such features are *not* accompanied by this term, the prevalent cartographic viewpoint is to treat this omission as a mapmaker's error, akin perhaps to inappropriately including a paper street on a topographic map—a judgment that would not have been cast several centuries ago.

This modern drifting apart of the city map and the city plan as visual genres notwithstanding, the use of innovative, and oftentimes artful, mapping techniques for the purposes of urban design and urban design presentation has been central to the development of the city planning profession in multiple national contexts during the twentieth century. In the United States, for instance, the artful use of mapping was prominent in the visual articulation of the City Beautiful movement at the beginning of the twentieth century. Influenced by the Beaux-Arts design school of Paris, which was associated with the architectural style of the French Second Empire and the master planning efforts of Baron Georges Eugène Haussmann in Paris during the mid-nineteenth century, City Beautiful advocates in the United States sought to incorporate what they saw as classical and Italian Renaissance urban design tropes with modern urban infrastructural imperatives, such as the building of railroads, highways, and park systems. The importance of cartography to the City Beautiful planners is reflected in one of the movement's better-known written works, the *Plan of Chicago*, presented by Daniel H. Burnham and Edward H. Bennett in 1909. Commissioned by the Commercial Club in Chicago, the *Plan* sought to guide the city's development away from what many saw as haphazard, messy industrial development and toward the grander, cleaner forms associated with the landscapes of nineteenth-century Paris and Renaissance Rome. The 150 drawings and maps prepared for its presentation were intended in part as works of art and displayed on canvas along the hallways of the Art Institute of Chicago well before their consolidation into the book.

This use of great public halls to display urban design plans was an important City Beautiful innovation. Insofar as public buildings such as art museums were visited by people from all parts of the growing metropolitan regions, the presentation of maps set to the scale of the metropolis became politically valuable. Thus, many of the *Plan of Chicago*'s aerial views, by the watercolor artist Jules Vallée Guérin, show vast expanses of metropolitan space, with farms, forests, and fields broken up by railway and road corridors, and much visual emphasis placed on the contrast between land and water. Moreover, certain design elements within the *Plan of Chicago* suggest that this imaginary aerial view of the city was itself an important factor in determining the design decisions of Burnham and his staff. For instance, the *Plan*'s dramatic symmetry of converging boulevards and harbor piers was designed to be perceptible only from above (fig. 725; see also fig. 1047).

Though the *Plan of Chicago* was unique for its scope and ambition, many of its cartographic themes are evident in prominent City Beautiful plans for other American cities, including Cleveland, San Francisco, Washington, D.C., and Saint Louis. During the 1910s and 1920s the movement shed some of its infatuation with the neoclassical design tropes associated with nineteenth-century Europe and developed instead an affinity for diagrams and schematics scaled to the metropolitan region. Of special interest to City Beautiful urban theorists like Charles Mulford Robinson and John Nolen were radial street diagrams, originally developed in Britain and France, which attempted to portray the geography of arterial roads leading from city centers as simplified, readily readable geometric patterns (fig. 726).

During the 1920s the cartographic paradigm in planning schools began to shift further. In New York and London in particular, the nascent school of location theory and urban economic geography began to produce city maps representing quantitative and qualitative economic information with distinctive dots and shaded areas. The city planners associated with the *Regional Plan of New York and Its Environs* (1929) drew heavily upon this innovative graphic genre for the formation of

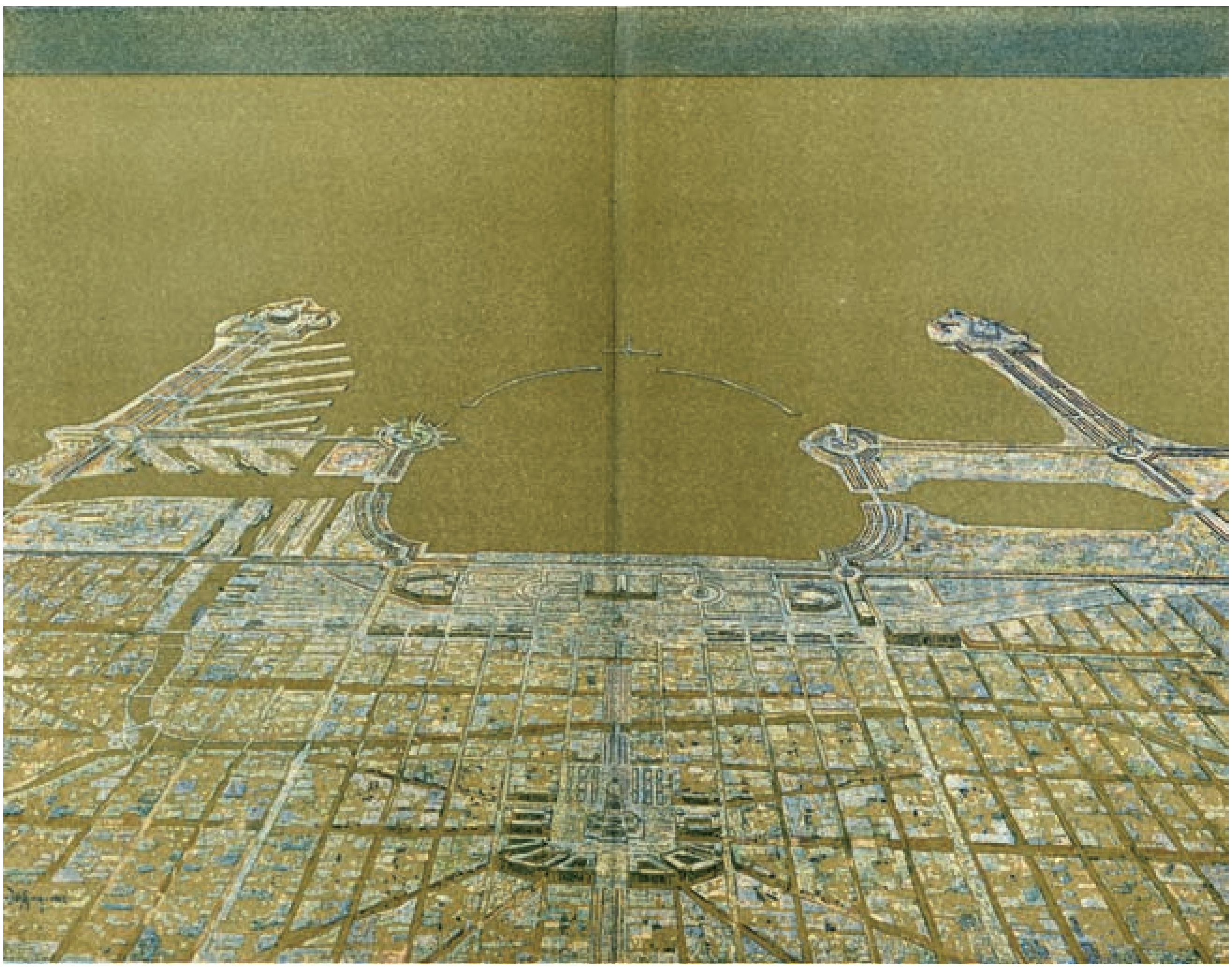

FIG. 725. PROPOSED DEVELOPMENT IN THE CENTER OF CHICAGO, 1909. *Chicago: View of the Proposed Development in the Center of the City*, by Jules Vallée Guérin. The bold symmetry of the plan of Chicago was designed to be perceptible only from above. (See also fig. 1047.) Size of the original: 25 × 32 cm. From Burnham and Bennett 1909, between 114–15 (pl. CXXXVII).

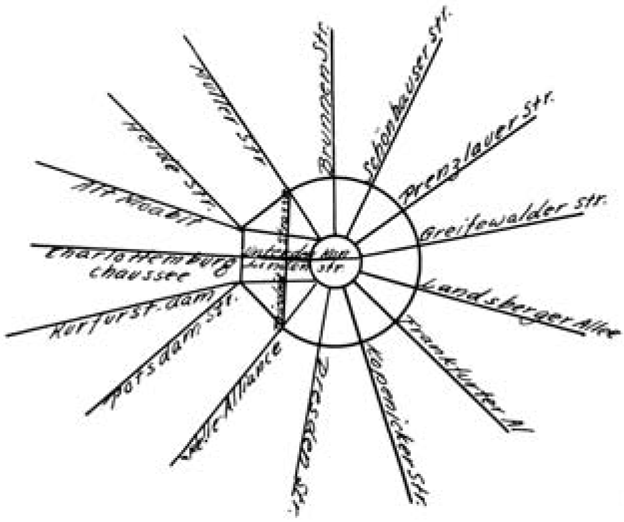

FIG. 726. THEORETICAL PLAN OF THE TRAFFIC CIRCULATION OF BERLIN, 1916. City Beautiful urban designers like Robinson often used simplified cartographic diagrams to portray urban arterial systems based on European examples such as this one of Berlin. The original was published by H. Inigo Triggs in *Town Planning: Past, Present and Possible* (London: Methuen, 1909), 132 (fig. 37).
Size of the original: 8.7 × 10.3 cm. From Robinson 1916, between 102–3.

their designs. The *Regional Plan*'s lead economist, Robert Murray Haig, produced a series of dot maps indicating the flight of many types of industries from the city center, Manhattan Island. In turn, the *Regional Plan*'s designers, most notably Thomas Adams and Harold MacLean Lewis, used these cartographic data to shape the contours of their plan—recommending, for instance, a new, nonindustrial infrastructure for Manhattan. Whether Haig's own economic findings were objective, or whether both he and the *Regional Plan* designers shared a wider elite bias against inner-city industry, is not clear. Either way, the *Regional Plan*'s innovative coordination of economic geography, the cartographic presentation of empirical data, and urban design principles anticipated an important connection between cartography and city planning that was to last throughout much of the rest of the century.

By employing both older and younger generations of planners, the *Regional Plan* was also noteworthy as the last gasp of Beaux-Arts visual tropes within the American planning tradition. Nonetheless, the City Beautiful visual tropes, especially those focused on neoclassical imagery and grand metropolitan vistas, were to be taken up elsewhere, especially by midcentury totalitarian regimes. In 1939, for instance, Adolf Hitler's lead architect, Albert Speer, showcased a massive model of the proposed reconstruction of Berlin, to be built after the Nazi conquest of Europe. Although visual aspects of the plan, such as the dramatic wide boulevards leading up to a gargantuan central dome, echoed Burnham's vision for Chicago, Speer's plan was presented entirely to a closed circle of German elites, rather than to a wider metropolitan audience.

In Britain and the United States, by contrast, the 1930s and 1940s were mostly characterized by the gradual development of the diagramming and cartographic data presentation techniques already evident in the *Regional Plan*. Planners in London during World War II used mechanical drawing instruments to produce simplified maps of the city, characterized by clean lines, with dark, double lines indicating proposed traffic corridors. Planners in the United States, also making use of engineering drawing techniques, produced innovative "hourly variation" charts portraying hourly flow of automobile traffic in and out of areas (fig. 727).

This preoccupation with the presentation and use of cartographic data for planning purposes continued into the 1950s and 1960s—though more so in Communist countries than in Britain or the United States. In 1966 the architecture faculty of the Moscow University published its planning treatise, *Novyy element rasseleniya*, which was enlarged, revised, and published in Italian (1968) and then translated into English as *The Ideal Communist City* (Gutnov et al. [1971]). It made use of dot maps at multiple scales to indicate areas of varying industrial development, each with different planning needs, and also included some comparatively abstract maps, rendered in pen and ink, showing the shape of settlements and cities under different modes of production (fig. 728). Interestingly, to explain the form of the ideal city under communism, these Moscow architects relied mostly on the medium of photography, not cartography.

The Ideal Communist City highlights another post–World War II trend in city planners' use of cartography: the presentation of obviously hand-drawn maps, or sketches, for stylistic presentation purposes—especially to add a tone of ideological intensity. The innovator of this stylistic trope was probably the Swiss architect and city planner Le Corbusier. While a key figure in the rise of the international architectural style known for its precise, minimalist presentation of straight, machine-cut lines of steel and glass, Le Corbusier was also influenced by the primitivist artistic movements of the early twentieth century. His affinity for presenting his urban design sketches as finalized, presentable forms reflected a rising cultural emphasis—both primitive and modern in its conceit—on the pure vision of the individual planner, uncompromised by social convention.

Such sketches, which became quite popular among planning theorists throughout the postwar period, provide an important window into political ideologies ani-

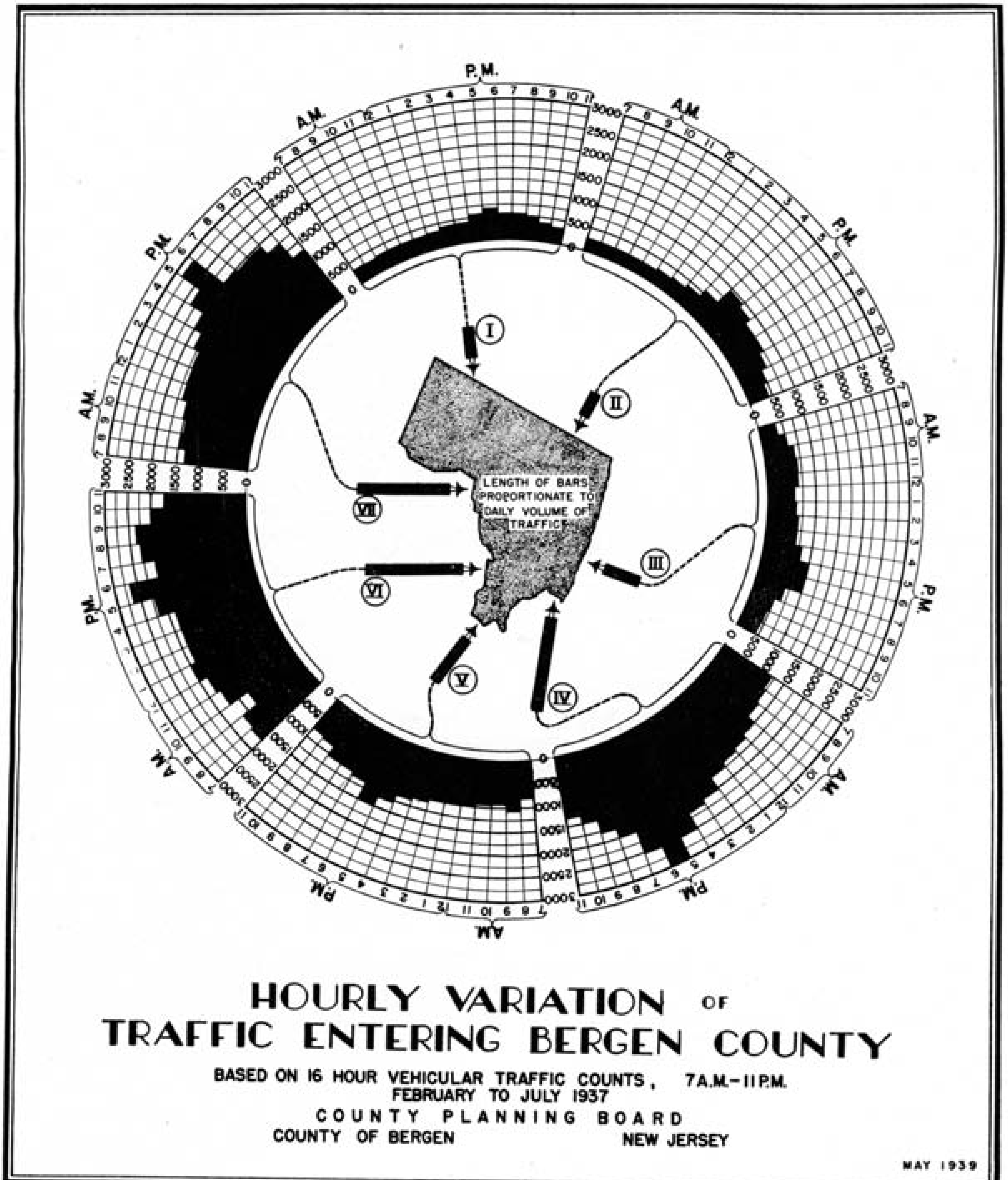

FIG. 727. *HOURLY VARIATION OF TRAFFIC ENTERING BERGEN COUNTY.* In a 1949 planning instruction book, American planner Harold MacLean Lewis drew attention to this "hourly variation" traffic chart produced by Bergen County, New Jersey. Size of the original: 16.7 × 14 cm. From Lewis 1949, 2:129 (fig. 19.7).

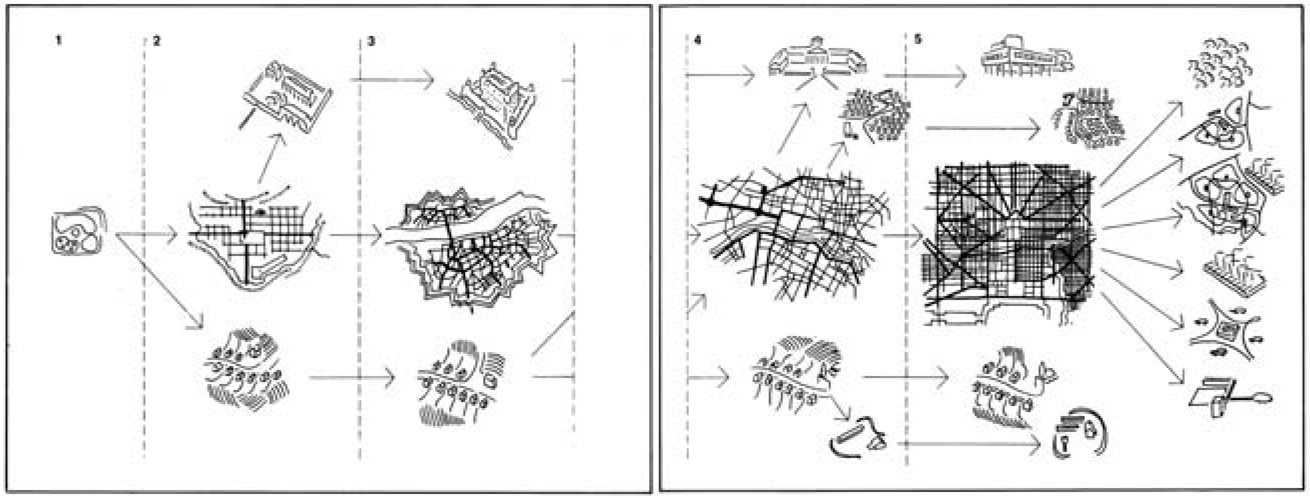

FIG. 728. SETTLEMENT SHAPES UNDER DIFFERENT MODES OF PRODUCTION. A late 1960s Soviet architectural study compared the theoretical shape of settlements and cities under different modes of production. Presented here are settlement patterns under (1) communal primitivism; (2) slavery; (3) feudalism; (4) competitive capitalism; and (5) monopoly capitalism.
Size of each original: 10.1 × 13.4 cm. From Gutnov et al., [1971], 24–25.

mating planners during this time. Sketch presentations turned up not only in *The Ideal Communist City* but also in Percival Goodman and Paul Goodman's socialist planning treatise *Communitas* (1947), Kevin Lynch's psychogeographic study *The Image of the City* (1960), and Jane Jacobs's *The Death and Life of Great American Cities* (1961). Although these works were primarily leftist in their political aims and inclinations, Le Corbusier's original use of the sketch map to present an urban design presentation had not been to entice a left-wing audience, but rather to convince authorities in the Vichy government to adopt his plans for the reconstruction of Algiers.

The midcentury stylization of cartographic presentation techniques in urban design ended in the early 1970s, partly because the modernist planning paradigm had failed to deliver on its social promises but also because computer technology had reinvigorated the longstanding linkages between city planning and social science research. For better or worse, by the late 1970s the dominant planning paradigm had shifted, in both tone and intent, from ideological to pragmatic. Rather than impose their design ideas on governments, planning schools now sought to rearticulate city planning as a useful administrative tool for translating government policies into real-world land use development and management techniques. The rise of computer mapping was instrumental in this transition. Computer-based geographic information systems (GIS), used primarily for rural land use management during the 1960s and 1970s, were adopted by many city planning schools and firms during the 1980s and 1990s, when the planning profession became ever more policy oriented, and the conceit of urban design fell increasingly out of favor.

In some places, though, the policy turn in city planning was less pronounced while the formal and aesthetic concerns surrounding urban design remained paramount. These concerns have always been politically important for cities undergoing tremendous social, economic, and physical change, whether the boomtown-like Chicago at the turn of the last century or the rapidly expanding office centers of the 1960s. Moreover, the late twentieth and early twenty-first centuries had their own boomtowns. The rapid growth in population and spatial extent of Jeddah, Saudi Arabia, for instance, is reflected in the ambitious urban design plans for the city's Kingdom Tower Project. The Kingdom Tower schematics exhibit a dramatic improvement in computer-aided rendering (fig. 729), a tool that had become especially useful for single buildings and neighborhood developers. Although the gap between the empiricist and urban design branches of the city planning profession had widened over the course of the twentieth century, by 2000 they shared a dependency on digital technology.

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SEE ALSO: Administrative Cartography; Census Mapping; Historic Preservation and Cartography; Land Use Map; Landscape Architecture and Cartography; Urban Mapping

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FIG. 729. BIRD'S-EYE VIEW OF KINGDOM TOWER, JEDDAH, SAUDI ARABIA. Produced with the aid of computers, many urban design renderings share an emphasis on the bird's-eye view with the 1909 plan of Chicago's watercolor drawings.

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Political Cartoons, Maps as. Maps as elements within political satirical graphics had a long-established history prior to the twentieth century, with classic examples produced by eighteenth- and nineteenth-century caricaturists, epitomized by the work of James Gilray. However, it is with the advent of wide-distribution print media and, more recently, electronic media, that the political graphic has become almost ubiquitous. Graphics containing maps have proliferated as audiences have become more geographically and geopolitically literate.

As an important subset of propaganda graphics, political cartoons are more commonly used to subvert ideological positions than to support them and to denigrate individuals or groups rather than glorify them. Maps become highly significant components of political cartoons in times of war, as Roy Douglas (1990) demonstrated with a wide range of examples from the various protagonists in World War II. Other commentators have explored their use in satirizing issues in international relations and geopolitics. John J. Johnson (1980) provided examples of maps in cartoons related to the geopolitics of the United States' so-called backyard in Central and South America. These cartoons explore issues such as the Monroe Doctrine and the invitation to Cuba to join the Union. More recently, the massive changes in the geopolitical landscape of Europe following the fall of the Soviet Union have attracted the attention of cartoonists and graphic designers working for the news media (Vujakovic 1992). The unequal relationship between the rich countries of the north and the poor states of the south has given cartoonists a strong incentive to incorporate cartographic images (Regan, Sinclair, and Turner 1988, 1994).

The nation-state as a "power container" (Giddens 1985, 13–14) is premised on territorial control. Mapping the national space defines the limits of control and relationships with surrounding territories. However, when maps are incorporated within satirical graphics, the message is often turned on its head, as when a cartoon shows a map (as an image of territorial integrity) being ripped apart (to represent civil war or the redistribution of land after the fall of a particular regime) or expunged. In this sense, the map *is* the territory and the act of fragmentation is geopolitically significant. This resonates with J. B. Harley's concept of the external and internal power of cartography. The act of mapping usually creates connotations of control, unity, and order, but such connotations are often subverted deliberately in these cartoons.

Various authors have examined the geopolitical significance of maps in political graphics (for example, Vujakovic 1990; Holmes 1991; Newman 1991; Pickles 1992; Herb 1997). Peter Vujakovic (1990) presented a basic typology of maps in political cartoons, with a specific focus on geopolitical issues and international conflict, and describing several specific ways in which maps are used. The first involves a map that represents the territorial arena in which an action is taking place. A classic example of this scene-setting device is a series of thematically related cartoons in which a territory is shown being swept clean of some supposedly negative influence or group. An example from the 1930s shows a Nazi broom clearing Germany of Jews, Communists, and intellectuals, while a Soviet example has Lenin wielding a broom atop the globe, sweeping it clean of monarchs, capitalists, and clergy. This repeated theme is invariably portrayed as a positive image, with the diminutive figures being swept away represented as vermin-like. It is only with the recent inversion of the concept of cleansing, in relation to ethnic cleansing, that this graphic device has itself been inverted; for example, a cartoon of former Yugoslav president Slobodan Milošević sweeping men, women, and children away in order to create exclusively Serbian areas (cartoon in *Die Welt* [Germany] 1997). In this last example, the map is implied rather than overt, perhaps because the artist (Klaus Böhle) did not wish to dignify the act with a legitimate territorial authority. Several twists on the cleansing theme exist, including a cartoon during World War II of the British general Bernard Law Montgomery "ironing-out" German forces from a map of Tunisia with a clothes iron (Douglas 1990, 165).

A related theme shows key protagonists literally fighting over the globe. Although this theme dates from the previous century and includes classics by Gilray, it was constantly revisited and reinvigorated as a metaphor for global geopolitical ambition during the twentieth century. A particularly intriguing example is an Italian postcard ca. 1941 by Aurelio Bertiglia showing caricatures of child-like Italian, German, and Japanese troops each kicking a British soldier from their respective geopolitical spheres of influence in Africa, Europe, and Asia; the map is highly simplified and reminiscent of medieval T-O tripartite world maps. John Pickles (1992, 211–14) discussed a related theme in which a person (for example, Winston Churchill in German propaganda) or regime (the Soviet Union or the Japanese Empire) is shown as either a spider or an octopus embracing the globe.

A second use subjects the map to some action, such as cutting it to represent a real, threatened, or desired territorial division. A classic example is a 1920s cartoon showing the British prime minister David Lloyd George about to cut Ulster from the rest of Ireland (Vujakovic 1990, 24). The territory as embodiment of the living nation makes the act of cutting or amputation an even more powerful visual metaphor. A large number of maps in cartoons show the dismemberment of European states after World War I and the more recent collapse of the Soviet Union and Yugoslavia. Territorial fragmentation is illustrated in various ways (see Vujakovic 1992). Two classic examples picture Soviet president Mikhail Gorbachev trying to mend a torn map of the Soviet Union with sticky-tape (fig. 730) and Russian president Boris Yeltsin attempting to halt the disintegration of a jigsaw map of the Soviet region (*Handelsblatt* [Germany], 30–31 August 1991). Other examples show maps—and by implication, territorial ambitions or empires—being rolled up. Examples from World War II provided by Douglas include two cartoons in the *Daily Express* (London) from 16 July 1943 and 2 April 1945 (1990, 179, 241). In the first, Allied soldiers roll back the rays of the Japanese Rising Sun superimposed on a map of the Pacific; in the second, Adolf Hitler gazes forlornly at the map of Europe while Allied soldiers roll it up from both the Eastern and the Western Fronts.

A third common category involves the use of anthropomorphic and zoomorphic maps. These have a long history and have been frequently adopted as a means of ascribing generally negative characteristics to a whole nation by representing its territory as a specific individual, personality type, or animal (for example, the Russian bear as a threatening beast). This device also reworks other classic geopolitical themes in subtle ways. A Peter Brookes cartoon commenting on German reunification showed West Germany as the head of Chancellor Helmut Kohl literally consuming East Germany (fig. 731). The image echoes theories of the "state as an organism" that dominated geopolitical thinking in the early twentieth century and influenced German concepts of *Lebensraum*. Similar concerns prompted Bill Gibbons's cartoon of a reunified Germany drawn as a "vicious muzzled dog" (Holmes 1991, 177).

Finally, the map as a national icon is often manipulated for satirical effect. An extremely clever series of images created by artist David Gentleman for his 1987 polemic *A Special Relationship* uses a combination of flags, maps, and other icons to unpack the complex political relationship between the United States and Britain

FIG. 730. MIKHAIL GORBACHEV CARTOON IN "STATE OF THE UNION TREATY," 1991.
Size of the original: 9.3 × 6.2 cm. From *The Economist* (London), 16 March 1991, 44. Permission courtesy of Kevin Kallaugher.

during the 1980s. Examples include a spoof twenty-two-cent postage stamp on which a map of the United Kingdom made up of the silhouettes of dozens of U.S. bombers commemorates the bombing of Libya from British airbases (fig. 732), and a picture of the U.S. stars-and-stripes on which one star is replaced by a minuscule map of the United Kingdom as the fifty-first state (Gentleman 1987). French cartoonist Jean-François Batellier adopted a similar stars-and-stripes approach, with the blue field shaped like a map of U.S. mainland while representatives of various developing nations are shown rolling up the red stripes as a sign of their disillusion with American global hegemony (Regan, Sinclair, and Turner 1988, 89).

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SEE ALSO: Journalistic Cartography; Persuasive Cartography

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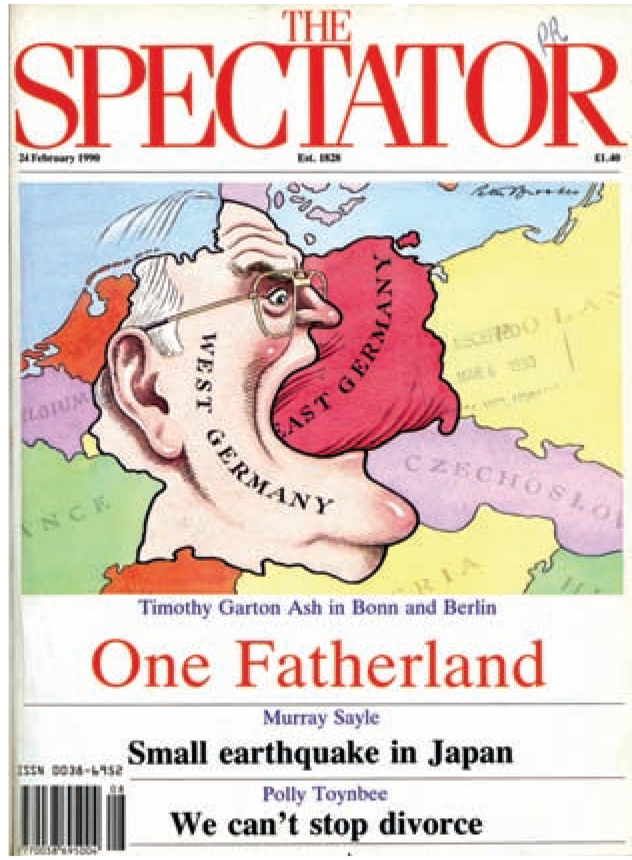

FIG. 731. PETER BROOKE'S CARTOON COVER PAGE OF GERMANY, 1990.
Size of the original: 27.5 × 20.5 cm. From *The Spectator*, 24 February 1990. Permission courtesy of The Spectator, London.

FIG. 732. DAVID GENTLEMAN, SPOOF "22C US STAMP," 1987. Showing the United Kingdom as base for Libyan bombing campaign by the United States.
Size of the original: 4 × 3.1 cm. From Gentleman 1987, unpaginated. Permission courtesy of David Gentleman.

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Post-Structuralist Perspectives in Cartography. See Social Theory and Cartography

Preußische Landesaufnahme. Following defeat by Napoleon in 1806 the Kingdom of Prussia launched a modernization campaign that, among other fundamental changes, created a map section within the General Staff in 1807. The map section catered exclusively to military needs. Its most notable achievement was the Preußische Uraufnahme, the country's first topographic survey, carried out by plane table between 1830 and 1865. The maps were published in color at 1:25,000, which became the basic scale for German topographic maps throughout the nineteenth and twentieth centuries. Contours replaced hachures in 1846. As late as 1868, road and railway planning and other civilian needs were served by redacted black-and-white versions of the military sheets.

Unification of the German states between 1866 and 1871 under the Deutsches Reich, dominated by Prussia, was accompanied by a rapid socioeconomic transformation from an agrarian to an industrial society (fig. 733), which included the adoption of the metric system in 1872 and the reorganization of Prussian surveying and mapping. In 1875 the Preußische Landesaufnahme was formed within the General Staff to carry out all surveying and mapping according to state-of-the-art scientific standards for Prussia as well as the minor northern and central German states. By contrast, the southern German states of Saxony, Bavaria, Württemberg, and Baden retained their independent mapping and surveying institutions. The Preußisches Geodätisches Institut, founded in 1877 to provide precise geodetic measurements, also served as the Zentralbüro für die Internationalen Erdmessung between 1886 and 1919. In 1879 the Berlin Observatory, at 37.00 meters above the median level of the North Sea at Amsterdam, was established as the vertical datum. Although the southern German surveys generally adhered to Preußische Landesaufnahme standards, there were exceptions, most notably in the vertical datum: While Baden used Strasbourg Cathedral (2.00 meters above the Berlin level) as its standard for leveling until 1909, Bavaria based leveling on a datum 1.74 meters above median sea level at Venice. In 1883 the standard meridian on Prussian maps was shifted from Ferro (Hierro) to Greenwich, but both meridians were printed as corner markers on map sheets until 1924.

In 1894 the Preußische Landesaufnahme became an independent department directed by a general quartermaster and consisting of four divisions: trigonometry for geodetic surveys; topography for plane tabling; cartography chiefly for the General Staff's map sheets, including printing units; and map collection. Later additions included a colonial section for German Southwest Africa (1904) and a photogrammetry section (1912). The whole department was staffed on 1 April 1914 by 395 soldiers, including 82 officers, and 516 civilians. Its main responsibilities included control surveying using triangulation and geometric leveling, basic topographic surveys, updating 1:25,000 survey sheets by plane table for about 11,000 square kilometers per year, and revising the related maps, published largely at scales of 1:25,000 and 1:100,000.

Advances in surveying and mapping techniques as well as increased military and civilian demands for greater detail led to the Preußische Neuaufnahme, an improved 1:25,000 map series based on plane tabling and covering Prussia and the smaller states in northern and central Germany. Planning began in 1875, and each of the 3,307 sheets published in its first edition between 1877 and 1915 covered 6′ of latitude and 10′ of longitude—an almost square map image. Multilateral agreements between the Preußische Landesaufnahme and the southern German surveys created three national map series essentially based on the plane table series: 1:100,000 (674 sheets, 559 of which were produced by the Prussian survey; derived by generalizing six full and three half sheets of the 1:25,000 series; first edition 1878–1910), 1:200,000 (196 sheets, 1894–1929), and 1:300,000 (102 sheets). The last of these was the main operational series of the General Staff and extended beyond the Imperial boundaries.

At the outbreak of World War I the survey—except for its cartography division—was temporarily shut down. But because the war lasted longer than originally anticipated, the department was reestablished on 29 April 1917, with the General Staff demanding the introduction of the Gauss-Krüger coordinate system, useful for long-range artillery.

Mapping was an expensive activity, justified politi-

FIG. 733. DETAIL FROM *SECT. BERLIN*, 1872, 1:25,000, NO. 1837. The south central portion of the sheet is occupied by medieval and early modern developments in Berlin, still noticeable by the traces of fortifications, and the most recent but extensive urban extensions governed by the master plan (1862) of city architect James Hobrecht to accommodate the rapidly growing Prussian and German capital (1872: 775,000 inhabitants). Middle and upper class neighborhoods emerge in the south and west around the posh park Tiergarten while working class quarters spring up to the north and east of the old town. Also evident is the Berliner Verbindungs-Eisenbahn (completed in 1877), connecting the rail termini, built across still agricultural landscapes less than three kilometers to the north and east of the royal palace on Spree Island in the medieval core of Berlin. Traditional rural and elongated village green settlements, like Lichtenberg and Weissensee in the east and northeast, begin to give way, in the northwest, to industrial complexes and adjoining worker settlements between the densely populated city fringe and Gesundbrunnen.
Size of the entire original: ca. 51.2 × 46.9 cm; size of detail: ca. 28.7 × 46.9 cm. Image courtesy of the Landesvermessung und Geobasisinformation Brandenburg, Potsdam. Permission courtesy of the Staatsbibliothek zu Berlin–Preußischer Kulturbesitz; Kartenabteilung.

cally as a key component of national defense. High cost had defeated attempts in 1875 and 1912 to transform the Preußische Landesaufnahme into a civilian department, but Germany's defeat in World War I forced the military to cut back on expenses and staff and pushed cartography into the civilian sector. Between 1919 and 1921 Prussian surveying and mapping were drastically scaled back, removed from military control, and consolidated with the much smaller southern German surveys. Even so, the Preußische Landesaufnahme essentially survived as the dominant "Berlin bureau" of the centralized Reichsamt für Landesaufnahme (1921–45) within the Reichsministerium des Innern and making up for the bulk of its 602 employees in 1921 (fig. 734). The former Berlin offices of Preußische Landesaufnahme were destroyed with much of their inventory by Allied bombing between 1943 and 1945. Institutional successors in coordinating the refederalized surveying of West Germany and, after 1990 the reunified Germany, were the Institut für Angewandte Geodäsie (1950–97) and the Bundesamt für Kartographie und Geodäsie (since 1997), both located in Frankfurt am Main.

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SEE ALSO: Bundesamt für Kartographie und Geodäsie (Federal Office for Cartography and Geodesy; Germany); Military Mapping by Major Powers: Germany

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FIG. 734. DETAIL FROM *BERLIN*, 1926. 1:25,000, Meßtischblatt, no. 1837. Only briefly slowed by the impact of World War I, the newly formed metropolitan area of Groß-Berlin (1920, 3.8 million inhabitants), an incorporation of six formerly independent towns and fifty-nine villages, the now fully industrialized city has reached and in the northwest sprawled across the ring railroad. Except for the historic center and the southwestern corner, most built-up areas are characterized by Wilheminian (Victorian) densely developed multifloor tenement blocks, many of which will be wiped out by Anglo-American bombing raids in World War II.
Size of the entire original: ca. 53.9 × 53.7 cm; size of detail: ca. 28.1 × 47.3 cm. Image courtesy of the American Geographical Society Library, University of Wisconsin–Milwaukee Libraries.

Prime Meridian. The prime meridian, also known as the primary meridian, null meridian, and zero meridian, is the conventional line from which the longitudes are reckoned. The prime meridian and its antemeridian at longitude 180° collectively define a great circle that contains both poles and divides the earth into the Eastern and Western Hemispheres. By convention, longitude is taken to be 0° on the prime meridian and is measured from 0° to 180° to the east (positive longitudes) and to the west (negative longitudes). The system of locating positions on the surface of the earth using geographical coordinates (latitude and longitude) began with the Greek geographers Eratosthenes and Hipparchus and was described by Ptolemy (second century A.D.) in his *Geography*. Ptolemy listed the geographic coordinates of about 10,000 places and adopted as his prime meridian a line passing through the Canary Islands, the westernmost part of the known world.

Until the last quarter of the nineteenth century, when the first international discussions of a common worldwide framework for longitude took place, the choice of a prime meridian for cartographic purposes was mainly a matter of tradition, national pride, and convenience. By the middle of the century many different and conflicting prime meridians were in use in Europe, Asia, and the Americas. Between 1871 and 1881, a universal prime meridian and a uniform standard of time were discussed at three International Geographical Congresses, which took place in Europe. Despite proposals for politically neutral solutions, like a meridian running through the Bering Strait or the Great Pyramid of Giza, the preference of most of the national representatives for the Greenwich meridian gradually became obvious because most of the world's navies were using the British Admiralty's charts and *Nautical Almanac*. In October 1884, twenty-five national delegates from Europe, the Americas, and Asia convened in Washington, D.C., for the International Meridian Conference. A resolution adopting "the meridian passing through the centre of the transit instrument at the Observatory of Greenwich as the initial meridian for longitude" was approved with twenty-two affirmative votes, with one negative vote

Table 42. Prime meridians on nautical charts and topographic maps in the nineteenth century

Country	Marine charts (19th century)	Marine charts (1914)	Topographic maps (1885)	Topographic maps (1898)
Austria-Hungary	Greenwich	Greenwich	Ferro	Ferro
Belgium	Greenwich, Paris	Greenwich	Brussels	Brussels
Denmark	Greenwich	Greenwich	Copenhagen	Copenhagen
France	Paris	Greenwich	Paris	Paris
Germany	Greenwich	Greenwich	Ferro	Ferro
Bavaria	—	—	Munich	Munich
Great Britain, Ireland	Greenwich	Greenwich	Greenwich	Greenwich
Italy	Greenwich	Greenwich	Rome	Rome
Netherlands	Greenwich	Greenwich	Amsterdam	Amsterdam
Norway	Greenwich	Greenwich	Ferro, Christiana	Ferro, Christiana
Portugal	Lisbon	Greenwich	Lisbon	Lisbon
Russia	Greenwich, Pulkova	Greenwich	Ferro, Paris, Pulkova, Warsaw	Pulkova
Spain	Cádiz	Greenwich	Madrid	Madrid
Sweden	Greenwich	Greenwich	Ferro, Stockholm	Ferro, Stockholm
Switzerland	—	—	Paris	Paris
United States	Greenwich	Greenwich	Greenwich, Washington	Greenwich, Washington

Source: Bartky 2007, 37, 98, 149.

(San Domingo), and two abstentions (France and Brazil) (International Meridian Conference 1884, 199–200). As clearly stated during the conference, this resolution was mainly a question of practical convenience. Statistics were presented showing that vessels already using the Greenwich meridian, including the merchant marines of the British Empire and the United States, accounted for 72 percent of the total worldwide tonnage. Also, nautical charts and sailing directions published by the British Admiralty had global coverage and were used by a significant number of European countries, including France. Finally, the *Nautical Almanac*, which listed the positions of the heavenly bodies and other ephemerides and was preferred by mariners of most navies, was based on Greenwich mean time.

Despite strong support for the proposal, participating countries were not formally committed by the votes of their national delegates, and no real progress took place in the following years. The sole exception was Japan, which in 1886 adopted Greenwich as its first meridian for counting longitude and time. Two further International Geographical Congresses were held in 1889 and 1891, in Europe, and the issue was once more discussed, though with no practical results. By the end of the nineteenth century the world was not notably closer to the effective adoption of a universal prime meridian than it was before the 1884 conference (table 42).

Significant progress did not occur until the first quarter of the twentieth century following significant advances in wireless communications, which underscored the value of standardizing the world's time zones. In November 1909, an international conference promoted by the British government chose Greenwich as the prime meridian for the 1:1,000,000 International Map of the World. In 1913, the Greenwich meridian was adopted by the European maritime nations for nautical cartography and became the accepted basis for universal timekeeping. Still, national maps of land areas continued to use a variety of reference meridians because most governments were reluctant to accept the costly alterations, especially for their large-scale topographic series. Only after World War II, which revealed an obvious need for cartographic uniformity in joint military operations, did the North Atlantic Treaty Organization (NATO) countries agree to establish a high level of standardization in topographic mapping, including the adoption of not only the Greenwich meridian but also common geodetic reference systems, map projections, and other parameters. Nonetheless, this agreement did not force the countries to completely abandon their own reference systems, which continued in use for many national maps throughout the twentieth century, typically in the form of overlapping graticules or additional longitude scales. A further significant step toward the universality of the Greenwich meridian was the development of the first earth-based global radio navigation system Omega (1968), later followed by the satellite navigation systems Transit (ca. 1970), GPS (Global Positioning System, ca. 1980), and GLONASS (Global'naya Navigatsionnaya Sputnikovaya Sistema, 1995).

Development of spatial techniques for geodetic surveying during the second half of the century dramatically improved the accuracy of geodetic positioning and made possible the implementation of more precise types of global reference frames, independent of plate tectonic motions, for which the concept of a fixed prime meridian was no longer relevant. In 1991, the International Union of Geodesy and Geophysics adopted the International Terrestrial Reference System (ITRS), consisting of a set of prescriptions and conventions, together with the modeling required to define the origin, scale, orientation, and time evolution of the related International Terrestrial Reference Frame (ITRF). Implementation of the ITRS was assigned to the International Earth Rotation and Reference Systems Service (IERS). Ultimately, the Greenwich meridian was superseded by the IERS Reference Meridian (IRM), which in 2008 ran about 100 meters east of the Greenwich Airy Transit Circle. Not attached to any fixed location on earth, the IRM's position is recalculated annually using coordinates for the many ground stations that make up the IERS network. Astronomical observations of heavenly bodies are no longer needed for determinations of coordinates and have been replaced by measurements based on orbiting satellites (GPS and satellite laser ranging), reference points on the moon's surface (lunar laser ranging), and signals from distant radio sources (very long baseline interferometry). Because the Eurasian tectonic plate is in constant motion, however subtly, the ITRS coordinates of the Royal Observatory Greenwich have been slowly drifting to southwest at about 2.5 centimeters per year.

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SEE ALSO: Conventions, Cartographic; Standards for Cartographic Information; Time, Time Geography, Temporal Change, and Cartography

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Printed Map. See Map: Printed Map; Reproduction of Maps: Reproduction of Maps by Printing

Printing, Color. See Color and Cartography; Reproduction of Maps

Privacy. For centuries, secrecy, privacy, and control have been major concerns in geography, cartography, and (later) geographic information systems (GIS) and science (GISci). During the latter half of the twentieth century the emergence of potentially invasive surveillance technologies forced a rethinking and reformulation of these concerns and their interaction.

Historically, some types of geographic and cartographic information were held as tightly as any other state secret. Secrecy is paramount in wartime because location information can spell the difference between victory and defeat. If commanders had their way, they would always know not only what the enemy might have in store for them, but where it is, how it's moving, and where it will be in the future. Likewise, they would deny the enemy even the barest scrap of information regarding their own whereabouts. Even individual soldiers have vested interests in keeping their locations and movements as private as self-discipline will allow. Troop locations, of course, are sensitive information, but so too are defensive works and access routes, transportation networks, research centers, production centers, supply lines, landforms, and hideaways. It is not just *who* and *what* but also *where* that must be held secret. Consider, for example, the measures taken by the United States and Germany to hide their respective nuclear programs during World War II and the consequences to Germany when its supply route for heavy water was discovered.

Secrecy applies to military intelligence, of course, but also to diplomacy and policy. In every negotiation, advantage can be gained by knowing the opponent's bottom line. In peace negotiations the bottom line often means a real line, that is, a geographical position—a point, a line, or an area—recorded on a map or in a GIS. The Paris Peace Conference following World War I, which was consumed with redrawing the map of Europe, is an extreme example. Geographer Isaiah Bowman served as U.S. President Woodrow Wilson's chief territorial advisor, and geographer Mark Sylvester William Jefferson led the American Geographical Society's team of cartographers, reported to have drawn as many as 300 maps per week at the height of the negotiations, each map representing a favored, acceptable, or unacceptable boundary. That same process has occurred in the aftermath of every war and in countless efforts to forestall wars. In every instance, secrecy is enforced as maps are produced by cartographers, disseminated among their own country's negotiators, shared with allies, and selectively presented to opponents as part of the negotiation.

Personal privacy has grown in importance over the past two centuries, with 1787 marking a significant turning point. Before the American Revolution, there was little expectation of privacy anywhere in the British Empire, even in one's own home. In 1787 the Constitution of the United States took a major step forward by outlawing search and seizure without a warrant legally issued by a judge. Contrast that move with what was happening in Britain. In that same year, British architect Samuel Bentham designed the panopticon—a building in which a single observer could watch everyone else without being seen—and his brother Jeremy Bentham promoted it as a utopian form of total surveillance for factories, hospitals, schools, and prisons. In Europe and America, the panopticon enjoyed a brief flurry of popular interest but fizzled over the next three decades after society came to regard it as a nightmare rather than a utopian dream. By 1975 panopticon had become synonymous with *prison*, and after philosopher-historian Michel Foucault published his influential *Surveiller et punier: Naissance de la prison* that year, the term became a metaphor for surveillance of all types. Eventually most advanced societies came to expect some assurance of privacy in their own homes. Courts typically have ruled that people have no expectation of privacy in public places, such as parks and streets, and people have generally accepted that loss of privacy as a perceived protection against crime. Video surveillance of public places through closed-circuit television (CCTV), introduced widely in the final decades of the twentieth century, and online imagery such as Google Street View have became the battleground over privacy in public space.

Technology has been a catalyst for raising public concerns about privacy and control. In the Bentham brothers' day, the technology involved in their panopticon was an architectural marvel. When television appeared in the 1940s, George Orwell envisioned a horrific future based on a pervasive system of visual electronic surveillance that he called Big Brother. Since then, an explosion of information and telecommunications technologies has raised an array of privacy issues. An individual might be troubled to learn that a personal record has been released in paper form to another person, but it is far more frightening to discover that the same record has been digitized, disseminated electronically to millions of recipients, and digitally integrated with information available from other sources. Geographer John Pickles (1991) made this point forcefully when he wrote about "the Surveillant Society." Later the Global Positioning System (GPS) led to what is openly called human tracking even by its proponents. Geographers Jerome E. Dobson and Peter F. Fisher (2007, 309–11) raised the stakes to include control as well as privacy when they cast the new GPS tracking technologies as Panopticon III and wrote about "geoslavery."

Privacy is a conundrum. From an individual perspective, privacy is typically viewed as a fundamental human right, especially in regard to personal attributes and activities. By contrast, distrust of governments, businesses, and other institutions fosters calls for openness, including citizens' access to their own records as well as to official correspondence, reports, and records of closed-door meetings. A case in point is the acknowledged contradiction between the U.S. Privacy Act of 1974 and the U.S. Freedom of Information Act (FOIA), originally passed in 1966. Virtually every federal form filed by an individual contains some sort of personal information that is protected from disclosure under the Privacy Act. Yet, any payment or action based on such information may be subject to claims of favoritism and therefore potentially releasable under FOIA. Geography and cartography have been impacted profoundly because so much of this information is associated with people *and location*. Even if disclosure rules restrict its release to aggregated formats, such as summaries by county or postal code, the value of this information is lost to geographic science if the spatial aggregation is too coarse for a potentially revealing analysis of suspected interactions such as the impact of toxic releases on public health.

Health records, in particular, have been considered sacrosanct, with profound, unfortunate consequences for medical geography. In the United States, the Health Insurance Portability and Accountability Act of 1996 (HIPAA) contains a privacy rule so prominent that many people mistakenly call the entire act the "Health Information Privacy Act." Its disclosure rules govern the release of health information on individuals so completely that HIPAA stymies high-precision geographic research on factors and causes linking local environments with local health. Patients routinely are presented with a statement affirming their rights to privacy except for release to insurers, the one entity most likely to react detrimentally to a patient's interests if adverse health conditions are found.

Privacy themes evolve over time. New technologies typically generate concerns that dissipate with familiarity. Orwell's fear of television is a case in point. Television is generally viewed as benign even though CCTV surveillance comes remarkably close to fulfilling the technological side of Orwell's vision. Likewise, in the very beginnings of GIS, a Yale University administrator viewed digital street and boundary mapping as such a danger to freedom that he kicked a nascent GIS effort off the campus (Cooke 1998, 52–53). Later, GPS receivers with digital streets, boundaries, and buildings became commonplace. Yet today hardly anyone worries about privacy and control, even as they watch those same technologies hounding characters—mostly bad guys but sometimes good guys—in movies and television shows. Satellite imagery had its day too, as the public became aware of its capabilities but often not its limitations. Farmers in the southwestern United States, for instance, became alarmed when they learned that overhead imagery could be used to monitor their water use in irrigation systems previously based, in large part, on trust and personal accountability. In 1998 in Albuquerque, New Mexico, radio talk show host Charlie Zdravesky assembled a notable cast of GIS specialists to discuss satellite surveillance, while strains of "Someone to Watch Over Me" lilted in the background (Dobson 1998). Agricultural concerns prompted his theme, but the invited experts dwelled more on the ability of credit card companies to monitor purchases—type of item and place of purchase as well as the dollar amount—and even sell this personal information to other companies. Although it was readily apparent by the century's end that satellite imagery can be used to monitor all sorts of things and that credit card purchases were monitored and marketed, complaints rarely rose above an exasperated whimper.

Society has routinely engaged in collective bargaining over privacy. Workers, for instance, trade privacy for wages. That is as true in the digital age as it was two hundred years ago, although increasingly the issue at stake has become *location* privacy. Often the trade-off has been personal freedom and privacy on the one hand versus personal safety and security on the other. Purchasers of General Motors' OnStar system, for example, invite surveillance in exchange for the feeling of security that comes with knowing someone will send help in an emergency. Taxpayers trade privacy for fairness. In most advanced nations, anyone can simply walk into a courthouse and get full access to detailed information about the value of anyone else's property, the taxes paid, and, in many places, the design and features of buildings including residences. A century ago it was subscription atlases and fire-insurance maps. In recent decades, it has become GIS and computer-aided design (CAD) drawings and online real-property databases. But privacy rarely emerges as an issue, presumably because homeowners are more concerned about the fairness of tax and insurance rates. Similarly, geographer Mark Monmonier (2002), studying the agricultural use of aerial photography in the 1930s, found that farmers' concerns over privacy had been allayed by promising useful information in return. The same trade-off occurred with soils mapping, where landowners allowed access to their land if they could get their own information (and everyone else's) back in return.

For many years the term *informed consent*, first used in 1957, governed medical practice, especially experimental procedures. Later it was expanded to cover privacy, especially in psychological and social research whenever human subjects were involved. Later still it was broadened expansively to cover field research involving interviews or participant observation. At this point it became a major concern of geography and cartography. In the United States, the National Research Act of 1974 called for the establishment of an institutional review board (IRB) at every research institution receiving federal grants. Originally, IRBs oversaw medical research, but later they came to monitor research involving human subjects in geography and cartography as well. As so often happens with procedural solutions to societal problems, the public discourse often focused not on the invasion of privacy per se but on whether or not the proper procedures were performed. In 2008, for instance, a multi-institutional team of American researchers monitored detailed movements of 100,000 people in a foreign country via their personal cell phone coordinates (González, Hidalgo, and Barabási 2008). Some privacy advocates were outraged because the researchers did not seek informed consent (Dobson 2009). Researchers rested their defense on anonymity, claiming the users' names had been stripped from their coordinates. Geographers responded that location *is* identity. Ultimately, the debate devolved to a procedural argument over whether or not the proper IRB approvals had been filed. One author said, "No." Another said, "Yes." This inconclusive standoff was and is typical of how most privacy arguments end.

JEROME E. DOBSON

SEE ALSO: Cadastral Map; Census Mapping; Photogrammetric Mapping: Air Photos and Geographic Analysis; Public Access to Cartographic Information; Tax Map

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Projections.

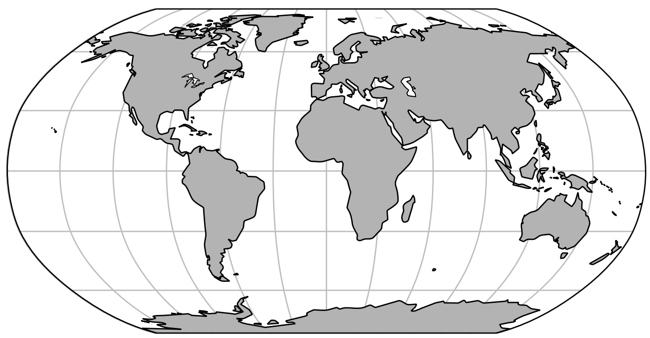
World Map Projections
Interrupted and Polyhedral Projections
Cultural and Social Significance of Map Projections
Regional Map Projections
Projections Defined for the Ellipsoid
Projections Used for Topographic Maps
Projections Used for Military Grids
Projections Used for Aeronautical Charts
Projections Used for Marine Charts
Projections Used for Statistical Maps

World Map Projections. Progress in mathematics during the nineteenth century, and the establishment of sound principles for analyzing and reducing map projection distortion by scholars like Carl Friedrich Gauss and Nicolas Auguste Tissot, had a profound impact on map projection development since 1900. Between 1900 and 1992 roughly 180 new map projections were developed, the large majority of which were intended as whole-world map projections (Snyder 1993, 274–86). As in many other cartographic domains, developments in map projection during the twentieth century were strongly influenced by the introduction of efficient computing devices. Improvements in computation technology, ultimately resulting in the development of high-speed digital computers, made it easier to calculate the position of graticule intersections for map projections with complicated mathematical formulas and to plot the graticule of these projections. Increased computational efficiency also led to a more systematic study of the distortion characteristics of commonly used projections (e.g., Canters and Decleir 1989) and to the development of low-error projections with less overall distortion than traditional map projections obtained by analytical methods.

The pseudocylindrical projection, with its straight parallels of latitude and curved meridians, became the twentieth century's most popular model for designing map projections. Many cartographers were attracted by the simple, straightforward appearance of the pseudocylindrical graticule, whereby alterations of the length and the spacing of the parallels offered endless possibilities for new designs. In the first half of the century dozens of new pseudocylindrical projections were proposed, with designs based on a flat pole line especially prominent. The best-known early examples of the flat-polar projection include designs by Max Eckert, Karlheinz Wagner, and F. Webster McBryde. One of the better-known flat-polar pseudocylindrical projections was the Robinson projection, invented by Arthur H. Robinson. Although developed in 1963, the Robinson projection became fashionable only toward the end of the century, after having been adopted by the National Geographic Society for some of its world maps. Also, in the former Soviet Union many pseudocylindrical projections were proposed, including projections by Vladimir Vladimirovich Kavrayskiy that became known in the West through the writings of D. H. Maling (1960). Frank Canters and Hugo Decleir (1989, 73–145) and John Parr Snyder (1993, 166–68, 189–224) offer comprehensive reviews of pseudocylindrical map projections, most of them developed in the twentieth century.

Other new projections used curved parallels to enhance the pseudocylindrical framing of world maps. Curving the parallels not only offered the cartographer greater flexibility in designing a new graticule but also made it possible to reduce the distortion of shape along the outer meridians, which is quite conspicuous on some pseudocylindrical projections. Near the end of the nineteenth century the Russian cartographer David Aitoff proposed a graticule with curved meridians and parallels that portrayed the world in an ellipse with axes in a ratio of 2:1 and with both the equator and the central meridian at true scale. By averaging the x and y coordinates of this projection with those of the equidistant cylindrical projection, the German cartographer Oswald Winkel obtained an innovative graticule with curved meridians, slightly curved parallels, and a straight pole line, known as the Winkel tripel projection. Introduced in 1921, the Winkel tripel became increasingly common as a framework for world maps: in late twentieth century atlas cartography, the Winkel tripel projection and the Robinson projection were perhaps the two most frequently used projections for world maps (fig. 735). In the former Soviet Union, Georgiy Aleksandrovich Ginzburg developed various world map projections with nonconcentric circular parallels and curved meridians, which were frequently used in atlases as well as for school maps (Snyder 1993, 248–50; Bugayevskiy and Snyder 1995, 143–49). Two other widely used world map projections with curved parallels are the Aitoff-Wagner and the Hammer-Wagner projections; still in use in 2000, they were proposed in the 1940s by Karlheinz Wagner (1949, 198–218).

In an attempt to reduce distortion in peripheral parts of the map, some cartographers experimented with interrupted map projections that accorded distinct parts of the earth's surface their own central meridian. This strategy avoided the extensive shearing close to the outer meridians of many noninterrupted map projections. Most of these interrupted projections have a continuous equatorial axis that connects locally centered zones based on either the same or on different projections. The interrupted pseudocylindricals proposed by J. Paul Goode early in the century played a key role in the promotion of these designs (fig. 736). Designers have suggested diverse arrangements for interrupted world maps (Dahl-



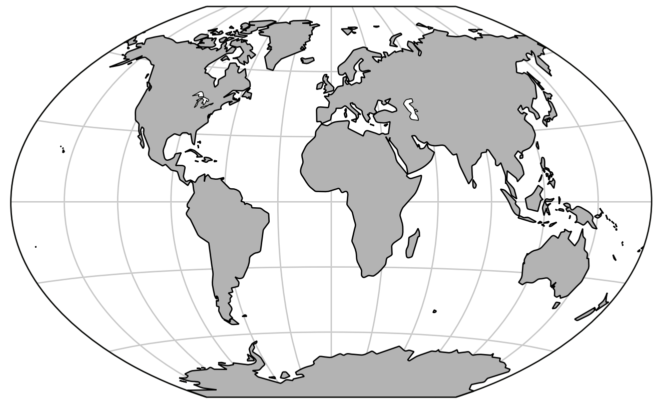
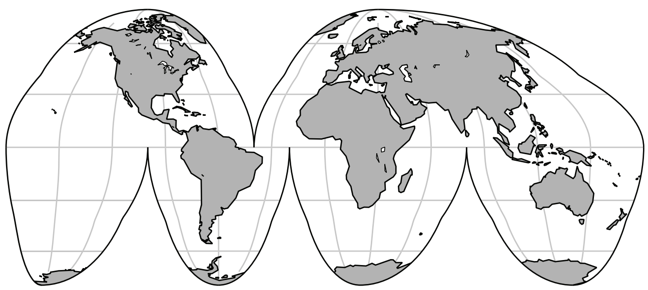


FIG. 735. THE ROBINSON (LEFT) AND WINKEL TRIPEL (RIGHT) PROJECTIONS. These were probably the best known and most frequently used projections for world maps at the end of the twentieth century. The straight parallels of the Robinson and the curved parallels of the Winkel tripel yield different patterns of areal and angular distortion.



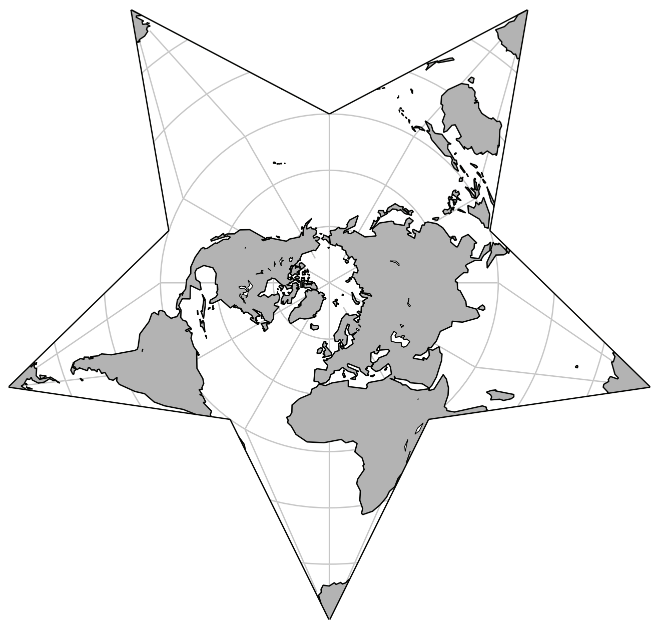


FIG. 736. GOODE'S HOMOLOSINE EQUAL-AREA PROJECTION (LEFT) AND BERGHAUS'S STAR PROJECTION (RIGHT). Goode's is probably the best known interrupted projection and leaves major land masses largely intact; Berghaus's star projection, with interruptions south of its continuous equator, slightly disrupts Africa in this version.

berg 1962), such as graticules with transpolar continuity resembling the shape of a star. A few authors produced condensed interrupted designs that purposely exclude irrelevant areas—omitting the oceans on maps for terrestrial distributions saves space for greater detail on land. A well-known example is the Oxford projection, used since 1951 for world maps in atlases published by Oxford University Press.

Although several prominent atlas publishers pioneered new map projections, commissioning innovative frameworks for their own maps on occasion, many cartographic publishers as well as the popular media continued to use map projections developed before 1900. A particularly revealing example is the continuing use of the Mercator projection, which became popular for world maps in the nineteenth century in spite of its excessive areal exaggeration in the polar regions. Notwithstanding criticism by leading cartographers who emphasized the projection's inappropriateness for world maps, the Mercator projection remained in use throughout the twentieth century. Although its use in atlases declined significantly since World War II, it was still a popular projection for wall maps in 2000 and frequently appeared in newspapers and magazines as well as in digital media and on television. Another example of the mapmaker's tendency to cling to familiar representations is the limited use of world map projections that focus on regions other than Europe or Africa. Although increased efficiency in coordinate computation made it easier in the 1960s and thereafter to produce recentered and oblique versions of world map projections, the use of oblique views never became popular, in spite of the various oblique world maps introduced in atlases by leading atlas publishers like John Bartholomew & Son in the 1940s and 1950s (fig. 737).

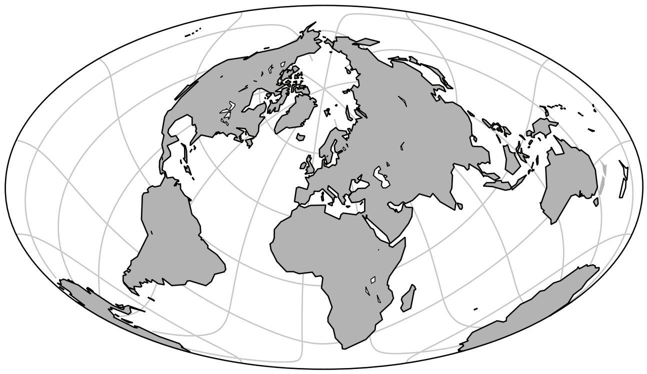


FIG. 737. BRIESEMEISTER PROJECTION (LEFT) AND JOHN BARTHOLOMEW'S ATLANTIS PROJECTION (RIGHT). As oblique equal-area map projections, not centered on the equator, these focus on distinctly different parts of the world.

New developments in map projection science during the twentieth century contrasted markedly with most map authors' and map publishers' conservative approach to map projection. Indeed, the increased computational efficiency that had made it easy not only to draw maps framed by the most complex projection but also to transform data from one map projection to another also cleared the way for the numerical treatment of map projections. An intriguing advance in map projection research since the mid-1970s is the development of low-error projections for world maps that minimize geometric distortion for the entire surface of the earth or for the area covered by the continents (fig. 738). Research efforts in this field resulted in a multitude of new projections, each with its own characteristics based on the distortion measure applied and the specific conditions imposed on the shape of the parallels and the meridians. Canters (2002) provides an overview of numerical approaches to developing low-error world map projections. Despite the comparative ease at the end of the twentieth century of producing eye-catching and arguably more functional designs, including low-error whole-world map projections, nonacademic map authors and commercial map publishers largely ignored these new options.

FRANK CANTERS

SEE ALSO: Atlas: World Atlas; Eurocentric Bias; Geographical Mapping; Mercator Projection; Peters Projection; Robinson Projection; Thematic Mapping; Tissot's Indicatrix; Wall Map

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Interrupted and Polyhedral Projections. Map projections inevitably distort. Three kinds of distortions can exist independently of each other: regions on the map may become disproportionately sized with respect to

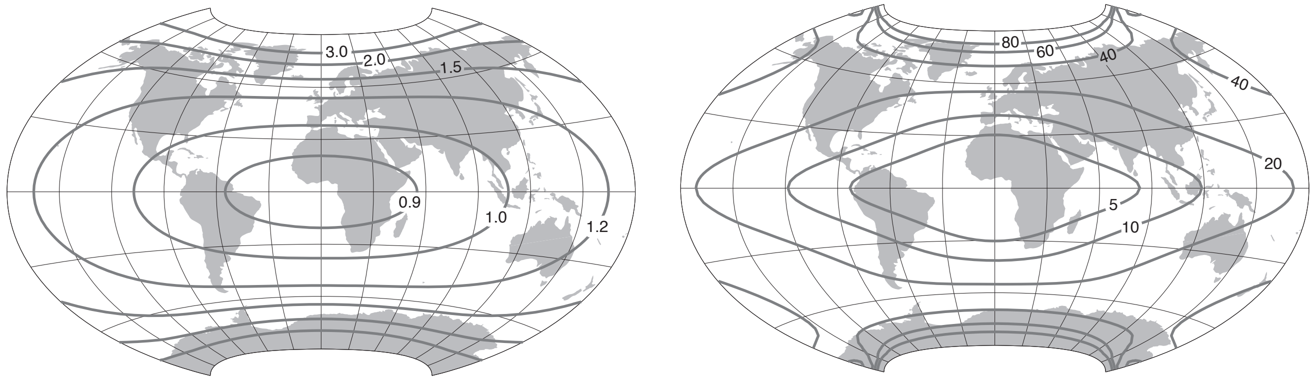


FIG. 738. THE CANTERS PROJECTION. A well-known example of a low-error map projection specifically designed to reduce the distortion of distance over the area covered by the continents, while maintaining the equal spacing of the parallels along the central meridian and the 2:1 ratio of the axes. Shown are lines of constant area scale (left) and lines of constant angular distortion (right).
After Canters 2002, 199 (fig. 5.17).

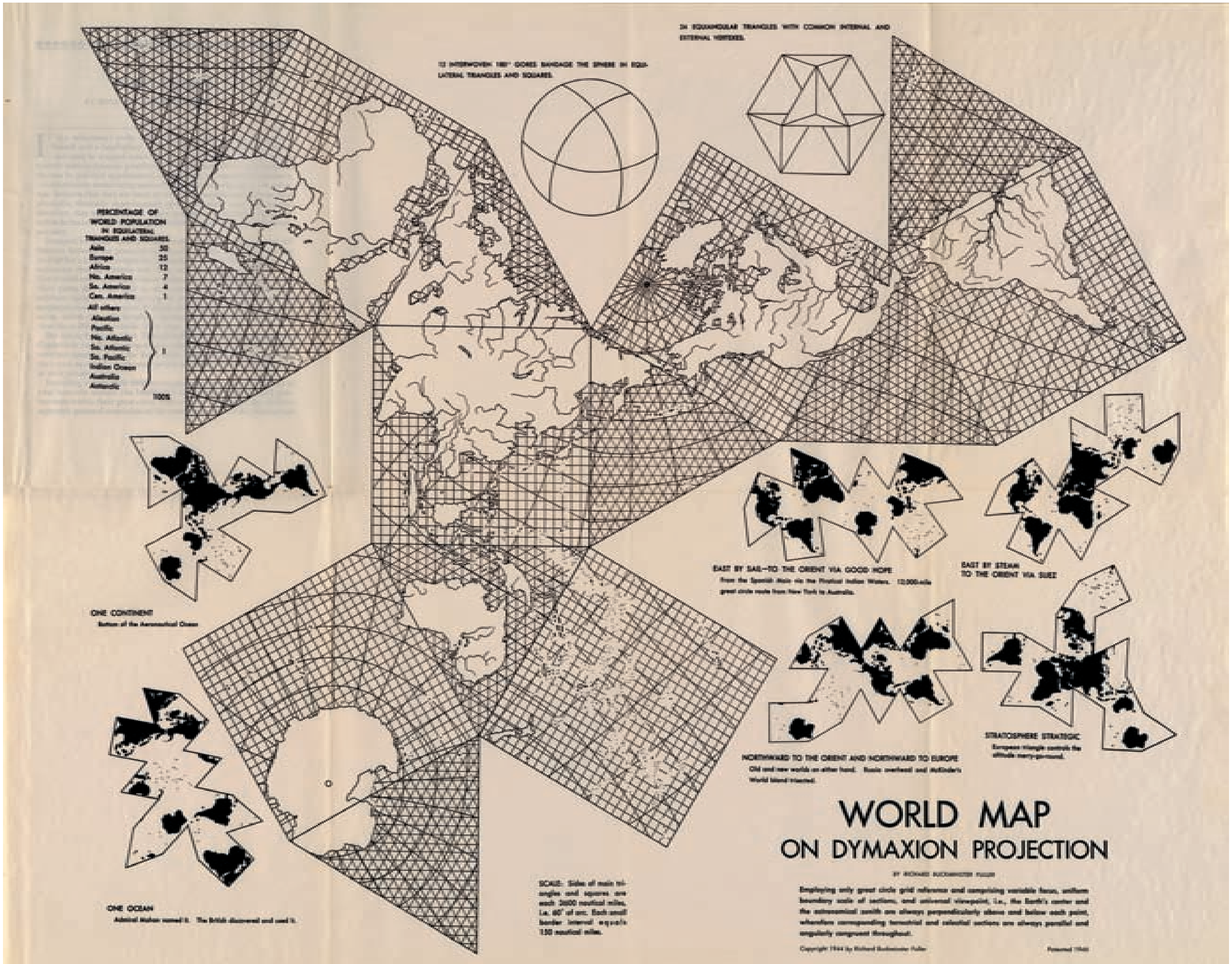
each other; directions, as measured from any point, may become skewed; and regions adjacent on the globe may become separated on the map. The more one kind of distortion is allowed, the less inevitable the others become. Because smaller portions of the earth's surface are more nearly flat than larger portions, greater accuracy can be coaxed out of maps of comparatively small areas. Hence one way to improve accuracy in land shapes and distance measurements is to cut up the sphere, project each slice onto a map independently, and then conjoin these regional maps, each along one edge or at one point, to another, in order to produce a map of a broader area. Separations that remain after conjoining are called "interruptions."

Every world map is interrupted at one point at least, and most are interrupted along an entire meridian. While normal parlance does not call typical maps interrupted, they certainly are, insofar as east and west become separated and the globe loses its natural continuity. Mapmakers have long understood that more interruptions can improve shapes. This principle contributed to the dominance of the double hemispheric representation in seventeenth- and eighteenth-century world maps, which are interrupted along two meridians. Many other interrupted configurations sprang up in the florescence of map projections during the sixteenth century, and developments continued into the twenty-first century.

Some interruptions have topological purposes beyond just improving accuracy. Gores (typically long, thin slices running from pole to pole) are intended to be pasted onto a sphere in order to make a globe. Polyhedral projections can be folded into three-dimensional polyhedra in order to approximate globes. The more facets, the closer to spherical. Spread out flat, a complete set serves as a world map in its own right. Double hemispheres portray the earth in easily digestible halves, evoking but improving upon the eye's view of a real globe, less than half of which can be seen at one time. Interruption is an essential feature of condensed projections, on which deletion of a large swath of the Atlantic Ocean allows an otherwise continuous cylindrical or pseudocylindrical world map to accommodate earth's landmasses at a large scale on a fixed page or sheet of paper (Snyder 1993, 178, 197).

Early interruption schemes strongly favored the symmetric. Globe gores came in rosettes, such as Antonio Floriano's 1555 set; lunes, such as Martin Waldseemüller's 1507 set from *Cosmographiae introdvctio*; or octants, as devised by Daniel Angelocrator in 1628. Double hemispheres came in many configurations, such as Franciscus Monachus's ca. 1527 circles, Oronce Fine's 1531 cardioids, the 1552 rectangles of Francisco López de Gómara, or the modified Ptolemaic framework of Johannes de Stobnicza's 1512 map. More elaborate, but still symmetrical, is the hemisphere flanked by hemidemispheres, or halves of hemispheres, first recorded by Giovanni Vespucci in 1524. Other early interrupted schemes evoke flowers, like Urbano Monte's 1604 circular Northern Hemisphere with four petals representing the Southern Hemisphere.

While Leonardo da Vinci toyed with polyhedral solids as art, the first known geographic projections onto polyhedra were suggested by artist Albrecht Dürer in 1525 (Dürer 1525). They saw little elaboration until the twentieth century, when a profusion of methods showed up in the literature. The most widely known example, R. Buckminster Fuller's "Dymaxion" (fig. 739), appeared in *Life* magazine (Fuller 1943). It was based on a cuboctahedron, one of the solids proposed by Dürer. Cuboctahedra have eight triangular and six square faces, and Fuller arranged his to avoid splitting up continental masses. A later version employed an icosahedron (twenty



12 INTERWOVEN 180° GORES BANDAGE THE SPHERE IN EQUILATERAL TRIANGLES AND SQUARES.
24 EQUIANGULAR TRIANGLES WITH COMMON INTERNAL AND EXTERNAL VERTEXES.
PERCENTAGE OF WORLD POPULATION IN EQUILATERAL TRIANGLES AND SQUARES.
Asia 50
Europe 25
Africa 12
No. America 7
So. America 4
Cen. America 1
All others
100%
EAST BY SAIL—TO THE ORIENT VIA GOOD HOPE
EAST BY STEAM TO THE ORIENT VIA SUEZ
ONE CONTINENT
NORTHWARD TO THE ORIENT AND NORTHWARD TO EUROPE
STRATOSPHERE STRATEGIC
ONE OCEAN
SCALE: Sides of main triangles and squares are each 3600 nautical miles, i.e. 60° of arc. Each small border interval equals 150 nautical miles.
WORLD MAP
ON DYMAXION PROJECTION

equilateral triangles) instead of a cuboctahedron. Coincidentally, economist Irving Fisher, who had presented his own polyhedral projection in 1943, also used an icosahedron (Snyder 1993, 269). Fuller and Fisher patented their projections, which probably diminished adoption because nonpatented low-distortion frameworks were widely available.

Projection methods—how to transfer points from the sphere to the flat facet—are important in polyhedral systems because carelessly chosen projections will not align the graticule or surface features along edges common to two facets. Much of the work on polyhedral projections has focused on the edge-matching problem, rather than the invention of novel polyhedra. Conformal projections naturally match along edges, and mathematical tools existed by the twentieth century to develop conformal projections on polygonal facets. Gnomonic systems also match edges naturally, though not without kinks; because of its simplicity and use since antiquity, the gnomonic projection dominates the history of polyhedral projections.

Bernard J. S. Cahill (1913) developed a "butterfly" interruption scheme as an octahedral projection tailored for flat use around 1912 and promoted it for use in weather maps. The butterfly concept continues to inspire new systems of interruption. The Waterman projection of 1996, for example, uses mathematical principles designed for close-packing of spheres to reduce distortion across the butterfly (Popko 2012, 20–21, 174–77). Agnes Denes (1979), in an eclectic art portfolio, demonstrates not only polyhedral projections but also projections onto the shapes of nautilus shells, eggs, toroids, and more.

The twentieth century also saw rapid development in asymmetrical interruption schemes. The homolosine, an "orange-peel" interruption developed in 1923 by J. Paul Goode (see figs. 736 and 784), was prominent through the remainder of the century in successive editions of Rand McNally's *Goode's World Atlas*. It arranges the interruptions to avoid slicing up continental masses, and helps viewers visualize why a map projection must distort. To accommodate world maps of maritime themes, Goode produced a similar low-distortion framework that interrupted the continents to avoid slicing up the oceans. Similar in intent was Samuel Whittemore Boggs's "eumorphic" from 1929 (Snyder 1993, 197–200). While projection can always be treated as a separate matter from interruption, the authors of both of these systems intended the interruption scheme to be paired with the particular map projection they developed for it. This is common practice.

The twentieth century's most elaborate interrupted maps were created by Athelstan Spilhaus, whose 1991 treatise demonstrated interruptions that follow continental edges in order to cleanly separate water from land (fig. 740). This technique can be used to show either continents or oceans to best advantage, depending on arrangement. Spilhaus also created maps with tectonic plates as edges. He referred to his creations as "interrupted world maps with natural boundaries" (Spilhaus 1991, 11).

The first truly irregular polyhedral projection system was described by Nathan McCall (2006), who devised a novel exploitation of Voronoi diagrams, a mathematical technique for dividing space into polygons defined by points (fig. 741). This approach lets projection designers tailor the polyhedron to favor regions of interest, effectively shoving the inevitable distortion off into areas less important to the map's narrative. Other promising avenues of future exploration include quantifying how interruptions ameliorate the other two kinds of distortion and development of new interruption schemes based on those findings.

DANIEL "DAAN" STREBE

SEE ALSO: Atlas: World Atlas; Geographical Mapping; Goode, J(ohn) Paul

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Cultural and Social Significance of Map Projections. Choosing a projection for a general world map is no scientific endeavor. All projections distort the earth's spher-

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FIG. 739. R. BUCKMINSTER FULLER, *WORLD MAP ON DYMAXION PROJECTION*. Fuller's arrangement of a cuboctahedron, one of Albrecht Dürer's proposals from 400 years earlier.

Size of the original: 45.5 × 53.7 cm. From R. Buckminster Fuller, *Fluid Geography* [1944]. The Fuller Projection Map design is a trademark of the Buckminster Fuller Institute.

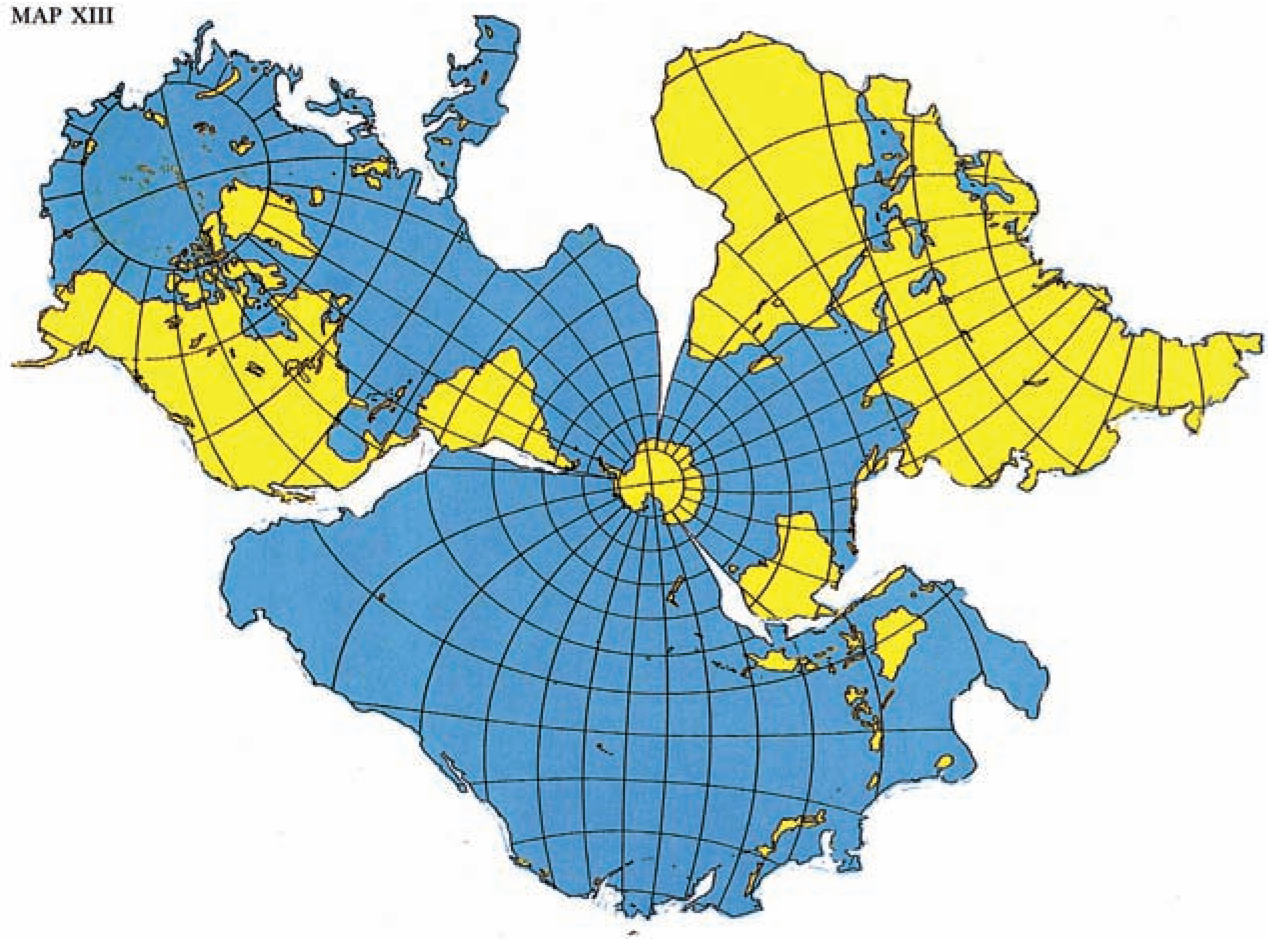

FIG. 740. ATHELSTAN SPILHAUS, COMPOSITE SHORELINE MAP XIII, 1991. Spilhaus sought to use "natural boundaries" as a way to ameliorate the impact of interruption.
Size of the original: 16.6 × 22.4 cm. From Spilhaus 1991, 41. Permission courtesy of the American Philosophical Society, Philadelphia.

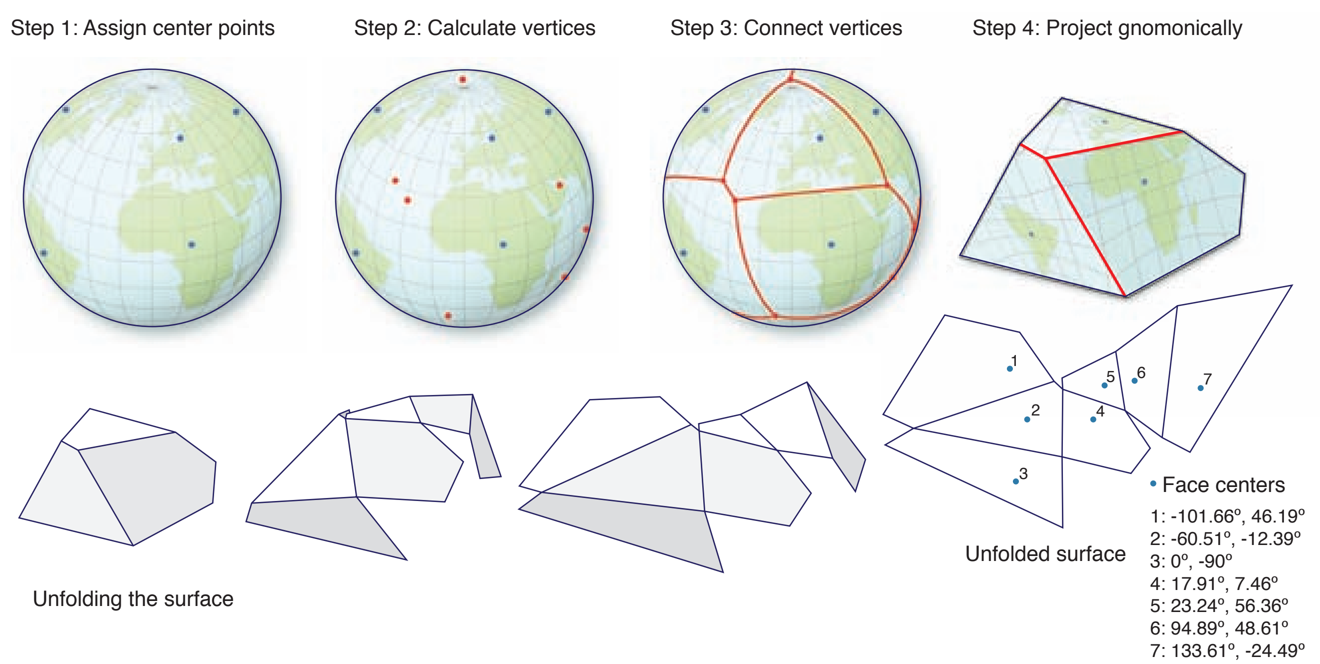

FIG. 741. WORLD MAP ON AN IRREGULAR HEPTAHEDRON, 2006. Nathan McCall uses Voronoi maps to construct irregular polyhedra in a controlled way.
Images courtesy of Nathan McCall 2006.

ical shape; indeed a map projection is distinguished by how it apportions distortions. The apportionment may go unnoticed up to a hemisphere in extent. Beyond that, distortion accelerates until, in a map of the entire earth, any projection selected has infinite distortion somewhere. This is not human failure; it is inexorable mathematics. Compounding the situation, three fundamentally different kinds of distortion—shape, area, and contiguity—may be introduced, and no impartial means exist to compare them. Therefore, map projection choice becomes largely an aesthetic matter. Does it look "right"?

A map of a city or nation or continent normally benefits from specific technical traits, such as minimal scale variation or adherence to a national standard. The chosen traits force which map projection to use. Obvious departures are generally blunders. The intrusion of aesthetics into projection choice is peculiar to world reference maps, and that freedom of preference has inspired the invention of a thousand projections, given justification to claims both defensible and outlandish, and ultimately stoked schisms and controversies. These world maps, so imbued with human judgment, form the story here.

Responding to Western cultural change, world map projection usage trended through clear historical periods: Ptolemaic maps in the fifteenth century, when too little of the globe was known for new projections to matter. Then, a Renaissance explosion of projection experimentation in the sixteenth century. Double hemisphere projections in the seventeenth and eighteenth centuries accentuating the Old/New World duality. The Mercator projection during the nineteenth century's age of scientific navigation. Innovation in projection development and use throughout the twentieth century.

Gerardus Mercator's nautical projection saw moderate use since its 1569 introduction, but its navigational value was undermined by seafarers' inability to reckon longitude accurately. By the late 1700s the longitude problem was solved, bringing the Mercator projection into its own. It had little pedagogical value as a world map, but it was so useful to the vital and prestigious enterprise of navigation that publishers rapidly adopted it. The Mercator projection dominated world maps for the next century and more, even though the projection cannot show the entire world because it inflates the poles to infinity. This circumstance vexed mapmakers and teachers, who promoted self-proclaimed alternatives. Misuse of the Mercator projection festered tensions that finally erupted, in the 1980s, into a traumatic controversy over how projections can influence the masses. Ironically, the Mercator world projection had already faded in use by then.

Thematic maps proliferated late in the nineteenth century. By then mapmakers had learned to preserve relative sizes on such maps, since spatial distributions are hard to interpret unless every square inch on the map represents a uniform number of square miles on the ground. World thematic maps were drawn on alternative projections to the Mercator, as typified by J. Paul Goode's homolosine and Samuel Whittemore Boggs's eumorphic, both interrupted equal-area projections invented in the 1920s.

There was some thought that people could be weaned off the Mercator by preserving familiar land shapes while reducing size distortion. Alphons J. van der Grinten, whose 1904 world projection was used by the National Geographic Society for decades, touted the Mercator appearance of landmasses on his projection. The projection can show the poles, remedying a serious objection to the Mercator. Ironically, van der Grinten maps often omitted the higher latitudes to present the poles as insets. O. M. Miller emphasized that shapes on his own modified Mercator world projection do not obviously depart from those on the Mercator (Miller 1942, 424). The Miller cylindrical projection was employed in the United States, and similar projections were used elsewhere.

Like sea navigation before it, flight exerted its influence on map projections in the twentieth century. Maps of air routes appeared as flying went commercial. Richard Edes Harrison's striking 1944 atlas launched the reader into low orbit (fig. 742), lavishly demonstrating geopolitical sensibilities in an age of world war and aviation. Azimuthal equidistant projections showing rings of equal distance from the center became common. These projections mirrored the zeitgeist, and indeed Harrison explicitly stated his agenda. During the Cold War, over-the-pole maps educated readers about the newly apprehended (for some) proximity of the Soviet Union with its bombers and missiles. Maps of the Distant Early Warning Line in the Arctic region in northern Canada, forming the first line of airspace intrusion detection, showed the Soviet menace looming on the horizon in perspective, sometimes bristling with missiles.

Before the Peters controversy of the 1980s, a main concern was that map readers might misinterpret the geographic space due to distortions in the projection. Often remarked upon, the Mercator world projection allots the same amount of space to Greenland as it does to South America, despite the latter's eightfold larger size. Obviously, students ought not to misconstrue Greenland as being so large, but few saw anything sinister in the situation since distortion is inevitable. Too large, as on the Mercator projection; too bent, as on the sinusoidal; too disjointed, as on Goode's homolosine: one is not necessarily worse than the others.

Or is it? Even in the cautious climate before the 1960s, the Mercator projection's popularity in Britain was claimed by some to arise from its inflated presen-

FIG. 742. RICHARD EDES HARRISON, *JAPAN FROM ALASKA*, 1944. This and other dramatic high-altitude, over-the-horizon perspective projection portrayals from the atlas draw the reader into the age of aviation and the geopolitics of World War II.
Size of the original: 34.7 × 53.8 cm. From Harrison 1944, 42–43.

tation of the British Empire (Kellaway 1946, 37). This claim, whether co-opted or reinvented by Arno Peters, became the archetype for an era of speculation into the power of maps. The Mercator projection was ubiquitous, the Peters camp insinuated. The farther a region is from the equator, the more the Mercator projection inflates its size. The tropics thus occupy much less space on the map than on the globe, reducing their apparent significance. Europe straddles the inflated midlatitudes, whereas many of the lands subjugated by imperialist Europeans lie in the diminished tropics. Ergo, mapmakers deliberately purveyed a distorted worldview, brainwashing generations with a cartographic illusion of European superiority.

Or so the speculation went. Peters presented a cylindrical equal-area alternative (fig. 743) and promoted it with the help of an industry that sprang up around his "new cartography." Though the technical claims for his projection ranged from false to unremarkable (Snyder 1993, 165), claims of social effects proved more resilient. Few studies informed the conversation, and in that void apologists argued that Peters deserved an audience (Harley 1991, 10–11). Speculations into the effect of maps on the public consciousness proliferated in Peters's wake. Books with titles like *The Power of Maps* (Wood with Fels 1992) aimed to persuade the reader that every map is a political document, and, far from representing objective reality, is nothing more than a "proposition."

A journal article by Wolf Schäfer (2005) proclaimed a catastrophe of bias in the teaching of history: "It may not be obvious, but the modern world map that is supposed to support the global history teachers . . . is in fact more often than not undermining their efforts." In emphasizing this great power of maps, he continued, "The iconic globe and its presentism overpower the local geographies of the past, and the modern world map and its false transtemporal ubiquity outshine the original history of globalization." However, the paper offered no evidence that anyone had actually ever been misled.

Understandably, cartographers think map projections are important. Hence each projection inventor hoping to displace the Mercator remarked on Mercator's mis-

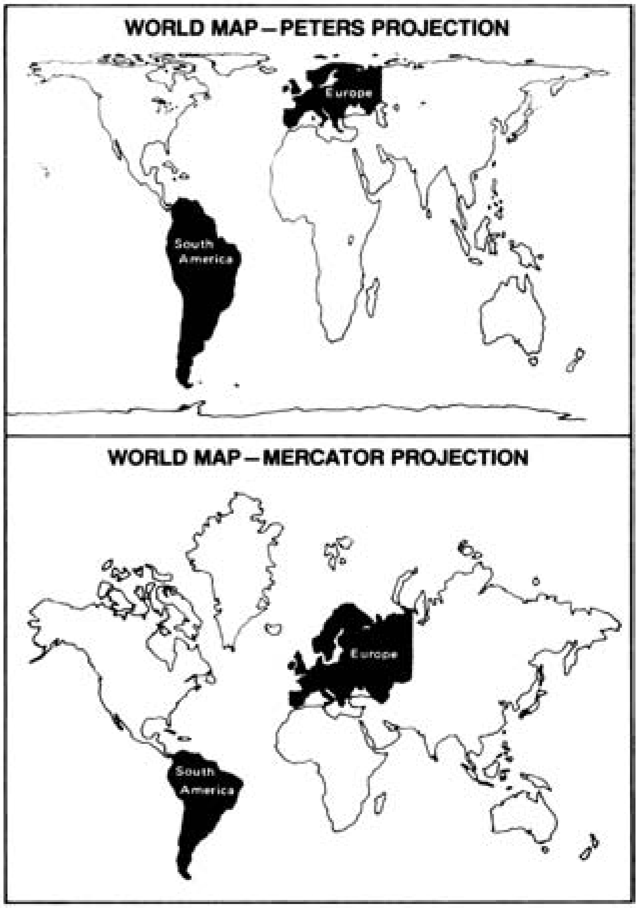

FIG. 743. "WORLD MAP–PETERS PROJECTION, WORLD MAP–MERCATOR PROJECTION," 1984. This juxtaposition of the Mercator and Peters projections emphasized the dysfunctional area exaggeration of the Mercator map and suggested the Peters worldview as a logical alternative.
Size of the original: 7.8 × 5.4 cm. From "A New View of the World," *Christianity Today* 28 (17 February 1984): 39–40, image on 39.

education of the public. A pamphlet issued by the American Cartographic Association in the heat of the Peters controversy stated, "We tend to believe what we see, and when fundamental geographical relationships . . . are badly distorted, we are inclined to accept them as fact if we see them that way on maps" (1986, 2). Apparently few questioned these truisms or considered the implication that the public is too dense to read cues from the graticule. The debate was over who should save the public—Peters or cartographers—rather than whether a savior was even needed. Such faith in the power of maps opens wide the door for cartographic messiahs.

It's not that projections have never been used for propaganda. Mark Monmonier (1991, 87–112) documented clear examples in Nazi and Cold War intrigues. Earlier in the century, Sir Halford John Mackinder launched his theory of the Heartland attended by an oval map centered on Eastern Europe (see fig. 323). The centering is technically defensible. But the projection he used is the rectangular Mercator, so the cropping deliberately misled, enhancing the marginality of regions Mackinder argued were at geographical disadvantage to the central Pivot Area by closing an artificial periphery around them.

Some practices were more ambiguous. George R. Parkin's *The British Empire Map of the World* (1893) repeated the Australian longitudes twice on the map. Was the cartographer intent on inflating British pride in the size of its empire, or only kindly duplicating an area whose continuity was disrupted by the edge of the map? Many countries center their world maps on themselves. Japanese map publishers have always used a precious spot color, red, solely for the homeland. Does this practice assert primacy or ease map orientation? While Monmonier doubted such (rare) propaganda succeeds, his skepticism bucked the postmodern trend (Monmonier 2004, 140–41).

Cognitive studies in the 1960s revealed that people compare area measures poorly, especially when the shapes differ (Ekman, Lindman, and William-Olsson 1963). These studies cast doubt on the importance of equal-area projections, undermining part of the Peters premise. No studies addressed whether the mapped size of a country correlates with perceived significance, but the fact that few people ever thought of Greenland as significant on the world stage should have suppressed enthusiasm for the premise. The work of Sarah E. Battersby (2009) and Battersby and Daniel R. Montello (2009), in an increasingly focused series of studies, failed to uncover any "Mercator effect," but instead only confirmed standard trends in psychophysical estimation. That is, people overestimate small areas and underestimate large areas.

After all the promotions of map projections to cure the worlds ills, all the tendentious maps, all the brouhaha over the Peters affair, we still know little about how projections influence society and are left without reasons to suppose they could (Monmonier 2004, 140–41, 173–83). The imprint of culture on projection choice is clear. The corollary is that to defy the aesthetics of the age means failure: such a projection is ugly. Conversely, to embrace the aesthetics of the age means impotence: such a projection is an artifact of the times, not a creator of it. Those who chose Peters's map chose it for the cultural message assigned to it. It was that message, not any innate trait of the projection, which seduced them. Those who rejected the Peters projection did so because they found its promotion offensive and the map devoid of redeeming technical merit. But both groups together formed a tiny minority. Meanwhile society at large sipped on, oblivious to the faint roiling in the teacup.

DANIEL "DAAN" STREBE

SEE ALSO: Eurocentric Bias; Mercator Projection; Persuasive Cartography; Peters Projection; Robinson Projection; Thematic Mapping; Wall Map

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Regional Map Projections. When a small country is portrayed on a single map sheet, it matters little which map projection is used. As long as the projection is well centered on the region portrayed, distortion will be negligible. But for small-scale maps of large countries, or for maps of entire continents or oceans, distortion can be substantial, especially if an inappropriate map projection is chosen.

In twentieth-century atlases the most common projection for continental maps was Johann Heinrich Lambert's azimuthal equal-area projection, which gradually replaced the Bonne projection for maps of Asia, North America, and Australia after Justus Perthes introduced the oblique version in the third edition of *Berghaus' Physikalischer Atlas* in 1892. In the second half of the twentieth century, equatorial or oblique versions of Lambert's projection also became increasingly common for maps of Africa and South America, which before had been based mostly on the sinusoidal projection. In 2000, the Bonne projection was still widely used for maps of Europe, as was the equidistant conic projection.

In addition, the equatorial aspect of Lambert's azimuthal equal-area projection was frequently employed for maps of the Atlantic Ocean or the Pacific Ocean, together with the sinusoidal and other pseudocylindrical projections. In the first half of the century the Mercator projection was still common for maps of the oceans, but after 1950 it was progressively replaced by other projections. By the end of the century the Mercator projection was seldom used for small-scale atlas maps, although occasionally the Mercator and other cylindrical projections, such as the Miller cylindrical, framed maps of Indonesia, Southeast Asia, the Pacific basin, and other large regions centered near the equator.

Maps of large mid-latitude countries were usually cast on an equidistant, equal-area, or conformal conic projection. Occasionally (and primarily in American atlases) the polyconic projection was used. Polar areas were mostly framed by an azimuthal equidistant or azimuthal equal-area projection. Use of the polar stereographic for small-scale representations of the Arctic and the Antarctic regions was less common. In his classic history of map projections, John Parr Snyder (1993) provided a list of regional map projections used in well-known, but predominantly English and American, twentieth-century atlases (table 43). Lev M. Bugayevskiy and Snyder (1995) presented an overview of map projections used for maps of large regions and published in the former Soviet Union, the United States, and other countries.

While most commercial mapmakers in the twentieth century followed conventional practices in choosing projections for their atlases and wall maps, academic researchers made significant progress on the development of low-error map projections, which made it possible to design maps for any part of the earth's surface with substantially less distortion. In the first half of the century, Russian cartographers like Nikolai Yakovlevich Tsinger, Vasily Vasil'evich Vitkovskiy, Feodosiy Nicolayevich Krasovskiy, and Vladimir Vladimirovich Kavrayskiy developed methods for optimizing the position of the standard parallels on equidistant, equal-area, and conformal conic projections, thereby minimizing the variation of scale within the area to be mapped (Snyder 1993, 175–78). In the early 1950s, G. Bomford and Georgiy Aleksandrovich Ginzburg independently proposed new projections, specifically developed for ocean maps, with oval instead of circular distortion patterns, to better match the elongated shape of the oceans and thus reduce overall distortion within the map.

In 1953 O. M. Miller took a mathematically more complicated approach. Using a transformation in com-

TABLE 43: Map projections in twentieth-century world atlases, major regions. From Snyder 1993, 180–81 (table 4.1).

	Region																	
Atlas	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Rand McNally (1916)	ME	—	—	—	PO	BO	BO	SC	BO	SI	SC	SC	SC	SC	—	—	—	ME
Zetterstrand and Rosén (1926)	SP	—	—	LA	TC	OL	—	AL	TC	TC	—	AL	—	—	RS	RS	RS	BE
Rand McNally (1932)	ME	EL	—	LA	SI	OL	BO	SC	BO	SI	SC	SC	SC	SC	—	—	—	ME
Bol'shoy sovetskiy (1937)	MK	EL	—	AE	—	—	—	—	—	—	—	—	SC	—	MO	EC	EC	—
Cram (1941)	ME	GL	—	AE	SI	BO	BO	BO	BO	SI	SC	AL	SC	SC	ME	—	ME	ME
J. Bartholomew (1942)	MI	EL	—	AA	SI	BO	BO	BO	OL	OL	?	AL	SC	BO	ME	—	PS	—
Lewis and Campbell (1951)	OH	EL	—	AE	EE	OL	LC	OE	OE	TM	OE	LC	LC	LC	MA	MA	MA	OE
J. Bartholomew (1958, etc.)	BA	—	—	AE	—	OL	—	BO	OL	OL	CT	CT	SC	—	EL	EL	—	BO
Hammond (1966)	AM	—	—	AE	OL	OL	BO	OL	OL	OL	SC	PO	SC	SC	—	—	EL	—
Union of Soviet (1954, 1967 ed.)	MP	EL	AE	AE	EL	OL	OL	LC	OL	OL	LC	SC	PC	LC	OT	UP	UP	—
Rand McNally (1971)	AC	—	—	LA	SI	OL	OL	SC	OL	SI	LP	LP	OL	PO	MC	—	MS	—
National Geographic (1990)	RO	—	—	AE	CT	TE	CT	CT	CT	CT	CT	AL	TP	AL	ME	ME	ME	—
J. C. Bartholomew (1982)	MJ	—	—	LA	EL	OL	BO	BO	OL	OL	SC	SC	SC	—	EL	EL	EL	—
Rand McNally (1983)	RO	—	—	LA	OS	LC	LC	OS	—	OC	LC	AL	LC	LC	PS	PS	PS	—
Times Books (1985)	TI	—	—	AS	OS	OL	OL	BO	CT	OL	CT	CT	SC	SC	EL	OL	EL	BO
Rand McNally (1986)	GH	—	—	LA	OL	OL	OL	SC	OL	OL	SC	PO	SC	PO	PS	PS	GP	—

Region number
1 world
2 Eastern and Western Hemispheres
3 Northern and Southern Hemispheres
4 polar areas
5 Africa
6 Asia
7 Australia
8 Europe
9 North America
10 South America
11 Canada
12 United States
13 USSR (European or all)
14 China
15 Atlantic Ocean
16 Indian Ocean
17 Pacific Ocean
18 Oceania

Projection symbol (sometimes indicating several projections as noted):
AA northern—AE; southern—LA
AC AE, Miller cylindrical, GH
AE polar azimuthal equidistant
AL Albers equal-area conic
AM AE, ME
AS northern—AE; southern—polar stereographic
BA "Regional," Lotus, Nordic, Tripel, ME
BE Behrmann
BO Bonne
CT Chamberlin trimetric
EC Eckert VI
EE equatorial azimuthal equidistant
EL equatorial Lambert azimuthal equal-area
GH Goode homolosine
GL globular
GP GH, PS
LA polar Lambert azimuthal equal-area
LC Lambert conformal conic
LP LC, PO
MA modified azimuthal equidistant (Bomford)
MC modified polyconic
ME Mercator
MI Kite, Gall stereographic, SI, ME
MJ "Regional," Gall stereographic, Nordic, TI
MK Gall stereographic, EC
MO Mollweide
MP Ginzburg modified polyconic
MS modified secant conic
OC (bipolar) oblique conic conformal
OE oblique azimuthal equidistant
OH oblique Hammer
OL oblique Lambert azimuthal equal-area
OS oblated stereographic
OT oblique TsNIIGAiK with oval isocols
PC oblique perspective cylindrical
PO polyconic
PS pseudocylindrical (unspecified)
RO Robinson
RS Rosén modified Lambert azimuthal equal-area
SC simple (equidistant) conic
SI sinusoidal
SP interrupted and flat-polar sinusoidal
TC transverse cylindrical equal-area
TE two-point equidistant
TI The Times
TM transverse Mercator
TP transverse polyconic
UP Urmayev pseudocylindrical

plex algebra proposed in 1932 by Ludovic Driencourt and Jean Laborde, Miller transformed an oblique stereographic projection for Europe and Africa into a new graticule with oval instead of circular lines of constant scale, but without sacrificing the conformality of the original graticule (fig. 744). Miller's so-called oblated stereographic projection was occasionally used in American atlases for continental maps. In the 1960s, map projection scientists inspired by Miller's work and supported by high-speed digital computing began to develop numerical approaches to transform standard map projections into new graticules by minimizing overall dis-

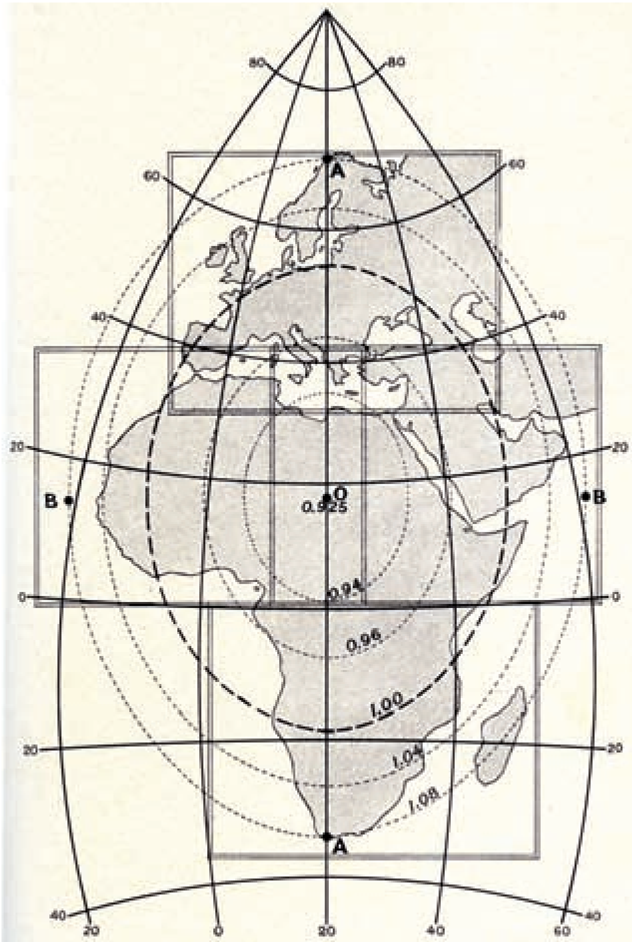

FIG. 744. O. M. MILLER'S OBLATED STEREOGRAPHIC PROJECTION FOR EUROPE AND AFRICA. Miller's map was a major source of inspiration for developments in numerical map projection research in the following decades.
Size of the original: 17.8 × 11.8 cm. From Miller 1953, 407 (fig. 1). Permission courtesy of the American Geographical Society, New York.

tortion for regions with irregularly shaped boundaries and varying in size from individual countries to entire continents (Canters 2002). Snyder and Waldo R. Tobler were the most notable pioneers of this approach. The Hammond optimal conformal projection, developed by physicist Mitchell Jay Feigenbaum and introduced in 1993 in the *Hammond Atlas of the World*, is one of the few practical applications of these new developments in twentieth-century commercial mapmaking.

FRANK CANTERS

SEE ALSO: Geographical Mapping; Miller, O(sborn) M(aitland); Thematic Mapping

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Projections Defined for the Ellipsoid. Though the earth's spherical shape had been known in Europe for two millennia, a dispute over details erupted in 1720. Isaac Newton had earlier calculated that the earth's spin must deform it into an oblate ellipsoid, a sphere squashed slightly at the poles. Yet surveys within France suggested that the planet was squashed at the equator instead. Subsequent measurements vindicated Newton but also exposed many regional variations in the earth's shape.

Spheres project more easily than ellipsoids, and ellipsoids more easily than the earth's true shape. While spherical models lack accuracy, an ellipsoid can always be found with a patch on it that closely matches the earth's curvature in the survey region. Hence ellipsoids came to dominate large-scale mapping in the nineteenth century, with each survey adopting its own ellipsoid best matched to the region under survey.

Ellipsoidal projections evolved in step with precision surveying. César-François Cassini de Thury devised his transverse cylindrical equidistant projection in 1745 for use in France's detailed survey, the first of any nation. Although superseded in France by the Bonne projection in 1803, Cassini's projection persisted elsewhere into the twentieth century. The American polyconic projection, developed around 1820 by Ferdinand Rudolph Hassler for U.S. coastal surveys, saw heavy use there for over a century.

Johann Heinrich Lambert's seminal work (Lambert 1772) turned map projections into a science. In it he described his conformal conic projection, which went largely ignored until the twentieth century (Snyder 1987, 92–94, 104, 124–26, 138–39). Ironically, of all early ellipsoidal projections, it is the only one that remained in wide use in the early twenty-first century. Lambert anticipated the ellipsoidal transverse Mercator as well (fig. 745), but its development was left to Carl Friedrich Gauss in about 1822. Gauss's work was distilled for practical application by Louis Krüger in his 1912 and 1919 monographs (Lee 1976, 97–101), after which its use increased rapidly.

By that time the difficulty of tracking directions on the old, nonconformal projections had become a problem. Modern artillery could fire projectiles beyond sight, requiring maps that preserve angles. Thus national surveys rapidly converted to conformal projections in the twentieth century, often choosing the Gauss-Krüger transverse Mercator or a variant; it works best for regions along a meridian. Other suitable conformal projections include

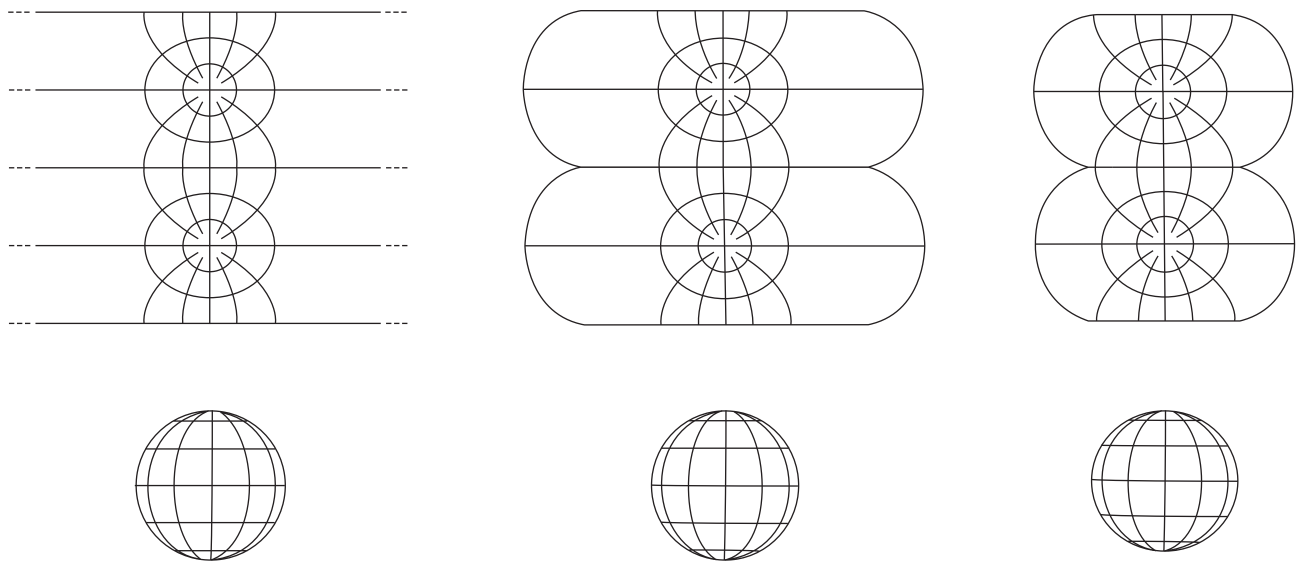

FIG. 745. THREE EXAMPLES OF AN ELLIPSOIDAL TRANSVERSE MERCATOR PROJECTION. Developed from a sphere (left), an earth-like ellipsoid (center), and a more oblate Jupiter-like ellipsoid (right). The spherical case is infinite in extent, but the ellipsoidal case is finite—a little-known fact.

Lambert's conic, for regions elongated along parallels; the stereographic, for roughly circular regions; and the normal Mercator, for regions along the equator.

Many ellipsoidal projections were developed in the twentieth century to improve accuracy over specific regions, but few were widely adopted. Increased computational power fostered the study and construction of ever more elaborate systems. Rather than constructing a projection ab initio, inventors started from existing ones and applied mathematical techniques to deform them favorably for the region of interest. A basic technique described by Jean Laborde in 1928 attracted increasingly sophisticated adaptations in the works of O. M. Miller, L. P. Lee, W. I. Reilly, and John Parr Snyder. One of the most intricate projections ever devised is Snyder's Space Oblique Mercator, designed for satellite tracking (Hessler 2004).

The twentieth century gave mapmakers tools to create optimal conformal maps of ellipsoidal bodies. The next century will consolidate these advances and broaden their scope to more complex shapes that model minor celestial bodies.

DANIEL "DAAN" STREBE

SEE ALSO: Conformality; Coordinate Systems; Figure of the Earth; Topographic Mapping: Overview

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Projections Used for Topographic Maps. The changing relationship between map projections and topographic maps in the twentieth century is essentially a straightforward story. Early in the century a wide variety of projections were used for topographic mapping, but by 2000 the variety had shrunk considerably. This progressive decrease had played out against a background of profound technological developments; various social, political, and military considerations; and new intellectual frameworks.

Topographic mapping is a familiar cartographic presence that evades tight definition. It has a long-standing identity as the characteristic sheet or basic map—a product of statecraft distinguished by a common visual appearance and fidelity to landscape geometry and traditionally conceived as portraying a balance of physical and human elements. Scales generally range between 1:10,000 and 1:200,000. Electronic topographic maps consisting of multiple thematic layers assumed new significance in the age of the geographic information system (GIS). In whatever form, the topographic map is multipurpose and cartographically significant.

A prime factor in twentieth-century topographic mapping was the evolving preference for conformal presentations. In 1901 this projection property was not common, but by 2000 it was a preferred, almost universal, feature of topographic maps. Conformality controls angular deformation and, over small areas, provides a generally reliable representation of geographical shapes. The shape factor tended to be somewhat exaggerated at the opening of the century, so much so that *orthomorphism*, a description now almost obsolete, was once the favored term. Despite occasional overstatement, the lack of angular distortion around points is useful for indicating relative direction and estimating distances and angles.

Early in the century, mapmakers generally appreciated conformality, at least in a subdued way, and it had few detractors, most notably Arthur R. Hinks in the first edition of his map projection text (1912, 4–6 and passim). A deeper appreciation of its usefulness evolved slowly, in response to a variety of sociopolitical and technical developments, most notably the institutional inertia of government mapping offices in which mapmaking was largely a manual process. Plotting a projection graticule, even when partially mechanized, was a painstaking drafting task even in the mid 1960s, and converting a multisheet topographic map series from one projection to another was a formidable logistic hurdle. The digital computer brought dramatic improvements to such tasks.

Trench warfare during World War I accelerated the adoption of conformal projections. Because precise target location was essential, conformality caught the attention of artillery surveyors. Tactical requirements at short ranges merged into medium-range strategic considerations, and conformality advanced from a preferred option to an absolute necessity.

As the century progressed, military considerations merged with national, civilian, and international mapping norms, and conformality became a standard requirement for topographic mapping. In contrast to the diverse array of nonconformal projections in use early in the century—variant forms, such as the Cassini, polyconic, polyhedric projections, were once common, as were equal-area projections, such as the Bonne—by the late 1980s, according to D. H. Maling (1992, 311), over 90 percent of the world's topographic mapping was conformal.

Issues driving this conversion included computation convenience, geodetic datums, reference grid formats, permissible scale errors, and the size and shape considerations of local geography. Increasingly, attention swung to versions of the transverse Mercator projection, a conformal projection centered on a meridian, and, in particular, a favoring of the Gauss-Krüger model, which applied a transverse Mercator projection to longitudinal zones three degrees wide. In 1923 Germany was the first to adopt Gauss-Krüger as a national system (Maling 1992, 353). The Soviet Union followed in 1928 for maps larger than 1:200,000 and laid the basis of the Soviet Unified Reference System. Other nations adopted the transverse Mercator pattern, most notably Great Britain, which abandoned its Cassini projection in the 1930s. The U.S. Geological Survey, which had used the polyconic projection for its topographic maps since the 1880s, adopted two conformal projections in the 1950s: the transverse Mercator for multicounty zones with a north-south elongation and the Lambert conformal conic for zones with an east-west elongation.

Implementation was slow, but the pace increased notably because of World War II and its aftermath, when the preferred geometric framework for artillery, missiles, and aerial navigation met the needs of Cold War alliances and international globalization. In the West, the political strength of the United States and the creation of the North Atlantic Treaty Organization (NATO) and other military alliances prompted a need for compatible topographic maps and coordinate systems (as well as standardized formats and symbols). Reflecting this priority, the U.S. Army Map Service in 1947 utilized the Gauss-Krüger platform to produce the Universal Transverse Mercator (UTM) system, which divides the globe into sixty north-south zones, each six degrees wide. This extensive system, an alliance of projection and reference grid, produced much discussion and some dissension, particularly over excessive fragmentation at high latitudes. After the UTM framework was modified to cover polar areas with the polar stereographic projection, another conformal framework, it became the dominant projection for worldwide topographic coverage.

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SEE ALSO: Conformality; Coordinate Systems; Topographic Map; Topographic Mapping: Overview

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Projections Used for Military Grids. Underlying the complexity of any military map is a mathematical structure. This is composed of a geoid, ellipsoid, datum, map projection, and grid organized as part of the design specifications. The geoid is the irregular real form of the earth; the ellipsoid the smooth fit to this reality; the datum the reference structure imposed on the ellipsoid; the projection the transference of that structure to a plane surface; and the grid a utilitarian device to supplement projection characteristics.

Grids are the result of trying to organize topography into an understandable and useful form. The resulting networks are closely allied with Cartesian coordinate systems, and the result is a combined presentation of visual and mathematical utility. They are used by military and other users for general reference and cartometric operations such as labeling, location, and measurements of points, lines, and areas, and, to a lesser extent, volumetric investigations. They are vital in military geographic assessment for various levels and kinds of planning. They are utilized in static or dynamic situations and applied in settings past, present, and future. They can be employed in multiple forms, as in secondary or triple grids and denoted graphically by lines or marginal ticks, which in a computer age can be optional. They are rarely used at scales smaller than 1:1,000,000.

The typical orthogonal grid is a venerable organizational tool in human intellectual, computational, and spatial enquiries. It makes an early appearance in the history of surveying and cartography dating back over 2,000 years. In the twentieth century it forged a more systematic alliance with projections; so close an alliance that a number of commentators have had to firmly point out that they are not identical (Thompson 1973, 756).

These elements—geoid, ellipsoid, datum, map projection, and grid—are subject to a multitude of possible interrelationships and, with the steady progress in the precision of earth measurements, underwent constant revision during the twentieth century. All these quantitative formulations, along with the resulting cartography, were fundamentally affected by both technological advances and the varied, often dramatic, social and geopolitical contexts of the times. Many changes took place but the basic conceptual issues remained essentially the same.

Geodesy defines the earth's shape and size while the projection is its visual arrangement for map purposes. The latter is exemplified by the graticule: the historical and universal reference pattern of lines of latitude and longitude annotated on a sexagesimal basis. This network, although a locational touchstone, is not always a premium in notation, computation, or visual comprehension for practical mapping operations and, thus, a grid is normally superimposed upon it. A known relationship between the grid and the graticule means that corresponding geographical values can be exchanged and positions determined. The need for this transfer to be as precise as possible is of paramount importance in practical mapping.

Grids are designed by different agencies for different reasons and are many in number and variety. Coordinates are expressed in linear units that over the century moved from a mixture of imperial and metric systems to being almost entirely metric. Their overall geometric form, despite some rare variations, is commonly rectilinear and rectangular. This enables spatial conceptions and descriptions to be couched in terms of squares, quadrants, quadrangles, cells, zones, and the like. The familiar 100,000 meter squares arrangement is a typical example. In the predigital part of the twentieth century and still vestigial at its close, this geometric simplicity greatly aided map construction calculations and graphic plotting, often via the devising of a master grid.

The various military agencies of the world, as an assemblage of significant and powerful groups in human affairs, are at the forefront of grid use—hence, military grids. The overlap, however, between civilian and military mapping agencies in the twentieth century was considerable, ranging from direct military control to actively shared technology and personnel, to common mapping interests of many kinds. For example, a World War II American document notes the supplying of 300 projections and military grids for federal agencies engaged in "war mapping" (U.S. Coast and Geodetic Survey 1942, 6). This overlap was even more marked by the year 2000.

Military activities concern territorial matters, exemplified by terms such as "war zone," "combat area," "theater of operations," and the like. They are thus fundamentally linked to geography and maps. This longstanding relationship involves the understanding, summarizing, and using of such knowledge for various kinds of combat, whether actual or anticipated, covering a profusion of logistical, intelligence, targeting, and similar tasks. Such considerations can be at various scales and can take place in a variety of land, water, and air settings and environments, as reflected by the division of military forces into army, navy, and air units. Mapping concerns, therefore, cover geographic and topographic maps as well as marine and air charts. These, while being responsive to specific user needs, increasingly rely on grid reference systems that are mutually understandable.

The conception, devising, and implementation of military grids had a relatively low-level emphasis at the beginning of the century as compared to the attention given to map projections. The difference seems to have been one of scale as much as application, as reflected in the notion of tactical and strategic situations. Military textbooks of the time linked projections to topographic and chorographic maps. Large-scale maps, however, were the concern of surveying and field mapping. Here, the practical use of rectangular coordinates was emphasized and promoted as easier than using geographical coordinates. The resulting networks, the grids, were described as “field rectilinear projection[s]” (Close 1905, 95–96). Grid and projection relationships were explicit but often not emphasized.

The advent of World War I changed things. Even in the lead-up period to the conflict, military texts were reflecting new settings as in instructions outlining “surveys under active service conditions” (Close 1913, 150–62). They also, albeit mildly, anticipated the closely engaged conditions of trench warfare and the need for artillery accuracy with the advocacy of suitable projections. The comparative choice between either distance or direction accuracy was not generally appreciated and had to be learned (Skop 1951). Also, to some extent, it was ad hoc: preferences were conditioned by what maps were available and what projections they were based on. Thus, while the significance of having a conformal projection, with its superior angular property for directional use, became apparent, it was often trumped by logistical matters.

Consequently, nonconformal maps were often used. An official opinion, for example, favored the polyconic for distance superiority, judging its errors as “entirely insignificant,” but also noting that “this is not a counsel of perfection, but of convenience” (Close 1913, 91). The Cassini, with its orthogonal graticule appearance and its relative ease of computation, was used by both the British and the Germans, despite its limitation in area coverage. The use of the nonconformal Bonne equal area projection was prevalent enough to be termed the *projection du dépôt de la guerre* (Close 1905, 102).

The need for precision in artillery targeting, however, soon became paramount (Monmonier 2004, 103–8). Conformal maps, with their directional utility, were preferred for military use, and by the end of the century they were almost universally adopted. Civilian agencies also preferred them. The military grid could be said to have acted as a catalyst in promoting common cartographic parameters across disciplinary, organizational, and international boundaries.

The decades following World War I saw an ever-increasing intensification in the search for ever-greater precision. Advances in geodesy were the agents of change. Improved measurements of the geoid produced better-fitting ellipsoids that, in turn, produced a succession of datums over the century. Among the most noteworthy was the military-linked World Geodetic System, which appeared in four different incarnations between 1960 and 1984.

These adjustments changed the geographic coordinates of locations portrayed on projections, and thus a corresponding change had to be made in grid arrangements. This constant change in the cartographic menu meant improved possibilities for worldwide cartographic frameworks, along with problems, logistic and otherwise, of transferring from one system to another, albeit somewhat diminished in an electronic mapping universe.

In addition, the twentieth century saw mapping become “global” in a rather different, more intense, way than before. A more pervasive international atmosphere, stemming from many roots, dovetailed with the flowering of mapping linked to aerial and orbital observations and measurements such as satellite imagery and Global Positioning Systems (GPS). Commonality rather than differences was emphasized as the world became tightly linked intellectually, referentially, and cartographically at different scales. Universal mapping systems became desirable and map standards had to be established for geodesy, projections, and grids. This universal notion, however, is always somewhat of a moving target responding to advances in technology and specific local needs.

For the military, the general consensus on the primacy of conformal mapping was accompanied by similar progress in the evolution of grids from national to international usage and a near-general agreement on system fundamentals by the end of the century: all this was set in the context of geopolitics. These trends led to a commonly repeated observation in the latter decades of the century that non–Universal Transverse Mercator/Universal Polar Stereographic (UTM/UPS) grids were being phased out.

The linear logic in devising a mapping system is computing an appropriate datum, choosing a projection, and then matching a grid to these defining elements. In working practice, the process is a little less than linear, but the general tasks are clear. Devising a reference system involves considering how much territory is to be covered, the choice of a zonal or similar tiling scheme, incorporation of any zone overlap, choice of units, selection of an origin and scale factor, and consideration of any requirements due to the orientation and shape of local geography. The prime example of synthesis was the devising of UTM and UPS grid systems based on the constantly changing requirements of conformal mapping; post–World War II combat, military, and political alliances; global awareness; and digital cartography.

The UTM/UPS system was an outcome of a progression in cartographic thinking engendered by practical experience and the prodigious mapping energy of World War II. It was preceded by the World Polyconic Grid (WPG), which remained in use until the late 1940s. The WPG was devised for coastal use and ill-advisedly employed for topographic purposes. A version was also the basis for the International Map of the World, a project spawned from a concern with small-scale global mapping of both land and sea as expressed in several late nineteenth- and twentieth-century geographical conferences. The recent MGRS (Military Grid Reference System), utilized by the North Atlantic Treaty Organization (NATO), refines the UTM and UPS labeling convention to cover the whole planet, and the interfacing of GPS and satellite imagery systems makes for a still unfinished agenda.

HENRY J. STEWARD

SEE ALSO: Conformality; Coordinate Systems; Warfare and Cartography

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Projections Used for Aeronautical Charts. No maps were required for the first flight by a heavier-than-air flying machine in 1903. Military planners quickly recognized the tactical merit of airborne reconnaissance and bombing, and the strategic advantage of controlling airspace for military purposes received greater attention than its use for commerce or civilian transport. Even so, improved aircraft made civilians aware of the potential benefits of flying, and aircraft design began to reflect the diverging needs of military and civil uses. By 1920 civil airlines were carrying mail along with a few risk-taking passengers. Emergence of the civil aviation industry thereafter created a demand for longer nonstop flights, for better navigation tools, and for less dependency on weather conditions.

The development of aeronautical maps in the twentieth century was analogous to the development of sailing charts in the sixteenth and seventeenth centuries. In both eras, the common denominator was the visual identification of specific landmarks and a clear definition of approaches to ports in all three dimensions—mariners were wary of undersea hazards while aviators worried about vertical obstructions. Initially, handwritten notes were compiled and exchanged between airmen. On cross-country flights aviators kept track of their position with readily available standard topographic maps, often cut into strips for use in open cockpits. Use of these maps was constrained by cloud cover and forward visibility and the requirement to relate map scale to the aircraft's speed and altitude. Depicting the third dimension became essential for terrain avoidance and landing, and special topographical maps evolved to show contour lines and other features using color coding compatible with cockpit lighting.

In the sixteenth century, maritime charts were developed to promote sailing beyond the visible shoreline. A similar need arose in aviation when instrument flying became possible in the late 1920s and the nonstop range of aircraft increased. Prior to World War II long-range flying consisted of multiple short trips. Topographical maps enhanced with flight tracks and compass roses were adequate for flying these individual segments. Approach and landing notes consisted of bundled standardized instructions not unlike the rutters used by mariners four centuries earlier. For this type of flying, topographical maps were used without consideration of the map projections on which they were cast. And large-scale approach and landing charts were essentially plane charts—cast on an equirectangular projection also known as the *plate carrée*—because their limited geographical coverage obviated the need for a more sophisticated geometric transformation. Specialized map projections were hardly necessary because many of these maps were not drawn to scale.

During World War II, as aircraft designers addressed the need to fly throughout a theater of operations as well as between theaters, the greatly increased length of nonstop flights created a need for aeronautical charts with a more suitable map projection. As in the seventeenth century, when the Mercator projection replaced earlier frameworks deemed less suitable for maritime navigation, aeronautical charts were given a Mercator framework for much the same reason: a straight line was a rhumb line, representing a route of constant bearing, which could be read from the chart with a protractor.

Although useful in the tropics and middle latitudes, the Mercator projection was inappropriate for higher latitudes because of increasing meridian convergence. When polar areas well north of seventy degrees became commercially important in the late 1950s, the polar stereographic projection was adopted there for flying charts along with techniques for coping with idiosyncrasies of the magnetic compass. For navigation over areas not covered by radio facilities, a professional navigator was required.

With the advent of new techniques based on the Doppler effect and inertial navigation, specially trained navigators were no longer necessary for long-range flights. This transition was complete by the early 1970s, when Boeing 747 and McDonnell Douglas DC-10 series aircraft were put into service. At the same time, Mercator maps were replaced by Lambert's conic projection with two standard parallels in order to extend the effective area of acceptable scale variation. Because flight patterns were different on opposite sides of the equator, standard parallels were typically set at 35°N and 60°N for the Northern Hemisphere and 10°S and 48°S for the Southern Hemisphere.

Radio facility charts, already cast on Lambert's conformal conic projection, became standardized for aeronautical charts during the same period, and individual airlines discontinued in-house map production, formerly considered a strategic necessity. As the number of radio beacons serving commercial long-distance traffic increased, the complexity of these charts increased as well. Global Positioning System (GPS) navigation did not emerge until late in the twentieth century, when the military agreed to guarantee a minimum availability in times of war, while dropping their demands for reimbursement of development cost. Electronic map displays became common on flight decks after 1980, as a visual component in a comprehensive navigation system that integrated enroute navigation, operational flight-management, automated aircraft attitude control, and navigation in the terminal area at the destination. In this milieu, graphic charts were no longer crucial in selecting and following the route, and the map projection assumed a purely passive descriptive role.

By contrast the more detailed large-scale approach and landing charts evolved from handwritten rutters, after 1915, through an era of in-house charts edited and maintained by individual airlines to standardized map series maintained by each country's civil aviation authority according to a legally prescribed format for standard and optional information. These charts offer a plan view of the relevant area as well as a vertical approach and go-around profile for each runway and approach system available. At the twentieth century's end these terminal-area approach and landing charts were still cast on equirectangular (plane chart) projections, sometimes without a constant horizontal and/or vertical scale.

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SEE ALSO: Aeronautical Chart; International Civil Aviation Organization; Navigation; World Aeronautical Chart

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Projections Used for Marine Charts. Defined by the needs of navigation, marine charts occupy a distinctive niche in the cartographic spectrum. The very word *chart*, rather than *map*, connotes this hallmark. Marine craft of all types share a basic need for safe, efficient, and economical passage, and accurate location is a paramount concern for the navigator. Throughout the twentieth century, the navigator's toolbox, including the projections used to frame marine charts, continued to evolve.

Because the primary requirement of a marine chart is to assist navigation, the relative significance of its map projection will depend upon the vessel, the hydrographic context, the scale of the chart, and the particulars of the voyage. While all of these factors are perennial, they have assumed a more organized presence with the increased frequency, length, and complexity of nautical voyages, the prevalence of national and international governance, and the effect of technological advances on the nature and use of sea charts.

Three requirements have commonly influenced the selection of projections for navigation charts: conformality, that is, the preservation of angles; relative stability in scale throughout the chart, implying a near-optimal representation of linear distances; and the representation of either rhumb lines or great circles as straight lines. Some less useful considerations are the preservation of shape over small areas and the use of a rectilinear grid (Stewart and Pierce 1944, 20; Maling 1992, 309; UKHO 1965, 44).

From the beginning of the century until perhaps its final decade formal instructions to mariners indicate that the calculation, planning, and plotting of a marine journey was a labor-intensive manual procedure. The twentieth century's technological revolution progressed through several stages that affected data collection, computation, compilation, presentation, and usage, with the analog environment giving way to a more powerful and flexible digital milieu when the electronic chart made its debut, not simply as an addition to the paper form, but as a significantly different way of navigating.

This radical new electronic context for map projections contrasts markedly with the relative stability, albeit with some refinements, of their use in earlier marine charting. Perhaps a dozen different projections have had some notable use in the twentieth century, but no more than half of them attained any real significance.

In the early years of the century, navigation manuals identified the Mercator, gnomonic, polyconic, stereographic, and Lambert conformal conic as the principal projections for marine navigation. The primacy of the Mercator was highlighted by detailed instructions on how to construct and use this type of chart. Procedures for manual compilation emphasized that chart scale may be adapted to fit the "allotment of paper" (Bowditch 1914, 21).

The Mercator solution was dominant for good reason. It is a conformal cylindrical projection with a fundamental advantage for navigation maps because rhumb lines—lines representing constant, true compass direction—always plot as straight lines. Because a Mercator chart shows true angles at points, a protractor can be used to read a rhumb line's bearing.

A common complement to the Mercator throughout the twentieth century was the gnomonic projection, which is not conformal but possesses a useful graphic property in that great circles, which describe shortest-distance routes between discrete points on the earth, plot as straight lines. This trait is valuable because the Mercator chart's rhumb lines, which typically describe spiral paths on a globe, depart markedly from direct, comparatively efficient great-circle routes, particularly over long distances. An astute navigator would use a gnomonic chart to divide the intended route into a few segments and transfer their junctions, or turning points, onto a Mercator chart so that a sequence of easily followed, straight-line, constant-bearing courses could approximate the comparatively direct great-circle route.

The polyconic projection has a varied history that includes its misapplication in a marine, rather than topographic, setting as a result of its adoption in the United States in the first half of the nineteenth century for mapping the shoreline and nearby coastal features. Despite its limited usefulness in marine charting, it remained popular, which speaks to the ability of experienced and asture navigators to arrive safely at their destination despite an unsuitable projection (Stewart and Pierce 1944, 25). At century's end, the polyconic projection was rarely used for marine charts, although it should be noted that the gnomonic label on some large-scale charts is a misnomer for a version of the polyconic (UKHO 1965, 78).

The stereographic projection, which is conformal, was used on marine charts before the twentieth century because it was easy to construct, useful for star charts, and good for sea surveying. Its principal value, however, was for mapping polar regions with a grid of concentric parallels and converging straight-line meridians. This virtue and its conformality account for its more recent role, since the late 1940s, as the mathematical framework for the Universal Polar Stereographic (UPS) grid system, a complement to the military-based Universal Transverse Mercator (UTM) coordinate system for areas north of 84°N or south of 80°S.

The Lambert conformal conic projection was widely used for marine charting until the appearance of the UTM grid after World War II, when it was superseded by the transverse Mercator projection. It offered almost-rectilinear great circles and at one time was commonly used for plotting radio bearings as straight lines. Even so, it was not suitable for high latitudes.

By the end of the century, vast improvements in computing, satellite imagery, Global Positioning Systems (GPS), and the integration of rich digital databases with electronic displays allowed the instantaneous composition of customized marine charts. Although map projections remained important as a visual construct, electronic computing and GPS had diminished the navigator's reliance on traditional approaches to fixing position and charting a course. Nonetheless, nautical manuals continued, at the close of the century, to stress the need to integrate navigation with various aspects of good seamanship, including the use of paper charts as backups for electronic aids and the need to understand the fundamentals of map projection.

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SEE ALSO: Coastal Mapping; Marine Chart; Mercator Projection; Navigation

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Projections Used for Statistical Maps. A number of map projections were used during the twentieth century for small-scale thematic maps printed singly or as part of world atlases. Many of these maps displayed statistical quantities such as population density by nation or state. By the end of the century the cartographic conven-

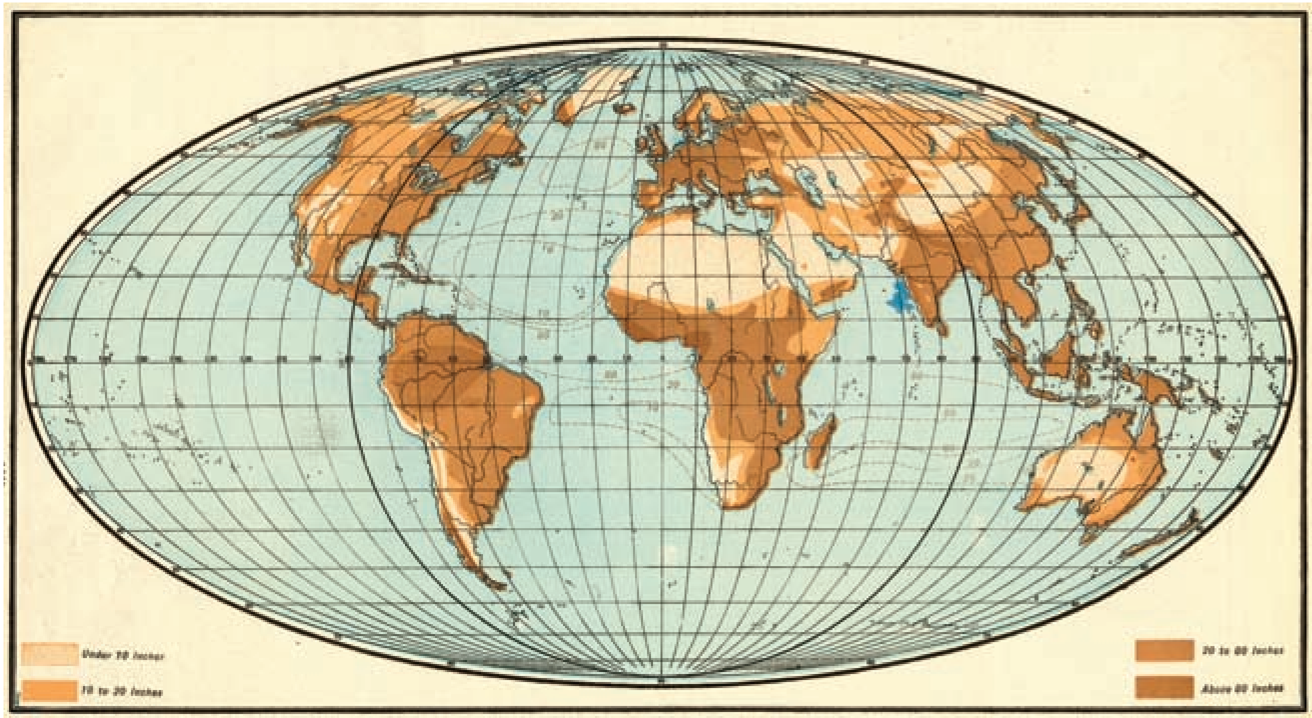

FIG. 746. *RAINFALL MAP OF THE WORLD* ON THE MOLLWEIDE ELLIPTICAL EQUAL-AREA PROJECTION. Size of the original: 14.9 × 27.3 cm. From James A. Bowen, *Grammar School Geography*, rev. Charles Redway Dryer (Chicago: Rand, McNally, 1901), 44 (fig. 79).

tion that statistical maps should be made on equal-area projections was widely, although not entirely, followed.

Throughout the century, statistical mapmakers used map projections from earlier times since their mathematics and distortion properties were well known and easy to understand. For example, in 1994 the United Nations Food and Agriculture Organization (FAO) used the non-equal-area plate carrée projection from around A.D. 100 for world maps of population and biomass density. The 1805 Mollweide elliptical equal-area projection was used more appropriately for a wide variety of world thematic maps in numerous publications (fig. 746). In the beginning decades of the century, continental thematic maps of South America and Africa were drawn on the sinusoidal equal-area projection first introduced in the sixteenth century. Atlas maps of continents were also drawn on the Bonne conic equal-area projection, and polar thematic maps were often on the polar aspect Lambert azimuthal equal-area projection invented in 1772. By the end of the century, the 1805 Albers equal-area conic had become the recommended projection for statistical maps of mid-latitude areas, a prime example being its use for all thematic maps in *The National Atlas of the United States of America* (fig. 747) and for statistical maps produced by the U.S. Census Bureau (see fig. 142). A politically controversial map projection was

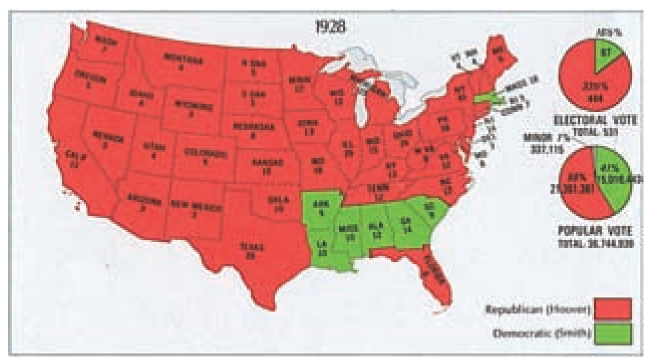

FIG. 747. 1928 U.S. ELECTION RESULTS. Size of the original: 5.3 × 9.8 cm. From U.S. Geological Survey, *The National Atlas of the United States of America*, ed. Arch C. Gerlach (Washington, D.C.: [Department of the Interior], 1970), 145.

the Gall-Peters, an equal-area cylindrical projection first invented by James Gall in 1855 and reintroduced by historian Arno Peters under his name at a press conference in 1974 (see fig. 679). Peters presented his projection as a politically correct world view superior to the Mercator cylindrical conformal projection often used for world wall maps. Statistical maps based on the projection were published by the World Council of Churches and continue to see use in some circles, although few major map publishers used the projection by the end of the century.

The twentieth century saw numerous new projections created for world and continental thematic maps appearing in a variety of atlases and other publications. In 1904 Alphons J. van der Grinten of Chicago presented his world in a circle or Van der Grinten I projection subsequently used by the U.S. Department of Agriculture, the U.S. Geological Survey, and the National Geographic Society (NGS) for world thematic maps. In 1906 Max Eckert of Germany presented his six pseudocylindrical map projections (see fig. 216). Of these, the Eckert IV was an equal-area, flat-polar map projection with elliptical meridians used for world thematic maps in numerous atlases, while the Eckert VI was an equal-area projection with sinusoidal meridians used for thematic maps in the *Bol'shoy sovetskiy atlas mira* (1937–40). In 1921 Oswald Winkel introduced his neither equal area nor conformal Winkel tripel projection, a modified azimuthal projection that is the arithmetic mean of the equirectangular and Aitoff map projections. The NGS used Winkel's projection for world thematic maps, and John Bartholomew & Son publishers started using the Winkel tripel in their atlases in 1958.

In 1916 geographer J. Paul Goode of the University of Chicago became interested in interrupted map projections and experimented with applying various interruptions to the Aitoff, sinusoidal, Bonne, and Mollweide. In 1923 Goode presented his most successful map projection called the homolosine, an interrupted fusion of the sinusoidal and Mollweide projections subsequently used in Goode's world atlas and numerous other thematic maps such as those appearing as inset maps on the NGS world political map. Geographer L. P. Denoyer of Chicago created the Denoyer semielliptical pseudocylindrical projection around 1920. The projection was neither equal area nor conformal but had equally spaced straight parallels. Denoyer-Geppert map publishers used it in thematic maps and atlases of the early and middle twentieth century. In 1926 British military captain J. E. E. Craster developed his Craster parabolic equal-area projection with parabolic-shaped meridians that was used for world thematic maps in textbooks. As the geographer for the U.S. Department of State from 1924 until his death in 1954, Samuel Whittemore Boggs was not happy with Goode's homolosine being widely used for thematic maps in world atlases. In 1929 Boggs, with the mathematical help of Oscar S. Adams, developed an alternative interrupted equal-area pseudocylindrical projection today called the Boggs Eumorphic.

Later, in 1942, at Boggs's request, mathematician O. M. Miller presented him with four cylindrical map projections as alternatives to other cylindricals in use: perspective compromise, modified Mercator A, modified Mercator B, and modified Gall. Boggs decided to use the modified Mercator B, and it became known as the Miller cylindrical, a projection then used for a variety of world maps in American atlases (Miller 1942; Snyder 1993, 179). In 1949 geographers F. Webster McBryde and Paul D. Thomas presented five equal-area pseudocylindrical map projections. One of these, now called the McBryde-Thomas flat-polar quartic, was widely used for thematic maps in midcentury geography textbooks.

In 1941 Karlheinz Wagner, another German cartographer, presented his Wagner VII, a modified azimuthal projection with a curved pole line. Also known as the Hammer-Wagner, this map projection was an equal-area variation of the Hammer (or the Hammer-Aitoff) projection. Its best-known use was for midcentury maps of climate statistics prepared by the U.S. Department of Commerce.

In 1946 Wellman Chamberlin, chief cartographer of the NGS, invented what is now called the Chamberlin trimetric projection for atlas maps of continents produced by the NGS, including small-scale statistical maps drawn around the periphery of the main physical or political map. This modified azimuthal equidistant projection is neither equal area nor conformal, but low-scale distortion exists throughout the mapped area. Arthur H. Robinson, in 1963, developed a flat-polar pseudocylindrical map projection for the NGS to replace the Van der Grinten I. The Robinson projection is neither equal area nor conformal, but rather is orthophanic, meaning that it is "right appearing." The NGS used the Robinson projection for world reference and thematic maps until 1998, when it was replaced by the Winkel tripel projection.

The later decades of the century saw a related development, the widespread use of statistical cartograms where geographic space was not distorted through map projection equations but rather the sizes of enumeration areas were varied according to the statistical value for each area. Both contiguous and noncontiguous cartograms were used by the media to show a variety of politically interesting statistics, from U.S. political election results by state to world petroleum production. Although not a statistical cartogram, a related invention was the "visibility base map" created by Mark Monmonier in 1982. This was a map of the United States where areas were adjusted to insure that the statistical quantities mapped were easily visible for all states. Areas of smaller states, such as Delaware and Rhode Island, were enlarged with compensating reductions in the size of larger states (Monmonier 1993, 178–80).

At the end of the century, polyhedral map projections were being developed to serve as the geometrical framework for statistical sampling of global-scale phenomena such as climate change and biodiversity loss. The icosahedral equal-area projection invented by John Parr Snyder in 1992 showed particular promise as each triangular face could be partitioned into equal-area triangular and hexagonal grid cells at different spatial resolutions.

There are a number of additional twentieth-century equal-area map projections not covered here. Many were just mathematical curiosities, while others were too complex to use as a basis for statistical maps. And, even in this day and age, there are those map projections whose construction methods have been lost to history.

A. JON KIMERLING, WITH INFORMATION FROM PAUL B. ANDERSON

SEE ALSO: Cartogram; Statistics and Cartography; Thematic Mapping; Tobler, Waldo R(udolph)

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Propaganda Map. See Persuasive Cartography

Property Mapping.

Property Mapping in Canada and the United States. Property mapping in Canada and the United States has changed considerably during the twentieth century, largely because of technological innovation, higher professional standards, and the introduction of police powers. All of these changes have contributed to increased cartographic knowledge and ability of surveyors.

As a specialization within the surveying profession, property mapping focuses on the determination and demarcation of property boundaries. Because of this responsibility, land surveyors must be licensed or registered by the state or province where they practice, and because licensure is a responsibility of the states and provinces, the requirements for becoming a professional surveyor and maintaining the license to practice vary among these jurisdictions.

Methods of Land Description

The method of describing land parcels is diverse, both within and between Canada and the United States, but with little change in general principles between 1900 and 2000. Typically, a land description is based on either metes and bounds or a rectangular survey system. Metes and bounds has been the conventional method of describing property, a legacy of England and other European countries whose emigrants settled in North America. The survey for a parcel begins at a known starting point (usually called the point of beginning) and describes the courses and distances that surround that parcel. A typical metes and bounds example, from a widely used surveying textbook, shows the relationship between a survey map and its associated verbal description, which includes bearing and distances (fig. 748).

A common problem with a metes and bounds description is that the point of beginning might not be known. In figure 748 the commencement point was identified

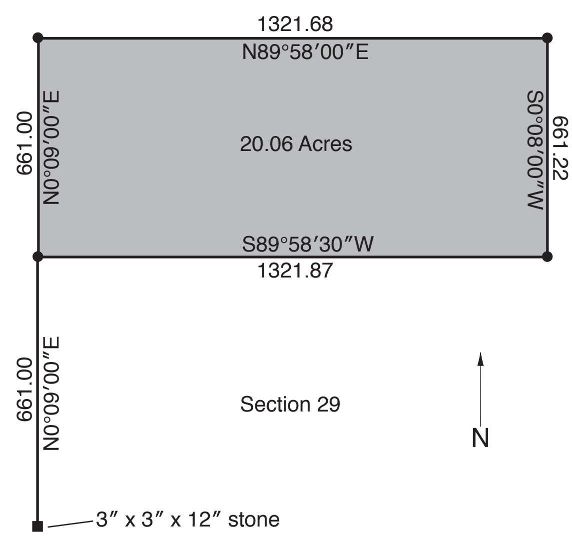

FIG. 748. EXAMPLE OF A METES AND BOUNDS DESCRIPTION. The shaded area would be: Commencing at a stone located on Main Street, thence N0°09′00″E a distance of 661.00 feet to an iron pipe set in this survey, said point being the point of beginning; thence N0°09′00″E a distance of 661.00 feet; thence N89°58′00″E a distance of 1321.68 feet; thence S0°08′00″W a distance of 661.22 feet; thence S89°58′30″W a distance of 1321.87 feet to the point of beginning; containing 20.06 acres more or less.
Modified from McEntyre 1978, 26 (fig. 2.2) and 27.

simply as a stone, without any specific indication of its location on Main Street. Other examples are even more vague. “Beginning at the hanging tree” and “Commencing at the corner of Alfred Town’s barn” indicate locations once widely known but now long forgotten.

Another metes and bounds example used in property descriptions is the long lots created by French settlers. Land parcels are characterized by being very narrow in width and long in depth. In the United States, these are often called the French Private Land Claims or French Land Grants. These lands are found along water bodies in areas of French settlements in Michigan, New Hampshire, Maine, and Ohio, and in Louisiana and other states along the Mississippi River. In Canada, long-lot parcels are also found in Quebec and along the Saint Lawrence Seaway and the Great Lakes (fig. 749).

The second method of subdividing property relies on a rectangular or grid survey system. In the United States this is referred to as the Public Land Survey System (PLSS). Although PLSS survey instructions have changed numerous times since the system was initiated by the Land Ordnance of 1785, its basic structure has remained intact. Land within a region is subdivided into townships, which are nominally six miles square and aligned with a baseline and a principal meridian. These lines are laid out on the earth in cardinal directions, with the baseline running due east-west, the principal meridian running due north-south, and sets of township and range lines running parallel to the baseline and principal meridian, respectively (fig. 750). Each township is subsequently divided into thirty-six sections, each nominally a mile square (fig. 751), although it is rare to find sections exactly one mile square. In theory, the township and section lines should run also in cardinal directions,

FIG. 749. EXAMPLE OF FRENCH LONG LOTS IN QUEBEC. Google Earth image of area on Île d’Orléans northeast of Quebec.
Image courtesy of Google Maps.

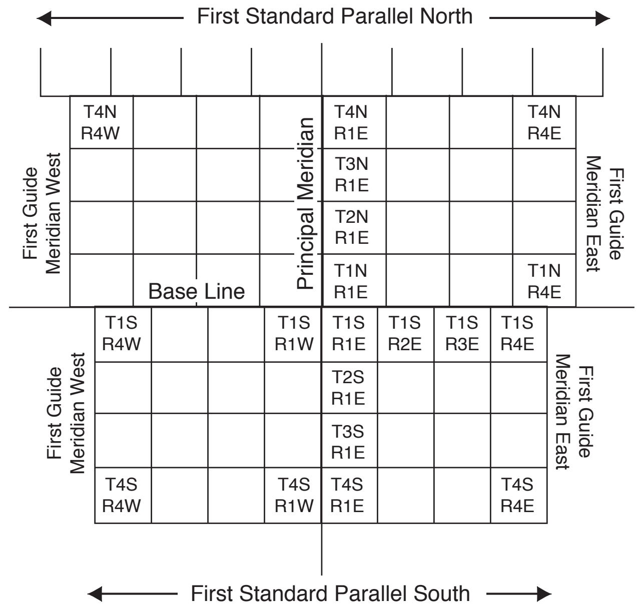

FIG. 750. CONFIGURATION OF TOWNSHIPS IN THE U.S. PUBLIC LAND SURVEY SYSTEM. Note that in this schematic the offsets are exaggerated for clarity.

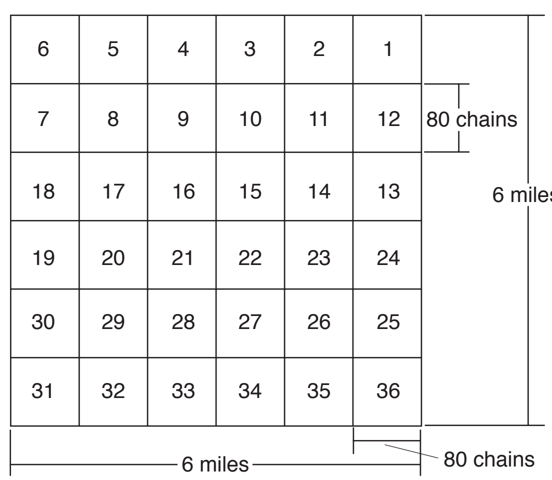

FIG. 751. NUMBERING SCHEME FOR SQUARE-MILE SECTIONS WITHIN A TOWNSHIP IN THE U.S. PUBLIC LAND SURVEY SYSTEM. Note that numbering begins in the upper-right corner.

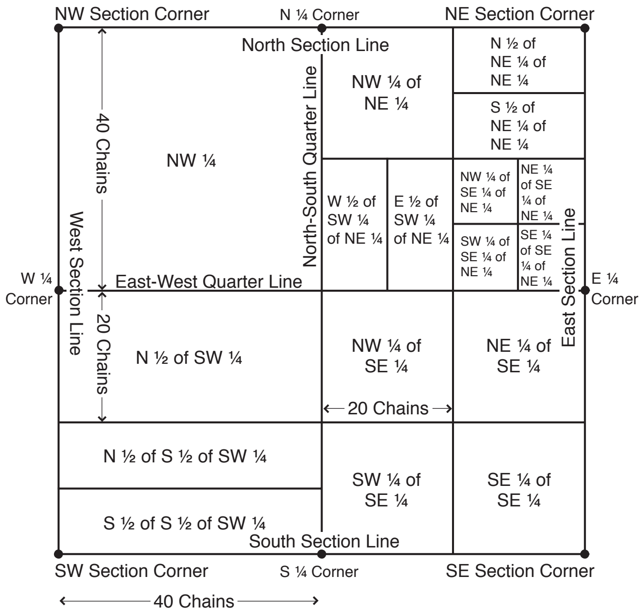

FIG. 752. EXAMPLE OF ALIQUOT SYSTEM FOR SUBDIVIDING SECTIONS WITHIN THE U.S. PUBLIC LAND SURVEY SYSTEM.

FIG. 753. TWO WILD T-2 THEODOLITES. A 1970s model (left) and an early 1929 model (right).
Image courtesy of Nicolàs de Hilster.

but because of errors in the surveys and convergence of the meridians, they do not. Therefore, correction lines must be laid out to make certain that a township's sides are very close to six miles in length. Finally, each section can be subdivided into aliquot parts, as shown in figure 752. Methods used in surveying the public lands are described by the U.S. Bureau of Land Management (1973).

In Canada, a similar subdivision method is used in the Dominion Land Survey (DLS), sometimes referred to as the Prairie Lands or Western Lands. A significant difference between the PLSS and DLS is that the numbering of the sections in the DLS begins at the lower-right corner instead of the upper-right corner as in the PLSS. Like the PLSS, the numbering scheme of the DLS follows a boustrophedon pattern.

Technological Innovation

In 1900 surveying by compass and chain was being supplanted by transit and tape. Later in the century these instruments would mature into the theodolite and the electronic distance measurement (EDM) instrument and eventually the total station. The plane table, used from the Middle Ages, would be replaced by the tacheometer.

The Wild T-2 (fig. 753), one of the most versatile theodolites in the world, began production in 1926. This was not the first theodolite, since instruments of this nature had been in use for over 300 years. Nonetheless, it did represent a significant change in the development of accurate angle-measuring instruments due to its precise construction and compact size. Other instrument manufacturers, mostly European, also introduced compact theodolites for high precision angle measurements to replace the large and bulky transit instruments used in the 1800s. In 1953, Erik Bergstrand, working with Svenska Aktiebolaget Gasaccumulator (AGA), introduced the Geodimeter (Model 1) EDM instrument using light energy (Cheves 1999, 18, 20). In South Africa, Trevor Lloyd Wadley introduced the Tellurometer in 1957 using microwave energy to measure distances. One of the main differences between these two instruments, other than the signal used to make the measurement, was that the AGA Geodimeter utilized two-way distance measurement whereby the light signal was emitted from the instrument, bounced off a reflector at the other end of the line, and received back at the instrument. Because the Tellurometer used one-way distance measurement, two instruments were required: the master unit and the slave unit at the other end of the line.

Because of cost and a wariness of this new technology, land surveyors did not widely use EDM equipment until the 1980s. By this time the cost of the instrumentation had come down, the instruments had become easier to use, the size of the instrument had been significantly reduced, the cost advantage of the instrument had become obvious, and the measurement theory was beginning to be understood and accepted by practitioners. The effects of EDM on surveying practice were enormous. First, it decreased the number of personnel needed for a field crew from three or four people to two. Second, the measurement of distance was more precise and consistent, provided that the instrument was being properly used. Third, the speed of surveys was increased, especially for large parcels or relatively low-relief terrain. Instead of taping from point to point, surveyors could drive to the ends of the lines and measure the distance in short order. Fourth, this new instrument helped facilitate the introduction of theodolites into normal surveying practice. In order to match the increased precision of EDM instruments, the theodolite was needed. Early instruments still had the EDM instrument separated from the theodolite, but instruments like the Zeiss Elta 2 (fig. 754) incorporated both instruments into a single body, known as a total station. Fifth, in the infancy of EDM instruments, the surveyor was required to set the instrument up independent of the theodolite. By the 1980s, EDM instruments were sufficiently lightweight to be physically attached to the theodolite. Finally, the use of EDM technology accelerated the computational capabilities of a surveying business, insofar as early generations of the equipment required numerous hand calculations, which were now carried out electronically. In the 1970s, electronics had evolved to the degree that the angular instruments themselves became automated using digital theodolites or automatic tacheometers. The main characteristic of this type of instrument was the automatic reading of angular measurements (Deumlich 1982, 254–55).

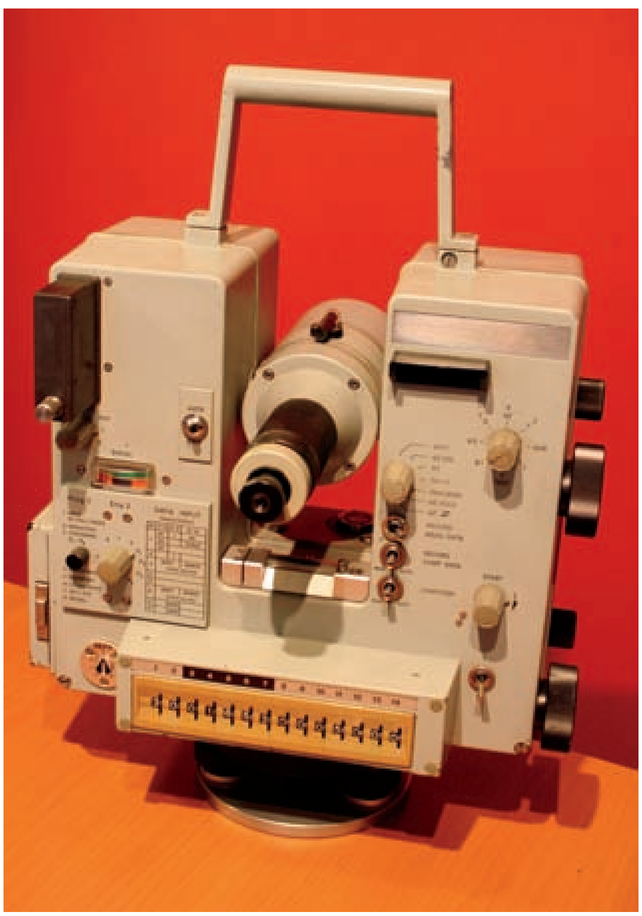

FIG. 754. ZEISS ELTA 2 THEODOLITE.
Image courtesy of Michel Chinal, Géomusée, Lyon.

The last significant technological change in land surveying was the introduction of the Global Positioning System (GPS) into normal practice. GPS grew from earlier satellite-based positioning and navigation systems, such as the Doppler satellite system. Satellite positioning had become an important geodetic tool by 1990, but when it first began to appear on the equipment market in the 1980s its application was limited in conventional surveying practice, except for establishing a precise network of reference stations. Early GPS receivers were very costly to most surveying companies, and relatively accurate estimates of positions required that receivers occupy two locations for one to two hours to generate a large number of estimates, the average of which would be suitably accurate. For this reason, surveyors looked on GPS with skepticism. Cutting-edge surveying companies began to incorporate GPS in their day-to-day operations for asset data collection and control purposes. In the 1990s, the unit price decreased, Selective Availability was turned off, high-accuracy reference networks (HARN) were established (soon to be replaced by the continuously operating reference stations, CORS), cost-effectiveness in the instrumentation increased, and reliability in the measurement process stabilized. These factors, along with ease of operations and processing, made GPS indispensible for many applications.

Technological change had an important impact on the cartographic aspects of conventional surveying practice. Total stations, GPS, and other electronic measurement devices led to increased reliance on computer processing and mapping. In the early days of computer mapping, companies plotted the survey points on a working sheet of paper and traced the final map with ink on mylar or other media. Over time, the quality of the graphics allowed surveyors to gravitate to computer-aided drafting (CAD) and computer-aided mapping (CAM) software packages. Coordinate geometry (COGO) made it easier for the surveyor to perform basic calculations and to depict those results on accurate maps and drawings.

The significance of the developments in surveying instrumentation on the land surveying community depended upon the concept of survey control densification. The concept was very simple: if a government agency provides accurate survey control using State Plane Coordinates at a sufficiently short interval, private-sector surveyors will use that control in their surveys. Beginning in the late 1960s, some surveyors began to talk about control densification programs. Kurt W. Bauer (1969), for example, discussed the control densification project whereby the Southeastern Wisconsin Regional Planning Commission determined State Plane Coordinates for the public land survey corners in that region. Phillip C. Johnson (1976) demonstrated that a favorable benefit-cost analysis could be performed for the establishment of urban horizontal control networks. Earl F. Epstein and Thomas D. Duchesneau (1984) took a different tack in describing the necessity for a geodetic reference network. Their basic premise was cost avoidance and the idea of creating compatibility between different map products, especially important to geographic information system (GIS) activities in which it is often necessary to conflate maps developed by different organizations for different purposes using different projection systems. These activities culminated in a control densification project by the National Geodetic Survey in Ada County, Idaho (Adler 1984). By the close of the twentieth century, the necessity of a hierarchical control network waned as GPS became more robust. HARN and CORS made the requirement for control densification obsolete in much of the country, although it remained a necessity in remote regions of both the United States and Canada. High-accuracy point positioning was now possible with only a single GPS receiver and extremely short occupation times.

Professional Development

Professionally, land surveying began to mature into a discipline unto itself. Beginning in the late nineteenth century, surveying and engineering societies began to emerge in order to keep professionals abreast of current developments. For example, the American Society of Civil Engineers was launched in 1852. In the early days, surveying was an important and integral component of these engineering-surveying organizations. But during the early part of the twentieth century, new and innovative engineering issues overtook surveying. The idea of transportation engineering began to draw more and more students into the profession. This and other engineering topics began to attract more students and became the focus of research in engineering schools. To update and balance the curriculum, schools began to replace surveying courses with these newer engineering topics over the century. In 1900, a typical civil engineering bachelor's degree was replete with surveying courses. Schools established survey camps where students would learn surveying in a real-world environment. By 2000, most civil engineering programs may have retained at most only one or two surveying courses.

To counter these developments within the civil engineering community, surveying organizations began to emerge to address surveying needs at both the state and national level. The Canadian Institute of Surveying (renamed the Canadian Institute of Geomatics) was incorporated in 1882, while the American Congress on Surveying and Mapping was formed in 1941.

Much can be said about the influence of these organizations on the evolution of the surveying profession. One of the important changes was the increased professionalism exhibited by their members. This resulted in land surveyors offering even better products to their clients. Professional organizations, particularly at the state level, pushed for legislation to raise the bar for the profession. In the 1970s legislation requiring professional surveyors to have a bachelor's degree in order to become licensed was encouraged, and by century's end, about half the states had this requirement. In Canada, where the requirement for becoming a professional surveyor is controlled by the province as it is by the state in the United States, all provinces required an equivalent to a geomatics engineering degree.

Other legislative activities were undertaken in the latter part of the twentieth century that affected the professional practice of land surveying. One of the major efforts was the requirement that a certificate of surveys be recorded for public inspection. An example of a surveying certificate, following Michigan's Certified Surveys Act (Act 132 of 1970) is shown in figure 755. The requirements for an Act 132 survey are: sheet size of 8½″ × 14″; black nonfading ink; scale not more than 500 feet to the inch (1:6,000); scale shown on map (graphical and numerical); certificate signed and sealed by surveyor; description of land; link to Public Land Survey System (PLSS) corners; witnesses to PLSS corners (four); curves defined by PC, PT, PCC, central angle, length of arc, degree of curvature, length and bearing of long chord; exact width of each street; and north arrow (Michigan Compiled Law §54.211–54.213).

Figure 756 shows an example of a certified survey following Wisconsin's Minimum Standards for Property Survey. The related map requirements are: convenient scale; exact length and bearing of all boundaries; description of monuments; description of the parcel; provide client name; stamp and signature of the surveyor; and source of the bearing (2011 Wisconsin Code §236.34). Survey requirements have varied significantly throughout the United States and Canada, with states, provinces, and municipalities differing in historical precedents and standards. Recording statutes have also varied from county to county and state to state.

Land Subdivision Development

During the early part of the twentieth century, land development grew at a quick rate. Urban industrialization led the middle class to escape the confines of a crowded

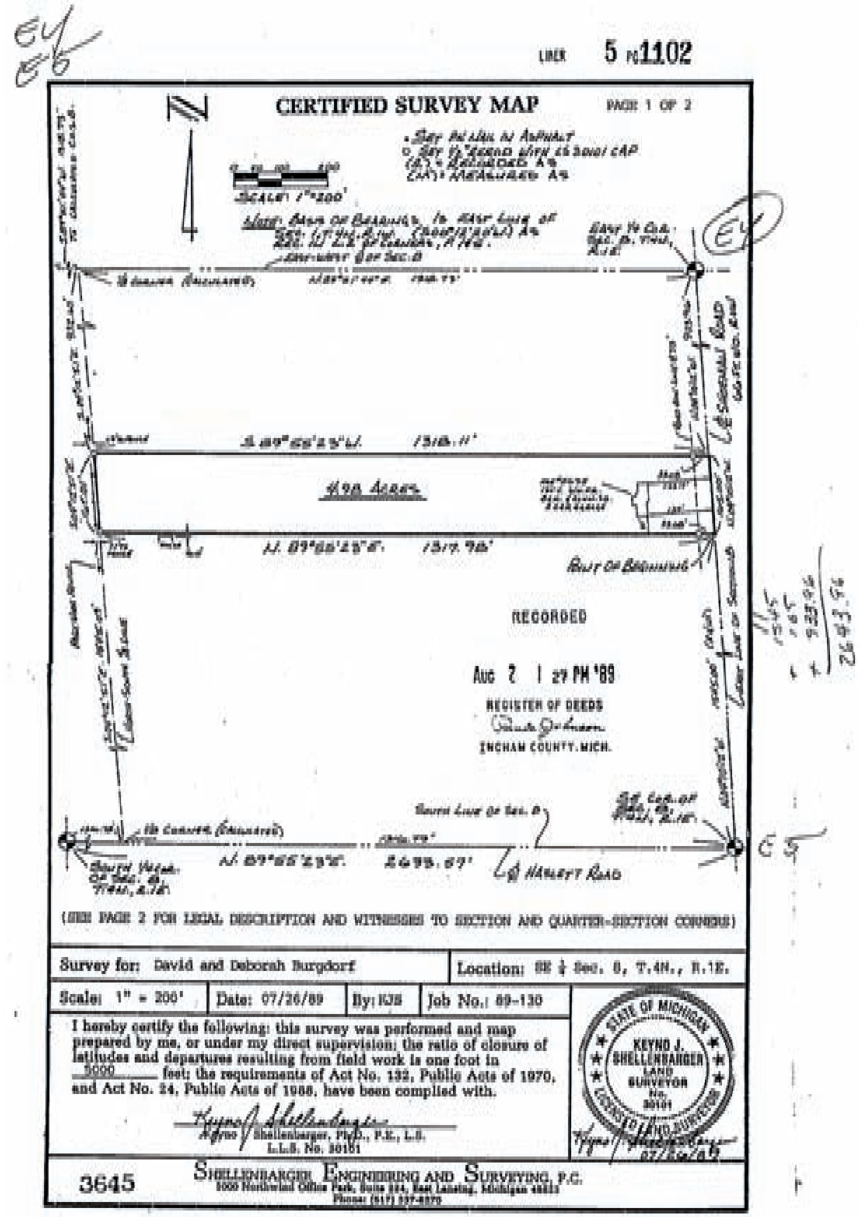

FIG. 755. CERTIFIED SURVEY MAP, INGHAM COUNTY, MICHIGAN, 1989. Map shows the SE ¼ Sec. 8, T4N, R1E, Williamstown Township.

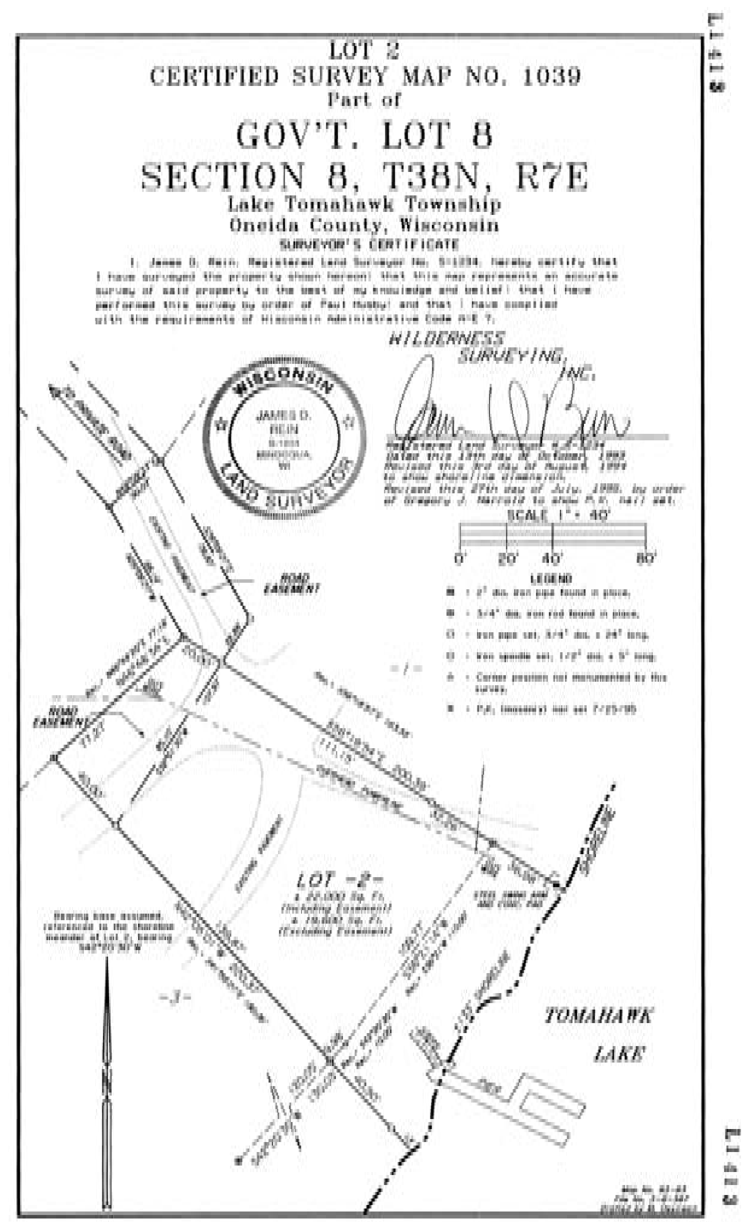

FIG. 756. CERTIFIED SURVEY MAP, ONEIDA COUNTY, WISCONSIN, 1995. Map no. 1039 showing part of Gov't Lot 8, Sec. 8, T38N, R7E, Lake Tomahawk Township.

city, first along trolley and commuter rail lines and then more widely as the automobile allowed outward mobility beyond public transportation routes. This in turn allowed many unscrupulous developers to create subdivisions in which lots were described in deeds but never laid out in the field, and basic utilities, such as roads, were not provided. After around 1920 cities began to look at land use controls to mitigate the consequences of incompatible land uses.

The introduction of subdivision control legislation transformed property mapping and land surveying during the twentieth century. Purchasers, local municipalities, and lending institutions began to require that subdivision plats contain more information that would help delineate boundaries within the platted lands. Surveying monumentation requirements were established in order to facilitate lot and block locations. Over the years, many states and provinces began to shore up their platting requirements. Minimum standards were established for linework, lettering, and annotations. Archival properties of the plat materials also became important in the preservation process.

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SEE ALSO: Electromagnetic Distance Measurement; Geodetic Surveying: Canada and the United States; Property Mapping Practices; Tax Map

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Property Mapping in Latin America. The forms and functions of property mapping in Latin America changed in the course of the century in response to technical developments in data capture and storage and the changing needs of Latin American societies. Some of those changes mirrored what was happening elsewhere in the world, but others were a consequence of the history of Latin America and its particular political, institutional, economic, and social environments.

The terms referring to property mapping in Latin America include *cartografía catastral* (cadastral cartography), used in academic and formal contexts; and *mapeo catastral* (cadastral mapping), a more colloquial term. In Argentina and Brazil practitioners used the words *agrimensura* (surveying) or *ingeniería en agrimensura* (engineering surveying). During the late twentieth century *topografía* (topography) was gradually replaced by *geomática* (geomatics), which included large-scale, digital, property mapping. In Peru, the field of *ingeniería geográfica* (geographic engineering) existed, which included property mapping. Moreover, *cartografía digital catastral* (digital cadastral cartography), including online access, became the prevailing mode of property mapping. As expected, these concepts were intertwined and varied from country to country. In Latin America, the main product of this cartographic mode was the *mapa catastral* (cadastral map), including rural, suburban, and urban landed property. Finally, during the last decade of the twentieth century a new type of property mapping emerged: *mapeo participativo* or *cartografía participativa* (participatory mapping), which produced some community maps in indigenous regions (Smith et al. 2009; Wainwright and Bryan 2009).

The cartographic representation of national territories in Latin America began with the setting of national borders, including coastal zones, after most countries gained independence. In most of the cases, colonial demarcations did not survive postindependence times. For instance, colonial Nueva Granada (Colombia), which stretched up to the Mosquitia, Honduras, Panama, and parts of Venezuela and Brazil, eventually, like Mexico, lost about half of its territory to powerful neighbors (Mendoza Vargas and Garcia 2005–7). In addition, the securing of international borders led to disputes and the loss of territory. Bolivia, for instance, became a landlocked state after losing its exit to the Pacific Ocean to Chile (Alvarez Correa 2000) and lost possession of the Gran Chaco region to Paraguay after the 1932–35 Chaco War (Mendoza Vargas and Garcia 2005–7).

When the outer borders were settled and secured, the mapping of the inner frontiers began. For instance, Argentina secured and colonized the indigenous Patagonia (1879), Chaco (1884), and Pampa territories by violently expelling or annihilating their resisting native inhabitants (Lois 2009). Thus, the national state map was drawn and recognized by the international community. By then, most Latin American countries had begun to map their inner territories, especially those perceived as "vacant," a process that spanned the early part of the century.

As elsewhere in the world, Latin American cartographic representations go hand in hand with military strategies. Cartography was instrumental not only in securing the outer and inner frontiers but also in taking lands from indigenous people. Indeed, in all countries in the region the military was involved in mapping at different scales, including large scale. As a rule, Latin American countries at some point set up a military cartographic office (Lois 2009; Alvarez Correa 2000).

In this region, property map production, distribution, and consumption during the century was the result of at least four intertwined factors: tax collection, agrarian reforms, selling or granting public land, and land lawsuits. The taxation of landed estates had the greatest influence not only because it led directly to the setting up of cadastres but also to the mapping of rural, suburban, and urban lands in all types of ownership. Thus, cadastral mapping was able to register, locate, and assess all parcels and supply strategic information for levying taxes. Consequently, with varying degrees of intensity, most Latin American states pursued the consolidation of cadastres in order to improve tax collection (Erba 2005; Portillo Flores 2007).

Property mapping helped improve the financial situation of national treasuries in all Latin American countries although the situation varied from country to country. For example, municipal Peruvian authorities were entitled to collect the *impuesto predial* (parcel property tax) that provided some funding for local development projects (Portillo Flores 2007). In Mexico, land use permits based on property mapping were issued by the municipal councils, which provided a continuous flow of tax revenue for the *municipios*. These permits were also a significant driver for map updating and accuracy, which led to the introduction of publicly funded state-of-the-art cartographic technologies in a few pioneering cases such as Argentina.

Agrarian reform, not a universal process in Latin America, was the second major factor driving property mapping (Kay 1999). These reforms, mostly with a rural orientation, had two purposes: first, to expropriate, survey, and subdivide great estates (*haciendas*, *ranchos*, or *fincas*) and to grant them to landless peasants; second, to transform social, collective property—such as the Peruvian *ayllu*, or the Mexican *ejido* and *comunidad agraria*—into private property in order to fight land fragmentation and to encourage land market consolidation (Smith et al. 2009).

The third driving factor of property mapping was the selling or granting of public land. For example, early in the twentieth century, the Mexican government granted lands to foreign surveying companies and colonists. Later, the state sold public coastal lands in order to encourage private entrepreneurs to build tourist facilities for the international market. In Panama the state mapped, granted, or sold most of the public lands next to the canal to public or private investors, once the country reverted from U.S. administration to the national government.

Finally, litigation spurred property mapping. Usually, the opposing parties had property maps drawn to bolster their claims to settle border disputes or secure property rights—examples include Belizean and Nicaraguan indigenous groups (Wainwright and Bryan 2009). Many testimonial property maps were drawn in the region as a result.

In terms of the area of land involved, tax collection and agrarian reforms were more significant in increasing property mapping than were lawsuits and selling or granting public land. Nonetheless, these four factors drove property mapping production, distribution, and consumption throughout the century. Although some privately led cartographic projects were carried out, in most cases it was the state that conducted property mapping (Lois 2009). Examples of property mapping include *condueñazgo* (landed co-ownership) partitioned into smaller plots in the first decade of the twentieth century (figs. 757 and 758); and a PROCEDE (Programa de certificación de derechos ejidales y titulación de solares) map, all from Mexico (fig. 759).

The economic changes and historical events that affected the form of property mapping in Latin America were regional and national in nature. Economic downturns compromised the development of most Latin American countries. Civil wars further slowed their cartographic projects, including the setting up of cadastres. For example, the Mexican revolution (1910–17) interrupted the project for large-scale mapping set up during the Porfiriato (1872–1910).

The relationships between property mapping and other types of cartography in Latin America were very close. In general, large-scale mapping was pursued after the medium- and small-scale mapping of the outer and inner (regional or provincial) borders in the early part of the century had been completed (Mendoza Vargas and Garcia 2005–7). For example, in 1919 the Argentinean Instituto Geográfico Militar began the cadastral mapping of provincial property in Mendoza, Santa Fe, Entre Ríos, and Buenos Aires (Lois 2009, 266). In addition, large-scale mapping was a corollary of the development of cartographic skills at the national level.

In Latin America, there were small variations in property mapping. Although property mapping was primarily related to cadastral registration, which included locational, economic, and legal data on the status of private, public, or social landed estates, it was used (with some restrictions) as a synonym for cadastral cartography (Erba 2005). Although property mapping was usually

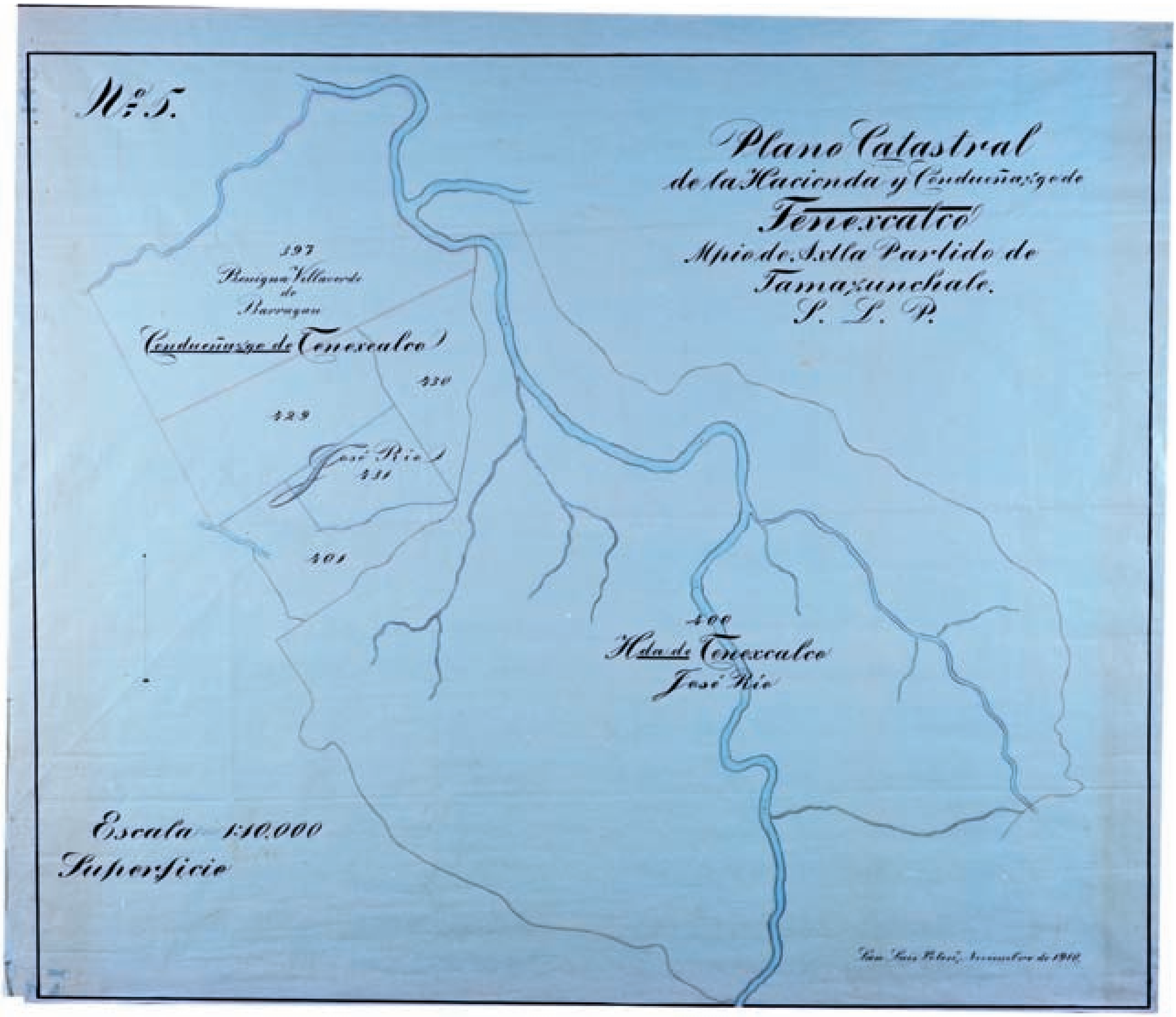

FIG. 757. "PLANO CATASTRAL DE LA HACIENDA Y CONDUEÑAZGO DE TENEXCALCO," MEXICO, 1910. Eastern Mexico, Axtla municipality, Tamazunchale Partido [district], eastern San Luis Potosí, Mexico, November 1910. Scale 1:10,000, map number 5, surveyor unknown, black ink on cloth paper.

Size of the original: 124 × 140 cm. Image courtesy of the Archivo Histórico del Estado Antonio Rocha, San Luis Potosí, Mexico.

large-scale mapping, it could range in scale from 1:1,000 to 1:20,000, depending on the size of the property represented. Property mapping served at least three purposes: to spatially identify the landed property as public, private, or social; to recognize and assess land value for taxation; and to allocate land for different uses.

Pre-1900 mapping practices and institutional structures, as well as some innovations, continued to develop during the twentieth century. In addition to the aforementioned factors, property mapping was dependent on three processes: the consolidation of cadastres, the implementation of surveying training programs, and the creation of professional organizations. There were further synergies between these institutional structures and

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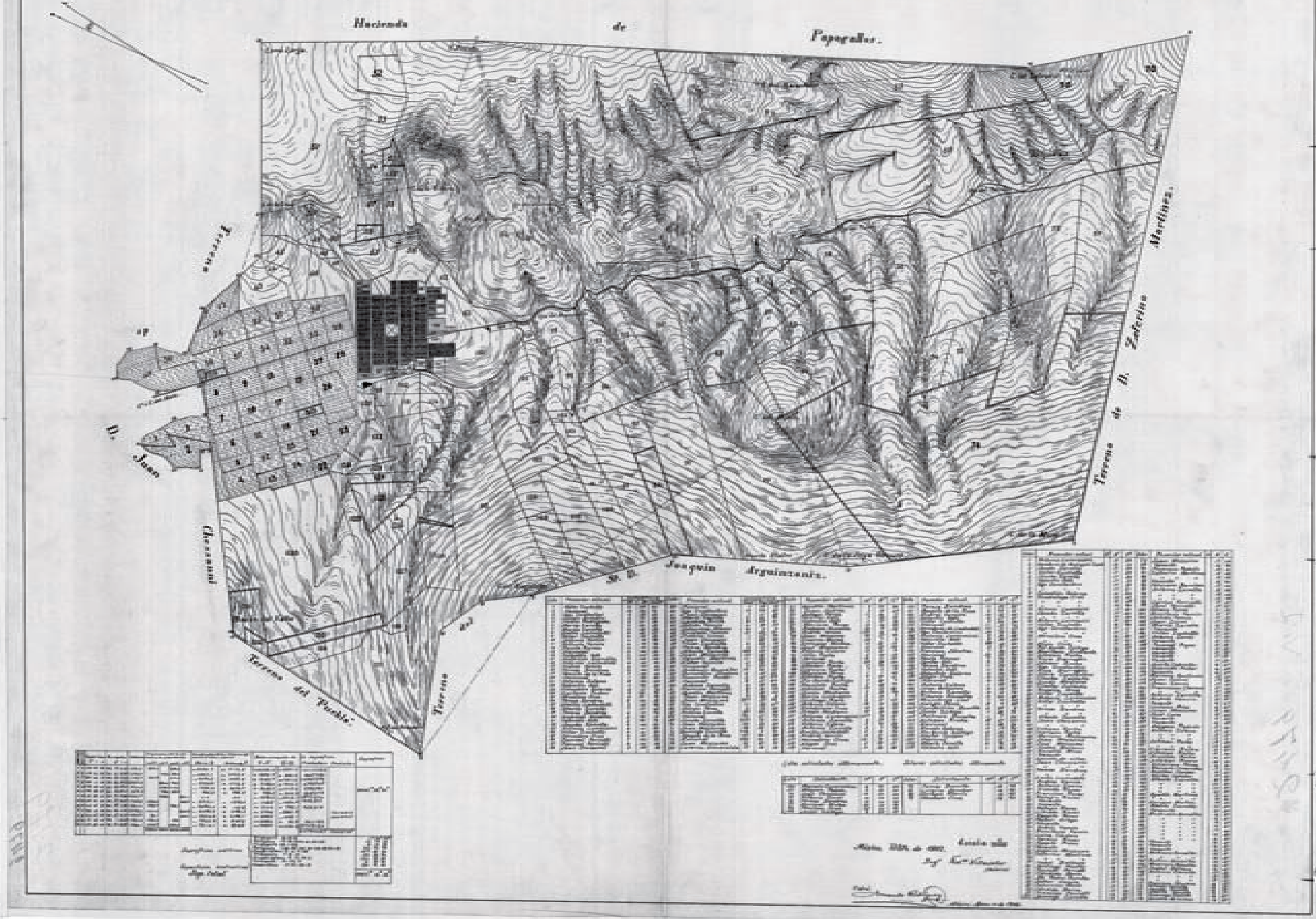
FIG. 758. "PLANO DE LA COLONIA DIEZ GUTIÈRREZ," 1903. Ciudad del Maíz, eastern San Luis Potosí, Mexico. Scale 1:10,000, signed by surveyor Ing. Federico Villaseñor. Coated paper.

Size of the original: 80 × 100 cm. Image courtesy of the Mapoteca Manuel Orozco y Berra, Servicio de Información Agroalimentaria y Pesquera, SAGARPA, Mexico City, D.F.

PLANO de la Colonia Diez Gutièrrez. Edo. de S. Luis Potosi.



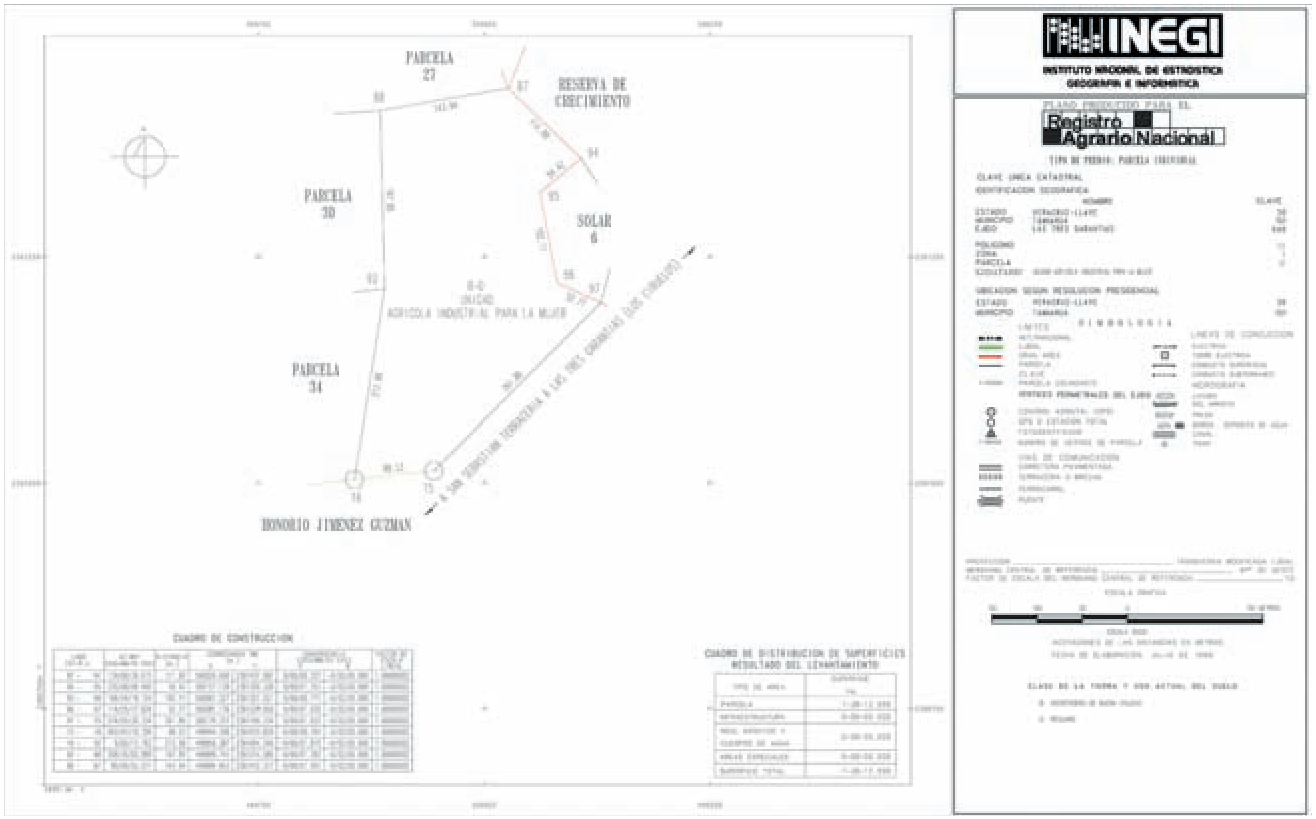


FIG. 759. PROCEDE PLOT WITH LEGEND, TAMIAHUA, VERACRUZ, JULY 1999. Cadastral map drawn by Instituto Nacional de Estadística, Geografía e Informática (INEGI) cartographers.

Image courtesy of the Instituto Nacional de Estadística y Geografía website.

changes in surveying technology. Despite the diversity, most Latin American countries established municipal, state, or national cadastres.

Professional training programs were consolidated during the century. Apart from the regular bachelors, masters, and doctoral programs in geography, undergraduate and graduate programs in surveying, engineering surveying, topography, geographic engineering, and geomatics were established in Mexico, Argentina, Brazil, Peru, Chile, and Colombia. Licensed Latin American surveyors also created professional organizations. For example, the Argentinean Consejo federal de catastro, founded in 1958 (Alvarez de López 2004), and the Federação nacional dos engenheiros agrimensores in Brazil, both with international affiliation, became very active professional guilds.

Institutional structures and technological change encouraged innovation. For example, most Latin American countries used geospatial technologies (for example, the Global Positioning System and remote sensing) to improve the accuracy of property mapping. They also began online access to georeferenced cadastral cartography (Alvarez de López 2004; Philips 2007). By late in the century property mapping in Latin America was evolving toward a "multifunctional" model of cadastre (Portillo Flores 2007, 43), which included a range of information related to landed property. The goal was to build a unique cartographic base to support the cadastre and the nomenclature of each land unit. It was also important to improve the coordination of all cadastres to solve problems with sharing and standardizing data.

Overall, the significance of property mapping for cartography, especially with respect to the larger scientific and technological contexts of the discipline, grew notably in Latin America during the twentieth century. International standardization of practices and design advanced. The impacts of mapping on society were diverse, ranging from the increased use of maps as tools of governance, the transition to electronic media, and the growth of overhead imaging—including local innovations such as videography or small-plane aerial photography—to the long-standing relationship between cartography and military operations. Although the intensity of the process varied from country to country, Latin American property mapping during the century became a dynamic cartographic field attuned to the development of global, modern cartography.

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SEE ALSO: Electromagnetic Distance Measurement; Geodetic Surveying: Latin America; Property Mapping Practices

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Property Mapping in Africa. The surveying of land as property is traditionally equated with cadastral surveying, which involves surveying the boundaries of a country's land parcels. All cadastral surveys produce cadastral plans, which can take two forms, namely, diagrams of individual properties and maps showing groups of properties. In both cases the drawing is planimetric and of a large scale (larger than 1:25,000). By the end of the nineteenth century cadastral surveying and mapping in Africa was confined to Egypt, the French-speaking coastal area of North Africa, the Belgian Congo, British South Africa, small areas of European settlement situated on the fringes of the continent, and pockets in the interior where mining development had taken place. This situation had not much improved by 1998; according to an assessment of the developing world, very little of sub-Saharan Africa was covered by any kind of cadastral survey (Fourie and Nino-Fluck 2000). In 1987 only 2.5 percent of Africa's land surface had been topographically mapped on scales of 1:25,000 and larger; the corresponding figures for Europe, South America, and Asia were 83.4 , 6.7, and 13.9 percent, respectively (Brandenberger and Ghosh 1990, 2 [fig. 1]). Although large-scale topographic maps are not the only cartographic documents showing property boundaries—but usually do—these figures suggest a low level of property mapping on the African continent.

The reasons for Africa's poor performance are varied. Although almost all colonial powers established survey departments in their African colonies, in some cases land surveying during colonial rule was financed almost entirely from current revenue, but even then only if other needs were not more pressing. Because cadastral surveys require an accurate geodetic base, the absence of a first-order triangulation network in many parts of the continent partly accounts for the lack of adequate cadastral systems. Other factors that hampered the establishment of sound cadastres in Africa include extreme combinations of climate, vegetation, and topography that rendered large areas of the continent unsuitable for agriculture and settlement; political instability; weak or nonexistent land policies; limited financial resources; inadequate technical and human capacity; poor management practices; the nationalization of land; and traditional land tenure systems that vested land ownership in the whole community rather than individuals. Because the land market in such areas had not developed, the value of land as a commodity did not warrant the expense of a formal survey.

Although cadastral surveying and land registration are two distinct processes, they are inseparably linked insofar as the prospect of land registration is in many instances the reason why land is surveyed, and the surveyor, in describing property boundaries, must work within the framework of a specific registration system. From a legal point of view, two types of registration systems can be identified: the Deeds System and the Title System. The Deeds System is basically a register of owners focusing on "who owns what" (without necessarily proving ownership), whereas the Title System is a register of properties describing "what is owned by whom" (Enemark 2003, 4–5). When delineating property boundaries, the land surveyor can use either a graphical or a numerical system or, in some cases, a combination of both (Simpson 1976, 370).

In Africa the choice between these various approaches was as much influenced by historical and cultural factors as by local circumstances. Many countries started off using one approach and later switched to another. Some former British colonies (e.g., Egypt and rural Kenya) used a graphical survey system modeled on the British system

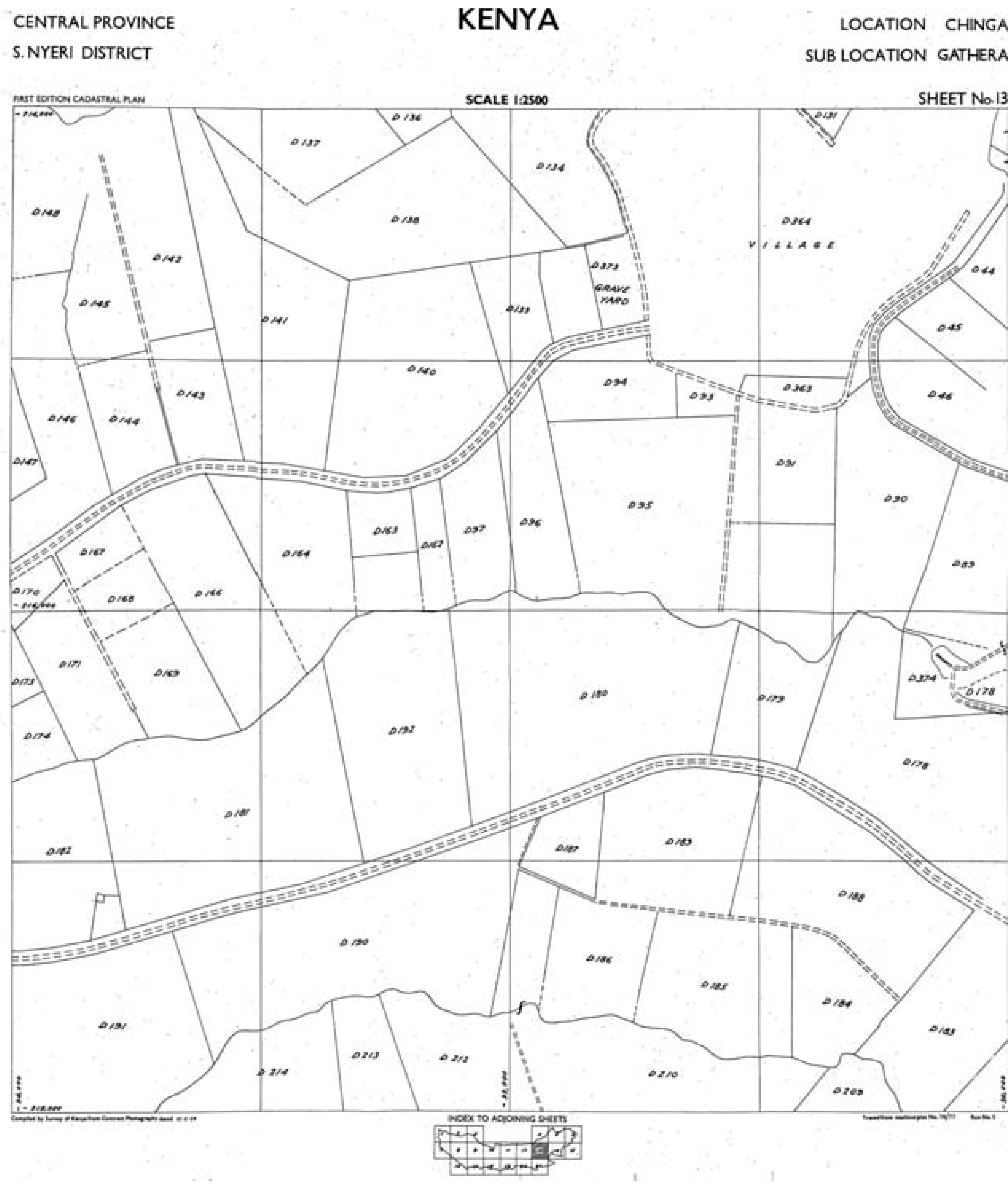

FIG. 760. REGISTRY MAP ON A SCALE OF 1:2,500 USED IN THE CADASTRAL SURVEY OF KENYA. Image courtesy of Elri Liebenberg.

whereby the central survey organization (the Ordnance Survey) published a large-scale (usually between 1:1,000 and 1:2,500) topographic map of the country that is used as an index map for title registration (fig. 760). Such a registration system is generally known as an "English" system and is particularly suited for countries where the majority of properties are clearly defined by visible features such as walls, hedges, streams, and roads (so-called general boundaries). In countries where the surveyor uses a numerical survey system, the most common

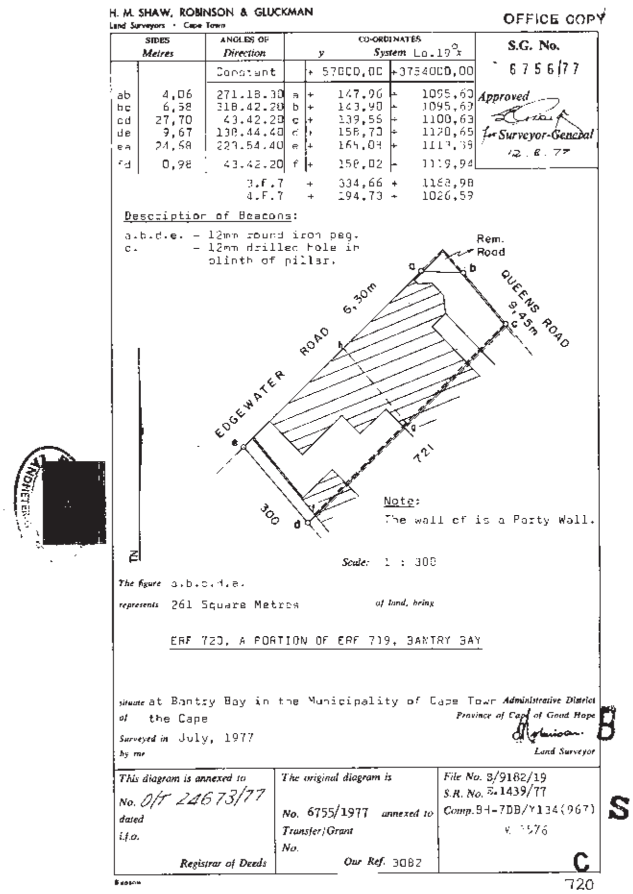

FIG. 761. SURVEY DIAGRAM OF A SINGLE LAND PARCEL, 1977. Survey at Bantry Bay in the Municipality of Cape Town, 1:300, July 1977.
Image courtesy of Elri Liebenberg. Permission courtesy of the Surveyor-General, Cape Town, South Africa.

method is to place boundary marks in the ground, followed by a survey to establish the position of the boundary marks relative to a control system. The boundary data may be presented in map form, but could equally well be presented in the form of printed lists, or digital records of coordinates, bearings, and distances. Since the boundary data have been recorded to the standard of accuracy specified for the survey system, the resulting cadastral map—either a diagram of an individual land parcel as illustrated in figure 761, or a map of a cluster of land parcels as illustrated in figure 762, or both—can be drawn to any scale (Simpson 1976, 371). In such countries the majority of properties usually are defined by invisible lines (also called “fixed” boundaries). The land registration system that followed is sometimes known as a “colonial system” and can involve either title registration (as for most countries in North and West Africa) or deeds registration (as in South Africa, Namibia, Swaziland, and Zimbabwe). In both cases the cadastral map functions as a registry map. In the case of title registration, the system is usually a modification of the so-called Torrens system, which was introduced in South Australia in the nineteenth century. Basically the Torrens system guarantees a person secure title of a land parcel once the land parcel has been surveyed and entered into a land register.

One of the oldest national cadastral surveys in Africa was undertaken in Egypt (Dowson and Sheppard 1945–46). After Egypt had become a de facto British colony in 1882, Britain realized that the Egyptian land tax system needed a drastic overhaul. In 1878 already an international commission recommended a reassessment of the land tax system based on an immediate cadastral survey of the country. The plane table survey, which was modeled on the British Ordnance Survey, comprised the surveying of approximately 2.5 million individually owned land parcels. Work began in 1879, but real progress came only after 1898, when Henry George Lyons was appointed director general. By 1907 Lyons had established a properly functioning land survey department, which executed an appropriate second-order framework for the cadastral survey, surveyed and recorded 2,346,962 land parcels, and produced 25,779 map sheets on a scale of 1:2,500 (Dowson and Sheppard 1945–46, 169). Until 1921, when they were replaced by a new series on a scale of 1:1,000, these maps formed the basis of the land registration system.

Land surveying in South Africa dates back to the 1650s, when the Dutch established a food supply station at the Cape of Good Hope. Although the South African land registration system is still based on Roman-Dutch law, a number of important rulings were implemented after British rule was established in 1806. Starting in 1813 all land parcels had to be properly surveyed and a diagram drawn up and registered in a central office. Another revolutionary development followed in 1857, when it was made compulsory for land surveyors to show on their diagrams the numerical values of boundary lines together with the angles of intersection. By the end of the nineteenth century, these and other improvements in the quality of surveys had put the South African survey profession on a sound footing. Logistically, however, the profession was burdened by a legacy of isolated and inaccurate surveys (Fisher 2004). The reason was a lack of geodetic control insofar as the geodetic survey of South Africa was not started until 1883 and not completed until 1907. Recommendations by a survey commission appointed in 1921 led to the Land Survey Act No. 9 of 1927, which consolidated numerous previous laws and required that all cadastral surveys be connected to trigonometric stations or to urban survey reference marks. This law was superseded by Land Survey Act No. 8 of 1997, which retained this requirement and provided for the appointment of a chief surveyor

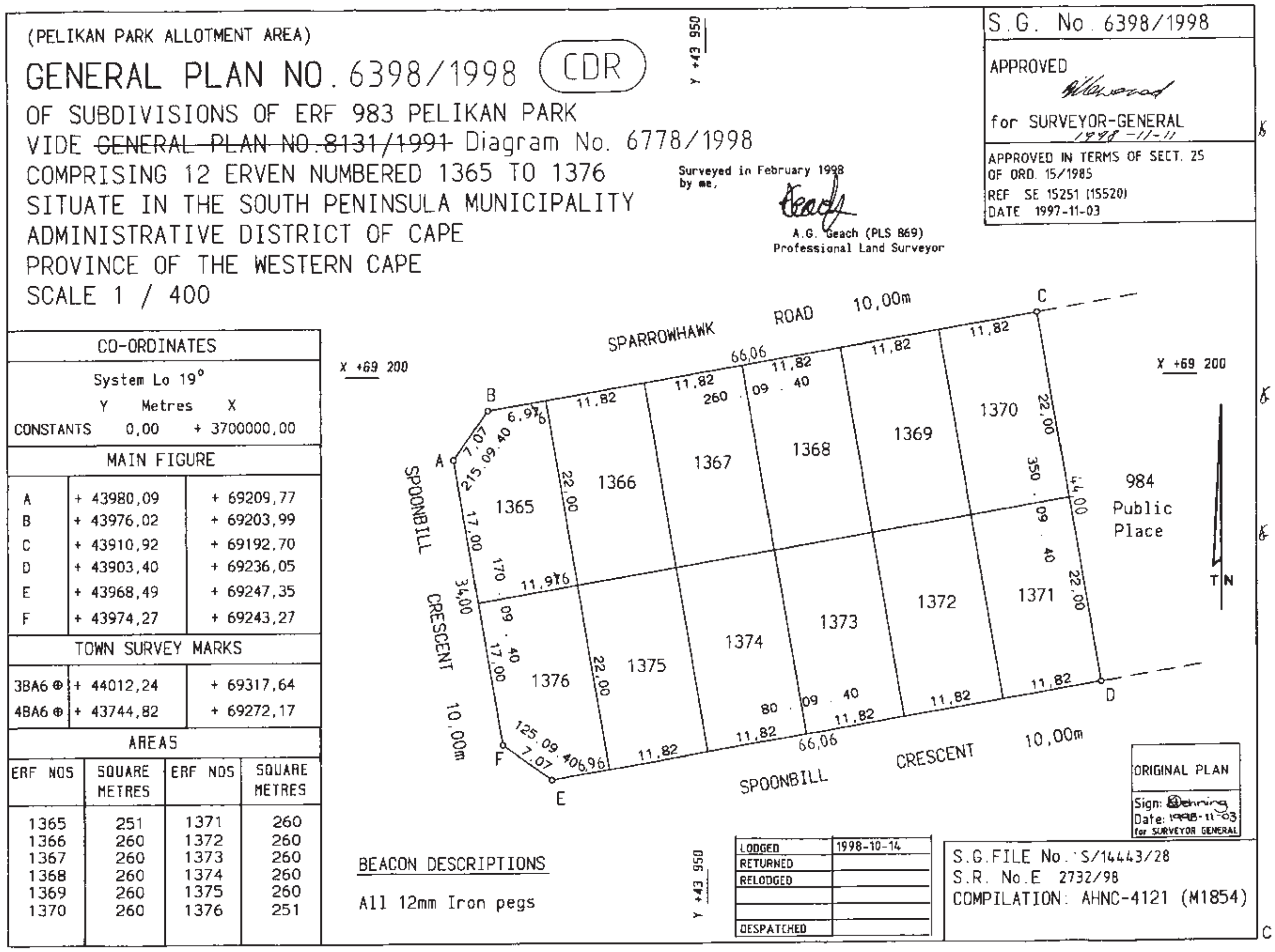

FIG. 762. GENERAL PLAN OF A CLUSTER OF LAND PARCELS, 1998. South Peninsula Municipality, Western Cape Province, 1:400. Image courtesy of Elri Liebenberg. Permission courtesy of the Surveyor-General, Cape Town, South Africa.

general charged with the control of all cadastral survey operations in the country. Traditionally South Africa has a deeds registry instead of a title registry with the survey diagram (or general plan) being the key to the system.

From 1900 onward Britain established survey departments in all of its colonies and protectorates in Africa. Although the War Office expected these departments to engage in topographical mapping, the practical need for surveys for the purposes of development and land administration compelled the local survey departments to devote most of their attention to cadastral surveys. Apart from surveying land for registration purposes, much cadastral work in colonial Africa also dealt with the surveying of mining concessions, surveys for road construction, and the surveying of towns. During the 1920s and 1930s, Sierra Leone, the Gold Coast, and Nigeria produced considerable quantities of gold and tin. In 1935 the Survey Department of Nigeria reported that twenty-seven surveyors were then engaged in the survey of mining areas in the country and that 359 mining leases and 102 prospecting licenses had been surveyed during that year (Bradley 1936, 489). Likewise, the surveying of urban areas for administrative and engineering purposes was common practice. After gaining independence, many former British colonies in Africa asked the Directorate of Overseas Surveys (DOS) for assistance in large-scale cadastral mapping to support the growing needs of urban planning, property valuation, engineering assessment and design, and farm planning and land registration (McGrath 1983, 141). By the 1950s the DOS increasingly used aerial photography, typically with the local survey department handling ground control and planimetric completion of map sheets in the field while the DOS took responsibility for aerial triangulation and the plotting and fairdrawing of the maps. From 1960–63 the DOS mapped the suburbs of Lagos on a scale of 1:1,200; in 1960–61 Nigeria requested twenty-five map sheets on a scale of 1:4,800; in 1961–62 a 1:2,500 series was prepared for Gambia; and in 1962–33 three farm settlements in eastern Nigeria required mapping on a scale of 1:2,500 to assist in farm planning. In 1962–63 the DOS also mapped eight townships in Sierra Leone at 1:2,500, and provided ground control for Port Harcourt in Nigeria at a scale of 1:4,800.

In Uganda the Buganda *mailo* (native estates) survey was one of the first cadastral surveys ever to be undertaken primarily for the purpose of establishing the ownership of land among indigenous Africans (Strickland 1936). According to the Uganda Agreement signed in 1900 between Britain and the indigenous peoples, the land of Buganda, situated on the north and west shores of Lake Victoria, was to be distributed among various tribes, chiefs, and missionary societies as well as to thousands of private landowners. All allocations were to be made in multiples of a square mile, hence the term *mailo*. The survey, commencing in 1902, soon burgeoned into an immense undertaking that was carried out by plane table and chain traverse. Index plans were maintained at a scale of 1:10,000, 1:5,000, or 1:2,500. The survey took much longer than anticipated and was not completed until 1936. Photogrammetric survey methods were tried, but the heavy vegetation cover made boundaries invisible from the air. Apart from the Mailo Register, Uganda also had a Freehold and Leasehold Register. In the freehold lands, aerial survey methods were used to plot control points from which individual traverses could be run.

The Survey Department in Kenya was established in April 1903. The influx of white settlers soon necessitated a systematic land survey, and prior to the 1950s, land titles were allocated according to the Registration of Titles Act of 1920. Almost all the land in the rural areas was held under customary tenure, and between World War I and World War II population pressure led to intensive cultivation and increasing subdivision and fragmentation of farm land. Between 1953 and 1955 the East African Royal Commission recommended that fragmented land be consolidated, and that African landholders, in townships as well as in rural areas, should received legal title. Land registration based on the English system of general boundaries was officially endorsed by the Native Land Registration Ordinance of 1959. This decision initiated a massive cadastral survey operation by the Survey of Kenya to produce the necessary maps using large-scale aerial photography. Base maps on a scale of 1:5,000, for consolidation and demarcation purposes, and final registration maps on a scale of 1:2,500 (fig. 760 above) were produced from 1:25,000 and 1:12,500 aerial photography, respectively (Ratzeburg 1960). From 1965 to 1978 the British DOS provided a sustained program of support that included the reconnaissance, premarking, and field observation of control for aerial triangulation, and the surveying of perimeter traverses around large areas by means of electronic distance measurement (McGrath 1983). Under the Registered Land Act of 1963 many millions of hectares were registered for hundreds of thousands of owners.

Zambia has a system of registration of deeds that evolved from concepts originating in South Africa. In 1976 it was reported that cadastral surveys covered only about 6 percent of the country and that the remaining 94 percent was held under customary tenure (Dale 1976, 269). In Tanzania (from 1895 to 1914 known as German East Africa, and from 1920 to 1961 as Tanganyika), the concept of cadastral surveying was originally introduced by the German colonial administration. The country follows a title registration system and all surveys are based on ground survey methods employing numerical techniques. In Namibia (previously South West Africa and a German colony from 1884 to 1914), the first surveys of farm land were undertaken in 1894. Because of the lack of a primary triangulation, farms were beaconed off using a compass and measuring band. After geodetic surveys were carried out between 1904 and 1910, all cadastral surveys were tied to the main triangulation. This situation continued after 1915, when South Africa took over the administration of South West Africa (Parry 1937).

France is considered the mother of the modern cadastre because early in the nineteenth century, Napoleon I ordered the complete cadastral survey of France including the compilation of maps and records showing the delimitation and ownership of all parcels of land, mainly for fiscal purposes. The French system also exerted considerable influence in the French colonies in North and West Africa (Larsson 1991, 29–30). Local survey departments were established, and the registration of titles was introduced in Tunisia in 1885; in the Belgian Congo in 1886; in Senegal, French Guinea, the French Sudan, and the Ivory Coast in 1906; and in Morocco in 1912. But because of the physical inaccessibility of many countries, cadastral surveys were undertaken only in minor portions of francophone Africa, mostly in urban areas.

Initially all land surveyors working in Africa were government surveyors, but private surveyors also gradually gained a foothold. As a rule, only licensed private surveyors could undertake a survey for title or deed registration. In almost all countries land surveyors belonged to a professional association founded to protect and serve both its members and the public. Currently the interests of land surveyors in twenty-three African countries are served by the African Organization of Cartography and Remote Sensing (AOCRS), which was established in 1988.

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SEE ALSO: Boundary Surveying: Africa; Cadastral Map; Directorate of Overseas Surveys (U.K.); Electromagnetic Distance Measurement; Geodetic Surveying: Africa; Land Systems Analysis; Property Mapping Practices

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Property Mapping in Europe. The need for taxation of real estate in the eighteenth and nineteenth centuries led to large-scale mapping throughout the Hapsburg Empire and to similar efforts in other parts of Europe. Property mapping in Europe in the twentieth century still recorded primarily three aspects: land ownership, tax value of land, and utility lines.

Changing technology, initially measurement technology and later electronic data processing, influenced how these tasks were executed and indirectly the responsible organizations. In an ideal world, ownership parcels would be measured once and the records maintained to reflect the few changes occurring. But in many countries it is difficult to maintain the necessary institutions, and a regular resurvey is a more reliable approach to mapping parcels for equitable taxation. The organization of land surveying in Europe thus varies widely, but in most areas the surveying records of land parcels are permanently maintained and used for both ownership registration and taxation. A few countries have a single organization (e.g., Switzerland), but many have two organizations: one for ownership or title registration and one for taxation. In these cases, surveying and mapping are done only once, and the resulting maps of land parcels are used for both purposes and maintained indefinitely (e.g., in Germany, the United Kingdom, the Scandinavian countries). A regular resurvey to produce a tax map, as is customary in the United States, is not usual in Europe.

In a few countries parcel mapping for legal and tax purposes is done by the same organization that is responsible for large-scale topographic mapping (e.g., the United Kingdom, Austria), but more common are separate national mapping agencies not involved in large-scale mapping. Parcel mapping is often organized nationally (e.g., Sweden, France, Finland, Austria, the United Kingdom), but in some nations it is organized at the province or state level (e.g., Germany, Switzerland). The execution of the necessary activities is very often completely or partially outsourced to land surveyors in private practice that either perform only the fieldwork (parts of Germany) or do the fieldwork and maintain the maps (parts of Switzerland). These licensed land surveyors are typically university educated (often possessing a five-year *Diplom-Ingenieur* degree) and have additional practical training on the job; often several years of practice are required.

European utility mapping, often described as AM/FM (automated mapping, facilities management) in the United States, became increasingly necessary in urban areas and is now common in a computerized form. Towns are often (partial) owners of the major utilities (water, sewage, electricity, gas), and the integration of individual utilities maintaining their separate maps to achieve comprehensive town utility mapping was easily accepted by politicians as a money-saving necessity. In exceptional cases, the integration of utility and ownership parcels was achieved very early; the city of Basel, Switzerland, for example, started its centralized utility mapping system (*Leitungskataster*) with integrated ownership parcels in the 1920s (figs. 763 and 764). Crucial for the functioning of integrated utility mapping systems are administrative rules that force the utilities to report any relevant changes in their installation to a central registry.

The cartographic techniques and the appearance of large-scale mapping changed after the introduction of electronic computers. Major shifts included a switch from plane table survey to polygon- and coordinate-oriented registries; replacement of blueprint reprography, which reduced cartography to black-and-white line drawings,

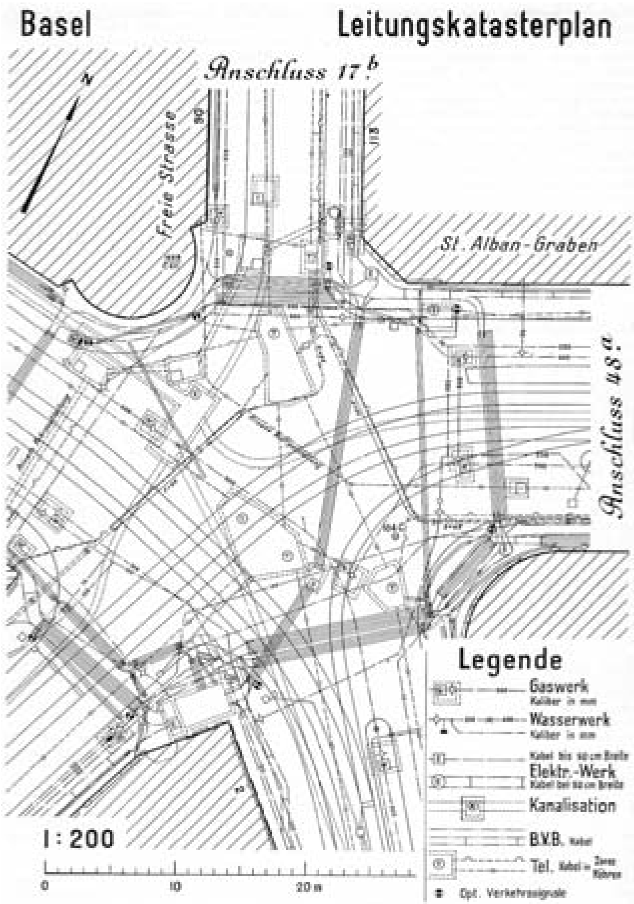

FIG. 763. *LEITUNGSKATASTERPLAN*, A HAND-DRAWN CADASTRE MAP FOR A MAJOR INTERSECTION IN BASEL, 1969.
Image courtesy of the Bau- und Verkehrsdepartement of the Canton of Basel.

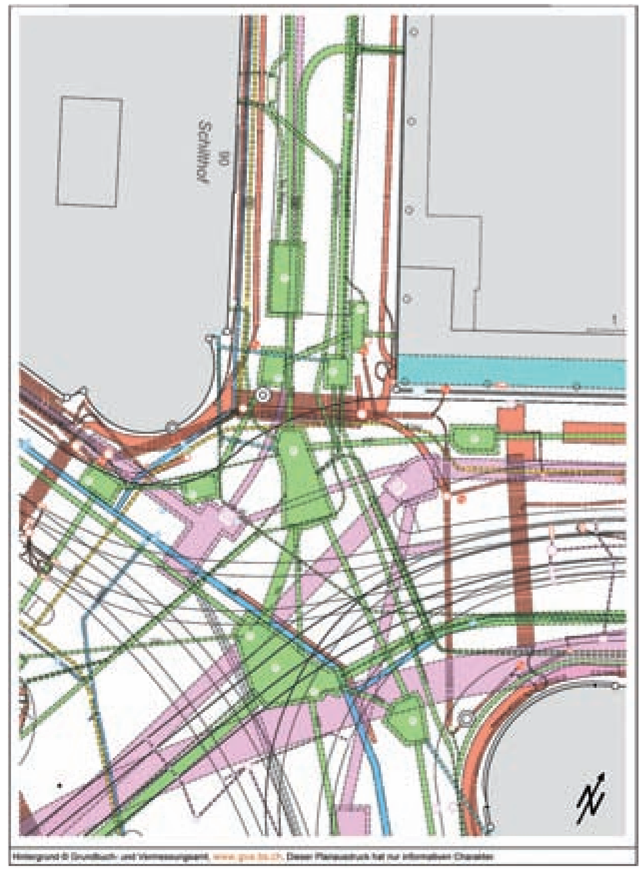

FIG. 764. COMPUTER-GENERATED CADASTRE MAP FOR A MAJOR INTERSECTION IN BASEL, 2012.
Image courtesy of the Bau- und Verkehrsdepartement of the Canton of Basel.

with computer-driven color plotters; automation of measurement instruments (electronic distance measurement, automatic registration, and Global Positioning Systems [GPS]), which reduced the expertise required for field crews; increased standardization (e.g., national standards for ownership and utility mapping); and computer graphics that reduced the need for graphical artistry. These developments were documented mainly in the gray literature (nontraditional, more informal, and often inaccessible or less accessible publications), which is highly compartmentalized by country and language, and few records survive. The following description is therefore of necessity partial.

The change most affecting cartography was the introduction of computers for storing and plotting large-scale maps. Land surveyors in Europe were among the first to automate the tedious and error-prone calculations in the early 1950s; in the 1960s centralized services offering survey calculations became common, and by the late 1970s computers (produced by Philips [the Netherlands] or Olivetti [Italy]) were often found in local surveying offices. Very precise plotters for cartographic output in ink on film (or photoplots) and very precise (0.01 mm) pricking of point positions were produced by various European companies (e.g., Gerber [Switzerland], Kongsberg Våpenfabrikk [Norway]). Experiments to draw large-scale maps with computers were undertaken because they promised that small changes could be done by simply editing the files that drove the plotters. Interactive editing tools produced in Europe (e.g., Ferranti [the United Kingdom] in cooperation with the city of Basel) became operational in the late 1970s.

The potential of computers for the maintenance of land records was recognized in the early 1970s. The AdV (Arbeitsgemeinschaft der Vermessungsverwaltungen der Länder der Bundesrepublik Deutschland), a voluntary working group of the surveying offices, started a project in 1976, the goal of which was the computerized management of parcel data and the automated plotting of the ALK (*Amtliche Liegenschaftskarte*, official parcel map). The project assumed that smaller-scale cartography could be derived from a more detailed survey. Quickly the need for a separate ungeneralized database and a cartographic data set became clear, and an effort on research in automated generalization was needed (Staufenbiel 1973). The project intended to produce a very detailed large-scale machine-readable geographic information system for Germany. At the end of the twentieth century, the project was nearing completion, but progress in the *Länder* (federal states) varies. Technically the project cooperated with the computer manufacturer Siemens using a mainframe operating system, BS2000, and the database management system UDBS based on the CODASYL standard. A geographical editing workstation was built, which was a precursor for the workstations that appeared in the 1990s.

Utility mapping was influenced by the DIME (Dual Independent Map Encoding) system developed by the U.S. Bureau of the Census. Numerous SORSA (Spatially Oriented Referencing Systems Association) conferences created a platform for interested towns to share their experience and solutions. Efforts by the larger towns were sometimes in conflict with regional and national large-scale mapping projects, and discussions about the cost-effectiveness of different solutions occupied many meetings in the 1980s, but were hardly ever conclusive.

In 1978 a conference on land information systems (LIS) was organized in Darmstadt (Eichhorn 1978). The LIS vision was to bring together all large-scale mapping into a single computerized repository and make it available equally to all interested services. It was conceived as a computerized version of the existing multipurpose cadaster, which was a manual overlay-based method used by many cities to combine the information from different utilities in order to obtain a comprehensive view. LIS was similar in concept to GIS (geographic information systems) and is now subsumed under this acronym, but it was originally conceived by different professionals (surveyors, town administrators, utility engineers) than the GIS vision produced by geographers. It was for some years propagated by the International Federation of Surveyors (FIG) and the conferences were seen as contrasting with the Auto-Carto meetings, where the focus was more on small-scale mapping and representations of geographic reality.

By the end of the twentieth century, the concepts of how large-scale mapping should be done had completely changed to that of GIS. The prevailing systems covered all aspects of collecting, managing, and representing spatial information, and most systems used one of the standard commercial software systems, nearly all of which were produced by U.S. companies. The conversion of records was under way; major cities were often introducing new systems where there was no centralized geometric record keeping before. As the potential for sharing updated collections between authorities was explored, difficult organizational, legal, and technical questions arose. Access to large-scale maps and the related records was typically granted for a fee, and sometimes other restrictions also applied (e.g., distribution only to legal professionals and banks in Germany).

The change in technology also substantially affected education and training. Manual cartography, the related training facilities, and university curricula began disappearing. University institutes either refocused on computer cartography or disappeared altogether. The ease of use of computerized measurement instruments reduced the need for university graduates to collect data, thereby decreasing the number of active professionals. This again affected education, and the number of technical universities offering surveying and mapping degrees was smaller in 2000 than in 1950. Before 1950 all professionals in large mapping organizations had surveying and mapping degrees. By 2000, the educational background was more varied, and some professionals had computer science or geography degrees.

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SEE ALSO: Administrative Cartography; Cadastral Map; Electromagnetic Distance Measurement; Geodetic Surveying: Europe; Property Mapping Practices; Tax Map

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Property Mapping in Russia and the Soviet Union. During the twentieth century, property mapping in Russia underwent changes in all the state systems of planning, designing, compiling, publishing, and using topographic and large-scale maps. This was caused both by political events and by the historical development of land surveying in Russian cartography. The political events were the changes in government in 1917 and 1991, which modified national economics, and the two world wars that produced significant border changes.

Many researchers (Komkov 1967; Komedchikov 2000; Postnikov 1989, 1996; Sudakov 1967) have attempted explanations of the historical background. By 1917, many cartographic documents existed (Novokshanova-Sokolovskaya 1967). The most important of these were the military topographic maps of the territories on the western boundary at scales of one (1:42,000); two (1:84,000); three (1:126,000); and ten versts (1:420,000) to the inch. Special topographic maps of European Russia and the regions of Caucasia, Central Asia, and the

Far East also existed. Topographic maps of several western and central provinces on scales of 1:16,800 and 1:21,000 had been compiled by 1845. Anatoliy Markovich Komkov (1967, 255) noted the very high quality (geographic accuracy, exactness, and completeness) of these maps as well as the extremely poor overall coverage of Russia's territory. On the eve of the October Revolution, more than four million square kilometers (less than one fifth of the territory) had been covered with topographic maps. Due to the different scales of these maps, they did not conform to one another either mathematically or in their content and design.

For many years, various institutions like the Russkoye geograficheskoye obshchestvo (RGO) (in 1884), the Akademiya nauk (in 1898), and military authorities (in 1911) attempted to solve the critical situation of mapping of the entire country by proposing a special Council of Geodesy (Sovet po geodezii). The academician Vladimir I. Vernadskiy in 1916 petitioned the Akademiya nauk for the unification of topographic survey and land measurement in Russia. An interdepartmental academic commission organized a few meetings but produced no results. Thus from its very beginning the Soviet government was confronted with an urgent need to create a national system of land surveying. In 1918, the geodetic bureau, a division of the People's Commissariat of Agriculture (Narkomzem), was formed to design a project of national land surveying. Based on the study, the Council of People's Commissars, Sovet narodnykh kommissarov, issued a decree to establish the higher geodetic administration, Vyssheye geodezicheskoye upravleniye (VGU), in March 1919. The VGU has changed its name many times since its establishment (Komedchikov 2006, 85; and see table 18). The last name of the VGU in the Soviet Union was the Glavnoye upravleniye geodezii i kartografii (GUGK). In 1992 it was changed to the Federal'naya sluzhba geodezii i kartografii Rossii (Roskartografiya).

According to A. V. Borodko (2004), the VGU, under the scientific-technical section of the highest council of the national economy (Vysshiy sovet narodnogo khozyaystva) had been organized for the centralization of all geodetic and cartographic work in the country, except military topographic surveying, which was planned and executed by the military topographical service—Voyenno-topograficheskaya sluzhba. Alexey V. Postnikov (2002) stated that the activities of both agencies were interrelated and under state control and also under the direct supervision of the Soviet security police.

This centralization implied that the VGU's responsibility included providing guidance and execution of all land measuring; the mapping of the entire territory of the Soviet Union; the integration of all the institutions related to geodesy and cartography; the design of unified standards, guidelines, methods, and means; and the research activities in geodesy, cartography, astronomy, optical instruments and devices, and education. Therefore, it was possible for the special scientific-technical council of the VGU under Feodosiy Nikolayevich Krasovskiy and the scientific board of the All-Union Cartographic Trust (Vsyesoyuznyy kartograficheskiy trest) under M. A. Tsvetkov to oversee the development of new theoretical and methodological foundations for topography, geodesy, and large-scale mapping. One of the first steps was the determination of a set of new scales based on the metric system for state surveying. This set of scales was 1:10,000, 1:25,000, 1:50,000, 1:100,000, 1:200,000, 1:500,000, and 1:1,000,000. Also specified was the projection, the sheet divisions, and the numbering of topographic maps at all scales based on the 1:1,000,000 International Map of the World. The establishment of the new national scales was of primary importance for the VGU because the previous set was based on measurements in versts used in surveying by the corps of military topographers, the Korpus voyennykh topografov (KVT). This resulted in many mismatches over such an enormous country as Russia (Sudakov 1967, 45–46). Krasovskiy calculated a new model of the astrogeodetic geoid, and proposed a new scheme for the national geodetic network (triangulation, leveling, astronomical observations).

The period from 1917 to 1940 was very important in the development of national land surveying, as a whole series of topographic maps was compiled under uniform standards. Due to the country's acute need for maps and the official change to the metric system, the VGU proceeded with compilation of new topographic maps using old sources based on verst scales. By 1926, about eight hundred topographic maps at 1:100,000 were published based on the three-verst-scale manuscript maps. Even so by 1940, the sheets of the 1:100,000 map did not yet cover the European part of the country. Due to the war, by 1942 a map at 1:200,000 scale was compiled to meet the army's requirements.

All topographical mapping had to be done under security regulations. By 1940, special guidelines controlled the execution of topographic, geodetic, and cartographic activities by all the institutions in the Soviet Union. In spite of the war and security requirements, the creation of the state map of the Soviet Union at a scale of 1:1,000,000 was completed in 1945. In 1947, the RGO awarded GUGK the Big Gold Medal for the creation of the state map. Komedchikov (2006) described in detail the history of the map's design and compilation. According to Postnikov (2002, 250), after World War II security regulations for topographic maps became more strict. Special instructions for using and storing topographic maps required them to be kept as secret and official-use-only documents. Even professional topographers using topographic maps for their field surveys had to sign an understanding to use the maps under strict rules.

Under these circumstances, the set of scales determined in the early 1920s became the basis for all work of land surveying. In 1948 systematic surveying at 1:10,000 and 1:25,000 scales started, but the first priority after World War II was a survey of the entire Soviet Union for 1:100,000 topographic maps. By 1954, the state project at 1:100,000 was completed and by the early 1980s topographic maps were being updated at the 1:25,000 scale. The maps at the scales of 1:1,000,000 and 1:500,000 were treated as documents of restricted use with the stamp "for internal service use only" and could not be used as a source for general-purpose mapping. All the mapping at larger scales fell into the category of secret materials. Compilation of maps for ordinary users could be based on the 1:2,500,000 maps.

During the years of land surveying in the Soviet Union only state topographic mapping under strict security control was accomplished. However, some special project maps concerning aspects of land tenure were completed. In 1960 an atlas of agriculture of the Soviet Union was published. More than three hundred scholars from different scientific institutions compiled a set of about three hundred original maps of natural conditions, evolution, and agriculture. The majority of these maps were designed and compiled at the regional level at the scale of 1:30,000,000 (fig. 765).

In the early 1970s topographic surveying at 1:5,000 and 1:2,000 scales in urban and other settled areas was started (fig. 766). This important form of land surveying was done under the guidelines of GUGK (GUGK 1982). By the beginning of the 1990s nearly 2,200 cities and 1,400 urban and agricultural settlements were provided with topographic plans at 1:2,000 or 1:5,000 scales.

This kind of state topographic surveying is the oldest in Russia (Postnikov 1996). The plans of town fortresses had been depicted in the sixteenth century from the time of Czar Ivan IV, and urban surveying had developed intensively under a 1720 decree of Czar Peter I. Many of these plans were combined into special geographic atlases. The topographic plans at 1:2,000 and 1:5,000 provided the initial data for large-scale and very large-scale land surveying. This type of surveying included buildings and cottages, underground (metro) tunnels, agricultural and forest plots for environmental purposes, individual economic objects, land reclamation (irrigation), and water resources management surveying at 1:5,000, 1:2,000, 1:1,000, and 1:500 scales. Land measurement at urban construction sites developed in Moscow, Leningrad, and other major cities. This was used for planning and demarcation of suburban cottage settlements but was limited under security guidelines and therefore was not for wide distribution. Underground geodetic land surveying was needed for the many hundreds of kilometers of underground systems in Moscow, Leningrad, and other Soviet cities where there was metro construction.

Gradually security restrictions on national cartography were reduced until the late 1980s. In 1989, the Voyenno-topograficheskaya sluzhba began to publish maps at 1:200,000 for use in business, industry, and agriculture and for sale to ordinary consumers. All these maps were based on military topographic maps and other formerly confidential data. Large-scale and very large-scale mapping of agricultural, forest, and irrigation plots and water resources management areas started in Russia in the middle 1990s. According to the resolution of the federal agency of real estate (Rosnedvizhimost) this land surveying was needed to create the state land cadastre and to evaluate the quality of different land parcels. The land plot became the basic unit of mapping, and cadastre plans showing the boundaries of the land plots became necessary documents. A set of cadastre plans for a region formed the basis on which current taxes were updated (described by Neumyvakin and Perskiy 2005). Similarly, individual plans of afforestations and estimations of the predominant species of trees were put together as forest management catalogs for individual regions.

In 2006, an atlas of the land resources of areas surrounding large Russian cities was published; it was a very important result of the state cadastre and land surveying work. Two volumes of this atlas display sets of four maps for each zone of thirty kilometers for each of the ninety largest cities. Every set of four maps (all at a scale of 1:200,000) includes one general chart and three maps showing land use patterns: (1) ownership (state, municipal, and private), (2) categories of grounds and cadastral valuation taking into consideration the designated end use and the value, and (3) quality rating based on eight classes (fig. 767).

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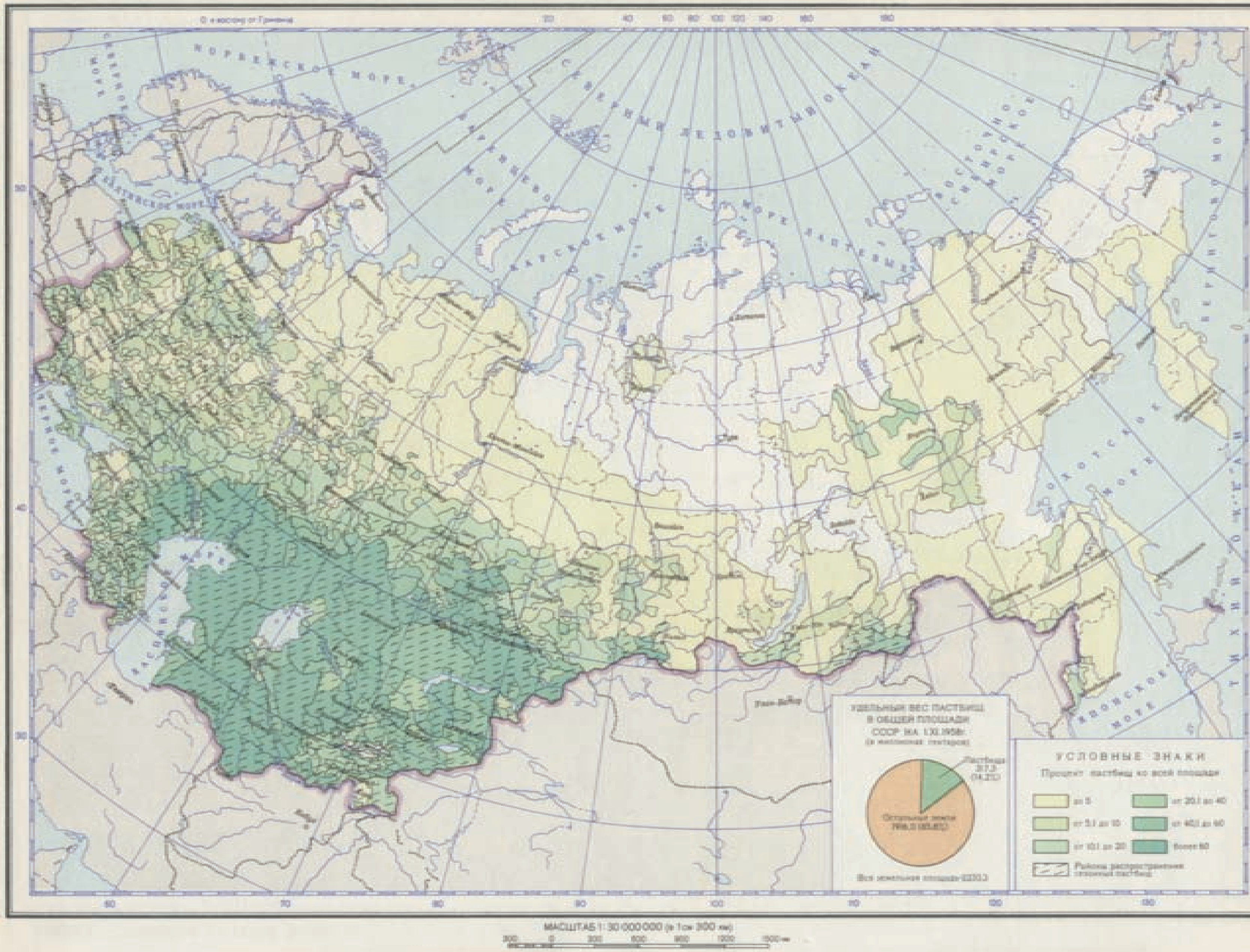
FIG. 765. PERCENTAGE OF PASTURE IN THE TOTAL AVAILABLE LAND IN THE SOVIET UNION IN 1958, 1:30,000,000. *Protsent pastbishch ko vsey ploshchadi* is one of three hundred maps in an atlas of agriculture presenting at small scale an enormous amount of statistic information gathered from all regions of the country on the basis of state surveys. Size of the original: 22.4 × 29.3 cm. From A. I. Tulupnikov, ed., *Atlas sel'skogo khozyaystva SSSR* (Moscow: GUGK, 1960), 94. Image courtesy of the Rossiyskaya gosudarstvennaya biblioteka, Moscow (Map Division).

ПРОЦЕНТ ПАСТБИЩ КО ВСЕЙ ПЛОЩАДИ



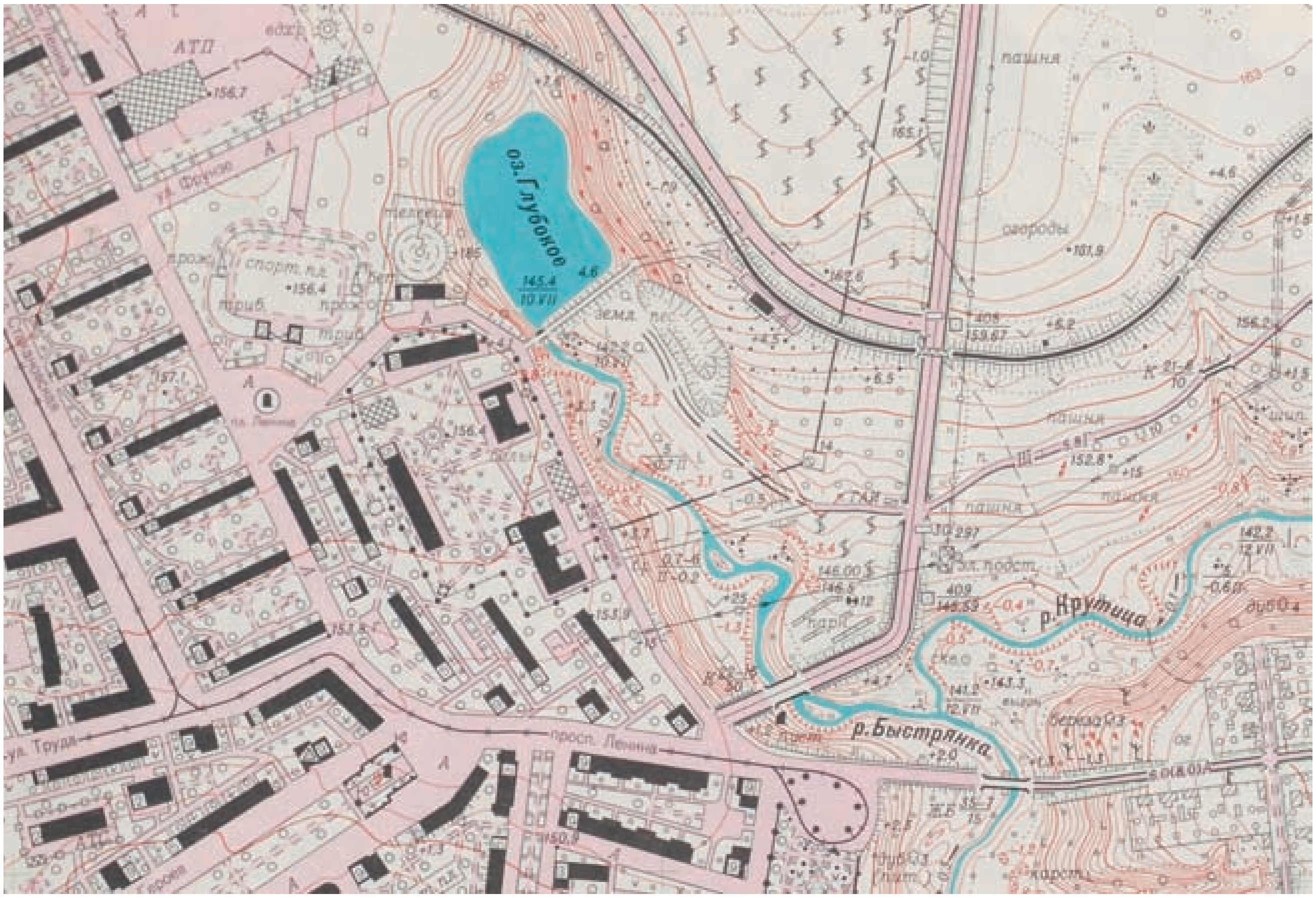


FIG. 766. DETAIL OF A LARGE-SCALE URBAN TOPOGRAPHIC MAP. This map is an example of urban topographic mapping at 1:5,000 scale within the specifications of the state topographic surveying framework. The survey was done in 1972, but the names on the map are fictional. The map is titled *RSFSR Ol'shanskaya oblast' Petrovskiy rayon* (Moscow: GUGK, 1977).
Size of the entire original: 52 × 48 cm; size of detail: 13.7 × 20.1 cm. Image courtesy of the Rossiyskaya gosudarstvennaya biblioteka, Moscow (Map Division, Ko 125/XI-44).

Land surveying based on aerial photographs started in the middle 1930s, and at the end of the century it was the basic method of large-scale land investigations. Several researchers (Zinchuk 1989; Zolotarev and Khar'kovets 2000; Knizhnikov 2004) described in detail the use of air photo images for afforestation studies, large-scale orthophotomaps for glaciological research, and phototheodolite stereo surveying for investigations of mountain regions (fig. 768). The most modern methods of land surveying include mobile scanning systems and satellite techniques. E. M. Medvedev (2006) described the use of ground scanners mounted on a mobile platform equipped with an integral navigation complex including a GLONASS (Global'naya Navigatsionnaya Sputnikovaya Sistema) receiver set. These systems are most suitable for the three-dimensional surveying of linear and area land objects.

The first use of space technology for mapping was in the 1970s. Rapid development of satellite techniques made very high-resolution digital images from space available. V. I. Kravtsova (2003) described in detail the receiving of spatial and height cartographic data by means of the satellite complex "Resource-DK," which proved efficient in topographic mapping as well as in land surveying.

To conclude, it is worth noting that property mapping existed in the framework of the state topographic survey until the 1990s. At the end of the century new technology, satisfying the requirements of modern land surveying standards, was in use. Property mapping in Russia exploited mobile ground systems data collection and digital data from space with a very high resolution.

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SEE ALSO: Electromagnetic Distance Measurement; Geodetic Surveying: Russia and the Soviet Union; Property Mapping Practices

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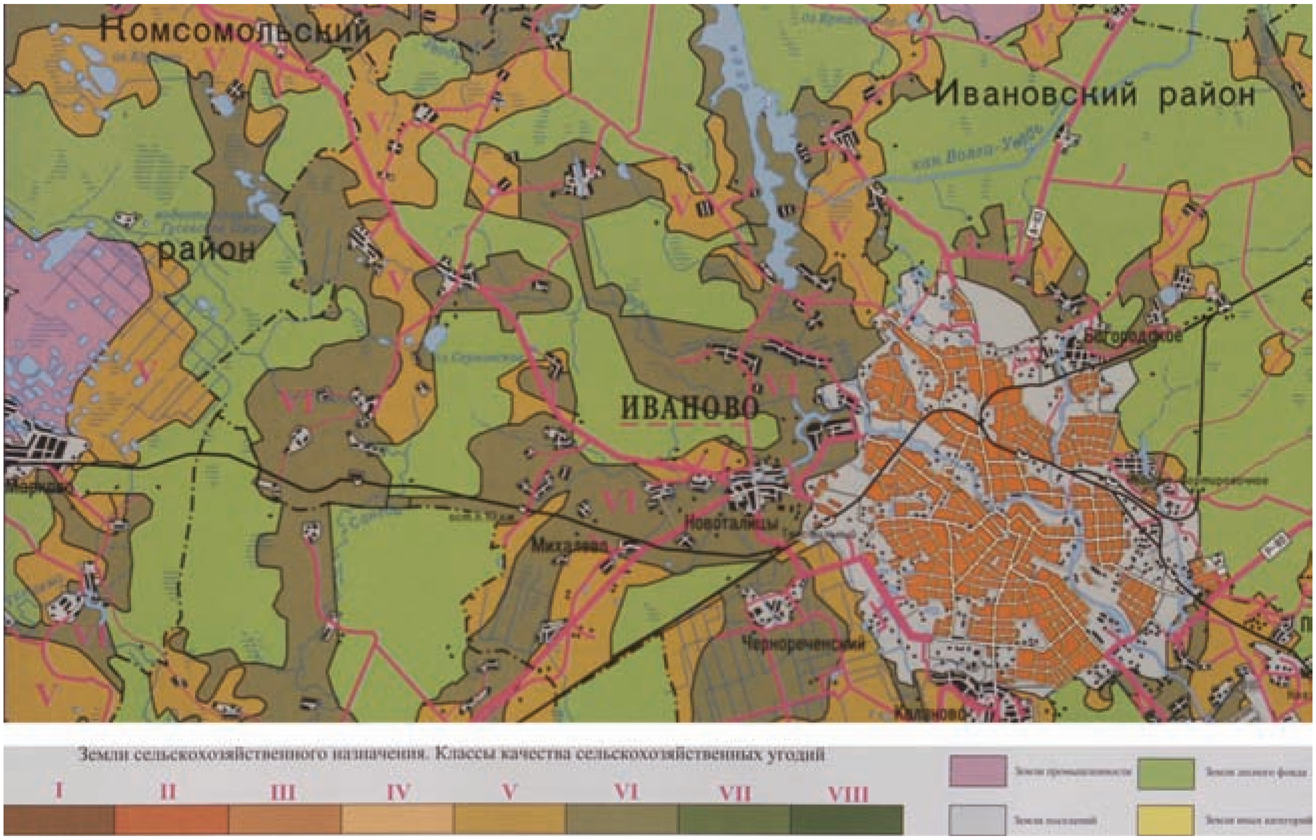

FIG. 767. DETAIL AND LEGEND FROM MAP ESTIMATING AGRICULTURAL LANDS, IVANOVSKAYA OBLAST, 1:200,000. The *Otsenka kachestva sel'skokhozyaystvennykh Ugodiy* shows land use patterns in the Ivanovo district and rates the quality of the agricultural land in eight classes (I–VIII). The four color categories on the right are industry, settlement, forest, and other.

Size of the entire original: 38 × 33 cm; size of map detail: 11.3 × 20.6 cm; size of legend: 2 × 29.6 cm. From *Zemel'nyye resursy territoriy, prilegayushchikh k krupneyshim gorodam Rossii* (Moscow: Rosnedvizhimost, 2006), 39. Image courtesy of the Rossiyskaya gosudarstvennaya biblioteka, Moscow (Map Division, Ko 3/24).

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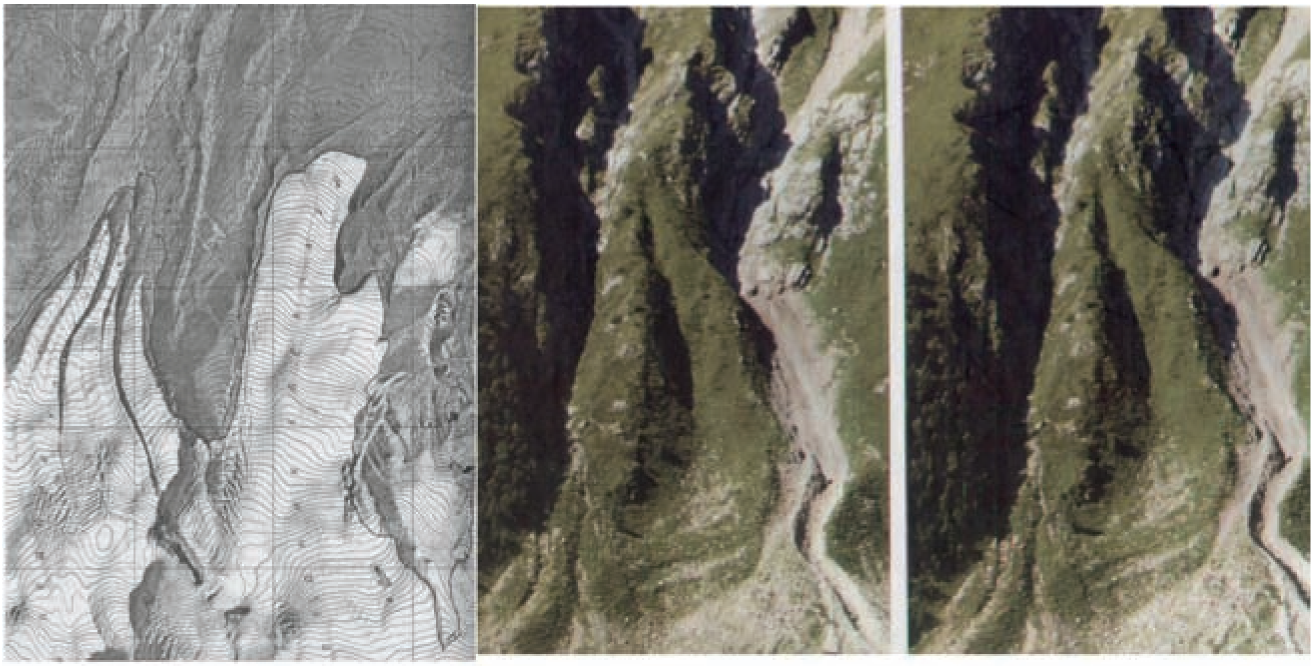
Property Mapping in Australia and New Zealand. Throughout the twentieth century, property mapping in Australia and New Zealand focused largely on the definition of property boundaries in accord with statute and legal precedent. This reflects a radical shift from



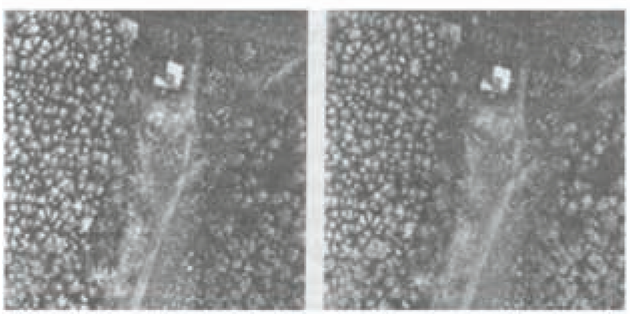


FIG. 768. THE RESULTS OF SPECIAL LAND SURVEYING TECHNIQUES. Top left: part of an orthophoto map of Mt. Elbrus compiled by air survey on 8 September 1997; an arbitrary coordinate system is used. Top right: ground phototheodolite stereo pair of a mud avalanche in the dangerous locality of the Cheget Mountains. Bottom: an example of air photo stereo pair used in forest investigations, 1:2,000.
From Zolotarev and Khar'kovets 2000, 176; Knizhnikov 2004, back cover and 46, respectively. Image courtesy of the Rossiyskaya gosudarstvennaya biblioteka, Moscow (Map Division, FB 11 87-3/11-3, 1 04-27/52).

the nineteenth century, when lands occupied for 40,000 years by indigenous peoples had come under a British colonial administration with a different approach. Each colony appointed a surveyor general, who was responsible for land and survey standards. Because of a shortage of qualified surveyors, property surveys often lagged behind actual occupation, and the English common law titling system became cumbersome. In 1858 Robert Richard Torrens introduced South Australia to a guaranteed titling system, which soon spread to all jurisdictions. The Torrens title system is based on the cartographic representation of boundaries on plans and a single certificate of title showing all interests instead of just a metes and bounds description with a chain of deed transfers. The system provided the necessary uniformity, and the reciprocal arrangements that developed in 1892 between individual boards of examining surveyors continued through the twentieth century.

Although the Australian colonies were joined in a federal system in 1901, state and territorial governments retained responsibility for land tenure and property mapping. To address issues of training and practice pertinent to this decentralized responsibility, a conference held in 1912 and attended by all surveyors general reinforced the reciprocity of surveyor licenses and the desirability of uniform survey plans. The acts and regulations of the various states and territories relating to property dealings continued to regulate property mapping, and some jurisdictions required registration for other kinds of surveying.

Property mapping made significant progress during the twentieth century, which ended with most land parcels under the Torrens system (Whalan 1982). Registered survey plans were manually examined for title use and then indexed on hard copy county or urban plans. As property description was traditionally related to a land parcel's current and past occupants, not to geography, cadastral plans were not directly compatible with topographic maps. The computer revolution of the 1980s changed procedures and paved the way for automated title registers, with online searching linked to an increasing range of property-related information. At the end of the century, following the electronic imaging of registered plans and transactions, most titling information was available online. This led to the remote filing, examination, storage, and dissemination of subdivision plans, which provided an alternative to the traditional paper documentation process used by land surveyors.

The need to integrate the broader fabric of cadastral information with other spatial data was initially met by digitizing cadastral index plans to produce digital cadastral databases (DCDBs). Because the index plans lacked geodetic survey control and thus showed only relative position between surveys, the digitized maps had limited utility in the field and were not easily or reliably integrated with more accurate information (Wan and Williamson 1995). Lack of geodetic control required accuracy upgrades, or recomputation of DCDB coordinates from survey plan measurements (Elfick, Hodson, and Wilkinson 2005).

Because introduction of the new Geocentric Datum of Australia (GDA94) was gradual, by 2000 most digital land surveying records needed to be related to the new datum by recomputation or transformation (Collier, Argeseanu, and Leahy 1998). The integration of land parcels identified by monumentation, but not georeferenced with other spatial data, remained an issue in some jurisdictions in the early twenty-first century. This problem reflected past pressure to carry out titling surveys without an adequate geodetic framework.

Utilities and local councils were responsible for large-scale survey plans and spatial data, while state governments remained responsible for the boundary information that provided a wider framework. In addition, the federal government had its own spatial data as well as the national cadastral data set and other national data sets produced by the Public Sector Mapping Agency (PSMA). A growing need to coordinate spatial data sets from local, state, and federal governments led to the creation of the Australia Land Information Council (ALIC) in 1986 (renamed Australia New Zealand Land Information Council [ANZLIC] in 1991) and to the concept of the Australian Spatial Data Infrastructure. Traditionally, the Intergovernmental Committee on Surveying and Mapping, which is integrated with ANZLIC, had been responsible for coordinating surveying and mapping between state and federal agencies as well as for developing the National Spatial Data Infrastructure.

Property mapping in New Zealand is similar to that in Australia although recognition of Māori customary land, the title to which was not derived from the Crown, made the titling system more complex. Originally administrated as part of the colony of New South Wales, New Zealand became an independent colony in 1841 (following the signing of the Waitangi Treaty) and a dominion in 1907. The Torrens title system was adopted in 1870 and replaced the deed registration system. The Native Land Court, established in 1862 (renamed the Māori Land Court in 1947), continued to administer customary Māori land throughout the twentieth century.

At the end of the twentieth century widespread demand in both countries for automated information management and more efficient access was met through online property information and land transfer systems. In Victoria online access to land title records was available in 2001, following digital deposit of survey plans. Similar systems were installed in other jurisdictions, including the New Zealand LandOnline, an advanced automated survey and title system, which phased out paper records. The benefit of improved integration of cadastral and mapping information within a digital cartographic environment was demonstrated by outside providers such as Microsoft, Google Earth, and Google Maps. Property mapping had become one element within the broader, highly linked spatial information industry.

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SEE ALSO: Electromagnetic Distance Measurement; Geodetic Surveying: Australia; Land Systems Analysis; Property Mapping Practices

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Property Mapping Practices.

PROFESSIONAL PRACTICE IN LAND SURVEYING
TRIANGULATION, TRILATERATION, AND TRAVERSE
MONUMENTATION AND RECOVERY
GLOBAL POSITIONING SYSTEMS AND PROPERTY SURVEYING

This composite examines the recent history of four key elements of property mapping, also known as land surveying. "Professional Practice in Property Mapping" provides an overview of the surveying profession, which not only subdivides land for sale or development but also describes or demarcates a broad range of structures and infrastructure, including foundations, highways, railways, bridges, and dams. "Triangulation, Trilateration, and Traverse" examines the techniques involved in laying out an original survey; "Monumentation and Recovery" addresses the challenge of marking boundaries no longer readily apparent on the land; and "Global Positioning Systems and Property Surveying" assesses the impact of GPS in the final decades of the century. The preceding composite, "Property Mapping," addresses the application of this suite of practices within major regions.

Professional Practice in Land Surveying. To many people, surveying is merely a technical application of measurement science—an accurate assessment insofar as the positioning and measurement involved in estimating the size and shape of the earth are inherently technical. But in a broader context, surveying is the application of measurement technology in gathering land-related information for the advancement of society.

The surveying profession encompasses a broad scope of practice that includes geodetic, topographic, and hydrographic surveys, which essentially determine the size and shape of the earth and its parts. In addition, seismic and geophysical surveys determine the subsurface geology of the earth's crust, whereas engineering and construction surveys help lay out infrastructure on, over, and under the earth's surface.

Land surveying, also called cadastral surveying, legal surveying, and property mapping, requires the use of precise instrumentation to define legal interests in real estate. As such, it is the application of measurement science to real property law in the determination of the limits of parcels ranging from private land holdings to international boundaries. A land survey is a legal exercise in the field to delimit the boundaries of either proposed or existing properties but in itself is not a mapping exercise.

The cadastral surveyor holds a unique responsibility in society, namely, looking out for the interests of both the client and the client's neighbor, who is a potential adversary. In this sense, the surveyor is in effect a public officer. Every survey prepared to demarcate a parcel of land becomes part of the public record, and the boundaries defined by that survey are etched upon the landscape of the earth potentially for all time. Survey plans form part of the cadastral base map that is relied on by all agencies involved in land management, whether they be government officials, public utility providers, land managers, or private land owners. As Justice Jean Leon Côté (2006, 129) of the Alberta Court of Appeal incisively observed, "A surveyor certifies to the whole world that a certain point or a certain plan ties in to a large, overall publicly-ordained scheme of things . . . . a surveyor has all sorts of public powers. You can enter on to private land, you can question people under oath, and you make judgments. It isn't just a mechanical matter, you weigh evidence and come to conclusions and that sticks and it is accepted by everybody, including the courts."

In many countries the practice of surveying includes land valuation, land economics, town planning, and real estate sales as well as more traditional aspects of land surveying. Surveyors over the ages have been the pathfinders to development of the hinterlands and had to be observant, resourceful, and environmentally conscious.

In light of the foregoing, it should come as no surprise that the surveyor must conform to a comprehensive ethical code. In addition to serving as a professional measurer and gatherer of land information, the surveyor must be well versed in real property law, geography, and adjudicative principles. As in other professions, the surveyor's ethics must reflect integrity, independence, and objectivity as well as a commitment to working with care and diligence and to maintaining confidentiality.

In Canada and the United States, surveyors are organized by province or state, a policy well established before the twentieth century. In most of the rest of the world it is more common for surveyors to be associated with national survey organizations. In Canada, professional survey associations all have full responsibility for the determination of entrance requirements, licensure, discipline, and the maintenance of competency. In most other countries the responsibility for licensure and discipline is retained by an agency of the government.

Instrumentation has been far less static as surveying technology evolved from the chain and compass era of the late nineteenth century to electronic distance measurement (EDM) and satellite positioning in the latter half of the twentieth century. EDM, which became common in the 1950s, evolved into total stations, which electronically measure both angles and distances, in the 1970s. The Global Positioning System (GPS) relying on signals from a constellation of twenty-four artificial satellites became common toward the end of the century. Surveyors were quick to adapt computers and related hardware to their practices because of the massive number of calculations required to check and reduce their work to a graphic format. Electronic plotters and land information systems soon followed to assist the surveyor with office work. By the end of the twentieth century many land registration offices required that property maps and other survey data be submitted electronically to promote efficient filing, retrieval, and even online access. Electronic retrieval of land information and its integration with geographic information systems (GIS) have not only increased the efficiency of land departments but also improved access by the general public.

The scope of the surveying profession changed considerably since 1900. At the turn of the century, surveyors were first on the scene in the development of many frontier areas. Their expertise was applied across a broad spectrum of what are now separate professions in their own right. The early surveyor was an engineer, town planner, mapmaker, and because of his (rarely her) impartial objectivity often even conscripted as an arbitrator or mediator to settle disputes. As frontier areas grew and prospered, and society became more advanced, specialists complemented and then relieved the surveyor of many of these extra duties.

The training of surveyors, particularly in North America, was usually an adjunct of civil engineering programs, with many civil engineers devoting their practices to surveying (McLaughlin 1981). Toward the middle of the century, as both civil engineering and surveying became more specialized, civil engineering programs became less oriented toward surveying, and the need for specialized surveying degree programs became evident. These programs, in turn, developed their own special focus in positioning and measurement and later in land information and land management. Surveyors were always gatherers of information—fact finders, if you will. Early surveyors laying out settlement patterns in frontier areas were assigned the additional tasks of reporting on soil conditions, topography, watercourses, timber, availability and quality of water, potential for water power, climate, availability of hay, fuel, stone quarries, presence of minerals, and kinds of game to be found. This information formed the basis for the only detailed mapping of frontier areas for land administration, conveyancing, and homesteading.

Specialized college-level survey programs developed to shift the training of surveyors from the civil engineer's focus on design to a broader concentration on land administration. Over the years this refocusing led to a redefinition of the term *surveying* and the adoption of the new moniker *geomatics*, which was enthusiastically adopted in the late twentieth century as the name for many surveying departments around the world. According to Canadian geomatics educators Pierre Gagnon and David J. Coleman (1990, 378), "Geomatics is a field of scientific and technical activities which, using a systemic approach, integrates all the means used to acquire and manage spatially referenced data as part of the process of producing and managing spatially based information."

In sum, over the course of the twentieth century the surveying profession in North America has evolved markedly from the surveyor who led a party of ten to twenty men on a six-month trek across uninhabited lands, measuring and laying out plots of land for settlement by anxious homesteaders. No longer largely dependent on the steel tape and optical instruments, the land surveying or property mapping specialist of 2000 relied on electronic satellite receivers, computer-assisted drafting, digital plotters, and massive land information systems to deliver maps and consulting services to land developers, governmental agencies, legal firms, and ordinary home buyers.

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SEE ALSO: Forensic Mapping

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Triangulation, Trilateration, and Traverse. A network of control points covering the area is required to make a map of a tract of land so that all details and map sheets fit together in a consistent manner. Thinking globally, a control network of coordinated points, based on a consistent reference framework, should first be established to cover the whole world. This network has then to be broken into smaller and smaller networks either by ground surveying methods, such as plane tabling, or from aerial or satellite imagery. This produces the necessary framework for the addition of map detail. The procedure, of working from the whole to the part, has ever been the goal of the mapmaker: a goal really achievable only with the coming of satellite technology in the 1980s, although astronomical methods, based on the earth's gravity field, did provide a partial solution in earlier times (Bomford 1981; Kulkarni 2006).

Even when the technology became available, the time taken to provide this control caused unacceptable delays in the mapping process, which had to proceed before properly processed coordinates were available. Maps were based on provisional coordinates, leaving the knotty problem of reconciling such maps to a new coordinate system at some later date. Only at the end of the twentieth century did computer systems allow an efficient reconciliation to become practicable and cost-effective.

Lacking the benefit of satellite technology for most of the twentieth century, the surveyor had no choice but to build a series of linked chains of control points covering the area to be mapped (Rainsford 1951; Hotine 1939). The methods used to establish these chains were governed by the available technology, both in executing the measurements and processing the results. To explain how the work was done, it is necessary to cite a few dates in the evolution of surveying technology, which has been described in some detail by J. M. Rüeger (2006).

Angle measurements were made by theodolites capable of achieving an accuracy of one sexagesimal second of arc. Major improvements in theodolite design were introduced in 1936 by Heinrich Wild (Strasser 1966). The hand recording of data was slow and subject to mistakes. By the 1990s theodolites infallibly recorded angles automatically, sometimes linked by radio to a nearby processor.

Until the advent of electromagnetic distance measurements (EDM) in the 1950s (Rüeger 2006; Frank 2006), distances were measured with steel and invar tapes or bands, often 100 meters long. The tape measurements were made either along flat ground such as railway lines, a common practice in the United States, or suspended in catenary in bush covered ground. One of the last long lines of thirteen miles was measured by 100-foot tapes in Kenya by the Directorate of Overseas Surveys (DOS) in 1957 (Humphries and Brazier 1958). Sometimes quicker but less accurate hybrid systems such as subtense bar or optical tachymetry were adopted. These methods were tedious in practice and of limited range. The introduction of Trevor Lloyd Wadley's microwave Tellurometer in 1957 (Rüeger 2006; Allan 1998) revolutionized surveying. With this system, two surveyors could measure lines of up to 150 kilometers in half an hour. Although the Tellurometer had some accuracy limitations due to uncertain refraction and multipath problems, it opened the way to close gaps in many national and international triangulation networks. This was usually accomplished by the running of traverses on towers over the flat terrain that had hitherto remained unsurveyed. The later 1960s development of short-range EDM based on infrared and laser technology further improved both speed and accuracy (Rüeger 2006; Allan 1998).

Early attempts in the 1960s to combine the theodolite and EDM produced a series of hybrids, such as a theodolite mounted on a Geodimeter 6 or the Wild DI 10 EDM mounted astride an optical theodolite (Allan 1998, 466–67). Soon the total station emerged as a combined theodolite and distance measurer, incorporating either an infrared beam or an optical laser. The first total stations were the Zeiss RegElta 14 and the Geodimeter 700, although it was left to the Hewlett Packard Company to coin the term "total station." Initially these instruments required a reflector (corner-cube or mirror) to be placed at the point to be surveyed; the most accurate work still requires this placement. However, many laser instruments do not require a reflector and merely rely on a hard surface for a suitable reflection.

By the end of the twentieth century semi-robotic instruments came into use. These devices, which do not require an operator in attendance, are directed by radio or optical signals initiated by an operator positioned at the remote roving reflector. This operator identifies and codes types of detail or special geometrical information, such as breaks in ground levels, to serve a computer software system from which maps are plotted almost automatically.

Other major factors affecting survey practice over the twentieth century have been the obvious improvements in transport, communication, data recording, and computation. All control networks require the establishment of a datum point and the azimuth of at least one line. Prior to the 1960s these were achieved by astronomical means. (Although satellite technology has largely replaced this method, knowledge of the earth's gravity field is still required.) Many inconsistent datums and continental coordinate systems formed the basis of topographical mapping, which, though consistent within itself, gave rise to mismatching at boundaries, in turn causing problems for political, cadastral, engineering, and military users, among others.

Prior to the 1950s a triangulation network was the most cost-effective way to provide control for mapping. A typical topographical triangulation scheme (fig. 769) consisted of the sides of the triangles about 40 kilometers long. The whole scheme would be recon-

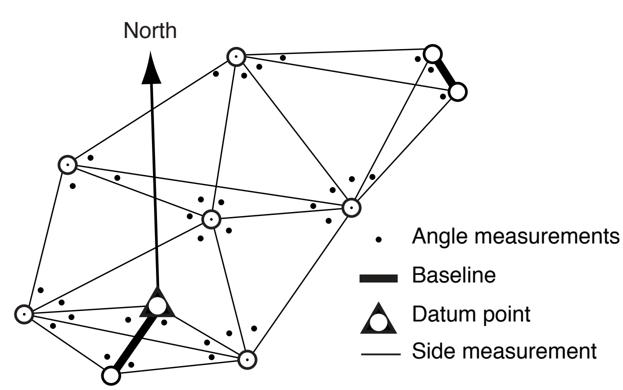

FIG. 769. TRIANGULATION NETWORK.

noitered, all lines of sight verified, and in many countries concrete pillars erected at all stations. The size of the triangles was determined by measuring at least one baseline, but always a second was measured to check and control the accumulation of error. In a continental survey, baselines were measured every 500 kilometers or so (Hotine 1939). These bases were measured laboriously by steel or invar tapes taking many weeks. For accuracy reasons, each angle of all the first-order triangles had to be observed at least sixteen times. The observing stations were marked either by opaque beacons or more often by lamps at night and heliographs by day. These latter procedures meant that each station had to be manned by a light keeper. Most countries in the world employed these techniques until the 1960s. Typical was the completion of a triangulation covering the 30th Meridian in Africa stretching from Cape Town to Cairo, which required the use of special towers to gain sight lines over Sudan (Rainsford 1951). The computation of these large triangulation networks was always a compromise between the desirable application of the well-known theory of least squares, developed in the nineteenth century, and the very practical limitation of mechanical calculation. The network of the Zambian triangulation of only about fifty stations took six weeks to manually adjust—a process that takes a few seconds today (Bomford 1967).

Trilateration is a method of forming a network from lengths alone, as shown in figure 770. This was used in small-scale surveys where the sides were taped or chained. It was never a practical procedure for long lines. With the availability of the microwave Tellurometer, which does not require optical visibility, the system was more useful, especially at times of poor visibility. The immediate benefit accruing from the Tellurometer was the strengthening of existing triangulation networks in which scale errors, often of several meters, had accumulated due to the inevitable piecemeal methods by which they had been adjusted and computed. Trilateration alone has the intrinsic weakness that its geometry yields fewer redundancies than an equivalent triangulation, so the usual practice was to include angular measurements in most networks. By the 1970s electronic computer simulations also made it possible to preanalyze networks to optimize their cost-effectiveness and accuracy.

A single direction and a single distance suffice to fix the coordinates of a new point from a previously established one (fig. 771). During the 1930s this radiation technique was widely used over short distances of up to fifty meters, distances being obtained from optical tachymetry. With the adoption of EDM the procedure became useful for longer lines. Although radiation by Tellurometer and theodolite was little employed, the electro-optical systems are well suited to the task, such that the total station became the workhorse of surveying, augmenting controls established by satellite systems and surveying details in its own right.

A chain of points that is joined together by successive radiations, as in figure 772, forms a traverse. This is the most generally applicable method of surveying; sometimes it is the only one, for example in mines or thick forest country. It suffers from the great geometrical weakness that any error, especially angular, propagates in a cumulative manner, producing large errors in position. The accumulating errors have to be controlled in some way. Angular or bearing errors are controlled by azimuth determinations from the sun or stars or by making magnetic bearings at each station. Positional errors are constrained by running loops of traverses in circuits. These practices are commonly used for cadastral mapping.

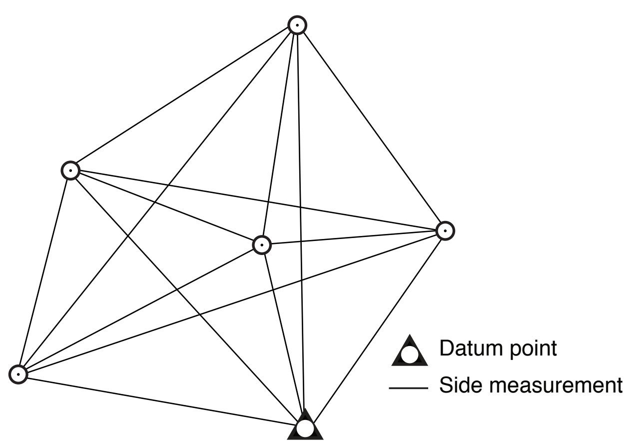

FIG. 770. TRILATERATION NETWORK.

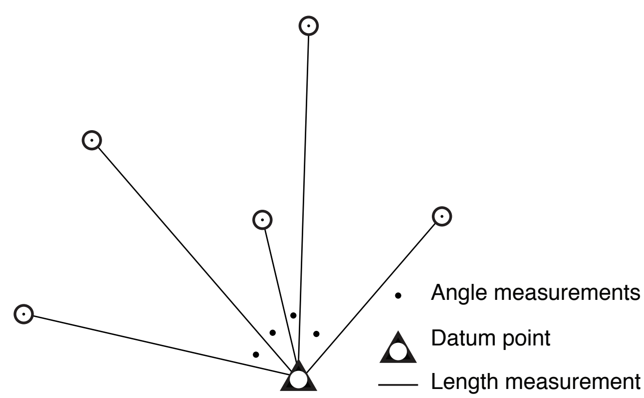

FIG. 771. RADIATION SURVEY.

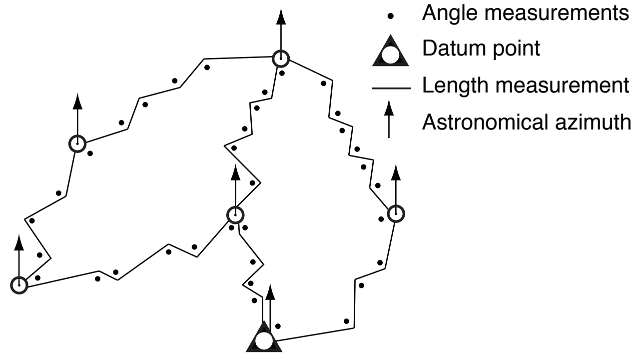

FIG. 772. TRAVERSE NETWORK.

In the 1930s in forested areas, such as the southern end of Lake Victoria, a crude rope and "hoo-cry" method was employed, in which a rope pulled tight through the trees supplied the distance, and a magnetic bearing was taken to the imagined source of sound made at the forward point of the line. This method was surprisingly adequate (Dale 1972, 1973). With EDM the traverse came into its own to establish topographical mapping control. Many triangulation networks had gone unfinished because of the difficulty of crossing expanses of flat ground. The use of special towers also became economical when following a motor road (Humphries and Brazier 1958). A very important survey by this method was the closure of the Australian triangulation networks by a long traverse across the northern part of that continent (Bomford 1960).

By the end of the twentieth century the above methods were almost entirely superseded by the three-dimensional trilateration networks of satellite systems such as NAVSTAR Global Positioning System and GLONASS (Global'naya Navigatsionnaya Sputnikovaya Sistema). At last the surveyor was truly working from the whole to the part to establish a worldwide system of geodetic coordinates and a truly consistent mapping coverage.

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SEE ALSO: Electromagnetic Distance Measurement; Global Positioning System (GPS); Plane Table

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Monumentation and Recovery. Monumentation is the process of marking on the ground the location of points whose coordinates have been determined by surveying techniques. It serves a number of purposes: demarcation of international boundaries; marking stations of a surveying network (such as a primary network); triangulation, traverses, and astronomical fixes; and marking the corners of properties.

The marking of international boundaries usually involves prominent monuments, often specifically designed for the boundary in question. Some marked boundaries also serve as fences to control the movement of humans or animals. Contrasting examples include the fenced border between the United States and Mexico, intended to control immigration; the double-fenced border between Botswana and Namibia, designed to prevent the spread of foot-and-mouth disease; and the comparatively open border between France and Switzerland, under no pressure from migration and marked by a series of discreet small granite blocks.

Permanence is no less important than prominence. The surveyors engaged in the demarcation of a section of the border between Nigeria and Cameroon in 1912 set ten-foot lengths of water pipe in a concrete and stone base with metal fingerposts on the top of the pipe to indicate boundary direction. Many of these beacons were still intact at the outset of the twenty-first century.

Monumentation of survey networks has varied widely from country to country. Heavily influenced by local traditions and materials, the specific form also reflects the preferences of the particular national survey and mapping agency. Pioneer surveyors in the United States and the British Empire favored ground marks much of the time because these required the least amount of materials for construction. However, in the case of high-accuracy surveys such as primary triangulation networks, the need arose for a more solid support for the theodolite

FIG. 773. ORDNANCE SURVEY TRIANGULATION PILLAR, WIN HILL TRIG POINT.
Image courtesy of David Cotton, Cambourne.

than the traditional tripod. This led to the development of concrete pillars by the Ordnance Survey for the retriangulation of Great Britain, initiated in 1936 to replace a primary network established in the late eighteenth and early nineteenth centuries (fig. 773). Martin Hotine (1937), who directed the retriangulation, prescribed a sophisticated design with specially cast brass elements such as the benchmark plate set in the side of the pillar and the three-pronged plate set in the top to receive the instrument. Within the British Empire, the Ordnance Survey practice was followed by many agencies, though usually in a simpler form of a cylindrical concrete four-foot pillar set in a sheet metal form with a central pipe marking the defined position. A metal vane could be set into the pipe to provide a target for daytime observations from a distance.

The U.S. Coast and Geodetic Survey preferred a ground mark in the form of an engraved brass disk set in a concrete block. But brass is a prized metal in many parts of the world, and such markers, too attractive to the local population, were often removed. So some agencies resorted to the simplest form of mark, namely, a hole drilled into a rock or a cement block. Elsewhere, there were local solutions. For example, in Borneo three-inch-square pegs, six feet or longer and made of a particularly hard wood called *belian*, were driven into the ground, which was very often swampy. These survived over astonishingly long periods and had no attraction to the population in the rain forests. They were used for both property and triangulation surveys.

In flat areas where surveyors required lines of sight of twenty miles or more, neither a ground mark nor a pillar was of much use for a theodolite. Marks might be set on the roofs of any available high buildings—in which case the mark had to be sympathetic to its location and not damage the roof in question. Alternatively, towers could be built over a ground mark or pillar. A classic design was the Bilby tower, a portable steel tower developed by the U.S. Coast and Geodetic Survey (Bilby 1929). The Ordnance Survey used a similar design in the east of England. One of the most extensive uses was for a network of primary traverses by the Directorate of Surveys in Botswana (Macdonald and Gibbs 1968). Towers could be raised to a maximum height of 104 feet and allowed interstation distances of up to twenty miles. Elsewhere, simpler towers of timber or pipework were constructed where needed (Macdonald 1961). In South and Central Africa, the pillar itself might be elevated on a twenty-foot-high masonry pedestal so that property surveyors might be able to use the station without difficulty at some future date.

Individual properties are normally marked with ground marks of various sorts, such as wooden pegs, concrete blocks, iron pipes, and proprietary ground markers. Thought had to be given to recovery of station position after willful or accidental damage. Marks might be removed by aggrieved property owners, road construction teams, or curious local people—in one part of Malawi, pillars were thought to mark the sites of gold deposits. Pillars were used as scratching posts by elephants in Botswana, which seriously affected their position. A common method of insurance was to set four buried "witness marks" twenty to thirty feet from the mark in question. The distances and azimuths to these marks were then recorded with the construction details and, when the need arose, could be accessed from the archives together with a written description of the location. By the end of the twentieth century, of course, recovery of station positions could most simply be achieved through the use of Global Positioning System (GPS) receivers (fig. 774), though account had to be taken of the possibility of old stations being in error when compared to the more precise definition of the GPS system.

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SEE ALSO: Coordinate Systems; Ordnance Survey (U.K.); Standards for Cartographic Information

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FIG. 774. AUSTRALIAN BRASS GROUND MARKER AND GPS UNIT. Marker is at the summit of Mount Cottrell in Melton.
Diameter of the marker: ca. 9.7 cm. Image courtesy of Darren Osborne, Melton.

ficers 1967: Report of Proceedings, 68–92. London: Her Majesty's Stationery Office.

Global Positioning System and Property Surveying. In 2010 the Global Positioning System (GPS) developed by the United States military was still the best-known global navigation satellite system (GNSS). Others included Russia's GLONASS (Global'naya Navigatsionnaya Sputnikovaya Sistema), China's Compass, and Europe's Galileo systems. Fully developed, each supported its own constellation of twenty to thirty radio-transmitting, earth-orbiting satellites. Although military satellite navigation systems can be traced back to the 1960s, their civilian uses emerged in the 1980s, initially limited to navigation positioning, not property surveying.

In conventional property surveying, the point of interest is a property marker: a point on a property boundary, a control point from which detailed measurements to property features can be made, or a control point for the photogrammetric mapping of property. The typical accuracy required of such points is two to five centimeters. As late as the 1990s, the basic tools used in property surveying were a tape measure for determining shorter distances, a level to determine height or elevation differences, and a theodolite set on a tripod to measure horizontal and vertical angles. At the end of the century, theodolites were largely replaced by total station surveying instruments that combined the theodolite with an electronic distance measurement device (EDM) to measure the angle and the distance to a point simultaneously. Starting from a position with known location and elevation, the coordinates of an unknown point were computed from the measured angles and distances using the triangulation method.

By 2010, GNSS receivers were increasingly replacing the triangulation method and associated equipment for determining the coordinates of unknown locations in property surveying. Receivers use the mathematical method of trilateration from range distances between the receiver and at least four satellites to calculate the coordinates of a survey point. Early GNSS receivers processed transmissions from only one satellite constellation, but by 2008 they increasingly processed transmissions from all systems, enabling surveying throughout the day.

For U.S. security reasons, an intentional degradation (called Selective Availability) of GPS transmissions to civilian users was implemented in 1985, when the technology was made available to civilians. This led to horizontal accuracies of only about 100 meters, although differential correction procedures were soon developed to overcome the degraded signals, realizing twenty-centimeter accuracies or better. Low-cost handheld GPS receivers with accuracies of about sixty meters, when used without differential correction, were marketed in the 1990s and soon captured the public's imagination. For many involved in resource mapping, these were adequate, providing much-needed data for geographic information systems. But the accuracies were not sufficient for conventional property surveying.

Accuracies improved the longer the receiver remained stationary; for example, subcentimeter accuracies could be achieved at points occupied for three days (Abidin et al. 2006). But this was not practical for property surveying, and real-time kinematic procedures were preferred where a single reference station provided the real-time corrections, giving up to centimeter-level accuracy.

In May 2000 Selective Availability was discontinued, and GPS reverted to a user-friendly technology in which expensive survey-grade instruments were capable of meeting the needs of conventional property surveying. Cheaper handheld GPS results also improved, achieving accuracies of ten to twenty meters.

The period of Selective Availability implementation coincided with major investments worldwide in cadastral mapping systems (Prosterman and Hanstad 1999), driven by the understanding that accurate land information encouraged economic development. For example, property mapping projects in South Africa used GPS-enabled palmtop computers to produce title plans, with accuracies of about two meters, in areas undergoing extremely rapid settlement (Barry and Rüther 2001). But for its conventional cadastre South Africa aimed for greater accuracies. Although methods to be used in cadastral surveying were not specified in the country's survey legislation, and any recognized methods were acceptable, most cadastral surveys used total station or GNSS methods. For South Africa, the accuracies of property surveying were specified in three classes, ranging from about four to twelve centimeters.

In the United Kingdom topographic maps at the largest available scale were the legislated basis of title plans. However, in remote areas the largest-scale maps inadequately distinguished small parcels, and the need for higher-accuracy property surveying was recognized by 2002. Historic errors in British mapping appeared when GPS surveying commenced, so software and an online converter were made available by the country's national mapping organization for transforming new GPS-based property surveys to the existing National Spatial Data Infrastructure (NSDI).

Property surveying methods have varied both between and within nations. However, GPS surveying with some supporting legislation, had, by the early years of the twenty-first century, sufficiently developed to meet the needs of the property sector.

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SEE ALSO: Geodesy: Satellite Geodesy; Global Positioning System (GPS)

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Psychology, Experimental Studies in. See Perception and Cognition of Maps: Experimental Studies in Psychology

Psychophysics. See Perception and Cognition of Maps: Psychophysics

Public Access to Cartographic Information. Public access to cartographic information changed tremendously during the twentieth century in response to legal and political shifts as well as to the technological transformation of cartography. The century began with manually collected data stored as hard copy on paper and requiring physical access for its use. Types of information expanded beyond traditional maps in the first half of the century to include aerial photographs and in the last half to include satellite imagery. Toward the end of the century the address-matching capability of geographic information systems made census data more explicitly and readily usable as cartographic information. More and more data were being stored in digital format, often as electronic files readily available for computer downloading. Still, throughout the century moves to increase public access were often followed by initiatives that had the effect of reducing access, in a tug of war continuing beyond 2000.

Public access to cartographic information begins with public information. According to David Rhind, "Government is almost everywhere the primary sponsor of the national geodetic framework and the source of 'framework' data. . . . Virtually all of this data was originally collected for the purposes of the nation state or subsets of it" (Rhind 1998, 1). He was writing in 1998 as director general of the responsible government agency in Great Britain, the Ordnance Survey founded in 1791. In the United States, under the Public Land Survey created by the Land Ordinance of 1785, the federal government had assumed responsibility for developing large-scale maps of geological, hydrological, and botanical features. Private-sector mapmakers, who had begun using this information to develop specialized maps for local markets in the nineteenth century, continued to do so throughout the twentieth century (McHaffie 1995, 118). This system of producing cartographic information included roles for both government and commercial sectors, laying the groundwork for public access to cartographic information (fig. 775).

In the United States, two major mapping agencies had begun producing a steady stream of standardized cartographic information for the federal government during the nineteenth century. These agencies, the U.S. Coast and Geodetic Survey and the U.S. Geological Survey, saw their responsibilities expand during the first quarter of the twentieth century. In 1925, the Temple Act gave these agencies responsibility for completing a "general utility topographical survey" of the entire United States by 1945, a period of just twenty years (McHaffie 1995, 119). This bold initiative was to draw upon an innovative source of data for maps, aerial photography.

Advances in aviation and photographic technology made possible significant developments in aerial photography during World War I. This new data source not only changed the nature of the cartographic process by replacing ground surveying with aerial photography and its interpretation but also enhanced the content of the resulting topographic maps (McHaffie 1995, 119). Innovations in aerial photographic technology during World War II, such as radar and false-color infrared imaging, also found postwar nonmilitary uses.

The next major advance in data collecting technology was remote sensing. The first U.S. satellite that returned

FIG. 775. CUSTOMERS BEING SERVED AT PUBLIC MAP SALES COUNTER, 1970s. The U.S. Geological Survey's Denver Branch of Distribution, Central Region.

From Morris M. Thompson, *Maps for America: Cartographic Products of the U.S. Geological Survey and Others*, 3d ed. (Reston: U.S. Geological Survey, 1987), 226.

photographic film, Discoverer 14, was part of the Corona system; it was launched and photographed Soviet Union territory on 18 August 1960 (see fig. 822). On its single day in orbit, it gathered more images than had been collected by twenty-four U-2 missions in the previous four years (Monmonier 2002, 22). Through the 1970s and 1980s, the U.S. Geological Survey collected and maintained satellite images "as an experimental system for gathering repetitive worldwide multispectral data for civilian uses" (McHaffie 1995, 125). During the 1990s the invention and diffusion of widely affordable Global Positioning System (GPS) devices added satellite signals to the array of publicly available cartographic information.

Ultimately, the terms and conditions of public access to cartographic information depend on the ability and legal right of governmental entities to copyright the information they collect. Copyright law varies from country to country. In the United States much cartographic information was in the public domain throughout the twentieth century because the federal government, by law, is not permitted to copyright information (Chrisman 2002, 278–79; Guptill and Eldridge 1998; Onsrud 1998). Such an abundance of uncopyrighted cartographic information was rare outside the United States. In most countries, the government is legally permitted to copyright and sell the information it collects and often does so, as in the United Kingdom (Rhind 1998) and Canada (Corey 1998). In these countries, the prices for maps and other cartographic information were set much higher than in the United States for most of the twentieth century.

Higher prices outside the United States had the effect of restricting public access to data, either intentionally or as a side effect of policies favoring at least partial recovery of the cost of collecting and maintaining information. The argument in favor of this was that taxpayers are shareholders. Therefore government agencies should maximize the return on their citizen shareholders' investment. This could be accomplished by making direct users of cartographic information pay for that privilege and the potential profits as a cost of doing business. Toward the end of the twentieth century efforts to privatize U.S. government operations provided additional motivation to charge higher prices for cartographic information (Onsrud 1998; Guptill and Eldridge 1998; Corey 1998).

A counterargument, raised in the late twentieth century, was that charging for geographic information violates the public right to know by discriminating against lower-income citizens wishing to use cartographic information, and it was argued that the very fact that the cartographic data sets had been assembled at taxpayer expense should entitle taxpayers to free access (Corey 1998; Guptill and Eldridge 1998; Monmonier 2002, 14). In an ideal "information commons," as described by Harlan J. Onsrud (1998), cartographic data would be freely available at little or no cost, on a timely basis, and with the highest level of accuracy and precision available.

During the mid-twentieth century open-records laws and the Freedom of Information Act (FOIA) became part of the legal foundation of public access to cartographic information in the United States. "Founded on the long standing principle that people in a democracy have a need and right to know what their government is doing," open-records laws seek to ensure free access to public records (Onsrud 1998, 141). The federal FOIA was signed into law on 4 July 1966 and took effect the following year. This law provides an avenue for average citizens to compel the federal government to release information (including cartographic information) unless doing so puts national security at risk. Information gathered through FOIA should include no additional costs, except the possible price of reproduction.

Timely access to cartographic data has not always been the norm, however. For example, the images gathered by the Corona satellites beginning in 1960, remained sequestered in National Reconnaissance Office vaults until 1995, when President Bill Clinton finally released them in the interest of science and history (Monmonier 2002, 25). Nicholas R. Chrisman (2002, 278) noted that census records, whose addresses make them cartographic information, are "locked up for 72 years" after their collection to preserve the spatial data privacy of individuals surveyed.

Data quality was another issue in public access to cartographic information during the late twentieth century. Among the most accurate and precise cartographic information held by governments was that collected for military purposes, for example, satellite imagery and signals for use by GPS devices. In the 1990s, as a compromise between national security and the public right to know, the federal government instituted a "policy of deliberate blurring" to ensure that "only military users [of its GPS locational data] received all the information needed to estimate location with great precision" (Monmonier 2002, 14). However, a shortage of the most accurate GPS devices during the Gulf War (1991) forced the military to issue lower-grade GPS receivers and to compensate by reducing the blurring error. Even without this correction, civilians who waited a longer time holding their GPS receivers in a single location or who had access to a precisely located ground station were often able to reduce their locational uncertainty to about one meter (Monmonier 2002, 15).

Following World War II receipts of surplus military maps and increasing quantities of legal deposit maps had spurred the formation and growth of academic map libraries, especially in North America and Europe (Geography and Map Group 1950). Wartime security restrictions on public access to such maps were lifted as time passed, although national security remained an issue in access to mapping of contested border regions and other zones of conflict throughout the twentieth century. Collections of paper maps in academic map libraries, as well as in other types of libraries, became important links in the chain of public access to cartographic information (fig. 776). By the late 1980s the number of map libraries in the United States had risen to more than 970, of which 20 held collections of at least 250,000 printed maps (Fortin 2003; Larsgaard 1998, 159–60). Map libraries also began collecting and providing access to digital geospatial data, a trend that continued to escalate after 2000.

Library collections of maps and other cartographic information were often available to the library's primary users at no direct cost, with the exception of copying. Not all map libraries circulated maps, so some method of copying them was often necessary. Hand tracing onto paper on a light table or using an adjustable overhead projector remained in use throughout much of the century but gave way over time to mechanical methods of copying maps (Geography and Map Group 1950, 458). Until the late twentieth century, mechanical copying processes usually employed photosensitive emulsions, exposed either by direct contact or with a camera. Negative blueprints, already in use by 1900, and photostat prints, introduced during the next decade, remained standard until libraries began to adopt microfilm photography for storing, viewing, and copying images in the 1940s (Geography and Map Group 1950, 464–65). Positive diazo or blueline prints replaced negative blueprints after the 1940s but gave way in turn to photocopying from the 1960s onward. In the 1990s digital cameras and scanners took over and made it possible to turn paper maps into electronic files. Copy services, usually offered by map libraries at less than commercial rates, shifted toward self-service copying after the 1960s, although large-format and high-quality copying remained more expensive specialty services.

In the 1990s, the National Digital Cartographic Data Base (NDCDB) added momentum to the conversion of existing maps into digital format. Digital conversion made it easier to provide public access to cartographic information, especially for use in geographic information systems (GIS), which at the end of the twentieth century were "still largely a public sector technology" (Ventura 1995, 466). As the price of GIS hardware dropped in the 1990s, access to cartographic and spatially referenced information became a relatively larger percentage of the cost of GIS (Rhind 1998).

The development and implementation of the Internet opened another avenue for public access to cartographic information in the 1990s. No longer were users of cartographic information required to make a special trip to a map library or to visit or mail order printed maps or aerial photographs from one or more government offices. It became possible to use a computer keyboard to look up data records or download base maps and other cartographic information. This is not to suggest that public access to cartographic information is uniform in all jurisdictions, even in the United States. While the U.S. Geological Survey and the U.S. Census Bureau began to make cartographic information available free for downloading, many state and local governments were slow to

FIG. 776. READERS CONSULTING SOME OF THE 60,000 POLITICAL, TOPOGRAPHICAL, AND HISTORICAL MAPS, 1950. The History Department Map Room, Los Angeles Public Library.

Image courtesy of the Los Angeles Public Library Photo Collection.

follow. As the twentieth century came to an end, Onsrud (1998, 146–49) expressed concern about the shrinkage of the "information commons" due to two external pressures. The first of these was the move to "reinvent government," which called on public organizations to adopt practices more commonly associated with private organizations. At the top of the list were privatization efforts designed to increase government's revenue stream. The sale of cartographic information became easier as data were converted from paper records to digital formats.

The second pressure on the information commons came from the expansion of intellectual property rights. Publishers and other owners of content stood to benefit most from the expansion of intellectual property rights, while the authors of the cartographic data and other innovators typically realized fewer benefits. Onsrud lamented the shift from a virtual data library model to that of a virtual bookstore for digital cartographic data, with free access giving way to fees (1998, 148–49).

Privatization of government services and copyright restriction had a significant impact on public access to Landsat imagery (Chrisman 2002, 278–79). Landsat image distribution "was finally privatized under the Earth Observation Satellite (EOSAT) Company" with the idea of passing on "the full cost of acquiring the data and maintaining the system to the consumer" (McHaffie 1995, 125). Subsequently, prices for Landsat images rose dramatically. For example, an image that cost $15 in 1980 was priced at $150 in 1989. The number of products sold dropped from 128,000 to a mere 4,000 during that same decade (McHaffie 1995, 126). Moreover, the application of copyright restrictions to both photographic and digital image products meant that all Landsat imagery produced after 1985 was effectively removed from the public domain (McHaffie 1995, 125–26). Despite short-term gains associated with the sale of cartographic information, especially for the government bodies reaping the financial rewards, such data became harder and more expensive to obtain.

In 1996, though, the launch of MapQuest (a wayfinding tool) made free cartographic information publicly available on the Internet. It was joined in 2005 by Google Earth and Google Maps, Internet sites that incorporate aerial photography and satellite imagery gathered by government agencies and also available online at no charge. These were the last affirmations of the apparently contradictory evolution of public access to cartographic information during the twentieth century. On the one hand, the variety, quality, and ease of access to cartographic information grew tremendously. On the other hand, while the price of access increased greatly for some cartographic products, it became free for others. It is highly likely that technical progress in cartographic information will continue into the twenty-first century, but it remains to be seen whether public access to this information will remain affordable.

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SEE ALSO: Cadastral Map; Digital Library; Intellectual Property; Libraries, Map; Marketing of Maps, Mass; Standards for Cartographic Information; Tax Map; Web Cartography

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