N

Names. See Geographic Names

Narrative and Cartography. On a real day, 16 June 1904, a fictional character, Leopold Bloom, navigated through the real city of Dublin. The peregrinations and encounters of Leopold Bloom were described by James Joyce in his novel *Ulysses*, published in 1922. Through the spatial description of Bloom's travels, Joyce wanted "to give a picture of Dublin so complete that if the city one day suddenly disappeared from the earth it could be reconstructed out of my book" (Budgen 1972, 69). Joyce framed his book as a cartographic archive as well as a fictional narrative according to Jon Hegglund's interpretation: "Cartography promises a surveying view, but this vantage is distant, abstract, and ahistorical. Narrative, conversely, can project individual movements through time and space but ultimately must rely on partial views and situated knowledges. *Ulysses* frequently represents spaces that hover between these two perspectives but cannot be resolved into either one" (2003, 166).

With *Ulysses*, Joyce sketched a fundamental distinction between traditional forms of cartography and narrative. While maps represent place and space, narratives are structured around time and a sequence of events. While maps typically provide a panoptic view of the world from above, narratives offer grounded, embodied perspectives. While maps present themselves as scientific and objective as possible, it is more difficult to dissociate narratives from their author and sense of partial perspective. In light of these fundamental distinctions between maps and narratives, they are often used together in a complementary way. Yet the relationship between cartography and narrative is more complex and more dynamic than first meets the eye.

The following discussion of that relationship, as it developed during the twentieth century, will begin by reviewing and considering the major roles played by maps in narratives. The extensive presence of maps in multiple forms of narratives such as novels, newspapers, films, comics, video games, and multimedia applications calls for a selective approach. A few representative examples have been drawn from literature and cinema. The discussion will end by exploring the double transformation of cartography in its relationship to narrative toward the end of the twentieth century. The emergence then of critical cartography demonstrated that maps themselves could also be read as narratives. At the same time, technological developments in cartography also heightened the narrative dimension of maps.

In regard to the presence of maps in twentieth-century literature, perhaps the most memorable maps have been those created in relationship to fantastical narratives. Such maps successfully transported readers to the now famous fantasy worlds, the Land of Oz (fig. 606) and Middle-earth (the map of Middle-earth appeared for the first time in 1937 in J. R. R. Tolkien's *The Hobbit*). The maps helped authors structure plots and organize the spatiotemporal dimensions of their stories. They also helped readers follow the narration and in a basic sense made real those imaginary worlds. The "reality effect" of maps draws on the purported objectivity and scientific nature of maps. The use of maps for bolstering the truth or realism of narratives is a technique that was used throughout the century in many different narrative forms.

In cinema, for example, maps were extensively used to materialize imaginary worlds as well as to connect plots to existing places. Since the origins of cinema at the end of the nineteenth century, maps had appeared in films as everyday objects hung on walls and unfolded on tables, but it was in the 1910s with the development of docudrama (a genre in which the limits between fact and fiction are blurred) that filmmakers began to fully exploit the reality effect of maps. Those early twentieth-century movies often claimed to objectively represent exotic places and people as a form of ethnographic, his-

FIG. 606. *MAP OF THE MARVELOUS LAND OF OZ, DRAWN BY PROF. WOGGLEBUG T.E.* The map of the Land of Oz, as it appears in the eighth book of the Wizard of Oz series, divides it into four countries bounded by deserts. In the center of the map, the Emerald City resembles a cyclopic eye. The map seems to look at us as much as we look at it.

Size of the original: 22.5 × 32 cm. From L. Frank Baum, *Tik-Tok of Oz* (Chicago: Reilly & Britton, 1914), inside front cover. Image courtesy of the Clifton Waller Barrett Library of American Literature, Special Collections, University of Virginia Library, Charlottesville.

torical, and geographic archive. In some of those docudramas, such as *Among the Cannibal Isles of the South Pacific* (directed by Martin E. Johnson, 1918), filmmakers started to add their own cinematic maps in order to help the audience locate the action (Caquard 2009, 47). The reality effect of the map was used to reinforce the veracity of the narration. As Tom Conley (2007, 4) pointed out, maps in films offer a guarantee that the film is "'taking place' in the area seen before our eyes," increasing the film's capacity to colonize, if you will, the imagination of the public.

That colonizing capacity was fully exploited during World War II with the emergence of cinematic propaganda maps. Propaganda maps are a type of persuasive cartography: they tell us the story we are supposed to believe. In the twentieth century they played an important role in telling official stories and contributing to the process of nation-state building, particularly in wartime (Pickles 2004, 37–41). During World War I, the way Germany and the United States were displayed on maps in German school atlases helped mobilize German support in favor of the war (Jacob 1992, 368). During World War II, with the use of cinema, propaganda maps became much more sophisticated. Not only did they appear in films, they were also animated.

The movie *Sieg im Westen* (directed by Svend Noldan, 1941), was a key example of the use of cinematic maps in propaganda films. In that Nazi movie, animated maps were omnipresent. More than thirty cinematic maps illustrated Germany's early military victories and the conquest of the Netherlands, Belgium, and France in the spring of 1940 (fig. 607). Through that film, German propaganda pushed forward the nature of cartographic animation while capitalizing on the power of animated

FIG. 607. MAP IMAGE FROM *SIEG IM WESTEN*, 1941. This still frame is from one of many animated maps in the Nazi propaganda movie.

maps for persuasion. It exemplified the idea that some maps and films have sought to control those living under their effects (Conley 2007, 38).

Sieg im Westen was also a milestone in the twentieth-century history of animated cartography, since it served as a reference to possibly the first scientific paper addressing the role and the potential of animation in cartography (Speier 1941, 325–28). It may have served as a source of inspiration for the later development of animated maps by cartographers. That development started in the late 1950s with the pioneering work of cartographer Norman J. W. Thrower.

So far, the discussion of the relationships between maps and narrative has been structured around examples of maps embedded in narratives. Yet, cartography and narrative also interacted in other ways throughout the twentieth century. At the beginning of the century, mapping the action of major novels was already a popular activity for certain readers. Often such external maps, as opposed to internal maps appearing within novels (Ryan 2003), were published in guidebooks of major cities like London and Paris, taking their readers in the steps of famous nineteenth-century characters (Bulson 2007). That relationship between literature, maps, and tourism continued throughout the twentieth century, as illustrated by the multiple maps of Dublin accompanying the many guides to Joyce's *Ulysses*. The use of maps for literary tourism increased dramatically toward the end of the century with the globalization of popular culture and the democratization of travel. Places appearing in popular novels and blockbuster movies were frequently mapped and became major tourist attractions. In the 1990s, the British Tourist Authority released its first "movie map" showing locations of famous films and TV series in order to attract filmgoers and boost the local economy. During the course of the twentieth century, real places associated with fictional narratives became popular tourist destinations, contributing to the commodification of places. In that process, maps served as central agents of commodification.

Another kind of relationship between cartography and narrative was articulated through the subdiscipline of literary cartography. There, external maps were used as heuristic devices to synthesize information and to reveal structures and patterns within novels. Literary maps enabled literary critics to study the complexity of the relationships between narratives and places in novels. Such maps helped academics extract the spatial dimension of the novel from its narrative flow. Literary maps "give readers something that novels do not: an image, a structure, a way to visualize form and narrative design" (Bulson 2007, 3). Franco Moretti aptly summarized the importance of literary maps when he observed that in modern European novels "*what* happens depends a lot on *where* it happens" (1999, 70). Literary cartographers drew all sorts of maps, ranging from very conventional to highly original diagrams revealing the structure of the narrative instead of its geography (fig. 608).

As indicated above, maps were used to bolster and analyze narratives in literature and cinema, transforming both of those forms of art in turn. What is less obvious is that narrative art forms also transformed the nature and purpose of maps. Maps embedded in a narrative structure, as in literature or cinema, were no longer (simply) the objective, panoptic, and spatial artifacts they were supposed to be; they became narrative artifacts themselves. As emphasized by Christian Jacob (1992, 360ff.), imaginary maps embedded in novels became powerful *matrices narratives* (narrative matrixes) contributing actively to the storytelling process and inviting readers to go on imaginary voyages and journeys. Cinema, simultaneously, transformed conventional maps into narrative elements. A simple road map, the type of map that Robert Macfarlane (2007, 140–45) considers a *grid map* rather than a *story map* since they "make the landscape dream-proof" and "encourage the elimination of wonder from our relationship with the world," can become a powerful narrative artifact when embedded in a movie. For instance, the conventional French Michelin road map appearing in the movie *Les Amants* (directed by Louis Malle, 1958) conveyed more than an itinerary; it proposed a "sentimental journey in which affective images play a decisive role in the narrative and spatial design of the feature" (Conley 2007, 125).

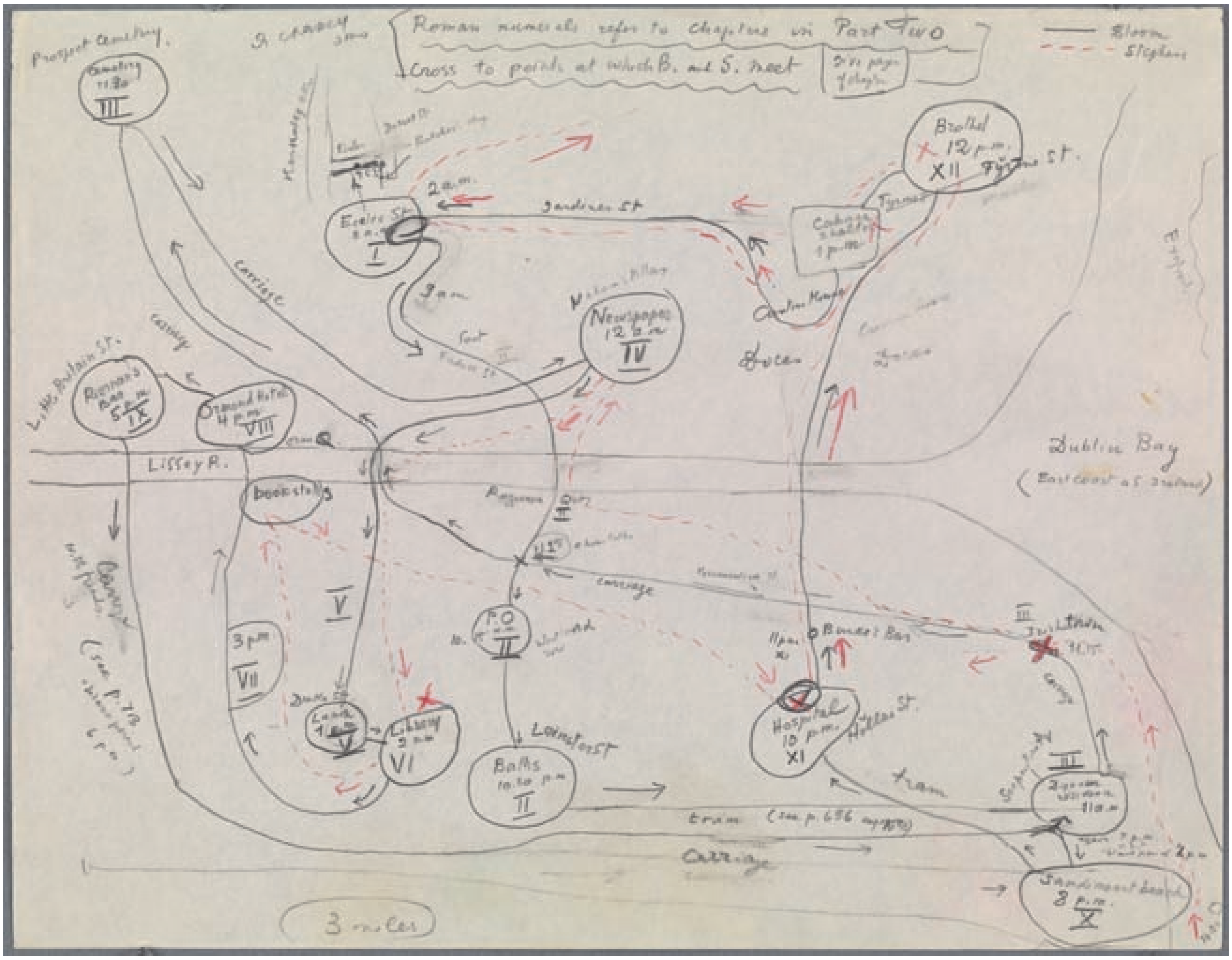

FIG. 608. VLADIMIR NABOKOV, LITERARY MAP OF *ULYSSES*, MANUSCRIPT DRAWING, [1969?]. This map of Bloom's and Stephen's travels in James Joyce's 1922 novel was drawn by Nabokov for his lectures on literature (published in 1980); it emphasizes the structure of the novel as well as its geographic dimension. Size of the original: ca. 21.4 × 27.6 cm. Image courtesy of the New York Public Library (Berg Collection, Vladimir Nabokov Papers). Permission courtesy of the Wylie Agency, New York.

As this brief overview has demonstrated, cartography and narrative were used together in largely complementary ways during the twentieth century. Yet the relationship between the two approaches to representation was less clear-cut and stable than it might seem. Through different forms of interaction, cartography and narrative actively transformed each other. Furthermore, just as narratives have an inherently spatial dimension, so too do maps have a narrative dimension. It was only toward the end of the twentieth century that the discipline of cartography directly engaged with the narrative dimension of maps.

The broad acknowledgment among cartographers that maps inherently contain a narrative dimension took not only time but a major paradigm shift from the map as a communication tool to the map as a narrative form of expression. In the 1960s, cartographers' engagement with the ideas of narrative was largely limited to comparisons with texts. Maps were defined as a mode of communication similar to text, with a vocabulary, an alphabet, and a syntax. That analogy with language underpinned the idea that the map should communicate information related to places as efficiently as possible. That perspective dominated the discipline of cartography until the late 1980s, downplaying the importance of personal, emotional, political, and narrative dimensions of the cartographic message, even if those dimensions remained embedded in many maps. As a scientific and objective representation of space, the map was not supposed to tell stories but to represent facts and to convey information efficiently.

The development of critical cartography in the late 1980s deeply challenged that scientific perspective. Critical cartographers revisited the analogy between text and map. Denis Wood (1987) explored the idea that maps could be read not only for the information they convey but also for the pleasure they provide. He argued that atlases can be compared to novels for their similar narrative structures and the stories they tell, as well as for the *"flush of pleasure"* (40) that readers may experience. Jacob (1992, 106–9), who envisioned atlases as being cinematographic, developed an analogous idea. For him, maps in an atlas were comparable to frames in movies. They cut the world into pieces (e.g., continents, regions, and countries) that were organized to generate an impression of narrative-like progression. In sum, by the 1990s, the idea that maps also have a narrative dimension had started to percolate into the discipline of cartography.

During the same time period, J. B. Harley (1989) pushed the analogy between text and map further. He argued that the map was similar to the text because both of them were culturally constructed. By comparing maps with texts, Harley was able to apply deconstructionist theories to unveil the multiple meanings of every map. Each map contained different levels of narratives, and critical cartographers started to pull them apart in a systematic way. Wood (1992, 48–69), for instance, critically analyzed the famous 1990 satellite composite map of the earth from space by Tom Van Sant and Lloyd Van Warren to demonstrate the implicit environmentalist discourse underpinning the scientific rhetoric of the map. Thus, by the 1990s, maps could no longer be understood "simply" as efficient tools for communicating accurate information; cartographers began to see them as complex narrative forms of representation with multiple levels of meanings.

Within cartography, those developments also favored the recognition and understanding of cartographic means of expression that had previously been marginalized. Oral maps, for example, became recognized for their own characteristics and functions. In many indigenous communities and non-Western societies, space had been described through oral stories for centuries. Those forms of oral maps served multiple functions, including the perpetuation of a unique way of sharing knowledge about places as well as claiming territorial sovereignty. As emphasized by Mishuana Goeman (2008, 300), "locating a dialogue that imagines space not as bounded but as the result of continuous, ongoing storytelling, is necessary for creating a strong, sovereign Native spatial discourse." Oral maps became a form of counterpower, a way of telling other stories in an alternative manner. Toward the end of the twentieth century the importance and relevance of such oral maps, as well as many other forms of alternative maps, gained recognition.

In addition to the deconstructionist impulse in critical cartography, the exponential development of digital technologies since the 1980s also transformed cartographic expression, heightening even further the narrative dimension of maps. Maps became interactive, animated, and dynamic. They were put together into series to produce animations showing systems and relations, as well as conveying narratives and stories. In that context, the role of the mapmaker was redefined, approaching the role of a playwright or screenwriter who "must not only tell a story but also capture and hold the audience's attention" (Monmonier 1992, 248). Story lines became overt pieces of the mapping project and cartographers looked to storytelling metaphors to facilitate navigation through the increasing volume of data (Cartwright and Hunter 1999, 262).

Those cartographic story lines became even more sophisticated with the maturation of the Internet at the end of the 1990s. Users could now navigate through sets of maps and multimedia objects, thereby generating their own path through virtual spaces. They could, furthermore, add their input using different media, such as pictures and personal descriptions of places, enhancing the participatory dimension of contemporary cartography. Live elements constantly changed the structure and the sense of the story as well as the shape and the function of the map. In some cases, the possible journeys through maps became unlimited. Such a development suggests that if there ever were a stable relationship between cartography and narrative, that relationship had truly exploded. In its place there had emerged infinite forms of cartographic narratives, the nature of which remained both elusive and fragmented.

During the twentieth century, maps and narratives interacted in many ways, using many media, for many purposes. Maps guided readers into fictional worlds. They increased the realism and persuasiveness of films, simultaneously blurring the limit between fiction and reality. They put tourists into the steps of famous characters, contributing to the commodification of real places. Literary maps also helped researchers decipher and better understand the workings of space in the novel. In return, narratives transformed maps into engaging storytelling elements.

By the end of the twentieth century, maps and narratives had become more and more interwoven and hybridized. That trend was the result of a complex set of processes. First, the relative decline of a purely scientific approach of cartography opened the door to alternative understandings of the function and power of maps as well as to alternative forms of mapping. Within cartography, that change opened the door to the study of maps themselves as narratives. Second, the vertiginous transformation in media and communication technologies also played a key role in refiguring the relationship between cartography and narrative. By the end of the century, digital maps were constantly present on our TVs, computers, mobile phones, and even in our cars. One could argue that the fundamental role of maps had not changed dramatically, since the digital, new-technology maps still actively conveyed the reality effect vis-à-vis the narratives they supported. Their omnipresence underlines, however, a profound change in the nature of social communication, whereby visual images and symbols (including cartography) increasingly displaced text. By the turn of the century, people were as likely to study Leopold Bloom's travels through Dublin via online mapping as they were to study them through direct engagement with Joyce's novel. Thus, the challenge facing students of cartography in the twenty-first century is to keep pace with rapid technological change while trying to interpret its evolving social implications.

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SEE ALSO: Animated Map; Cinema and Cartography; Journalistic Cartography; Literature and Cartography; Persuasive Cartography; Time, Time Geography, Temporal Change, and Cartography

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National Aeronautics and Space Administration (U.S.). From inception, the primary goals of the National Aeronautics and Space Administration (NASA) were the exploration and monitoring of the earth's environment. Starting in the 1960s, each decade brought more NASA contributions to the field of digital cartography. By the end of the twentieth century, NASA had been responsible for several major advancements in digital cartography.

The early exploration of the moon and planets during the 1960s saw the development of the first space-borne imaging sensors, early geopositioning/pointing knowledge subsystems, and the first digital image processing language (VICAR—Video Information Communication and Retrieval) to enhance images and transform them to an appropriate map projection. The Lunar Orbiter spacecrafts sent images of the moon, the Mariner spacecrafts sent digital pictures of Mars, and the TIROS (Television Infrared Observation Satellite) series transmitted weather images of the earth. It was the July 1965 launch of TIROS-10, the first polar orbiting weather satellite, that carried the AVHRR (Advanced Very High Resolution Radiometer) sensor, a "whisk broom" sensor that efficiently imaged along the orbital path by sweeping side to side at a rate fast enough to keep up with the satellite's forward motion. The AVHRR design was the precursor to the higher-resolution Landsat Multispectral Scanning System (MSS) and Thematic Mapper (TM) sensors launched into earth orbit during the 1970s and 1980s. The need to correctly project imagery taken by the NASA imaging sensors required the development of digital processing functions that mimicked standard photogrammetic processing (particularly in the lunar and planetary missions). But it was the development of the weather and land observing satellites in the 1970s that led to the development of digital cartographic contributions.

In July 1972 the Earth Resources Technology Satellite (ERTS 1) was launched with two imaging sensors, a Return Beam Vidicon (RBV) camera and a MSS. The RBV camera, which operated in a fashion similar to airborne camera systems, experienced technical difficulties early in the ERTS 1 mission and performed poorly on ERTS 2 and 3. As a result, the MSS whisk broom system came to be the primary high-resolution imagery source for earth applications.

Severe geometry problems can develop with along-track scanning systems when spacecraft (or aircraft) attitude changes (in roll, pitch, or yaw) occur. These problems led to the development of several key digital cartographic processing procedures. The first procedures were the development of a series of algorithms that corrected systematic distortions associated with the MSS whisk broom design, after which ERTS 1 images were basically distortion-free. The second development was the systematic correction of errors in the ephemeris due to the spacecraft clock drift. The procedure, developed at the NASA Goddard Space Flight Center used surveyed ground control patches (such as airport runways) to correlate with new imagery and correct the pixel geopositioning information to within 1:250,000 national map accuracy standards. The third development was an attempt by the U.S. Geological Survey (USGS) to develop a new map projection that closely followed the ERTS MSS track. The new Space Oblique Mercator projection was conformal, a cylindrical projection with the center of the projection along the center of each image; however, the design failed to provide a map projection that could be readily used in geographic information systems because any error in satellite ephemeris would induce irretrievable projection distortions. The adoption of the earlier Universal Transverse Mercator (UTM) projection in the late 1970s supported geopositioning updates, image projection corrections, and proved to be a valid interface to other mapped information and geographic information systems (GIS).

One additional earth-observing mission was the launch of the Jet Propulsion Laboratory's (JPL) Seasat, the first synthetic aperture radar (SAR) satellite, in 1978. Land imagery from Seasat confirmed the horizontal distortions in radar imagery associated with relief and subsequent terrain "layover." It was Richard M. Goldstein of JPL who put the terrain "layover" characteristic to a new use by the digital combination of two nearly identical Seasat orbit paths, and through interferometric processing, extracted height elevations, thereby establishing a new method for producing digital elevation models (DEMs) (Goldstein, Zebker, and Werner 1988).

The 1980s saw three key advances within NASA that supported cartography-related technology. The first contribution was the launch of Landsat 4 with the TM sensing system. Landsat 4 had the more accurate Global Positioning System (GPS) receiver on board for spacecraft ephemeris calculation, as well as the TDRSS (Tracking and Data Relay Satellite System) Onboard Navigation System (TONS). As a result, users could project portions of TM images to 1:50,000-scale accuracy standards and integrate the thirty-meter resolution data into a wide variety of GIS systems and applications. In response, a satellite-dependent GIS applications industry sprang up during the early 1980s, despite the relatively high cost of the satellite data. The second notable contribution, geospatial tagging of TM imagery, was developed in the late 1980s as confidence in the georegistration process and procedures grew. The significance of this development was that geolocated TM imagery prepared by one user could be easily shared with another user. Two geospatial tagging formats were developed, GeoTIFF for the commercial sector, and HDF/GRID for NASA. As HDF/GRID was based on the subroutines developed for GeoTIFF, mathematical continuity for projection expansions was maintained between the two formats. The projection and geodetic control information in GeoTIFF used the European Petroleum Software User Group library, a de facto international standard; this explained why GeoTIFF was adopted by the Open GIS Consortium as their standard for remote sensing image exchange. The third key technical advance involved the development by several organizations, both commercial and academic/government, of raster-based GIS technology. The development of raster-based and raster ingest capabilities illustrated the potential for satellite data to serve as a map product and, when coregistered, provide time series and land cover change data for analyses.

It was during the early 1990s that broad-area inventories based on Landsat TM were developed and integrated into the U.S. National Atlas and other national land inventory programs. Global decadal change studies based on historical AVHRR imagery were also developed as initial demonstrations to support NASA's Earth Observing System (EOS). By the late 1980s, the demonstrated capability to accurately map and coregister satellite imagery was a key reason for the EOS project's adoption of rigorous cartographic requirements for its ground data processing system. It was at this time, that NASA and the Defense Mapping Agency (DMA) (now the National Geospatial-Intelligence Agency) combined resources to prepare the first global geolocated set of Landsat image mosaics on the UTM projection. NASA provided cloud-free Landsat TM imagery, DMA provided DEMs and surveyed ground control points, and the Earth Satellite Corporation prepared the geolocated and ortho-rectified mosaics. The adherence to cartographic requirements, particularly the integration of DEMs to assure the ortho-projection of satellite imagery, has greatly enhanced the accuracy and utility of EOS data analysis since 2000. It was a key reason for NASA's support of the Shuttle Radar Topography Mission (SRTM). SRTM was a joint NASA/U.S. Department of Defense (DoD) mission to use interferometric synthetic aperture radar (InSAR) to prepare digital elevation models of the earth from 60°N to

56°S at a resolution of one arc second (ca. 30 m). DoD paid for the development of a sixty-meter boom and outboard SAR receiving antenna that was attached to the shuttle *Endeavour* carrying a SAR transmit/receive antenna in its cargo bay. In just eleven days in orbit in February 2000, the SRTM was able to acquire the data that, when processed with continent-spanning transects that used kinematic GPS measurements, exceeded a mean vertical accuracy of nine meters and even better horizontal accuracy. The significance of the mission has been profound. For the first time, the eastern coastline of Chile has been accurately mapped, and the location of islands in the Pacific has been improved upon since initial explorations by Captain James Cook in the late eighteenth century. The SRTM elevation files, available to the public, have provided a key advancement to digital cartography for the third millennium.

The pioneering work of NASA space imaging provided a basis for the expansion of digital cartography. Without the development of computer techniques for photogrammetric correction of digital images from space by NASA and its support contractors, the new millenium's rapid deployment of commercial high-resolution satellites and Google Earth global maps accessible to the public via the Internet would not have occurred.

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SEE ALSO: Astrophysics and Cartography; Geodetic Surveying: For the Planets; Globe: Views of Earth from Space; Landsat; Remote Sensing: (1) Earth Observation and the Emergence of Remote Sensing, (2) Satellite Systems for Cartographic Applications

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National Atlas. See Atlas: National Atlas

National Atlas of the United States of America, The. *The National Atlas of the United States of America* was published in January 1970. It was a traditional hardbound collection of maps portraying America's social, economic, and physical conditions in the mid-1960s. Eight years of work went into its production, and critical reaction was positive. Yet *The National Atlas* did not sell well, and a second edition was never approved. The program was sharply curtailed until 1997, when it was reauthorized as a set of digital cartographic products and services delivered via the Internet.

After World War II public and private organizations promoted the production of a national atlas. A prototype designed by Samuel Whittemore Boggs, geographer of the Department of State, was released in 1952. This was underwritten by the American Council of Learned Societies, prepared by the American Geographical Society of New York, and presented to ten commercial publishers. None of these organizations could commit the financial resources necessary to produce a national atlas and recommended that a suitable federal agency take on the task.

From 1954 through 1961, the National Academy of Sciences sponsored a committee to set cartographic standards and to coordinate efforts among government mapping agencies to create a loose-leaf national atlas. Eighty sheets were produced before June 1960, when Detlev W. Bronk, president of the National Academy of Sciences, recommended to Secretary of the Interior Stewart L. Udall that the U.S. Geological Survey (USGS) be assigned responsibility for leading the compilation of a national atlas. The following year Udall instructed the USGS to establish suitable support to lead and carry out the project and to pursue essential interagency cooperation and gather support from academic and business communities to produce *The National Atlas*.

The National Atlas was first funded in 1963. Arch C. Gerlach, chief of the Geography and Map Division at the Library of Congress, was reassigned to the USGS to serve as atlas editor and project director. In 1967 Gerlach became the chief geographer there. USGS officials reassured Congress that their estimated cost to produce a national atlas ($2,354,000) would be fully recovered through sales of an atlas book and individual maps retailing separately.

The published twelve-pound tome included 765 maps at four primary scales, from 1:2,000,000 to 1:34,000,000. These were arranged in thematic sections devoted to the physical, historical, economic, and sociocultural characteristics of the United States. Regional base maps and an index to 41,000 geographic names were also included. The 15,000 copies of *The National Atlas* intended for public sale were priced at $100 each. By 1970 the cost of producing the bound volume and twenty-two separate sales editions (single sheets) had risen to more than $3 million.

An internal forecast of sales volume in 1969 estimated that 21,600 copies of *The National Atlas* would be sold within three years. However, by late 1973 less than 9,000 books had been purchased, and in 1975 the USGS steeply discounted its remaining stock. Although sales revenue was not sufficient to continue an active program after 1977, over the next twenty years the USGS continued to produce a limited number of separate maps that conformed to national atlas specifications.

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SEE ALSO: Atlas: National Atlas; U.S. Geological Survey

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National Center for Geographic Information and Analysis (U.S.). The idea of a geographic information system (GIS)—a computer application dedicated to capturing, handling, and analyzing geographic information—has its roots in several independent projects of the 1960s (Foresman 1998). By the early 1980s, when the first commercial GIS software packages began to appear, these independent tracks had converged into a widespread consensus: that geographic information constituted a distinct type of information in which every fact was linked to some specific location on or near the surface of the earth, that one could build a software package to perform a wide variety of functions on this type of information, that to do so would exploit fundamental economies of scale in software development, and that the result would have both widespread application in science and substantial commercial value.

The academic world is notoriously slow to react to such opportunities, however. Although many believed that GIS could be useful for scientific discovery in the disciplines that concern themselves with the earth, there were few compelling examples of best practice and little had been done to adapt GIS to the specific needs of science. Although many academics were interested in teaching about this new technology, notably in departments of geography, there were few guidelines on which to base a syllabus, and until P. A. Burrough's *Principles of Geographical Information Systems* (1986), there was no satisfactory textbook.

Also in 1986 Ronald F. Abler, a newly appointed program officer in the geography program at the National Science Foundation (NSF), saw an opportunity to address these and related issues by promoting the concept of a national center to be funded by the foundation (Abler 1987). The NSF issued a solicitation for such a National Center for Geographic Information and Analysis (NCGIA) in 1987, and in the summer of 1988 announced its award to a consortium of three universities: the University of California, Santa Barbara, as lead, together with the State University of New York at Buffalo and the University of Maine. A commitment was made to fund the center for eight years, subject to satisfactory performance, and approximately $10 million was provided over that period. A network of regional research laboratories was established in the United Kingdom at roughly the same time, though with a shorter time span and a focus that was more applied and local. Over the next two decades a number of similar efforts were funded in many countries.

As befits a project funded by the NSF, the center's primary mission was to conduct research to improve GIS as a tool for scientific research by removing some of the impediments that were seen at the time as limiting its value. The consortium chose to organize its research efforts around a series of research initiatives, each designed to focus on a specific topic for a limited period of time, and to engage the broader community in this effort to the greatest extent possible. The first initiative, on the accuracy of spatial databases, began in late 1988 with an international meeting of roughly thirty specialists and lasted for approximately two years. It was followed by another nineteen initiatives over the period of NSF funding on topics ranging from the visualization of uncertainty to the societal impact of GIS. Although funding to build and maintain the center ended as planned in 1996, a substantial NSF award to Project Varenius allowed the consortium's research to continue in modified form until 1999.

The consortium arrangement and the research initiative mechanism proved highly successful in terms of research productivity. Many of the initiatives led to published books and some to permanent international conference series. For example, the second initiative, on the language of spatial relations, resulted in a NATO Advanced Study Institute and book (Mark and Frank 1991) and the establishment of the Conference on Spatial Information Theory (COSIT), an international biennial series that continues into the twenty-first century. By 1996 well over 1,000 papers had appeared in refereed journals describing NCGIA-sponsored research.

NCGIA's systematic study of geographic information, and the fundamental issues surrounding GIS, spawned the new field of geographic information science (Goodchild 1992) in the early 1990s and led to the renaming of several journals and departments. In proposing Project Varenius in 1996, the center's principals grounded GIScience in a triangle, with each of the center's three foci at one of the vertices: the human (including issues of cognition and human-computer interaction), the computer (including issues of database and algorithm design), and society (for example, the impacts of GIS on privacy) (fig. 609).

Besides research, NCGIA was commissioned by the NSF to "augment the United States' supply of experts in GIS" (Abler 1987, 303). Despite the appearance of the first GIS textbook (Burrough 1986), there was still considerable confusion in 1988 about how to teach the subject—was it merely a matter of learning which buttons to push, or were there principles that students needed to learn if they were to succeed in a GIS career? In late 1988 NCGIA began a project to assemble a set of teaching materials and to distribute them as a guide to instructors. A draft collection of seventy-five units, each one including notes, illustrations, and references, was assembled from a network of contributors, edited and tested during the 1989–90 academic year, and made available in the summer of 1990. Over 1,500 copies were distributed, and the *NCGIA Core Curriculum* became a defining document for GIS education. A number of related projects followed, including a set of materials for GIS courses in technical programs in two-year colleges and a core curriculum in remote sensing. In less than two decades an abundance of textbooks and a clear consensus on curriculum (DiBiase et al. 2006) confirmed that the field of GIS education had matured to become an important part of student training in many disciplines.

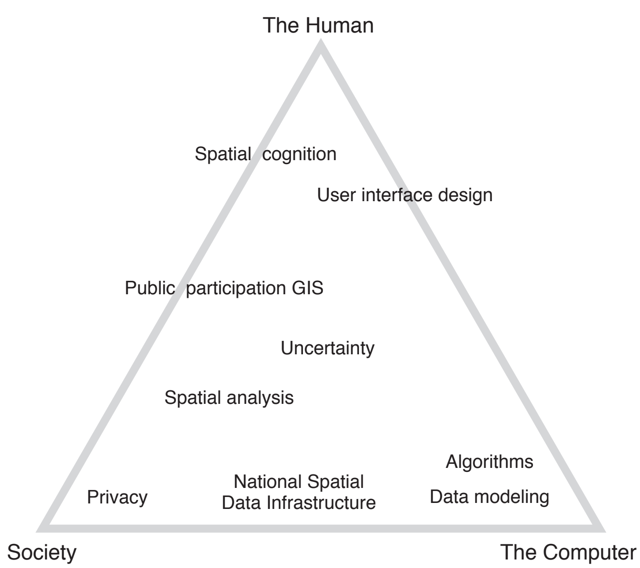

FIG. 609. TRIANGULAR DIAGRAM SHOWING RELATIONSHIPS IN NCGIA. Diagram describes the relationship of the center's nine research topics to the center's three foci–the individual human map user, society in general, and computer technology.

A twenty-year reunion held in late 2008 in Santa Barbara was attended by many of the principals, participants, and observers of NCGIA's early years. In his presentation surveying the contribution of NCGIA, Stephen C. Hirtle, professor in the School of Information Sciences at the University of Pittsburgh and a participant in Project Varenius and several NCGIA activities, noted that "the NCGIA has fostered leading research through engagement with wider research communities, consistently brought multiple voices to the table to address issues of concern, [and] manage[d] to examine both theoretically interesting problems and motivated real-world applications, often within the same meeting or research endeavor" (Hirtle 2008, conclusions). NCGIA entered its third decade as a loose collaboration between the three original founding institutions, which remained committed to advancing the understanding of the nature, theory, and technology of geographic information.

MICHAEL F. GOODCHILD

SEE ALSO: Electronic Cartography: Intellectual Movements in Electronic Cartography; Geographic Information System (GIS): (1) Computational Geography as a New Modality, (2) GIS as a Tool for Map Analysis and Spatial Modeling; Tobler, Waldo R(udolph)

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National Geographic Society (U.S.). The National Geographic Society occupies a unique place in the United States. Though a private institution, it has at times enjoyed a close relationship to the federal government. This is exemplified by the Society's cartographic work, which has earned it a reputation as an authoritative source of geographical information, one that even federal agencies and the military have relied upon in the twentieth century. The Society was founded in 1888 in Washington, D.C., at a particularly fertile moment for scientific institutions in America, both in the federal government and the emergent universities. Indeed, each of the Society's six founders, and many of its original members, worked at some time for the new federal bureaucracies. The Society's purpose was to bring together those working in the disparate areas of geographical research and practice. This was, to be sure, a small constituency, and thus the Society grew slowly in the early decades, and its journal, *National Geographic Magazine* (later *National Geographic*), remained technical and specialized.

A turning point came with the Spanish-American War, which enabled the Society to position itself as a source of geographical information on the nation's newly acquired territories. In those crucial years at the turn of the century, the Society began to supplement its magazine with occasional maps related to the Sino-Japanese War, the Spanish-American War, the Anglo-Boer War, and the Russo-Japanese War. Though not produced by the Society, these maps began to establish the Society as a source of cartographic information.

About a decade later, after returning from a tour of Europe, the Society's president—Gilbert Hovey Grosvenor—requested a map be made of the Balkan states and Central Europe. When World War I began in August 1914, Grosvenor was able to issue this map through the monthly *National Geographic Magazine*, a timely act that gained the Society 100,000 new members and extended its cartographic reputation (Poole 2004, 114). Maps were much in demand during wartime, and those available left much to be desired. When war broke out, most map companies simply reissued existing maps, whose scales were far too small to be suitable for more than an overview of the battlefield.

Even more interesting was the tendency for newly drawn maps to replicate existing cartographic styles. The first map created by the Society—a map of the Western Front drawn in 1918 by its newly established Cartographic Division—hid the contours of battle in a dense landscape of place-names. Yet the Society's primary goal was just this: to create a map that included nearly all names on the battleground, and certainly every name mentioned in the news. In fact, the Society specifically noted that this small map, measuring approximately 71 by 84 centimeters, contained as much information as French and German maps four times as large. The effort to include so many place-names was actually appreciated by map users, despite the effect it had on the clarity of the map as a whole.

Albert H. Bumstead, the National Geographic Society's chief cartographer from the 1910s until his death in 1940, echoed this sentiment in 1915. Discussing his vision for the Society's maps, Bumstead decided to erase the contour lines that marked elevation. While he found contour lines valuable, he acknowledged that to lay map readers "they are nothing but a confusion." Elevation was information easily sacrificed in the interest of communicating other elements, such as place-names (Schulten 2001, 181). This emphasis on locations rather than understanding the landscape as an entity characterized the American culture of cartography throughout the late nineteenth and early twentieth centuries.

The Society gained a number of members during World War I and thereafter began to more systematically market its niche as a geographic authority. In 1921 the Society issued its new map of Europe, specifically designed to reflect the changes established at the Paris Peace Conference, including the redrawn Poland and the new nations of Estonia and Latvia (*Map of Europe Showing Countries as Established by the Peace Conference at Paris*, February 1921). The map appeared in the press room of the U.S. State Department, and Bumstead quickly followed this with the first of its most popular and influential maps—the general reference world map—in 1922 (Garver 1990, 131). By this point the Society was sending National Geographic bulletins with maps and abstracts of articles to more than 2,000 daily and weekly news outlets in the United States (Poole 2004, 130). And the Society's work in cartography, exploration, and photography also meant that the name of the Society's leader—Gilbert Hovey Grosvenor—began to appear on maps as well, such as "Gilbert Grosvenor Island" in the Canadian Arctic and "Gilbert Grosvenor Mountain Range" in Antarctica (Poole 2004, 146).

In some regards the Society maintained conventions; until 1975, for instance, it almost always mapped the world with the United States at the center. This was not unusual, as nearly all of the most popular atlases at the time did the same thing. The Society also made an effort to continually rethink its use of map projections. Just after the World War I armistice, Grosvenor asked Bumstead to devise a projection that maintained the graphic unity of the Mercator projection but was more accurate. The Mercator projection—the most commonly used projection at the time and widely accepted for its directional accuracy—was unsatisfactory to Grosvenor for its gross exaggerations of the polar regions. In doing this, Grosvenor recognized the limits of the Mercator projection as well as its tremendous visual appeal. In its place, he selected the Van der Grinten projection as the basis for the Society's first world map in 1922 (Schulten 2001, 195).

Alphons J. van der Grinten designed this projection at the turn of the century. It modified the spatial distortions of the Mercator projection and replaced its rectangular shape with a circular one. The Society relied on this projection for nearly all its world maps until 1988 (fig. 610). Its decision to use this projection nicely reflects its concern with both correcting for the well-known flaws of the Mercator projection while also creating a world that mimicked the unified shape that the widespread use of the Mercator projection had entrenched in American minds.

Perhaps the high point of the Society's cartographic work came during World War II. From 1936 to 1947 the Society created thirty-eight maps, and distributed over 37 million copies of these to its members. By 1950 the Society printed 1.9 million copies of each map it created. Most of these were mailed as supplements to the *National Geographic Magazine*, which had a circulation that exceeded one million by 1940. But the Society also carried a broader reputation for both geographic accuracy and cartographic innovation. It experimented with over a dozen projections in its wartime maps and drew these maps to fit the circumstances of the crisis rather than extracting maps from a preexisting collection.

For instance, the Society's map of Japan issued in April 1944 used an azimuthal equidistant projection so that readers could follow the course of bombers as straight lines outward from Tokyo. The Society used this same technique in maps of Europe and the Near East (May 1940 and June 1943) and experimented with a new projection for its maps of Asia (December 1942) and the Soviet Union (December 1944).

The Society's maps enjoyed a steady demand from its members as well as the armed services during World War II. The July 1944 map of Germany became the basis for enlargements of Allied ground and air forces in Europe, and the Pacific map was used by the U.S. State Department, the White House, embassies, and the military. Perhaps the most well known of these wartime uses was the Christmas exchange between Franklin D. Roosevelt and Winston Churchill in 1943. Roosevelt kept a set of National Geographic maps during the war, and after noticing Churchill's admiration for the maps, Roosevelt requested a set be made for Churchill. The Society's maps were also printed as part of the *Newsmap* series for instructional purposes for active servicemen. Even more widely circulated were the Society's maps that appeared in *Yank*, an army weekly with a circulation of over three million. The War Department ordered more than one million maps from the National Geographic Society for use at all levels of combat and strategy (Schulten 2001, 212).

In the 1930s the Society also became more selective about the use of place-names, in part realizing that greater selectivity meant more creative and compelling maps. When introducing its revised map of the world in 1932, the Society defended the decision to print fewer names by explaining that execution of the map depended upon the geographer's judgment of particular placenames. Advances in printing also clarified detail and enhanced readability. This was in large part the work of Bumstead and staff cartographer Charles E. Riddiford, whose techniques involved drawing and photographing each letter of the alphabet so that labels could be reproduced in any size without sacrificing legibility. Bumstead first used this photo-lettered type in the political map of the United States published in May 1933.

The cartographic division of the Society also began to use color more carefully and delicately, for instance, by omitting the heavy layer tints that separated nations and instead using neutral background colors and darker shades to mark boundaries, rivers, and highways. All of this was done to improve the appearance, elegance, and readability of the map. Bumstead's techniques were so popular that the Society patented and used them for decades thereafter. Perhaps the greatest influence of the Society's maps has been in these production and printing techniques (Schulten 2001, 210 and n12). Photocomposition created a clearer, simplified and more elegant map that commercial map companies hurried to replicate after the conclusion of World War II.

The Society's maps also became fixtures in the media as reference sources for reporters and as models for journalistic cartographers. After the war, the Society diversified its cartographic work, exemplified by maps of the earth's interior and the solar system. The Society printed its first atlas in 1960, covering the United States. The following year it released its first globe and two years later issued the first edition of its highly regarded world atlas (National Geographic 1998).

The Society embraced technological advances in cartography at midcentury, producing maps ranging from the ocean depths to outer space. In 1967 it produced the first in a series of maps of the world's ocean floors. Two Columbia University geologists, Marie Tharp and Bruce C. Heezen, converted depth soundings into a three-dimensional diagram, which was then rendered into a relief map by Austrian artist Heinrich C. Berann (fig. 611). The Society also used Landsat images to create its July 1976 photomosaic of the continental United States. The map was based on a survey of over 30,000

FIG. 610. *THE WORLD*, NATIONAL GEOGRAPHIC SOCIETY, 1932. World map on the Van der Grinten projection, 1:43,000,000.

Size of the original: 63.7 × 95 cm. From *National Geographic Magazine* 62, no. 6 (December 1932), map supplement. Permission courtesy of the National Geographic Society, Washington, D.C.

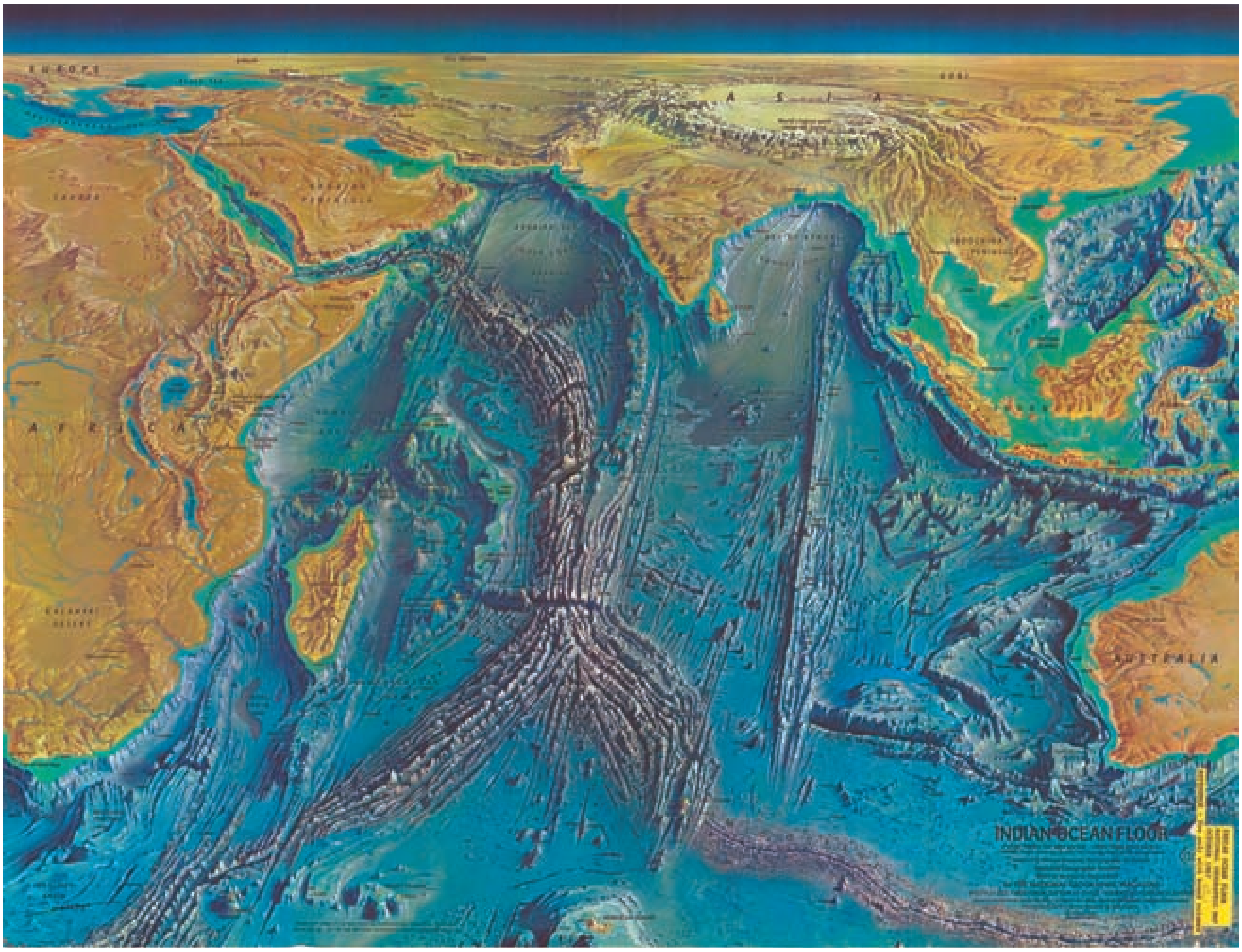

FIG. 611. *INDIAN OCEAN FLOOR*, NATIONAL GEOGRAPHIC SOCIETY, 1967. The first ocean floor map commissioned by the society was the Indian Ocean, which was followed by maps of the rest of the world's ocean floors. Scale not given.

Size of the original: 48 × 63 cm. From *National Geographic* 132, no. 4 (October 1967), map supplement. Permission courtesy of the National Geographic Society, Washington, D.C.

images created by multispectral orbiters, 569 of which were used to create the map (National Geographic Society 1998). Cartographic work that had previously taken years was now reduced to hours.

By the end of the century, the Society had also printed maps of acid rain, opium and poppy production, the geology of geological faults, and the inside of a human cell (Garver 1990, 134). The first map created entirely by digital cartography appeared in December 1983, a historical map of Europe based on the projection of the Society's own Wellman Chamberlin. It also extended its reach into historical cartography in the second half of the twentieth century, with a series of historical maps (*The Making of America*) as well as the noted *Historical Atlas of the United States* in 1988 (National Geographic 1998).

In December 1987 the Society appointed a panel of cartographers to reevaluate its choice of projection, and soon thereafter adopted one designed in the 1960s by Arthur H. Robinson. Like the Van der Grinten projection, Robinson's was an uninterrupted picture of the world, and one that reduced the discrepancies of size in the most northern and southern latitudes. The Society used the Robinson projection for its world maps from about 1988 to 1998, when it was replaced by the Winkel tripel. All three of these projections were unique for striving for greater cartographic accuracy while also conveying a coherent, unified picture of the world. Though the Society began to contract out its cartographic production at the end of the twentieth century, its influence in the conceptualization, execution, and distribution of maps of every kind in the twentieth century was formidable.

SUSAN SCHULTEN

SEE ALSO: Marketing of Maps, Mass; Projections: World Map Projections; Robinson Projection; Scientific Discovery and Cartography

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National Geographical Institute (France). See Institut Géographique Nationale

National Geographical Institute (Spain). See Instituto Geográfico Nacional

National Reconnaissance Office (U.S.). See U.S. Intelligence Community, Mapping by the

Nation-State Formation and Cartography. The nation-state is not an invention of the twentieth century. It emerged, arguably, in Europe as both a concept and a structure in the seventeenth century (Elden 2005). But as European imperialism spread throughout the world, so too did the European-style nation-state. By the twentieth century, and particularly after decolonization and the fall of Communism, the concept and construction of nation-states had been readily adopted and adapted throughout the world.

Theoretically, a nation-state merges a homogeneous population (the nation) within sovereign and internationally recognized boundaries (the state), which are controlled by a specific set of agencies and institutions (also the state). The nation-state functions to maintain control over a demarcated territory as well as to organize a national citizenry and arguably to instill democratic, capitalistic, and patriarchal systems. The construction of national identity is central to the nation-state and is often conceived along racial, ethnic, and cultural lines. But in the last quarter of the twentieth century scholars began to question the coherence and origin of nation-states and national identities. As Benedict R. O'G. Anderson (1991) famously argued, the nation is not a preexisting natural entity, but an imagined political community. Moreover, globalization, multinational corporations, multistate political unions, migration, and transnational identities continually challenge the idea that nation-states are homogeneous or sovereign. Indeed, nation-states do not contain homogenous populations, nor are their borders impermeable; instead they are diverse, fluid, and contested spaces. Regardless of the constructed, changing, and tenuous character of nation-states, the world has been divided among these normalized spaces in which political and administrative boundaries hypothetically coincide with a nationally defined group. As the guiding principles for organizing the world, nation-states have had powerful and lasting manifestations on identity formation and geopolitical conflict in the twentieth century.

As a modern social construction, the nation-state has been formed and assembled through numerous discourses and processes that have varied over time and space. The state, as an administrative and coercive power, has a heightened role in creating and maintaining the nation-state. As James C. Scott (1998) argued, the nation-state's environment and society become readily apparent, or "legible," through state-led programs and policies. Even so, in the twentieth century, the nation-state was built and sustained not solely by the state but also by educational institutions and the media as well as through everyday practices.

There are many ubiquitous processes and symbols that are involved in creating and perpetuating the boundaries, unity, and identity of a nation-state. Numerous studies have highlighted how a nation's collective memories and national narratives are constructed and sustained through icons and structures such as museums, censuses, monuments, memorials, traditions, sports, anthems, currency, stamps, flags, and maps.

The invention and maintenance of the nation-state is inextricably linked to cartography. Whether at the scale of the world or nation-state, maps are crucial tools that create and make visible the space of a unified nation-state, provide tangible evidence of its existence, and even allude to its character. By demarcating its borders and giving names to its territory, maps link people and land to create a sense of place and national identity (Kashani-Sabet 1999; Thongchai 1994). Maps can also create and express historical national narratives, stake claims to disputed territory, and double as symbols for the nation-state. Further, detailed large-scale maps of natural resources, land tenure, and human demographics aid nation-state formation by allowing the territory and people to be known and controlled.

Often considered accurate and objective representations of the world, maps socially construct and normalize spaces such as nation-states. Maps are not mimetic devices, or imitative representations, but are images that create and reflect certain ideas and features of a complex and diverse world. When used consciously or otherwise to create an image of homogeneity, historical longevity, and national pride, maps are designed to support certain ideas or suppress others. Thus, minority groups or embarrassing national histories are often marginalized on national maps. For example, a detailed national map of the United States would rarely delineate the horrors committed against indigenous peoples and African Americans over several centuries or the internment of Japanese Americans during World War II. Though most maps are not deliberate attempts to ignore certain people and silence ideas, they disseminate socially constructed geographic knowledge and endorse dominant views of the world by subtly reinforcing the location and perceived character of nation-states.

Cartographic technologies of the twentieth century have made it feasible for numerous groups to produce maps. Thus, not only the state or wealthy patrons, as was traditionally the case (Harley 1988), have produced national maps, but also commercial publishers, nongovernmental organizations, indigenous peoples, and resistance groups. Regardless of who produces them, national maps are generally concerned with the construction, acquisition, and maintenance of territory, as either a symbol of national unity or a debating point in a geopolitical dispute. Coupled with arguments that maps can homogenize people and places, simplify complexity in favor of dominant discourses, create and endorse socially constructed knowledge, and present a misleading facade of scientific accuracy, it is crucial that they be read critically.

From the immense variety and modes of maps that exist, a few types of maps were commonly used to aid nation-state formation in the twentieth century. Categories of these cartographic icons of nation-state formation inevitably overlap insofar as many of these maps have overtly functional goals, while others are more blatantly symbolic and ideological.

For centuries, maps have served to promote knowledge about territory and give order to nature and society. Christopher Saxton's *Atlas of England and Wales* (1579) and imperial mapping projects such as the British Survey of India (ca. 1765–1843) and Napoleon's *Description de l'Égypte* (1809–28) are early examples of the attempts to map and know territory. In the pursuit of geographic knowledge and power during the twentieth century, imperial powers and independent nation-states initiated and financed extensive surveys and mapping projects to understand, demarcate, and control their foreign and domestic territories. Cadastral, topographic, and demographic maps have divided and recorded national territory, its resources, and its inhabitants so that the state could know, label, tax, and control its territory (Scott 1998). Technological advances during the twentieth century in geographic information systems (GIS) and remotely sensed data have helped to further such mapping projects.

Though not entirely divorced from functional maps, some maps serve a more symbolic role, shaping geographical imagination and national consciousness. With scales generally too small for use as analytical tools, national maps provide a visual image of the extent and location of the nation-state, delineate the particular features and peoples that are included and excluded, and often narrate the history and culture of the nation-state (Craib 2002). Symbolic national maps include wall maps, tourist maps, national or historical atlases, and even trademarks for businesses or government agencies. Such maps are pervasive, rendering the outline of the nation-state an easily recognizable symbol that continually, albeit subtly, constructs and reminds citizenry of the nation-state's existence and its national identity (Billig 1995). Anderson (1991, 175–78) referred to such maps as "logos," in which the outline or form of the nation-state is a symbol that invokes meaning and values that may have little relation to the geography of the nation-state.

National atlases are perhaps the best exemplar of national maps. Such atlases have several roles, but their classic function is as a symbol of nationhood, national unity, and national pride (Monmonier 1997, 369; Sparke 1998, 480–82). While the defining criteria are ambiguous, most national atlases are collections of thematic maps of an independent country. In addition to historical maps that narrate the nation-state's past, they typically include statistical and physical maps as well as general reference maps covering the country section by section at a somewhat larger scale—all of which enhance their power as pedagogical and reference tools for use in homes and classrooms. Often considered an authority on the nation-state's geography, the national atlas is a convenient source of base maps and other data for making other maps. Though the 1579 *Atlas of England*

and Wales may be considered the first national atlas, it was during the late nineteenth and early twentieth centuries that Western countries began to produce national atlases as a symbolic assertion of their national identity and historical legacy. The United States, Canadian, Finnish, and Scottish governments all produced national atlases during this period, but it was in the mid to late twentieth century, as nation-states in Asia, Africa, and South and Central America gained their independence, that production of national atlases increased dramatically (Monmonier 1997).

Commercial and media mapping have also helped create and perpetuate the existence and perceived character of nation-states. As Susan Schulten (2001) has shown, popular mapping in *National Geographic* has helped shape Americans' geographical imaginations by producing and asserting dominant narratives and norms of the nation-state. To reinforce Schulten's point, the National Geographic Society, in a 2007 advertisement on its website, touted its *Historical Atlas of the United States* as "a unique reference that makes the nation's past come alive as it captures the moments, people, and places that have shaped our country's history," exemplifying how a nation-state's history is narrated through cartography. Media mapping can also have a strong impact on defining and reifying national ideas in the minds of its citizens. In the Western world, maps in news magazines and newspapers and on television are pervasive, if not ubiquitous. These maps often assert established norms and values while also engaging in contentious geopolitical and national debates.

School textbooks and atlases are also crucial tools in building national sentiment; indeed these texts inculcate and normalize the geography of the nation-state as well as its historical narratives and virtues (Kashani-Sabet 1999, 180–215). Guntram H. Herb (2004) and Betty S. Anderson (2001) showed that in Germany and Jordan, respectively, maps in textbooks and atlases helped construct and visualize territorial and national narratives. In a more geopolitically contentious space, Yoram Bar-Gal (1996) explored how the Israeli state and Zionist organizations created and published maps in school textbooks, atlases, and the media to assert the existence of the state of Israel through the process of territorial socialization. Conversely but not surprisingly, textbooks published in much of the Arab world generally use the place-name Palestine to delineate what is also commonly considered Israel. In a backlash campaign against the use of Palestine as a label, the American Jewish Community in 2004 sponsored a leaflet showing maps of Palestine published in Syrian, Palestinian, Lebanese, and Saudi Arabian textbooks and asking, "How can there be peace in the Middle East if Israel isn't even on the map today?" (fig. 612).

FIG. 612. *HOW CAN THERE BE PEACE IN THE MIDDLE EAST IF ISRAEL ISN'T EVEN ON THE MAP TODAY?*, THE AMERICAN JEWISH COMMITTEE, 2004. This leaflet, also published as a full-page newspaper advertisement in the *New York Times* and *Boston Globe*, 5 May 2004, asserts that certain nations of the Arab world are silencing Israel by using the label "Palestine" on their maps in school textbooks and therefore perpetuating violence in the Middle East. The captions on the map details are: upper left, "Syrian fifth-grade schoolbook *Geography of Syria*"; lower left, "Lebanon Ministry of Tourism map"; upper right, "Palestinian Authority schoolbook *Atlas of Palestine*"; lower right, "Saudi Arabian 6th grade schoolbook *Geography*.
Permission courtesy of the American Jewish Committee, New York.

There are a multitude of contexts in which national atlases, school maps, and media maps have been used in the formation and reproduction of the nation-state. Indeed, the twentieth century widened the uses of cartography not only to construct, but also to contest, the nation-state.

Independence movements and geopolitical disputes such as the Israel/Palestinian conflict have frequently invoked nationalist mapping. By drawing boundaries and appending labels to places, maps have a powerful role in asserting territorial claims and declaring autonomy.

For this reason, nationalist maps are often considered propagandistic, as part of a deliberate and systematic attempt to shape perceptions and behaviors. With iconic symbols and bold colors, these maps are generally considered less scientific and accurate than other maps. Though maps used during geopolitical disputes and independence movements often contain blatantly pointed political and often nationalist messages, caution should be exercised before describing a map as either accurate or propagandistic. Because of necessary cartographic generalization, a world or regional map can include only a limited number of features, and because its design and content are generally framed in the dominant discourses of the society in which it is produced, even a seemingly banal or apolitical map will assert certain social norms and biases.

Following both world wars, Europe witnessed a flood of nationalist mapping as empires dissolved and new nation-states formed. For example, in the Balkan region in the late nineteenth and early twentieth centuries, different geographical discourses, including cartography, were used by Serbs, Greeks, Bulgarians, and Turks to narrate national histories, emphasize their distinct identities, and normalize the borders that divided them (Peckham 2000). Herb (1997) provided a detailed analysis of the maps manipulated by German nationalists and the Nazi Party to delimit national boundaries, reclaim stolen territory, and garner support against the Allies (fig. 613). The end of the Cold War similarly initiated national mapping projects. Estonia, Latvia, Lithuania, Belarus, Ukraine, Poland, Romania, and Hungary all launched cartography programs that realigned themselves away from Russia and toward Europe. Some of these nation-states also produced maps to assert distinct noncommunist national and historic identities. With the breakup of Yugoslavia in the 1990s, the Croatian government created maps that claimed and asserted its location within Western Europe and away from Russia. On one tourist map (fig. 614), symbols touting Croatian cultural and historical identity assert the country's uniqueness in the Western world while other symbols carry a subtly contradictory, irredentist message by pointing out significant concentrations of Croats in adjacent Bosnia-Herzegovina (Zeigler 2002).

FIG. 613. RUPERT VON SCHUMACHER, *EIN KLEINSTAAT BEDROHT DEUTSCHLAND*, GERMANY, 1934. This nationalist map was used to give the impression that the German nation-state was threatened by smaller and weaker Czechoslovakia.
Size of the original: 10.1 × 12.1 cm. From Rupert von Schumacher, "Zur Theorie der Raumdarstellung," *Zeitschrift für Geopolitik* 11 (1934): 635–52, esp. 645.

After World War II and the decolonization of much of the world, many newly independent states approached the task of constructing nation-states within imperially imposed boundaries. The new boundaries and ruling structures often divided local, religious, and ethnic communities while combining other groups that were frequently at odds with one another. Regrettably, the colonial legacy of borders that defy preexisting geographical divisions of the inhabitants have sparked many geopolitical conflicts. Even so, maps have used other nationalist symbols, ideas, and rhetoric to define and perpetuate the idea and shape of the new nation-states, which then facilitated a sense of place for their citizens.

The maps created by postcolonial nation-states generally reflected geographic concepts, borders, and cartographic techniques dictated by colonial legacies and postwar treaties. Colonial powers often had well-established mapping institutions that were at times absorbed and maintained after independence. Even so, new nation-states did not simply replicate practices inherited from the colonizers. Able to alter imperially imposed ideas and structures such as place-names and boundaries, as well as control the general content and politics of the map, many postcolonial states created national and historical maps that ignored their recent colonial past and stressed their age and existence prior to colonization (Thongchai 1994). Textbooks also frequently emphasized allegiance to the new leaders of the country as the legitimate and rightful heads of the nation-state (Anderson 2001). Renaming the nation-state and its cities often accompanied decolonization and such toponym changes and the disputes over them are readily reflected in maps.

The *National Atlas of Egypt*, published in 1928, six years after the country gained nominal independence, exemplifies this type of postcolonial relationship. "Commanded" by the Egyptian King Foud I and with the monarchy's emblem prominently displayed on the title

FIG. 614. CROATIA TOURIST MAP. Created by Darko Stefanec in Zagreb in 1993, the map was published by the Croatian Tourism Board. It uses numerous symbols and icons to show unique Croatian cultural and historic sites along and just over its border with Bosnia-Herzegovina.
Size of the entire original: 60 × 74.4 cm; map only: 55.7 × 57 cm. Image courtesy of Professor Donald Zeigler, Old Dominion University, Norfolk. Permission courtesy of the Croatian National Tourist Board, Zagreb.

page, the atlas makes no mention of the country's recent colonial past even though it was published in English, not Arabic, and was produced by British cartographers working at the Survey of Egypt. With its content primarily focused on the country's physical geography, the atlas had neither a cultural nor a historical narrative. But following complete independence from Britain in 1952, the Egyptian government funded numerous school atlases and tourist maps with clearly defined Egyptian national narratives, including its Arab identity and ancient Pharaonic past (fig. 615).

In a similar vein Thongchai Winichakul (1994) dis-

FIG. 615. *ARAB REPUBLIC OF EGYPT* (NO DATE, CA. 1983). This tourist map shows both Egypt's Pharaonic past though numerous iconic symbols as well as its Arab identity in its official title, the Arab Republic of Egypt. Size of the original: ca. 28.8 × 29.2 cm. Image courtesy of the Geography and Map Division, Library of Congress, Washington, D.C.

cussed how British authorities introduced the idea of the nation-state to Siam (which changed its name to Thailand in 1939) in the late nineteenth century, and how the concept was adopted by Siam's leaders. Although Siam was not officially colonized during this period of European influence, legitimate, "true" knowledge imported from Europe displaced indigenous conceptions of space, geographic vocabulary, and mapping. Siam emerged as a Western-style nation-state in the late nineteenth and early twentieth centuries through modern geographical discourses, of which the map was the primary technology. Maps produced after the decline of European influence did more than merely represent the Siamese nation-state—they preceded, anticipated, and constructed it.

By the mid-twentieth century Thailand, like many other modern nation-states, distributed Western-style historical atlases and maps designed to create and perpetuate its geography and long history.

Intimately related to the cartographic construction of national identities after decolonization are geopolitical disputes over imperial boundaries left behind. Since maps are often considered objective and accurate, they are frequently used both to assert territorial claims and to garner international support. For example, after Saddam Hussein's forces invaded Kuwait in 1990, the Kuwaiti government produced two national atlases to prove the sovereignty of their nation-state and refute Iraqi claims that Kuwait was historically part of Iraq (or Mesopotamia). Published in 1992, these atlases are collections of historical maps produced from all around the world, which attest to Kuwaiti claims that Kuwait (or Grayn as it was also called) was always separate from Iraq. One of these 1992 atlases, *Kuwait in World Maps*, was produced in Arabic, English, French, and German to assert worldwide that Kuwait "never was a part of this state [Iraq] at anytime" (p. 14) and that "throughout its ancient and modern history, Kuwait has been a free and proud country" (p. 184); the second atlas was published in Arabic only (fig. 616).

Easily recognizable and ubiquitous, the map as a logo for national autonomy was, and still is, a powerful symbol for independence movements (Anderson 1991, 175). Counter-mapping is a broad genre, but generally it refers to maps that offer alternative interpretations and conceptualizations of places (Johnson, Louis, and Pramono 2005). As a form of resistance against the state and state territorial divisions, counter-mapping is evident in places such as Kurdistan and Palestine, both of which claim some degree of independence but are not internationally recognized nation-states. National maps in the shape of Kurdistan, as well as necklace charms that can be worn close to one's heart, have been created, sold, and used to assert the territorial unity and coherence of a nation that is divided between Iran, Iraq, Turkey, and Syria (figs. 617 and 618). These cartographic symbols also employ the powerful nationalist symbol of the Kurdish flag to assert further that Kurdistan is a unified nation (Culcasi 2006). The Palestinian group Palestine Remembered has reinforced its nationalist demands by creating and selling maps that textually and

FIG. 616. DETAIL FROM A MAP OF ASIA BY AARON ARROWSMITH, 1829, IN A KUWAIT ATLAS OF 1992. This historical map is one of numerous maps that shows Grayn, or Kuwait, as a separate entity from Mesopotamia. Size of the map detail: ca. 12 × 11.7 cm. From Abdullah Yousef al-Ghunaym, *al-Kuwayt: Qirāʾaj fī al-kharāʾit al-tārīkhīyah* (Kuwait, 1992), 23.

FIG. 617. MAP OF KURDISTAN NECKLACE CHARM. Both the necklace and the map in figure 618 can be purchased online, and both are powerful symbols that create and represent Kurdistan as a contiguous and united nation-state, though it is divided between the internationally recognized states of Iran, Iraq, Turkey, and Syria.
Size of the original: 2.5 × 3.3 cm. Permission courtesy of the Kurdistanshop, Netherlands.

graphically narrate the Palestinians' plight since 1948, when Israel became independent. Their map describes the "depopulation" of their land by Zionists, and asserts their "right to return" (fig. 619). Though less symbolic than the necklace charm of Kurdistan, this powerful political message gains legitimacy through demonstrably factual and accurate maps.

Maps have also been used by indigenous groups to assert and attempt to reclaim territorial sovereignty. In 1987 the Gitxsan and Wet'suwet'en of Canada used Western cartographic conventions to produce maps in a lawsuit against the Canadian government (Sparke 1998). Indigenous groups attempting to reclaim sovereignty have recently adopted web-based cartography and GIS technologies, which might have a substantial impact on land claims and nation-state formation (Johnson, Louis, and Pramono 2005).

The concept of the nation-state has been questioned as socially constructed and imagined. This construction

FIG. 618. NATIONAL MAP OF KURDISTAN. Compare figure 617.
Size of the original: 49.9 × 70.1 cm. Permission courtesy of the Kurdistanshop, Netherlands.

PALESTINE 1948
COMMEMORATION OF AL NAKBA
The Towns and Villages Depopulated by the Zionist Invasion of 1948
Prepared by : Salman Abu-Sitta, Copyright 1998.
The dispossessed Palestinians ...
Where do they come from ?
After 50 years of dispossession, where are the Palestinian refugees today?
Denial of the Right of Return is perpetuation of Ethnic Cleansing which is a War Crime.
Where is their land ?
Should and Can the Palestinian Refugees Return Home ?
Yes. Because the Right of Return is ......
Why did they leave ?
Sacred,
Legal,
There is no legal or moral justification for bartering a Palestinian State, which is a political act of sovereignty, with the Right of Return, which is an inalienable Right.
... and terrorized by massacres at ...
Possible.
Ben Gurion's Doctrine: "Destruction of Palestine is a necessary condition for the well-being of Israel."
Ben Gurion destroyed 78% of Palestine. Sharon completes its destruction.
(WEST BANK)
Legally, the Return can ONLY be implemented to the refugee's original home and land in 1948, not anywhere else, even in Palestine.
Jerusalem
When did they leave ?
A Palestinian Village, 1948
LEGEND
Depopulated Towns and Villages :
SAND DUNES
Palestine Land Society
Right of Return Congress
The Feasibility of the Refugees' Return
© 1999-2005 PalestineRemembered.com

is in part facilitated by cartographic discourses, which have played a key role in producing and reproducing the nation-state. By recording the land, labeling it, and providing an easily recognizable symbol for the nation, maps not only reflect preexisting places but also construct and create the reality of nation-states. As Firoozeh Kashani-Sabet (1999, 74) summarized, maps provide "visual proof" of the reality of nation-states. There are, of course, other symbols, discourses, and processes involved in the formation of the nation-state in the twentieth century. But as a tool for identifying, controlling, and staking claim to territory and citizens as well as for serving as a symbol or logo for the nation, maps have not only influenced the formation of nation-states worldwide but fueled debate about their legitimacy.

KAREN CULCASI

SEE ALSO: Atlas: National Atlas; Colonial and Imperial Cartography; Counter-Mapping; Geopolitics and Cartography

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NATO (North Atlantic Treaty Organization). See Military Mapping by Major Powers: North Atlantic Treaty Organization

Navigation. Navigation is the art and science of determining the position of a vehicle on land or sea or in the air and directing it from one place to another. Three primary navigation techniques evolved from the earliest days of sailing ships and were well established by 1900: dead reckoning (DR), piloting, and celestial navigation (Maloney 1985). They were quickly adapted for air travel during the first decade of the century, with modifications for an aircraft's speed, limited flight endurance, restricted work area, and three-dimensional operational space. The capabilities of these traditional techniques were extended during the century to accommodate new and faster modes of transportation using electronic sensing innovations such as radio waves, radar, and inertial systems. Satellite navigation was introduced near the end of the century.

The basic method of navigation during this century remained DR, a technique for determining or projecting position from a previously known position. Tools and instruments associated with DR were maps and charts, magnetic and gyrocompasses for determining direction, marine logs and airspeed meters for determining speed or distance, and watches for measuring time (fig. 620). The invention of the gyrocompass by German scientist Hermann Anschütz-Kaempfe in 1904, with advancements by American inventor Elmer Ambrose Sperry, greatly improved seagoing DR since it indicated true rather than magnetic north and was unaffected by a

(*Facing page*)

FIG. 619. SALMAN ABU-SITTA, *PALESTINE 1948, COMMEMORATION OF AL NAKBA*, 1998. This map, available in English and Arabic, is sold online. It details the towns and villages of Palestine "depopulated" by the Zionist "invasion" and the "Right of Return."

Permission courtesy of Salman Abu-Sitta, Palestine Land Society, U.K.

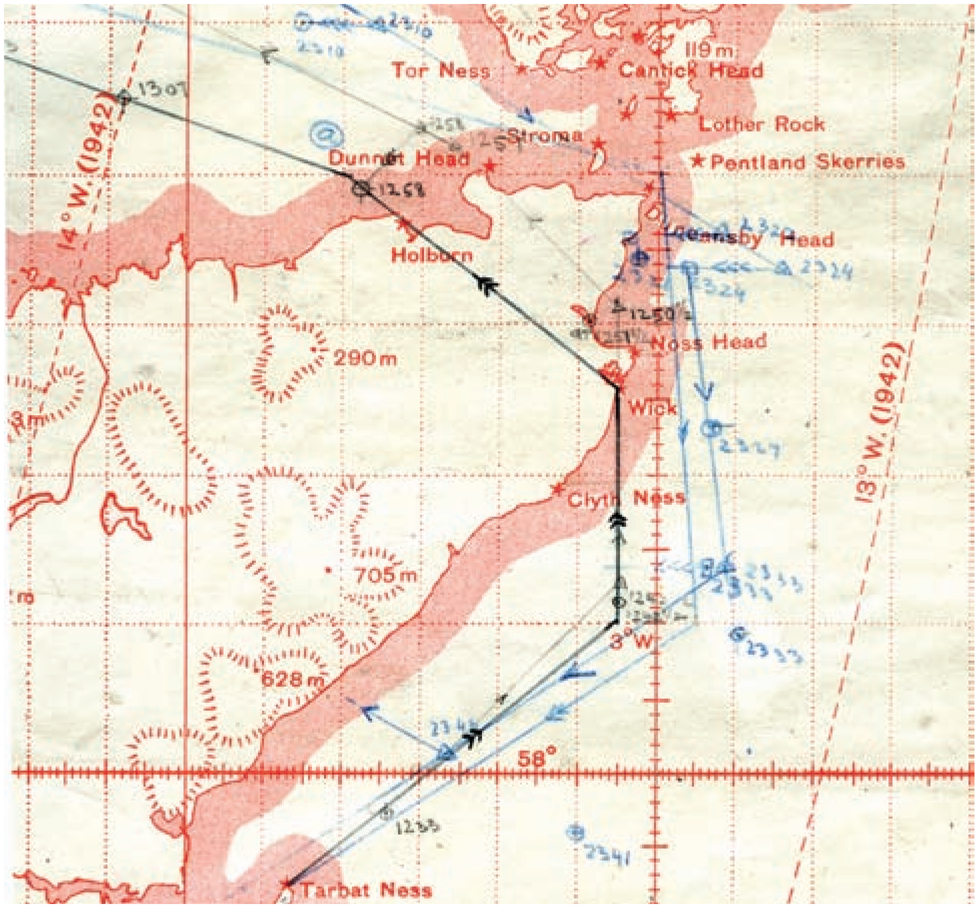


FIG. 620. DETAIL FROM *PLOTTING SERIES (THIRD EDITION) NORTHERN APPROACHES, SHEET N.W. 57 1/2/12*. Great Britain, War Office, Geographical Section, General Staff, No. 4080. Mercator projection, 1:1,000,000 at 56°N (London: Drawn and Heliographed at Ordnance Survey, 1941, 3d ed., 1941, 3d ed., 1942). Annotated in pencil by Royal Air Force navigator Andrew Sverma. Example of several dead reckoning plots, the basis of twentieth-century navigation, that were used to determine or project position from previously known points using distance and direction.

Size of the entire original: 76 × 108.5 cm; size of detail: ca. 13.5 × 13.5 cm. Image courtesy of the Ralph E. Ehrenberg Collection.

ship's rolling, pitching, or metal construction. Later gyrocompasses were used to drive repeaters, auto pilots linked to heading selectors, and electromagnetic logs (Sorg 1976–77).

Gyrocompasses were too heavy and costly for aircraft, but a variety of magnetic compasses were developed to cope with the vibration, buffeting, and acceleration associated with early flight. The vertical card compass with head-up displays, introduced by the British Admiralty in 1915, eventually became the international norm.

Sperry devised a directional gyro for aircraft in the late 1920s. Also known as a heading or directional indicator, it included a gyroscope that maintained selected directions for a limited time and was more reliable than the magnetic compass in tight turns. The directional gyro became fully operational during World War II and grew in importance in the 1950s with the beginning of transarctic navigation, which required nonmagnetic heading references.

A trio of towed or hull-retractable sensing devices developed during the first decade of the twentieth century superseded the traditional marine patent log, a towed rotating propeller for measuring a ship's speed and distance. These included the impeller-type log, a widely used propeller-driven electrical transmitter, invented by Vasiliy Ivanovich Chernikeev for the Russian navy in 1917; the pitot-static log, an air pressure–measuring device; and the electromagnetic log that used the principle of electromagnetic induction (May and Holder 1973, 115–18). Airmen also adopted the pitot tube during World War I as their standard airspeed meter by virtue of its size, lack of drag, good gauge of stall speed, and simple cockpit connection (Wright 1972).

Since wind velocity is greater on airships and aircraft

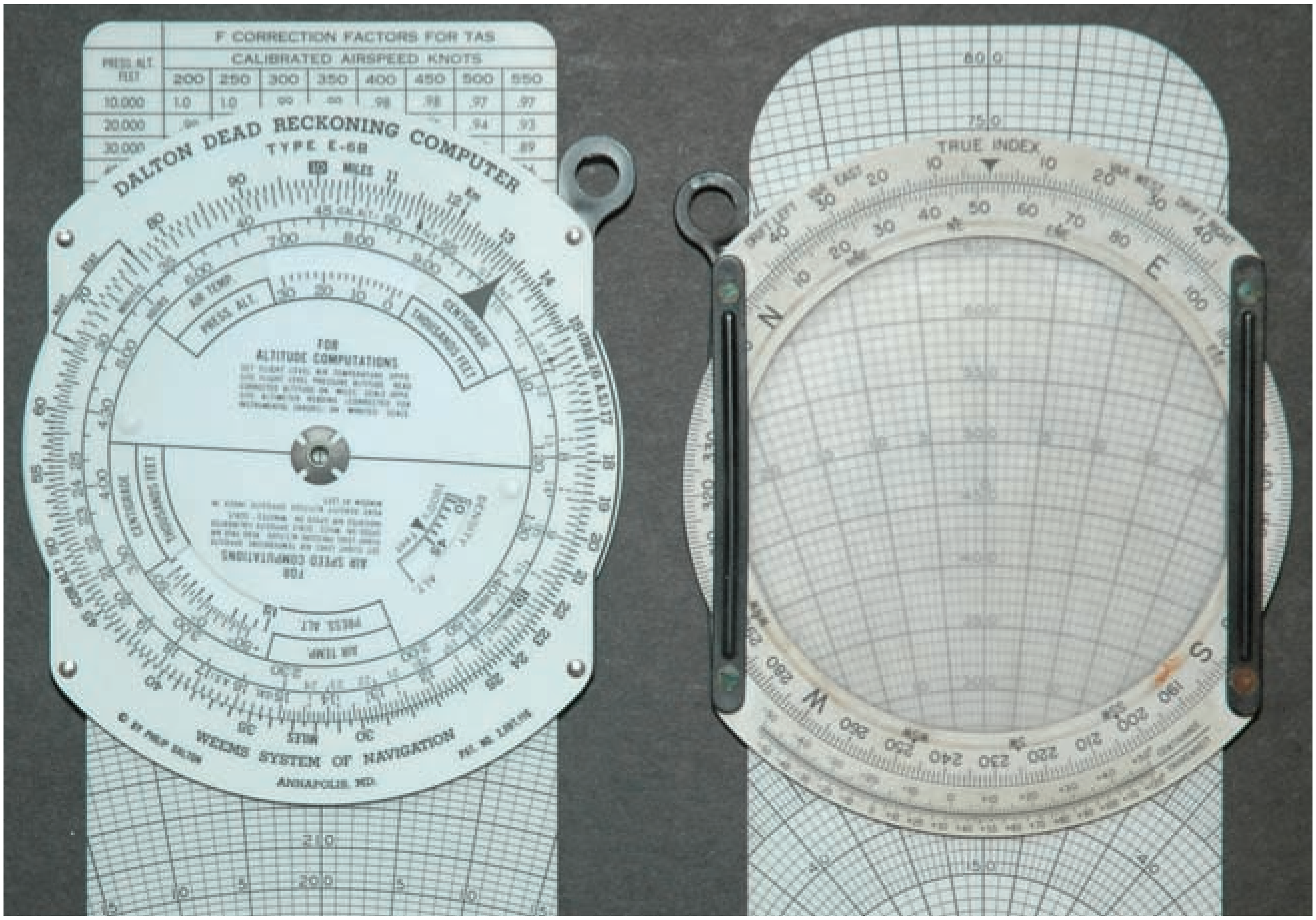


FIG. 621. DALTON DEAD RECKONING COMPUTER, TYPE E-6B, BY PHILIP DALTON. Annapolis: Weems System of Navigation, ca. 1940, plastic construction. One of several air navigation computers with circular slide rule (left) and rotating compass rose on the back (right) that appeared during the 1920s and 1930s to simplify dead reckoning navigation. Size of the original: ca. 28 × 9.7 cm. Image courtesy of the Ralph E. Ehrenberg Collection.

than surface ships, airmen calculated course and position using the wind triangle, a version of vector analysis that compared an aircraft's track and groundspeed. Initially solved graphically, this process was simplified by the end of World War I with the development of DR handheld analog computers (fig. 621). Before the installation of worldwide meteorological stations during World War II, airmen used driftmeters to compute wind direction and velocity. The first driftmeters, developed in France about 1910, were sighting devices that consisted of wires stretched over an opening in the fuselage below the pilot. Gaetano Arturo Crocco, associated with the Servizio Aeronautico of the Italian army, was the first to link driftmeters and DR computers, a concept improved by Harry Egerton Wimperis of the Royal Air Force (RAF) during World War I. Gyro driftmeters were in use by 1938 (Ayliffe 2001, 228, 230).

Piloting or pilotage (the preferred aeronautical term) was a method of navigation that relied on frequent or continuous reference to visual land and seamarks, compass bearings, and map reading. It was often combined with other navigation techniques. Mariners depended on pilotage for coastal and inshore navigation, using general and coast nautical charts (fig. 622). Aviators used pilotage techniques for "low and slow" flying. Because aviators viewed natural and cultural landmarks from high altitudes that were often partly obscured by hazy weather conditions, only the most prominent features were indicated on aeronautical charts. Railroads were the most important. Many airways were established along the routes of railroads, which were dubbed the "iron compass" because they were considered more dependable than early magnetic compasses.

Celestial navigation, the mariner's traditional method of finding longitude and latitude on the high seas, remained the only worldwide position fixing system for both air and sea navigators until the early 1970s (fig. 623). The basic tools for celestial navigation remained the sextant, the chronometer (later, the quartz watch), the *Nautical Almanac*, and navigation tables

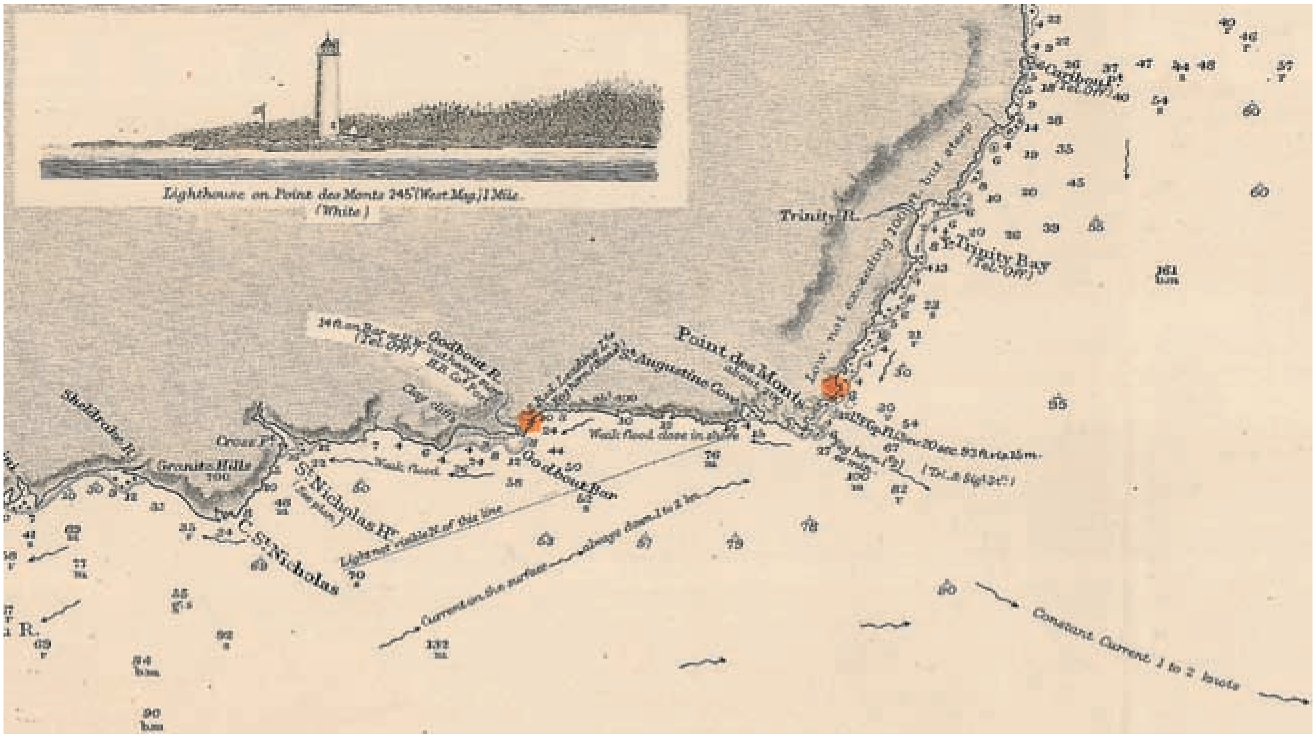


FIG. 622. DETAIL FROM *RIVER ST. LAWRENCE WEST PT. OF ANTICOSTI TO SAGUENAY RIVER*, 1922, NO. 307, BY W. J. L. WHARTON, HYDROGRAPHER, BRITISH ADMIRALTY. From surveys by Captain H. W. Bayfield, 1:393,000, engraved by Davies & Company and published by the British Admiralty, London. Detail of typical information found on large-scale charts used for pilotage, the most fundamental form of navigation, which was based on map reading and reference to visible landmarks.
Size of the entire original: 67 × 100 cm; size of detail: 10.3 × 18.4 cm. Image courtesy of the Earth Sciences and Map Library, University of California, Berkeley.

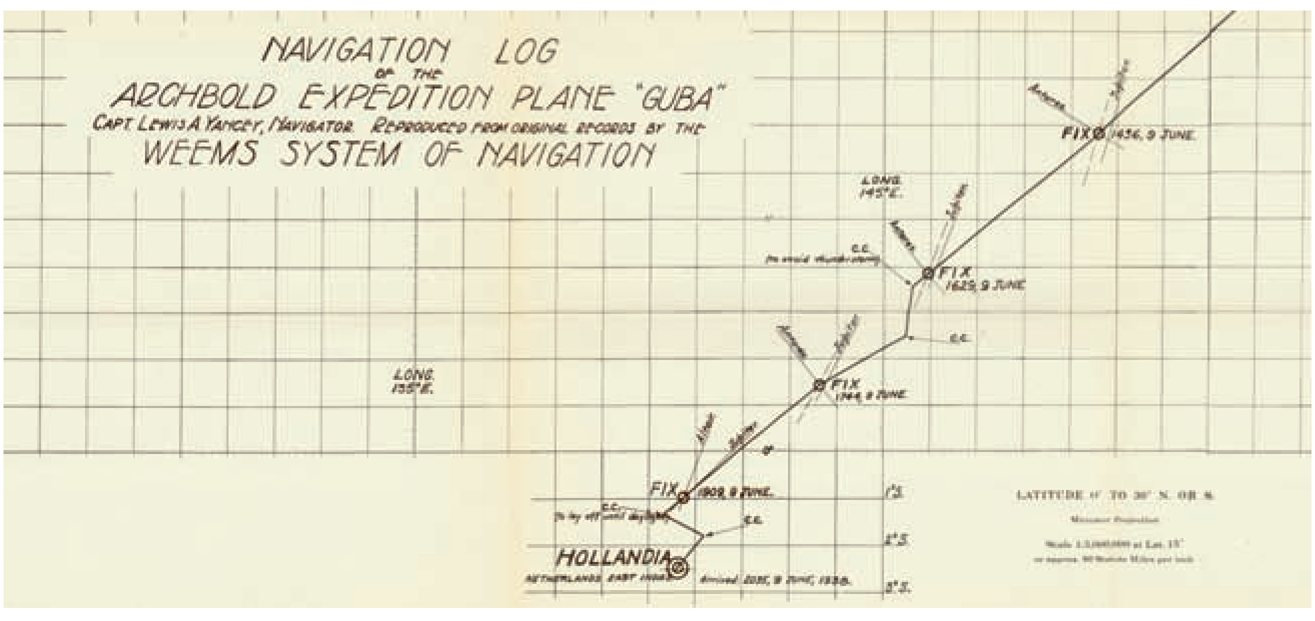


FIG. 623. DETAIL FROM THE *NAVIGATION LOG OF THE ARCHBOLD EXPEDITION PLANE "GUBA,"* 1938, BY LEWIS ALONZO YANCEY. Reproduced from original on *Navigation Sheet No. 1*, by Weems Systems of Navigation, Annapolis, Maryland. Lithograph facsimile. Mercator projection, 1:5,000,000. Detail of a typical dead reckoning plot with a series of intersecting lines of position (fixes) obtained by celestial observations during a trans-Pacific flight in 1938.
Size of the entire original: 66.7 × 86.4 cm; size of detail: 21 × 46.8 cm. Issued separately with Philip Van Horn Weems, *Air Navigation*, 3d ed. (New York: McGraw-Hill, 1943). Image courtesy of the American Geographical Society Library, University of Wisconsin–Milwaukee Libraries.

(later, calculators or computers). During the first decade, the British Royal Navy's adoption of the *intercept* or Marcq St Hilaire method, an advanced nineteenth-century system of position line navigation, and the introduction of radio time signals that improved the precision of chronometers, simplified finding a ship's position at sea.

Air navigation was aided by the introduction of the bubble sextant, a standard marine sextant fitted with a spirit level that substituted for the horizon, a basic requirement for measuring the altitude of celestial bodies (fig. 624). The Butenschön firm of Hamburg first produced it for German and French balloon and airship navigators. Major advances followed during the interwar years in connection with pioneering transocean flights. The process of observing celestial bodies with handheld sextants in open aircraft turrets under freezing conditions at high altitudes was greatly improved with the inventions of the astrodome in 1939 and the periscopic sextant during World War II. Mechanical averaging devices for bubble sextants reduced inaccuracies caused by air turbulence. They were developed in part from studies conducted by the RAF in 1936 that used probability theory for the first time for navigation (Williams 1992, 116–19).

Celestial navigation required some competency in spherical trigonometry, but the introduction of the innovative *Air Almanac* in 1933 by U.S. Navy Captain Philip Van Horn Weems simplified the process for airmen working under difficult conditions in fast-moving aircraft. Many small surface craft operators later used it.

Radio offered the easiest method of determining position and to some extent course direction. The basic methods of radio direction finding (RDF) were developed in Europe during the first decade of the century and adopted quickly by mariners, who began using ship-borne RDF position fixing following its acceptance by the Cunard Line, a British-U.S. shipping company, in 1912. Airmen relied primarily on ground-based RDF stations, as complex RDF circuitry was easier to monitor, maintain, and repair on the ground than in the air. The first ground stations for air navigation were established in northwestern Europe in the 1920s, a legacy of World War I. Aircraft positions were determined by triangulation from airport stations and then relayed to pilots by radio.

Airborne radio navigation began in the 1930s with the radio range and the cockpit radio compass. The radio range consisted of a series of ground-based radio beacons that continuously transmitted radio signals for four bearings in Morse code, which were received and interpreted through a pilot's headphones. Patented by German radio pioneer Otto Scheller in 1907, this system was developed by the U.S. Bureau of Standards for the Department of Commerce and installed throughout the United States. Some 400 radio directional beacons ultimately made up the American radio beam airways system (fig. 625). Eventually 990 radio range beacons were installed worldwide. The radio range was the first air navigation system that was used without reference to

FIG. 624. U.S. ARMY AIR CORPS NAVIGATOR DEMONSTRATING BUBBLE SEXTANT. Lieutenant Albert F. Hegenberger prior to pioneer flight from San Francisco, California, to Honolulu, Hawaii, 28 June 1927.
Image courtesy of the McDermott Library, U.S. Air Force Academy.

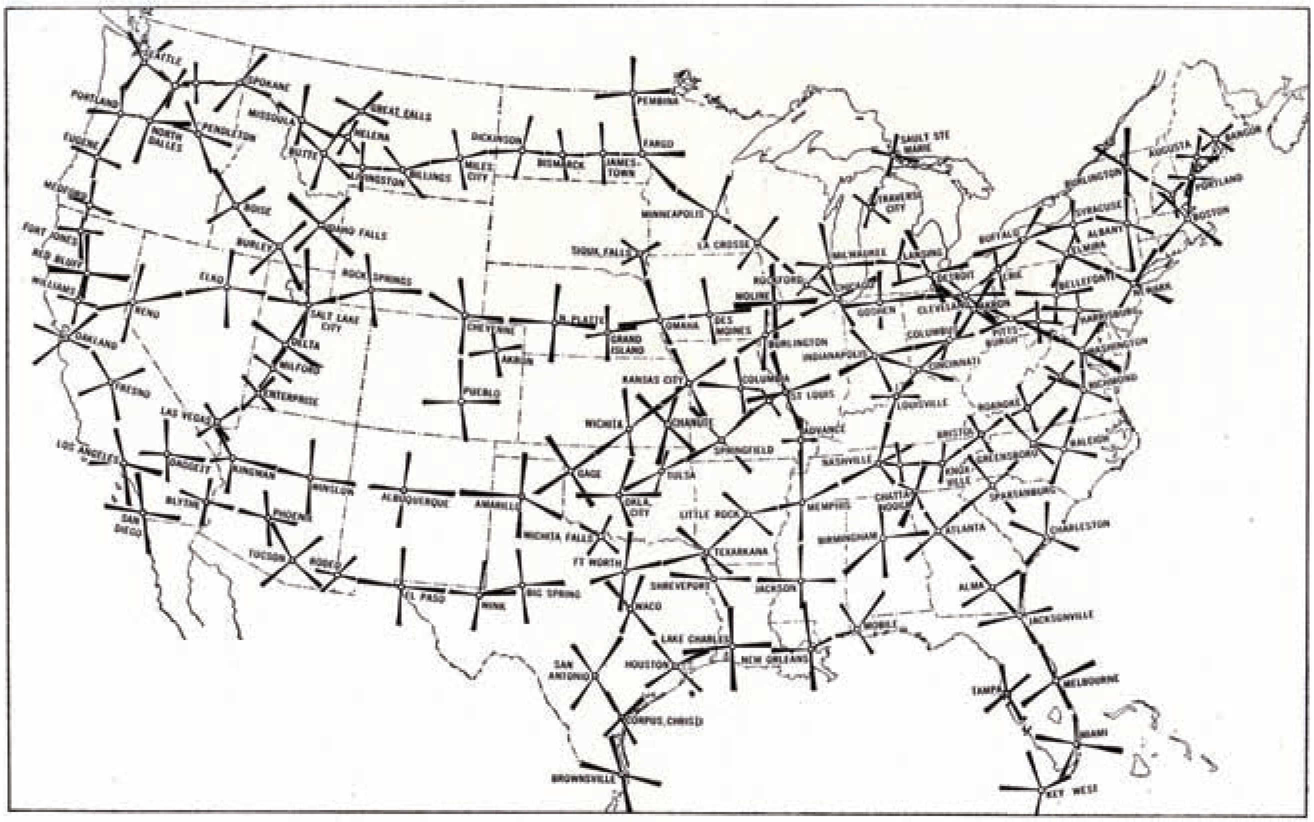


FIG. 625. *THE RADIO RANGE SYSTEM OF THE DEPARTMENT OF COMMERCE*, 1939. U.S. Department of Commerce, lithograph. The American radio range system, consisting of series of four-course line-of-sight radio transmitter installations, greatly aided air navigation since it required only the use of a compass, radio receiver, radio range network chart, altitude data, and airfield locations.

Size of the original: 10.6 × 17.1 cm. From Thoburn C. Lyon, *Practical Air Navigation and the Use of the Aeronautical Charts of the U.S. Coast and Geodetic Survey*, 3d ed. (Washington, D.C.: United States Government Printing Office, 1939), 53 (fig. 46).

visual landmarks, geographic coordinates, or navigation instruments. "It was, arguably, the greatest revolution in navigation since the chronometer," according to historian J. E. D. Williams (1992, 189).

The cockpit radio compass was an airborne homing device that made possible off-airways flying by displaying the direction of a radio station or nondirectional beacon (NDB). It became feasible with the development of small rotating loop aerial receivers. An automatic radio compass (ADF) followed, with a visual indicator displaying a 360° scale and rotatable pointer that automatically registered relative bearing (Moon 1950, 399). The ADF required no calculations or chart work, and it remained popular throughout the twentieth century due to its simplicity and ease of use.

Hyperbolic navigation emerged during World War II to compensate for the lack of ground-based radio aids in enemy territory. Hyperbolic navigation was a form of radio navigation in which hyperbolic lines of position (fig. 626) were established for determining position from synchronized signals emitted from two or more ground radio stations. The radio pulses were read on cathode ray tubes and plotted on charts overprinted with lattice grids. Hyperbolic radio navigation aids were generally classified as an area coverage system since both bearing and distance were obtained from several radio transmissions covering a large area (as opposed to point-to-point systems such as radio range, where a single radio transmitter provided bearing and sometimes distance).

Four major hyperbolic navigation systems were developed in Germany, Great Britain, and the United States: Gee, designed by British electrical engineer Robert J. Dippy and used primarily for air navigation by the RAF and U.S. Eighth Air Force; Loran (long-range navigation), created under the aegis of the U.S. National Defense Research Committee for long range naval convoys and transoceanic flights; Sonne (later Consol), developed by Ernst Kramar for German bombers and U-boats; and Decca Navigator, devised by U.S. engineer William J. O'Brien for the British Admiralty with support from the Decca Record Company (Blanchard 1991).

In the postwar years, these wartime navigation sys-

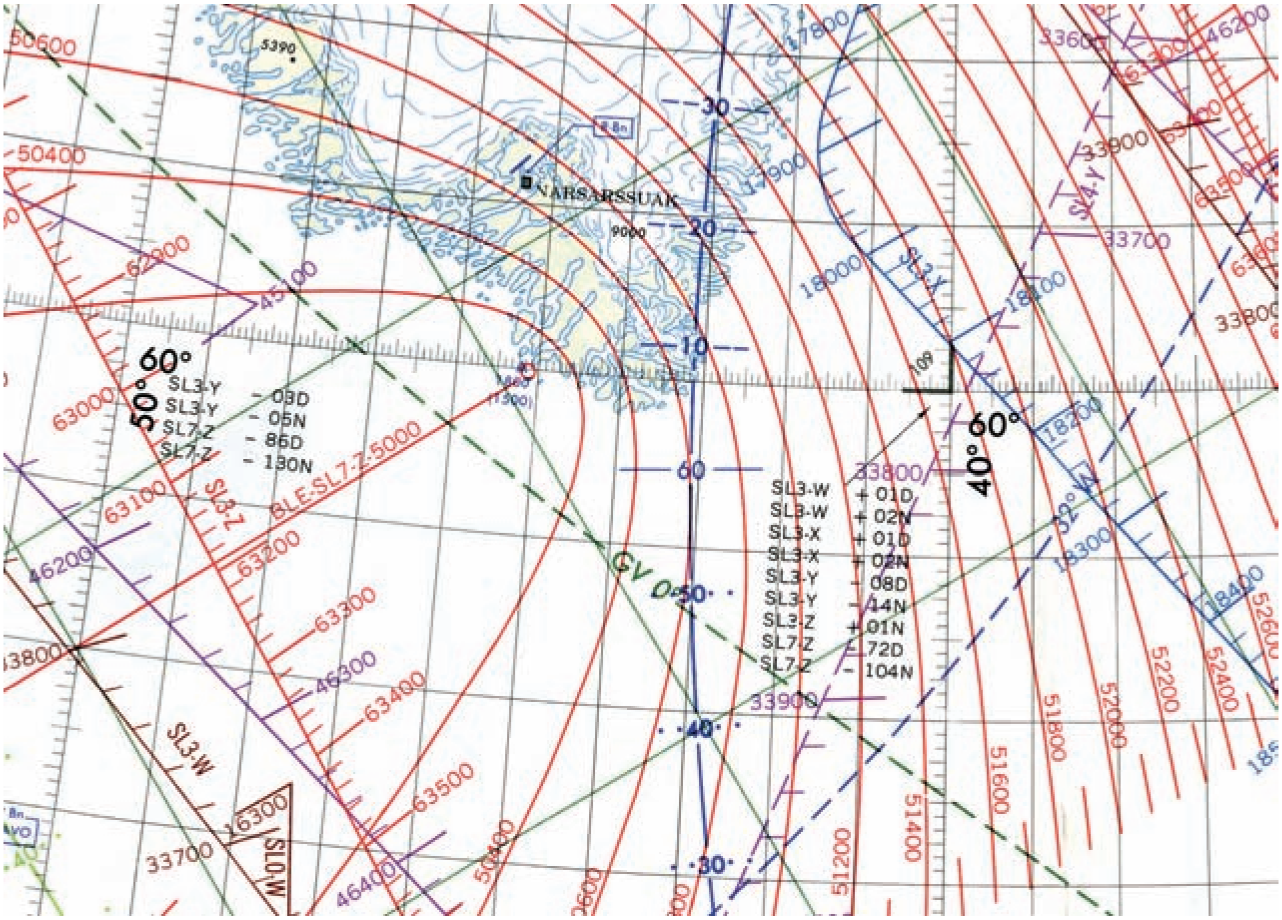
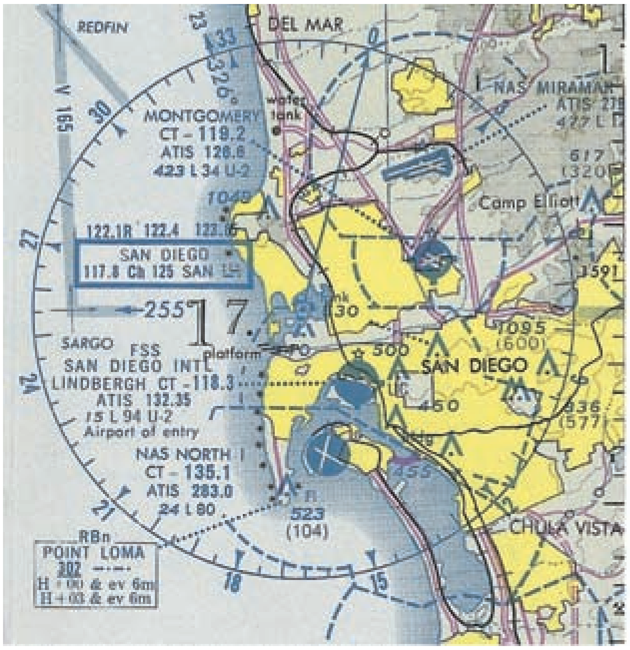


FIG. 626. DETAIL FROM *USAF GLOBAL LORAN NAVIGATION CHART / NORTH ATLANTIC OCEAN GLC-3CN*. Air information current through 3 September 1965. Lambert conformal conic projection, 1:5,000,000, lithograph. St. Louis: United States Air Force Aeronautical Chart and Information Center, 1st ed., September 1965. A typical Loran-C lattice chart overprinted with different color lines of hyperbola derived from several chains of master and slave radio transmitters, introduced during World War II for long-range navigation.
Size of the original: 105 × 146 cm; size of detail: ca. 12 × 16.8 cm. Image courtesy of the Geography and Map Division, Library of Congress, Washington, D.C.

tems were converted to peacetime use, and several new systems evolved in response to growing commercial markets and the Cold War. Loran (renamed Loran-C in 1957) and Decca Navigator supplemented air and marine celestial navigation during oceanic crossings, and found new uses as aids in coastal and helicopter navigation. Consol was also used on oceangoing liners as a check system and on small craft not equipped with Decca Navigator or radar. In the high-density air traffic areas of Western Europe and North America, networks of radio beacons, radio ranges, and area coverage systems such as Loran, Decca, and Consol were established to bring structure and order to aircraft traffic flow.

Two newly created specialized agencies of the United Nations with broad responsibilities that included air navigation helped guide these developments: the International Civil Aviation Organization (ICAO), headquartered in Montreal (1944–), and the Inter-Governmental Maritime Consultative Organization (later International Maritime Organization [IMO]), located in London (1959–).

In the United States, VOR/DME (very-high-frequency omnidirectional radio range stations with distance measuring equipment) and its military counterpart TACAN (tactical air navigation) replaced the four-course radio range system, beginning in the late 1940s. VOR/DME was a directional beacon system that provided radiating radio signals in all directions as well as distance from aircraft to beacon (fig. 627). The data were presented visually on cockpit dials rather than aurally through headsets. VOR/DME became the international standard for short-range navigation by ICAO in 1947 under protest by Australia, Canada, New Zealand, and the United Kingdom, all of which favored Decca. In 1959, Britain championed Decca once again, recommending that it be adopted as a second international standard by ICAO on equal footing with VOR/DME but was rejected a second



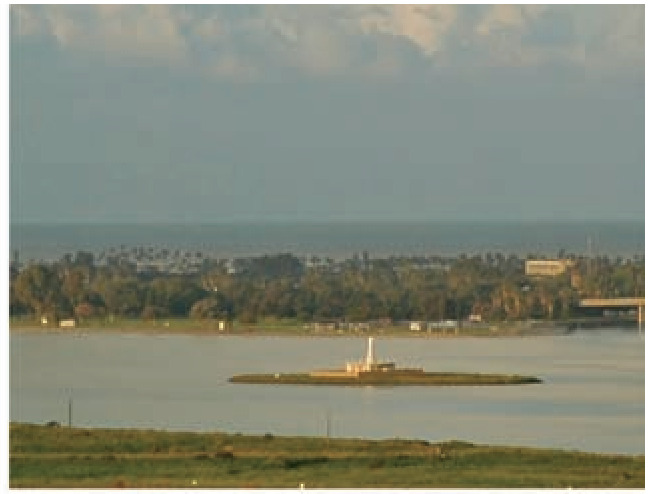


FIG. 627. DETAIL OF SAN DIEGO FROM *LOS ANGELES*, SECTIONAL AERONAUTICAL CHART, AND PHOTOGRAPH OF SAN DIEGO MISSION BAY VORTAC INSTALLATION. The chart (left) is on a Lambert conformal conic projection at 1:5,000,000 (15th ed., 15 August 1974) and shows a compass rose symbol with the system of radio aids to navigation that were used during the last half of the twentieth century to determine an aircraft's geographical positions within their range by bearing and distance, centered on the San Diego, California, Mission Bay VORTAC installation (right) identified as "Mission Bay 117.8 Ch 125 MZB." Obstructions to navigation such as high towers are depicted by inverted Vs and elevation in feet. Airport runways are illustrated with blue insets.
Size of the entire original (left): 52.3 × 139 cm; size of detail: 8.5 × 8.2 cm. Photograph courtesy of Ralph E. Ehrenberg.

time. Although Decca was superior in some respects to VOR/DME, most ICAO members believed it was too complex and time-consuming for use by general and commercial aviators (Karant 1959).

Radar (radio detection and ranging) determined distances and bearings of unseen objects by timed and reflected (echoes) radio signals. Developed independently in Britain, Germany, and the United States in the mid-1930s, radar was initially used for detecting and targeting aircraft during World War II. Two critical British inventions increased its value for navigation: the multicavity magnetron valve that led to microwave (centimetric) radar, a technology that produced shorter wavelengths of finer resolution with a tighter beam and greater resistance to noise; and the plan position indicator (PPI), a unit that displayed returning echoes in the form of temporary maps on the phosphorescent screens of cathode ray tubes along with altitudes, ranges, and bearings (fig. 628). Radar facilitated ground control of aircraft in the air and during instrument landings, improved the resolution of terrain features that assisted map reading, extended navigation range, aided collision avoidance in sea and air, detected underwater obstructions, and provided position fixes (Howse 1993).

Following World War II, airborne radar was initially used by airlines to avoid turbulence. Beginning in 1955, weather radar systems were specifically designed for commercial aircraft. Analog monochromatic cockpit radar weather maps were replaced by digital color sets in the late 1970s, but not without some resistance from pilots who favored the earlier map displays (Steenblik 1986).

One of the most important new radar navigation developments was airborne Doppler, a revolutionary self-contained long-range navigational aid that for the first time provided continuous ground speed and drift data without regard to visual ground contact or weather conditions. Developed by the U.S. military and made available commercially to the world's airlines in 1958, it was the first navigation aid capable of providing position fixes over vast areas of the globe not equipped with ground beacons (Fried 1993). Doppler radar also became an essential navigation aid for low-flying helicopters, prized for its accurate hovering indications and its dependable position fixing in hilly terrain, urban settings, and offshore environs where visibility constraints prevented the use of standard line-of-sight radio navigation aids such as TACAN and VOR/DME. Later it was

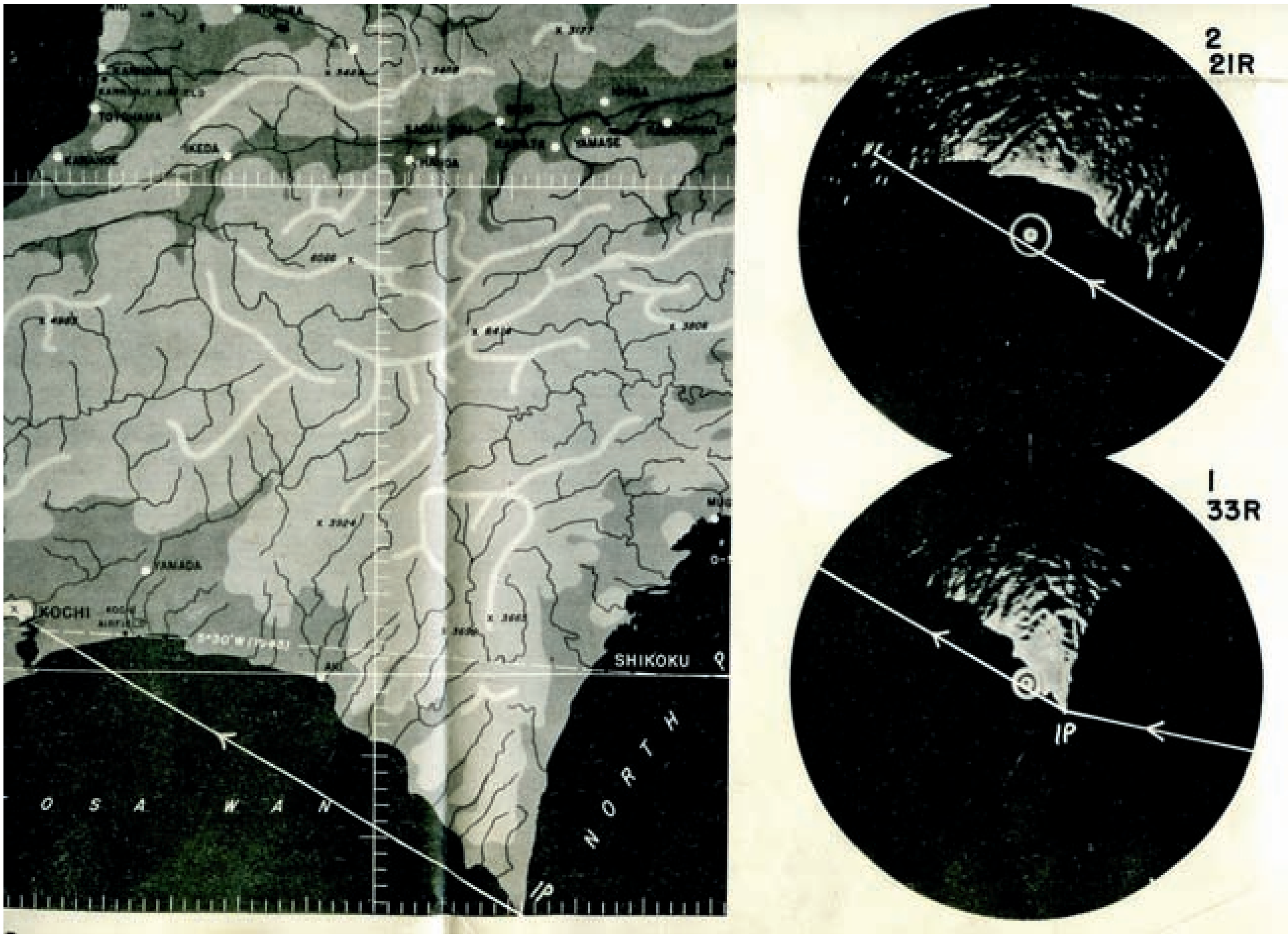


FIG. 628. DETAIL FROM *APPROACHES TO KOCHI ACTUAL SCOPE PHOTOS ALT. APPROX. 10,000′*, SHEET RM-59. U.S. XXI Bomber Command, A-2 Section, reproduced by the U.S. Army 949th Engineer Aviation Topographic Company, June 1945. An early example of a radar navigation map with radar scope images designed to guide pilots to their destinations.
Size of the entire original: 41 × 41 cm; size of detail: 21.3 × 29.7 cm. Image courtesy of Ralph E. Ehrenberg.

used for positioning the Apollo lunar landing module and guiding military drones.

Shipboard radar was particularly important for coastal navigation and piloting in congested areas, position fixing, and collision avoidance, and during periods of low visibility due to fog, mist, or falling rain. Several shipboard radar systems were developed in the 1960s in response to a series of ship collisions. True motion radar distinguished between fixed and moving objects. Automatic course-tracking radar with built-in computers was designed to track selected targets for faster radar data processing. These new radar systems were supported by revised collision regulations issued in 1960 and 1972 by the International Conference on Safety of Life at Sea (May and Holder 1973, 235–48). By the 1990s, all vessels over 500 gross registered tonnage (GRT) were required by IMO to carry radar and those over 10,000 GRT a minimum of two radar units in addition to an automated radar plotting aid (Williams 1992, 216).

Departures and arrivals remained the most dangerous parts of voyages and flights, particularly at the increasingly crowded airports and harbors after midcentury. Mariners and airmen developed similar techniques and equipment to manage traffic flow. Air traffic control (ATC) relied heavily on radar monitors for maintaining airway surveillance at major airports and the safe, efficient, and orderly sequence of instrument landings and takeoffs. Initially, aircraft were identified by voice communication, but eventually aircraft transponders provided basic data directly to radar monitors.

Within the shipping industry, coastal and port traffic flow was aided by the development of radar beacons with responders (racons), devices that automatically provided bearing and range information in response to an interrogating signal. First tested by the British Admiralty in 1949, racons were used for long-range navigation as well as landfall identification. Port radar services began in Liverpool in 1948 to assist vessels without radar, but eventually evolved into harbor radar information centers at major ports such as Rotterdam and Southampton.

Traffic growth, improvements in speed, and a series of dramatic collisions both in the air and at sea in the 1950s led to a variety of new navigation techniques. Pressure pattern navigation, devised during World War II to take advantage of atmospheric pressure distribution to achieve optimum flight, became standard practice with the introduction of long-haul jet aircraft in the 1950s flying at jet stream altitudes (Bellamy 1996). Controlled airspaces were instituted in the United States in 1964 and later expanded worldwide by the ICAO, which divided airspace into two categories governed by different navigation rules: VFR (visual flight rules) for flights below 18,000 feet mean sea level, and IFR (instrument flight rules) for flights at higher altitudes, used primarily by jet aircraft. Similarly, mariners used weather routing to determine optimum and strategic routes with help from the British Admiralty's *Routeing Charts*, beginning in 1963. Ship separation schemes and shipping lanes were developed for high-density shipping areas, following a proposal by Spanish navigator Rear Admiral J. García-Frías in 1956 (Beattie 1978, 174, 178). Worldwide hyperbolic long-range marine and air navigation was achieved in 1983 with the Omega system, a very low-frequency radio system consisting of eight transmission stations.

The advent of inertial navigation systems (INS) and global navigation satellite systems (GNSS) revolutionized navigation. INS was a sophisticated self-contained all-weather DR system that made celestial navigation obsolete and contributed to the decline of the aerial navigator's profession as his or her duties were combined with those of the pilot. INS continuously kept track of a vehicle's position, speed, and attitude from a known starting point by using a combination of gyroscopes, accelerometers (inertial sensors), integrators, and computers. The German V-2 missile guidance system developed during World War II is generally considered the first operational INS. Additional improvements were made during the Cold War, initially for U.S. and Soviet long-range cruise and ballistic missiles. SINS (ship INS) was developed by the U.S. Navy for guiding nuclear submarines that remained submerged for extended periods. Its value as a navigation aid was widely publicized during the *USS Nautilus*'s under-the-ice crossing of the North Pole in 1958. U.S. military pilots used INS outputs from the missiles they carried prior to launch until their aircraft were outfitted with their own systems in the early 1960s. Commercial airliners began using INS in 1968, beginning with the long-range Boeing 747 (Wrigley 1977; Greenspan 1995).

GNSS was a worldwide space-based radio navigation system similar to hyperbolic systems except that the transmitters were located in orbiting artificial satellites rather than earth-based beacons. Both the United States and the Soviet Union created GNSS systems at the height of the Cold War. The U.S. Navy's Navigation Satellite System (Navsat), generally known as Transit, was the first (1964–96). Transit was created to correct the drift associated with the inertial systems that guided a new class of Polaris missile carrying submarines. The Soviet Union's Tsikada (Cicada), similar in design and purpose, was launched in 1976. Transit and Tsikada were low-orbit systems that provided continuous two-dimensional position fixes (latitude and longitude) primarily for marine navigation. Transit was widely used by the merchant marine, fishing fleets, and pleasure craft community following its release for civilian use in 1967 (Clarke 1998).

Navstar Global Positioning System (GPS) gradually superseded Transit, beginning in 1989. Designed primarily to meet the requirements for aircraft navigation, it was a highly sophisticated second-generation U.S. Defense Department satellite navigation system. GPS provided extremely accurate three-dimensional position (latitude, longitude, and altitude), velocity, and time information from twenty-four satellites placed in high orbit. The extensive use of GPS by the United States and coalition forces during the Persian Gulf War (1990–91) revealed its value as a navigation aid to a worldwide audience. The Soviet Union's global navigation satellite system, GLONASS (Global'naya Navigatsionnaya Sputnikovaya Sistema), initially provided two-dimensional global position fixes, with two- and three-dimensional fixes available by 1995. Both Navstar GPS and GLONASS were designed for unlimited military and civilian use worldwide, but in degraded form for civilian users (Parkinson et al. 1995).

INS and GPS contributed to the development of real-time flight deck displays that combined both spatial and textual data, including a variety of electronic navigation charts (ENC) and maps (Stringer 1984) (fig. 629). Less progress was made at sea, where INS remained one of several navigation tools due to the extended duration of voyages and high cost. While some advances were made in the development of nautical ENCs, national and international rules and regulations restricted their use (Williams 1992, 173; Rogoff 1990–91). It was not until the end of the century that the IMO approved ENCs and the Electronic Chart Display and Information System (ECDIS), a real-time GIS-based maritime electronic chart system (Norris 1998, 321–22).

At the close of the century, government agencies con-

FIG. 629. COCKPIT OF CESSNA CITATION TEN BUSINESS JET. View of a typical aircraft electronic flight deck instrument display panel ENC showing approach to Juneau airport.

Image courtesy of Cessna Aircraft Company, Wichita.

sidered replacing the unconnected and expensive earth-based systems, such as Loran-C, TACAN, and VOR, with GPS. At the same time, the international and civil communities continued to push for less restrictive use of GPS.

Navigation remained primarily a marine art during the first three decades of the century, with piloting, DR, and celestial navigation methods changing little from the nineteenth century. The introduction of radio range, hyperbolic, and radar navigation dramatically altered this paradigm. Later, INS and GPS contributed significantly to the automation of navigation begun by radio. Most of these innovations were directed and financed by the military, primarily to solve navigational problems imposed by the unique requirements of aircraft and submarines. Navigation evolved during the century from an art practiced by skilled navigators with few technical tools to a technology conducted by a coalition of air and marine navigators, systems designers, electronic experts, and software programmers.

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SEE ALSO: Aeronautical Chart; Cave Map; Global Positioning System (GPS); Marine Chart; Orienteering Map; Projections: Projections Used for Marine Charts; Wayfinding and Travel Maps: In-Vehicle Navigation System

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