C

Cadastral Map. *Cadastral map* defies a single definition because of wide variations in cadastral systems and in the purposes and content of cadastral maps. A European perspective of "a map showing land parcel boundaries [that] may also show buildings" (UN Economic Commission for Europe 1996, 89) contrasts with an American view of cadastral maps as showing "the boundaries of subdivisions of land, often with the bearings and lengths thereof and the areas of individual tracts, for purposes of describing and recording ownership" (Thompson 1981, 253). A related term, *cadastral plan*, has been defined as "a large-scale plan showing the boundaries of one or more land parcels and their relationship to adjoining parcels, prepared for the purpose of illustrating or creating legal title" (McGrath and Sebert 1999, 614). A plan was usually prepared from a survey of an individual parcel for an individual owner. An extension of this concept was the plan or series of plans to represent horizontal subdivision of a building into individually owned flats, apartments, or condominiums with common areas owned jointly. Although the concept of horizontal subdivision long predated the twentieth century, it was given modern legal definition in most European countries after 1930 and in Australia, Canada, and the United States from 1961. *Cadastral index map* is a third term, defined as "a plan, used for indexing purposes, showing the relative location of all land parcels in an area" (Dale 1976, xx). Simpson (1978, 148) recognized four principal uses of an index map: to identify on the ground a plot shown in the register; to assist in boundary relocation; to enable subdivision; and to calculate plot areas.

The late eighteenth and nineteenth centuries witnessed major changes in land tenure in Europe as large estates were broken up and common land was enclosed. Cadastres were created to facilitate taxing land. The modern systematic cadastral map had its origin in the Napoleonic French cadastre introduced in 1807. This required the construction of large-scale *plans parcellaires*. Legislation was enacted during the second half of the nineteenth century to allow registration of legal rights and transactions in land in either of two principal modes: registration of documents (deeds) or of parcels (titles). Not all deeds systems were supported by individual cadastral plans or cadastral index maps. In contrast, a cadastral plan prepared by a private surveyor was an integral component of registration of titles when introduced in South Australia in 1857.

The volume of cadastral maps created during the twentieth century rose substantially due to natural increases in population, net immigration, new agricultural settlement, urbanization, and the development of land markets. Ernest MacLeod Dowson and V. L. O. Sheppard (1956) provided a valuable summary of cadastral plans as a component of the prevailing land records in twenty-one countries. In the second half of the century schemes for land reform and registration of newly created rights in land accounted for greatly increased cadastral mapping in Africa, Latin America, Southeast Asia, Eastern Europe, and the Commonwealth of Independent States (CIS, consisting of most of the republics of the former Soviet Union).

Graphical methods of cadastral surveying were used widely for the first half of the twentieth century and for much longer in a few jurisdictions such as India. Chain surveys and plane tabling were the principal techniques, allowing cadastral plans and maps to be produced directly from the surveys. The maps were drawn in pencil or India ink on paper using a variety of drawing instruments. Lettering was prepared manually or by mechanical template. Preprinted lettering and symbols on adhesive film became available during the 1940s and later were produced with mechanical phototypesetters. The introduction of vinyl chloride, and subsequently polyester, plastic drawing materials had little impact on the production of cadastral plans. Small numbers of copies of plans or maps were made by blueprint or diazo methods long after the introduction of xerography in 1950.

The innovative glass arc theodolites introduced in the 1920s allowed easier traversing with steel tapes and thus the computation of coordinates of the turning points on parcel boundaries from which cadastral plans and maps were generated by manual plotting. From the late 1960s short-range electromagnetic distance measurement (EDM) devices began to replace tapes. Twenty years later the so-called total station, combining an electronic theodolite, EDM, data collector, and onboard software for processing observations, helped to accelerate field surveys and the production of plans and maps on personal computers and associated peripherals. The development of computer-assisted drawing (CAD) software, and later a wealth of survey-specific software for producing coordinates, plotting boundaries, and inserting labels, helped to eliminate much of the manual effort needed to produce cadastral plans and maps.

Aerial photographs and photogrammetry were employed in cadastral surveys and the production of cadastral maps from 1931. They offered economy of scale in systematic cadastral surveys provided that most parcel boundaries were marked by air-visible signals at boundary turning points or by walls, hedges, or fences. Invisible boundaries were added by field completion surveys. Photogrammetry was unsuited to individual cadastral surveys or to sporadic revision of cadastral maps. Where circumstances warranted and regulations permitted, unrectified and rectified photographs provided supplementary data, analog and (subsequently) digital photogrammetry were used to produce line maps, and in the 1970s orthophotographs served as base maps for cadastral overlays (table 10).

Considerable variation in cadastral systems affected the functions and characteristics of cadastral plans and maps and made it difficult to describe a typical cadastral map (Williamson and Enemark 1996). The scale of a cadastral plan was determined mainly by the size of an individual parcel or subdivision, by the need to show the detail legibly, and often by regulations governing cadastral surveys and plans. For example, Province of Ontario Regulation 42/96 required the following to be shown: rights of way and easements affecting the parcel, bearings and lengths of straight lines, the geometry of curved lines and streets, topographic detail that formed the position of a boundary, the identification of each existing subdivision unit, origin of bearings, north point, and the scale of the plan. Peter F. Dale (1976), among other scholars, questioned the relevance of such detail to the lay user and the cost of producing it. The scale of cadastral index maps ranged from 1:1,000 to 1:50,000, the choice dependent on the sizes of individual parcels

Table 10. Fifteen methods of producing cadastral maps

Method	(a) Topography	(b) Cadastral Boundaries	Comments
1	Surveying	Surveying	Surveyed at same time
2	Surveying	Digitizing existing map	
3	Photogrammetry	Photogrammetry	Field completion (FC) carried out after (a)
4	Photogrammetry	Surveying	FC after (a)
5	Photogrammetry/survey	Surveying	Soft topography by photogrammetry, hard topography and cadastral boundaries by survey
6	Photogrammetry	Digitizing existing map	FC after (a)
7	Photogrammetry/survey	Digitizing existing map	Soft topography by photogrammetry, hard topography by survey
8	Digitizing existing map	Digitizing existing map	
9	Digitizing existing map	Surveying	
10	Rectified photo	Rectified photo	FC for invisible cadastral elements; cadastral line map as overlay
11	Rectified photo	Surveying	Cadastral line map as overlay
12	Rectified photo	Digitizing existing map	Cadastral line map as overlay
13	Orthophotography	Orthophotography	FC for invisible cadastral elements; cadastral line map overlay
14	Orthophotography	Surveying	Cadastral line map overlay
15	Orthophotography	Digitizing	Cadastral line map overlay

"Soft topography" includes shorelines, riverbanks, streams, ditches, and ponds. "Hard topography" includes roads and buildings.

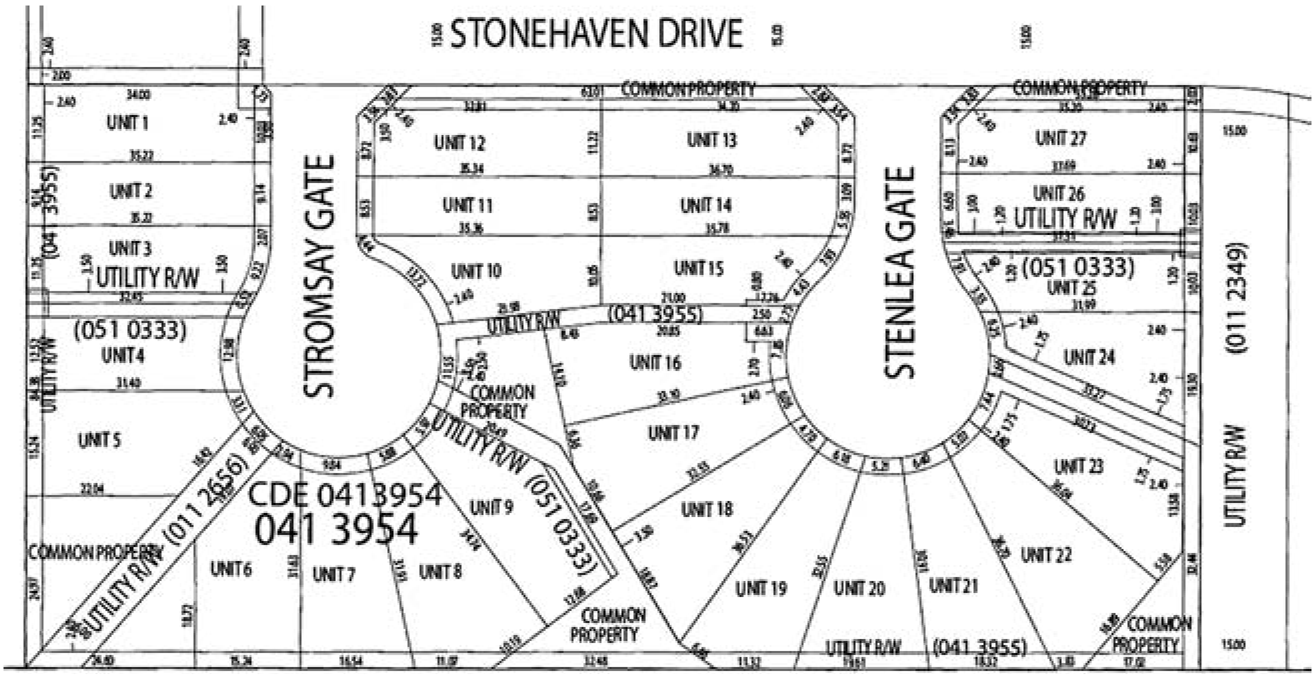

FIG. 116. EXAMPLE OF AN ONLINE URBAN CADASTRAL DIGITAL BASE MAP—CARSTAIRS, ALBERTA, CANADA.

Image courtesy of AltaLIS Ltd., Calgary.

and the amount of detail to be shown. Though accuracy requirements varied, and to some extent were influenced by prevailing survey technology, plottable accuracy was sufficient for most practical purposes. In some cases, for example in Kenya, air-visible boundaries were traced from enlarged aerial photographs to serve as interim cadastral index maps. Index maps were usually in series on standard sheet lines. The minimum content was parcel and block boundaries, including topographic features defining partial parcel boundaries, and a unique number or other identifier for each parcel (Dale and McLaughlin 1988).

Keeping the cadastral index map up-to-date was a recurrent concern. The outcome was influenced by policy, technical methodology, and periods of economic constraint. The ideal was, and remains, continuous updating to reflect daily changes in the parcel fabric. Cyclic revision was practiced in some jurisdictions, and elsewhere batch updating was a practical response to lack of time and resources. The Netherlands illustrates the intention to reconstruct an entire cadastral map by field methods. It was begun about the turn of the century, stopped in the 1970s due to the high cost, and replaced by the construction of a new topographic map, *Grootschalige BasisKaart Nederland* (GBKN), at scales of 1:500, 1:1,000 and 1:2,000 (for rural areas). The GBKN was constructed mainly by photogrammetry, used as a base for renovation of the cadastral maps, and soon integrated with cadastral information (Van Hemert 1988).

After 1980 there were numerous national or state projects to create graphic digital cadastral databases (DCDBs) as complements to computerized land registers (fig. 116). The databases were intended to ease the work of land registries and cadastre offices, promote consistency in parcel-based data sets, rationalize maintenance of the cadastral map, and assist registry customers. The principal approaches were to digitize existing cadastral plans, or cadastral index maps, and then to merge the resulting digital files into a single database. Manual digitizing and editing were used most frequently in the early years. Scanning cadastral maps and then vectorizing and editing the raster data were introduced later. For example, in South Australia the DCDB was created between 1984 and 1988 by digitizing cadastral boundaries from 1:2,500 maps in urban areas and 1:10,000 or 1:50,000 in rural areas. Buildings subdivided horizontally were captured in 1999. In a few countries second-generation DCDBs were designed to incorporate topology and thus permit modeling of the cadastral data. This was reflected in the vision of Cadastre 2014 (Kaufmann and Steudler 1998), which foresaw the future role of the cadastral map not as a means of storing information but as a means of representing cadastral data stored in databases. The status of digital cadastral mapping at the close of the century was recorded in 2001 for Europe, the CIS, and much of Canada (HM Land Registry 2001, 133–35). In the 1990s some jurisdictions recognized the digital cadastral map as one of several core data sets in a projected national or state spatial data infrastructure. The adaptation of the digital cadastral map to the broader purpose of providing a government-wide spatial infrastructure continues.

The primary users of cadastral data, plans, and index maps throughout the century were public- and private-sector organizations and individuals concerned with development policy, land policy, land tenure, the land market, and land administration. Users included agencies active in land allocation and settlement; surveyors; registries; cadastres; land valuers and assessors; notaries; lawyers; property owners; and companies engaged in land development, real estate transactions, banking, mortgages, title insurance, and property insurance (fig. 117). By the 1970s it was recognized that there were many other actual or potential users of land information held in map or other formats (Dale 1976), and that many specialized data files depended heavily on cadastral information (Ziemann 1975). The late twentieth century saw most Western cadastral organizations transformed from a producer to a user orientation. This transition involved treating information as a resource, with particular attention to costs, financing, and the public good as well as examining the pricing, marketing, and delivery of cadastral data, of which the cadastral map was an important element. Rapidly evolving Web technology in the 1990s focused attention on delivering cadastral data and value-added services online, which in turn heightened concern about freedom of information, user fees, and appropriate controls. The British Columbia Online Cadastre is one example of web-based access to cadastral maps and related parcel data.

GERALD MCGRATH

SEE ALSO: Administrative Cartography; Atlas: Subscription Atlas; Cadastral Surveying; Land Use Map; Privacy; Property Mapping Practices; Public Access to Cartographic Information; Tax Map; Web Cartography

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FIG. 117. THE CADASTRE OF LAND HOLDINGS AND ITS POSITION AS BASE FIELD OF A LAND DATA AND INFORMATION SYSTEM. Government functions directly related to property are shown.
Diameter of the original: 13 cm. From Ziemann 1975, 14 (fig. 2). Permission courtesy of the Canadian Institute of Geomatics, Ottawa.

Cadastral Surveying.

A cadastral survey has been defined as "a survey of the boundaries of land parcels" (Dale 1976, xx). The Bathurst Declaration (Grant and Williamson 1999, appendix IV) provides a broader definition in "the surveying and mapping of land parcel boundaries in support of a country's land administration or land registration system."

The origins of modern cadastral surveys are found in eighteenth- and early nineteenth-century Europe. They were closely associated with the breakup of large rural estates, enclosures, and taxation of land. The development of legal frameworks and mechanisms for the registration of rights to land, coupled with industrialization and urbanization, contributed to the expansion of cadastral surveying in the second half of the nineteenth century. The much larger number of cadastral surveys undertaken during the twentieth century is attributable to natural increases in population, immigration, opening new agricultural land, housing, expansion of land markets assisted by improved credit arrangements, and, after 1989, radical changes in land tenure in Eastern Europe and the former Soviet Union. Thus cadastral surveys were associated primarily with the settlement, registration, valuation, and administration of land as well as with the planning and inventory of physical infrastructure and utilities. Cadastral surveys and the related survey records have also been inputs to modern land information systems.

Cadastral surveys to locate, define, describe, and retrace boundaries or corners of land parcels are governed by laws and regulations. Using the Province of Ontario as an illustration, the *Surveys Act*, *Regulation 1028* on the "Ontario Co-ordinate System," and *Regulation 1029* on "Survey Methods" govern surveys of boundaries. There is a corresponding *Surveyors Act*, which recognizes the Association of Ontario Land Surveyors (AOLS) as a body of private professionals, and *Regulation 42/96* on "Performance Standards for the Practice of Cadastral Surveying." AOLS is responsible for licensing, regulating, and disciplining its members and for prescribing and governing standards of practice and performance. In other jurisdictions cadastral surveyors have been employed within government. Additional functions of a cadastral surveyor have included conducting mortgage surveys; contributing to land consolidation; determining the potential, use, or value of land; preparing development plans; arranging for registration of a property; and settling an issue relating to ownership and boundaries. The last quarter of the twentieth century generated much questioning of the high standards set by survey laws and regulations and their impact on land transactions, land registration, and economic development. Commentators recommended revision of survey regulations to improve productivity and reduce costs and the adoption of simple and cost-effective methods (UN Centre for Human Settlements 1990; Farvacque and McAuslan 1992). The United Kingdom throughout the twentieth century, and several African countries for parts of it, applied the approximate boundary concept of "general boundaries" (Dale 1976, 29–33) and their depiction on large-scale (1:1,250, 1:2,500, and 1:10,000) maps. Physical features such as walls, hedges, fences, planted vegetation, ditches, streams, and roads were central to this concept.

Prior to 1970 the technical execution of cadastral surveys was by graphical methods such as plane tabling or chain surveys, from which cadastral maps were produced, or by instrumental methods. The most common of the latter was traversing by theodolite and steel tape, to which modern glass circle theodolites with optical micrometers contributed substantially from the 1920s. An optical subtense bar for measuring distance indirectly was used in a few countries, and polar measurements by optical tacheometry were used where appropriate. Instrumental methods facilitated the computation of geographical, projection, or grid coordinates for both control and boundary turning points. However, neither surveys by graphical methods nor instrumental surveys were necessarily connected with the national control survey framework. Thus island surveys resulted as in Denmark and Australia (Williamson and Enemark 1996).

Electromagnetic distance measurement (EDM), introduced in the 1950s, eclipsed existing labor-intensive methods of measurement by wires or tapes, and led rapidly to the replacement of triangulation by traversing. The early Geodimeter and Tellurometer EDM instruments employed visible light or microwaves to measure up to 150 kilometers for geodetic applications. Short-distance measurement devices followed in the late 1960s, and employed near-infrared radiation or microwaves. Most of these devices permitted measurements up to 3 kilometers, and thus were adopted for cadastral surveying where regulations and economic considerations permitted. Cadastral survey computations relied on mathematical tables and manual processes until mechanical calculating machines appeared in the 1920s and electrical versions later. Though Hewlett-Packard released its first desktop computer in 1968 (HP 9100A), nonprogrammable handheld electronic calculators, and then programmable versions, played very significant roles in survey computations throughout the 1970s and 1980s. Personal computers and an innovative geospatial technology industry resulted in a wealth of software programs dedicated to survey calculations, adjustments, the production of coordinates and heights, and plotting the results graphically.

Continuing technological innovation brought electronic theodolites with microprocessor systems and, by the early 1980s, the so-called total station. This combination of an electronic theodolite, EDM, data collector, and onboard software for processing observations was widely used in cadastral surveying. It increased productivity and enabled high accuracy to be achieved, but brought into sharper focus discussion of the standards of measurements required in cadastral surveys. In the mid-1980s the U.S. Department of Defense began to implement the Global Positioning System (GPS). Although the constellation of twenty-six satellites did not reach its initial operational capability until 1993, the surveying community had already devised differential methods of establishing positions within 1–2 centimeters with high-order receivers. Rapid technological developments encouraged the production of lower-order receivers. GPS was used extensively for creating new control survey networks, for example in Hungary (UN Economic Commission for Europe 1996), and for densifying networks for cadastral surveys. So-called submeter GPS receivers provided coordinates that were sufficiently accurate for cadastral surveys to be undertaken at low cost and with greater efficiency, as demonstrated in Albania and Belize (Barnes and Eckl 1996). In some jurisdictions, for example Alberta, survey regulations were revised to permit the use of GPS in appropriate cadastral surveys. However, cost and capacity inhibited some private-sector cadastral surveyors from absorbing the methodology into their daily practice.

Producing cadastral surveys from aerial photographs using photogrammetry began in Italy in 1931. For photogrammetry to be cost effective the surveys had to be systematic and not sporadic. Ideally, parcel boundaries were air-visible with the turning points marked by signals as in rural Norway (Onsrud 1988), or the complete boundary was occupied by a physical feature (as noted above). The latter approach to producing registry index (line) maps was used in Kenya after 1957 (Dale and McLaughlin 1988), though subsequently preliminary index diagrams were created by tracing the visible parcel boundaries shown on enlarged, unrectified photographs. Rectified photographs were used elsewhere. An early test of orthophotographs for compiling cadastral maps occurred in El Salvador in 1968. Although orthophotomaps were produced from the late 1960s in some European countries for large-scale base mapping, their use as bases for cadastral overlays became prominent later. The availability of Indian IRS-IC five-meter resolution satellite data and the advent of higher-resolution U.S. data from the IKONOS and Quickbird satellites, launched in September 1999 and October 2001 respectively, prompted investigations of how and to what extent such data could be applied to cadastral surveys. They continue.

Research, field notes, and survey plans are important outcomes of cadastral surveys. Throughout the century it was common practice for the appropriate government department to check the outcomes produced by cadastral surveyors. Ontario and New Zealand illustrate significant changes in this practice within the evolving application of quality assurance. In 1986 AOLS began to assume responsibility for checking fieldwork and plans in Ontario by creating the Survey Review Department. In 1998 Land Information New Zealand (LINZ) introduced survey accreditation and audit processes that relied on surveyors maintaining the necessary standards (Bevin 1999). Responsibility for cadastral surveys in unitary states was usually centralized. In federal systems responsibility for land was typically assigned to the provinces or states. In the United States responsibility at the state level was devolved to the county level. There were two principal organizational models in unitary and federal states: a single department responsible for cadastral surveys, mapping, and land registration; or two departments, one responsible for surveys and mapping and the other for registration. The two departments reported to the same or different ministers. Cyprus and Uganda are unitary states with a long-established single department. In contrast, the Province of New Brunswick integrated land registration, surveying and mapping, and property assessment within the Geographic Information Corporation in 1990. Austria, Germany, England and Wales, and Scotland illustrate jurisdictions with two departments. HM Land Registry (2001, sec. A) identified organizational structures at the close of the century in forty-two Economic Commission for Europe countries, of which eighteen are in Eastern Europe and the Commonwealth of Independent States (made up of most of the former Soviet Union).

Central and local governments made, commissioned, and used cadastral surveys to fulfill their statutory functions. These included the custody, leasing, and alienation of public lands; registration of rights to land and transactions; valuation of property; physical planning; compulsory purchase or expropriation of private lands; and the provision of physical infrastructure and utilities. Cadastral surveys helped owners and property developers establish rights to and convey land, assisted by lawyers, notaries, banks, and mortgage companies. Thus for most of the twentieth century cadastral surveys were integral to governance, the provision of specific services, and the protection of individual rights. Increased attention to protection of the environment during the last quarter of the century and new domestic and international roles for nongovernmental and community-based organizations enlarged the range of applications for cadastral surveys. Further, some cadastral organizations gradually recognized that there were new markets for cadastral (and registration) data and responded with newly developed products and services. The concept of a national, state, or regional spatial data infrastructure (SDI) is potentially significant for a cadastre that has been digitized and is supported by digital cadastral surveys. Although SDI received increasing attention and varying degrees of commitment from 1990, incorporating a cadastre and cadastral surveys into an SDI remains a work in progress.

The state of Nordrhein-Westfalen (NRW) in Germany illustrates how this might be achieved. Its official cadastral information system is the ALKIS (Amtliches

Liegenschaftskataster Informationssystem), which consists of the cadastre and its associated large-scale map. NRW views the ALKIS as core spatial data. The related concept of the ATKIS (Amtliches Topographisch-Kartographisches Informationssystem) is to base all German topographic data sets on the basic digital line map (at 1:10,000 or 1:25,000 scales) in order to create the national SDI. These will also be core data. In NRW the ALKIS is a part of this concept as it contains parcel boundaries and cadastral buildings. Vertical integration of cadastral (ALKIS) and mapping (ATKIS) data is the goal. Achieving this will depend on appropriate strategies and mechanisms for cartographic generalization, which will be needed at several steps.

GERALD MCGRATH

SEE ALSO: Administrative Cartography; Cadastral Map; Photogrammetric Mapping: (1) Aerial Photogrammetry and Cartography, (2) Air Photos and Geographic Analysis; Property Mapping Practices

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Canada Geographic Information System. Devised to generate statistical summaries of land quality data originally portrayed on hardcopy maps, the Canada Geographic Information System (CGIS) pioneered or otherwise advanced several techniques fundamental to the development and application of geographic information systems (GIS). These contributions include data capture with a computer-controlled drum scanner, data conversion from a scanned raster image to a vector representation, treatment of land polygons (areal units such as census tracts, soil units, or forest stands) as a sequence of surrounding boundary lines, and map overlay. As an integrated system for map analysis that became fully operational, CGIS not only demonstrated the efficacy of GIS concepts but highlighted many of the technical and managerial impediments to successful implementation.

CGIS is rooted in the Agricultural Rehabilitation and Development Act of 1961, which called for a comprehensive assessment of renewable resources, especially in marginal areas. In 1962 the Department of Agriculture launched the Canada Land Inventory (CLI), which mapped land capability for agriculture, forestry, wildlife, and recreation at scales between 1:50,000 and 1:250,000. The CLI also mapped current land use and census subdivisions; its growing inventory of map sheets, which eventually numbered more than 10,000, provided a strong incentive for computer-based analysis.

According to Roger F. Tomlinson, the idea for CGIS can be traced to his "chance meeting" in 1962 with Lee Pratt, director of the CLI (Tomlinson and Toomey 1999, 468). Tomlinson, who had trained as both a geographer and a photogeologist, was working at the time at Spartan Air Services in Ottawa, which provided an opportunity to explore computer-assisted mapping, including a digital method for calculating the amount of a particular land type within a given administrative area—the essence of map overlay. Extending this concept to a large database suggested an electronic strategy for converting paper maps to a digital format, tabulating summary statistics, analyzing interrelationships, and evaluating alternative uses of marginal lands. Encouraged by Pratt, Tomlinson presented his ideas that November to a government seminar on land capability inventory. Impressed with his presentation, the Agricultural Rehabilitation and Development Administration (ARDA) commissioned a feasibility study that led in turn to the ARDA Data Coordination System, renamed the Canada Geographic Information System in 1966. In 1964 the ARDA hired Tomlinson to direct the project, which became fully operational in 1971.

Cost-effective conversion from hardcopy compilations to an electronic map demanded specialized hardware, raster-to-vector software, and substantial manual processing. A key component of the input system was a large rotary scanner, ordered from the International Business Machines (IBM) Corporation at a cost of roughly $180,000 Canadian. Delivered in 1967, the ma-

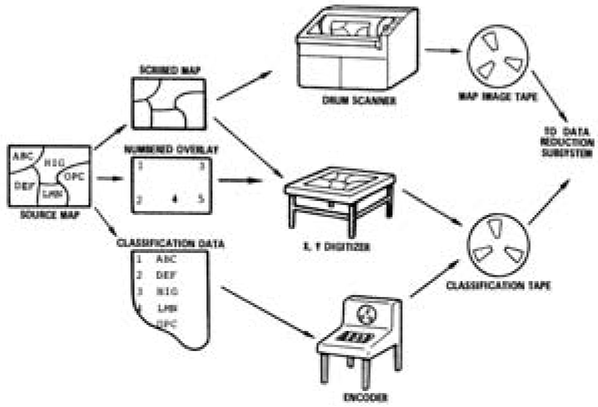

FIG. 118. INPUT PROCEDURE FOR THE CANADA GEOGRAPHIC INFORMATION SYSTEM.
Size of the original: 13.1 × 19.3 cm. From Environment Canada, Lands Directorate, Land Management Information Systems 1973, 65 (DOI: 10.3138/7970-2661-201R-7077). © University of Toronto Press, 1973. Reprinted with permission from the University of Toronto Press.

chine could scan an entire map sheet at a resolution of 250 pixels per inch in about ten minutes, and was in service for fifteen years. (Only one similar machine was ever built—a backup unit for IBM's Ottawa office.) Map sheets were scribed manually before scanning to provide sharp lines of uniform width as well as to remove classification codes and other annotations that could confuse line-following software. A point within each polygon was digitized manually on a 48″ × 48″ digitizing table and assigned a unique integer that was linked to the land category code for the polygon (fig. 118). Once the map was scanned, software decomposed the network of boundary lines into discrete boundary segments called *arcs* and worked out the map's "arc-polygon" data structure, which described each land polygon as a sequential list of surrounding arcs. A point-in-polygon algorithm then used the file of digitized points to relate each polygon to its land classification. Although commercial GIS software took over in the mid-1980s, and no new data were entered after 1989, CGIS had enormous impact as an operational exemplar of a large spatial database.

The historical significance of this preeminence is questioned by Nicholas R. Chrisman, who points out that the ground-breaking CGIS software never migrated to a commercial system. Moreover, Tomlinson's widely accepted status as the "father of GIS" reflects not only his pivotal role in CGIS but also his activity during the 1970s and 1980s as an organizer of conferences and chair of the International Geographical Union's Commission on Geographical Data Sensing and Processing. In Chrisman's view, it is pointless to proclaim a single origin for GIS or to designate a particular individual as its father inasmuch as the technology for processing map information electronically reflects the collective thinking and experimentation of a broad community of innovators (Chrisman 2005).

MARK MONMONIER

SEE ALSO: Electronic Cartography: (1) Data Structures and the Storage and Retrieval of Spatial Data, (2) Data Capture and Data Conversion; Environmental Protection; Geocoding; Geographic Information System (GIS): GIS as a Tool for Map Analysis and Spatial Modeling

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Cartobibliography. The term cartobibliography embraces both the process of describing maps and the resulting lists. The brief description and listing of maps goes back to the sixteenth century (Waterbolk 1977), but the systematic compilation of separate lists of maps and the development of standards for producing such lists are almost entirely twentieth-century phenomena and inevitably tied to practices in libraries.

Map Description

One of the first attempts at codifying library cataloging was the ninety-one rules expounded by Anthony Panizzi in 1841 for the library of the British Museum. Panizzi made no particular mention of maps, but the museum began applying the rules to its printed maps about 1843, and by 1862 a paragraph on "maps" calling for their entry under the name of the area shown had been added immediately after rule ninety-one ([Panizzi] 1866, xxv). These rules governed the compilation of the first edition of the museum's catalog of printed maps (British Museum 1885) and were reprinted without change almost a decade later (Library Association 1893).

Philip Lee Phillips, the first map librarian at the Library of Congress, outlined his system just before the turn of the century (Phillips 1899) and wrote a special section on maps and atlases for the definitive edition of Charles A. Cutter's *Rules for a Dictionary Catalog* (Phillips 1904). Since Cutter's 1904 rules became the basis of Library of Congress cataloging and since the library began distributing printed catalog cards in 1901 (though not for maps), these rules quickly became a standard in American libraries.

In Germany and elsewhere in Central Europe, the Prussian *Instruktionen*, first published in 1899, were adopted by many libraries, although only in their second edition of 1908 were there separate rules for map description (*Instruktionen* 1908, 166–70). The map librarian at the Royal Library in Dresden published an influential account of their practices (Hantzsch 1904), and these and the *Instruktionen* continued to guide German library cataloging for fifty years and more (Kramm 1958).

The cataloging codes for libraries in Italy, including that of the Vatican, tended to follow the lead of the Anglo-American rules and included brief sections on maps (Italy. Commissione 1922, 13–14; Biblioteca apostolica vaticana 1931, 30), while the Bibliothèque nationale in Paris relied on unpublished internal documents until the appearance of their detailed rules at midcentury (Bibliothèque nationale 1951).

As in so many things cartographic, World War II had a profound effect on map libraries. The sudden need for maps led to the development of several systems for their description and retrieval, but in their effort to speed up the process, many of these called for a rather bare-bones tabular sort of description or "check-off" system that was better suited to modern topographic series than to more individualistic productions (Murphy 1945; Parsons 1946; Wilson 1948). Two librarians from the U.S. Department of State produced the most detailed manual for map librarianship to date, in which the rules for descriptive cataloging alone run to ninety-five pages (Boggs and Lewis 1945).

From early on, there were efforts to coordinate the British and American codes and to make them more international, a goal that was partially realized with the publication of the first edition of the *Anglo-American Cataloging Rules* (*AACR*), with a section on maps that included input from R. A. Skelton and Helen Wallis (American Library Association et al. 1967, ix, 272–81). After much international consultation, a 258-page map cataloging manual emerged in 1982 (Anglo-American Cataloguing Committee 1982), and by the time of its second edition (2003), the Anglo-American Cataloging Code, on which it is based, could be said to have achieved worldwide currency, having been translated into twenty-five languages (see the website of the Joint Steering Committee [JSC] for Resource Description and Access [RDA], translations).

The description of older cartographic material began to get special attention early in the century by the British bibliographer Herbert George Fordham, who is credited with coining the word *cartobibliography* (Fordham 1912). Thirty years later the American Lloyd A. Brown published a monograph on the subject that is still consulted (Brown 1940). Work on a cooperative project to catalog pre-1900 maps of the Middle West resulted in an extensive manual for antiquarian map cataloging, which although never formally published, was rather widely dispersed through photocopies and microfilm (Karrow 1977). The description of early cartographic material in libraries has been the subject of several articles (Vick and Romero 1990; Kandoian 1999; Romero and Romero 1999; Prescott 1999), and a recent manual on map cataloging devotes a chapter to "historical maps" (Andrew 2003, 193–210).

Our discussion of cartobibliography so far has focused almost exclusively on the use of map descriptions in libraries for the inventorying and retrieval of library collections, an activity usually referred to as map cataloging, or *enumerative cartobibliography*. But in the last half of the twentieth century, increasing attention was paid to what has been called *analytical cartobibliography* (although the adjectives "critical" and "descriptive" are sometimes applied to such efforts). By analogy with well-established usage in the book world, these terms refer to a practice whose primary interest is in describing the physical aspects of a printed object as an end in itself or as a means of understanding the history of its production and distribution. Descriptions crafted with this end in view tend to be more detailed in their recording of the placement and appearance of bibliographical elements as well as more precise in their recording of measurements; they may include more or less elaborate descriptions of paper or printing technique and usually attempt to distinguish between small variations in what might on first inspection appear to be identical maps.

The descriptive bibliography of printed books was well established by the 1950s, and early in that decade, Coolie Verner began to publish studies in which he applied some of the methods of analytical bibliography to maps (Wallis 1981). His discussions of the theoretical and methodological foundations of his work were few and scattered, but highly influential (Verner 1965, 1974, 1975, Verner and Stuart-Stubbs 1979, 225–83). Much of the discussion around analytical cartobibliography has centered on terminology, especially the use of the terms "edition," "printing," "issue," "plate," and "state" (Campbell 1989; Tanselle 1982). Analytical cartobibliography seems primarily to have been practiced in Anglophone countries and has received little attention since the 1980s.

Lists of Maps

Moving from the description of maps to the accumulation of those descriptions into usable lists, we enter an enormously productive area, and again, one with relatively few precedents before the twentieth century.

English county maps weigh heavily in the history of published *analytical cartobibliographies*, beginning with Fordham's pioneering lists of maps of Hertfordshire and Cambridgeshire (Fordham 1907, 1908) and reaching the peak in lists of maps of Warwickshire (Harvey 1959) and (again) Hertfordshire (Hodson 1974). These latter cartobibliographies set a new standard by clearly distinguishing every appearance of a given map, whether printed from copperplates or from lithographic stones via the very common nineteenth-century process of "lithographic transfers."

Turning, finally, to the subject of more general lists of maps, lists generated to try to record all the maps of a region or in a repository (sometimes called *enumerative cartobibliographies*), our field becomes vast, and we can only suggest the broad trends. There are literally thousands of such lists, the vast majority being twentieth-century products, using descriptions growing out of the largely library-oriented standards outlined above.

Figure 119 shows an analysis of 3,390 records in the WorldCat database identified as lists of maps and published between 1875 and 2000. The 1960s and 1970s saw a steady rise in annual production, to a peak of 100 in 1976, after which a gradual decline begins. The strong increase in production after 1960 almost certainly reflects growth in the field of map librarianship and on map studies in general, while the continuing declines since the late 1980s may correlate with the ever-growing reliance on WorldCat itself and other online databases for descriptions of maps. For a classified, annotated listing of some 115 published cartobibliographies and map catalogs, see Karrow (1997).

For the last three decades of the century, an ever-greater percentage of the map descriptions formulated by librarians went into online databases rather than printed catalogs or cartobibliographies. By 2008, the online catalog WorldCat, the largest bibliographic database ever created, served 69,000 libraries in 112 countries around the world. In that year the WorldCat database contained approximately 1 million map records, including some 100,000 records for pre-1900 maps (fig. 120). WorldCat records are available to anyone with an Internet connection.

The largest online database devoted *solely* to old maps is the IKAR Database of Old Maps, a German cooperative project listing cartographic materials printed before 1850. In 2002 IKAR, which is also open to anyone with an Internet connection, contained descriptions of some 223,000 map titles.

ROBERT W. KARROW

SEE ALSO: Collecting, Map; Histories of Cartography; Libraries Map; Libraries and Map Collections, National

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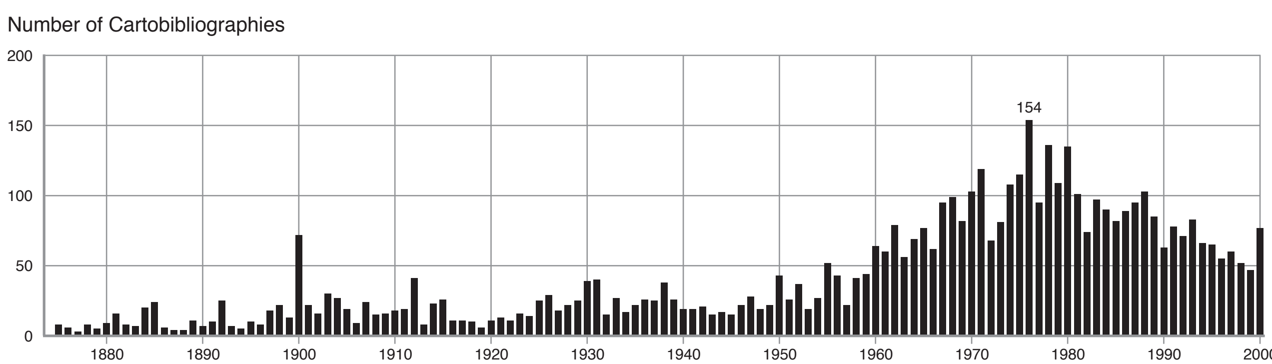

FIG. 119. PRODUCTION OF CARTOBIBLIOGRAPHIES, 1875–2000, BY YEAR OF PUBLICATION. Compiled by Robert W. Karrow from records in WorldCat.

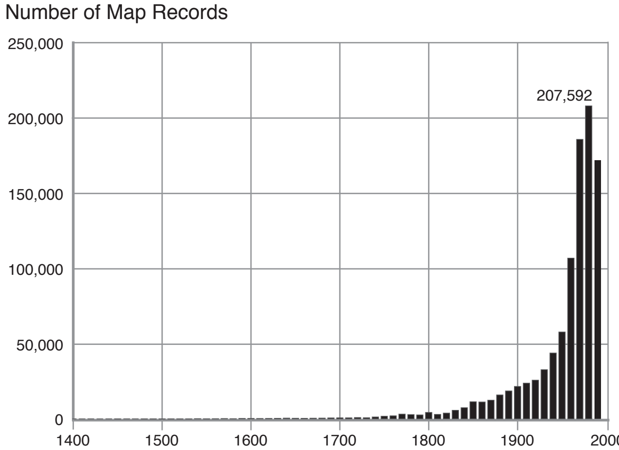

FIG. 120. MAP RECORDS IN WORLDCAT, BY DECADE OF PUBLICATION. Compiled by Robert W. Karrow.

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Cartogram. A cartogram can be thought of as a map in which at least one aspect of scale, such as distance or area, is deliberately distorted to be proportional to a variable of interest. In this sense, a conventional equal-area map is a type of area cartogram, and the Mercator projection is a cartogram insofar as it portrays land areas in proportion (albeit nonlinearly) to their distances from the equator. According to this definition of cartograms, which treats them as a particular group of map projections, all conventional maps could be considered as cartograms. However, few images referred to as cartograms look like conventional maps.

Many other definitions have been offered for cartograms. The cartography of cartograms during the twentieth century has been so multifaceted that no solid definition could emerge—and multiple meanings of the word continue to evolve. During the first three quarters of that century, it is likely that most people who drew cartograms believed that they were inventing something new, or at least inventing a new variant. This was because maps that were eventually accepted as cartograms did not arise from cartographic orthodoxy but were instead produced mainly by mavericks. Consequently, they were tolerated only in cartographic textbooks, where they were often dismissed as marginal, map-like objects rather than treated as true maps, and occasionally in the popular press, where they appealed to readers' sense of irony.

The heterogeneous development of cartograms in the twentieth century is partly reflected in the many names that exist for cartograms. For instance, cartograms that distort area have been termed anamorphosis; diagrammatic maps; map-like diagrams; varivalent projections; density equalized maps; isodensity maps; value-by-area maps; and even mass-distributing (pycnomirastic) map projections. The subcategory of cartograms in which area is drawn in proportion to population have also been given many names, including political map; demographic map; population scale map; and many very specific titles such as "Population Map for Health Officers" (Wallace 1926). Moreover, there are noncontiguous (Olson 1976) as well as contiguous (Tobler 1973) varieties, and—insofar as an infinite number of correct continuous-area cartograms can be produced (Sen 1975) for any given variable—many visually different cartograms have been drawn scaled to the same quantity, usually population. Even so, by the end of the century it had become clear that only one area cartogram will approximate the best, least distorting solution (Tobler 2004). In the early twenty-first century a practical means for achieving that solution became available (Gastner and Newman 2004).

Motives for drawing cartograms were often related to the rapidly changing political geography of the twentieth century and the late nineteenth century, which was marked by the upheavals of industrialization, the concretization of nation-states, and the consequent need to visualize their statistics. The earliest known area cartogram is French statistician Émile Levasseur's cartogram of Europe ca. 1870, which depicts countries in their "correct" size, in this case, their correct physical area (I have not found where the "Statistique figurative" was originally published). Levasseur's aim, it seems, was to imply that Russia was somehow balanced by—if not a threat to—the combined European landmass. In the context of the political maps and data graphics of the era, his cartogram not only created an impression of an invulnerable Russia but also reinforced the threat of its land area in a way uncannily similar to the Soviet Union's depiction on a Mercator world map a century later, as seen on U.S. television screens during the Cold War.

In the final decades of the nineteenth century Russia was considered the largest potential threat to the new political systems emerging in Europe, and similar images implied that it had to be taken more seriously than traditional cartographic treatments might suggest. It is perhaps no mere coincidence that Levasseur's cartogram was created using data for around the same year as Charles Joseph Minard's *Carte figurative* (drawn in Paris in 1869) showing the mounting losses of French army troops during the Russian campaign of 1812–13. On that well-known map—arguably a linear cartogram, but rarely discussed as such—a flow line that shrinks in width during the advance and retreat of Napoleon's army provides a dramatic description of the ill-conceived invasion.

While many *mappaemundi* and other ancient maps resemble modern cartograms because land was often drawn in rough proportion to its perceived importance, the modern cartogram is a comparatively recent invention. And because all but the simplest cartograms were tedious to produce by hand, more cartograms were probably produced in the first few years of twenty-first century than throughout the whole of the twentieth, thanks to new, highly efficient algorithms. These computer-generated cartograms were largely area cartograms because software for producing linear cartograms (and sophisticated flow maps) lagged behind that for creating their value-by-area counterparts.

The twentieth century also witnessed the theoretical description of cartograms yet to exist in practice (Angel and Hyman 1972). Examples include cartograms on which travel time is shown as distance not just from a single point, but between all points on the map. Such a linear cartogram would be possible—this has been proved mathematically if not visually—were the map to be drawn as a two-dimensional surface, or manifold, undulating within, wrapped up in, and occasionally torn within three-dimensional space, and thus no longer akin to the flat map of traditional statistical cartography. Moreover, linear and area cartograms could be combined in this way and together merged into quantity-by-volume cartograms, on which, for instance, each person's life was accorded an equal volume in a deliberately distorted block of space-time. Such possibilities have been described and developed (Dorling 1996), but several decades often elapse between the proof of what is possible and its realization. Thus an intriguing part of the history of cartograms in the twentieth century has been imagining new possibilities demonstrated by existing theorems but not yet realized.

Because the software was not widely available, computer generation of what are seen as traditional cartograms remained problematic through the early years of the twenty-first century and was nearly impossible as well as largely impracticable through the end of the twentieth century. Manual methods were daunting for anyone eager to base a cartogram on a large number of small area units. Many months, even years, could be spent creating a cartogram by hand showing, for instance, the populations of parliamentary constituencies of Britain in 1964, only to see their boundaries redrawn again by 1970, making the cartogram obsolete except for historical studies. Designers willing to accept suboptimal solutions could turn to analog approaches based on trial-and-error manipulation of hundreds of cardboard tiles (fig. 121) (Hunter and Young 1968) or thousands of ball bearings and hinged metal joints (Skoda and Robertson 1972). Early experimentation with computer modeling was frustrated by the massive computational demands of creating near-optimal solutions (Dougenik, Chrisman, and Niemeyer 1985), but substantial improvements in computer architecture toward the end of the century led to a plethora of algorithms able to cope with the iterative shifting of millions of vertices. Well after the end of the century mapmakers (this writer included) intent on drawing cartograms for atlases of socioeconomic data were still using paper and pen, albeit with a little aid from computers, to achieve aesthetic effects that computer algorithms alone could not.

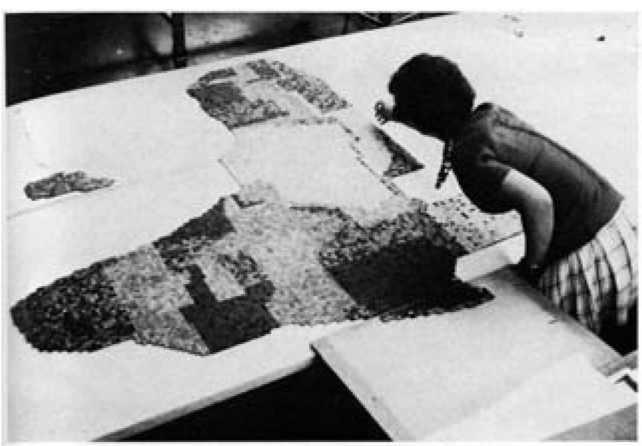

FIG. 121. PRODUCING A CARTOGRAM OF AFRICA. Melinda S. Meade moves thousands of tiles to produce a Hunter and Young type of cartogram.
From John M. Hunter and Melinda S. Meade, "Population Models in the High School," *Journal of Geography* 70 (1971): 95–104, esp. 97 (fig. 1). Reproduced by permission of Taylor & Francis.

Automated production of cartograms was instigated by the theoretical work of Waldo R. Tobler in the last third of the century. His seminal publication argued that cartograms could play a key role in the political redistricting that follows America's decennial population census (Tobler 1973). Tobler's review of the development of computer cartograms, published thirty-one years later, is one of the most useful summaries of the field (Tobler 2004). A 1909 isochronic map of travel time from Berlin (fig. 122), a redrawn portion of which was included in his 1961 doctoral dissertation (Tobler 1961, 104), demonstrates the extreme contortions confronting construction of linear cartograms—Africa would literally be turned inside out, as it was politically during the twentieth century. That four decades elapsed without an efficient algorithm for describing this pattern with a cartogram attests to the difficulty of producing linear cartograms by machine.

However theoretically intriguing, cartograms have seen little practical application beyond the dramatic comparison of disparities among nations or between population and land area. For example, equal-population cartograms, once proposed as an objective approach to political redistricting, have (to this author's knowledge) never been employed for that purpose. The resulting areas would be far too hard to manipulate for subsequent partisan political gain. Even so, population cartograms have frequently been used to depict the outcome of elections—most frequently when the winning political party controls only a minority share of a territory's physical area. In these cases, a traditional base map could be misleading in implying that the party that had lost had in fact won. Cartograms were repopularized early in the twenty-first century in showing the results, across more than 3,000 counties, of the highly contested U.S. 2000 presidential election (Gastner and Newman 2004). Because Republican presidential candidates in the twentieth century tended to win in sparsely settled, comparatively rural areas, conventional maps—sometimes based on polls and released before an election as a forecast—could greatly exaggerate the party's strength.

Continuous-area cartograms (in contrast to a rectangular statistical diagram) have been used to detect clustering in the population—especially for cancers and other medical conditions. The example in figure 123 is an equal-population cartogram based on over 100,000 areas in Britain; the superimposed surface represents the chances of dying from childhood leukemia over an eighteen-year period in the latter half of the century. The risk of dying was highest in the areas shaded white, where cases appear to cluster. However, on closer examination many of these areas include hospitals that treated

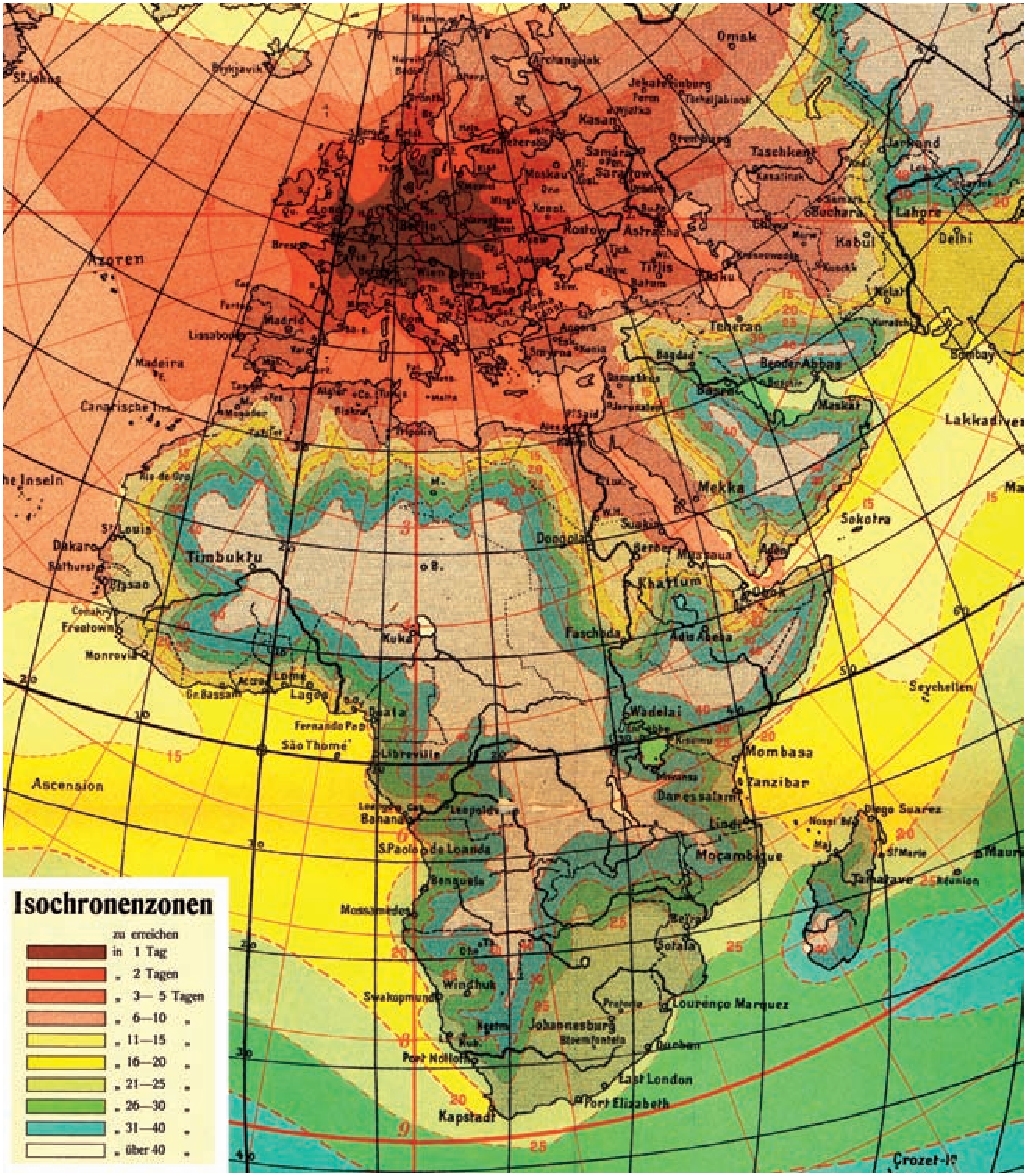

FIG. 122. TRAVEL TIME IN DAYS FROM BERLIN AT THE START OF THE TWENTIETH CENTURY. Detail (with legend inserted) from Max Eckert's 1909 *Isochronen-Karte der Erde* (see fig. 676). Size of the entire original: 65.2 × 64.5 cm; size of detail: ca. 20.1 × 17.6 cm. From Max Eckert, "Eine neue Isochronenkarte der Erde," *Petermanns Geographische Mitteilungen* 55 (1909): 209–16, 256–63, pl. 25.

FIG. 123. CASES OF CHILDHOOD LEUKEMIA IN POPULATION SPACE IN BRITAIN, 1966–83. White indicates the areas of highest risk for death. The basic distribution of childhood leukemia (9,411 cases are shown) is extremely evenly distributed, although techniques can be used to emphasize the slight increase in density, as has been done on this map.
After Daniel Dorling, "The Visualisation of Spatial Social Structure," PhD thesis, Department of Geography, University of Newcastle, 1991, pl. CLIX. Image courtesy of Daniel Dorling.

sick children or other areas with unusually high concentrations of such children. Medical cartography of this kind has often been frustrated by a dearth of meaningful case clusters.

Finally, over the course of the twentieth century the most important uses of cartograms have not been in political or economic mapping or for the discovery of clustering of disease but in social, environmental, and political mapping. Figure 124 shows one example—the world's nations redrawn with areas proportional to the size of the collective environmental footprints of their inhabitants. Understandably, the United States, Europe, and Japan are especially large. The explicit use of cartograms for social and environmental advocacy began with the work of political scientist Michael Kidron, widely known as a revolutionary thinker, cartographer, and joint author of the earliest of the *State of the World* series of atlases, initiated in 1981. The series was continued by Dan Smith, who had worked with Kidron on *The War Atlas: Armed Conflict—Armed Peace* (1983). Although early editions of the *State of the World Atlas* included few cartograms, these were more likely to be remembered by schoolchildren taught with the books (including this author). The widespread use of cartograms in social, political, and environmental campaigns is readily apparent to anyone who searches for these map-like images on the web.

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SEE ALSO: Airline Map; Demographic Map; London Underground Map; Mathematics and Cartography; Tobler, Waldo R(udolph); Wayfinding and Travel Maps: Public Transportation Map

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Cartographic Duplicity in the German Democratic Republic. Germany's defeat in World War II left the country divided into zones of occupation controlled by the United Kingdom, France, the United States, and the Soviet Union. When formal military occupation ended in

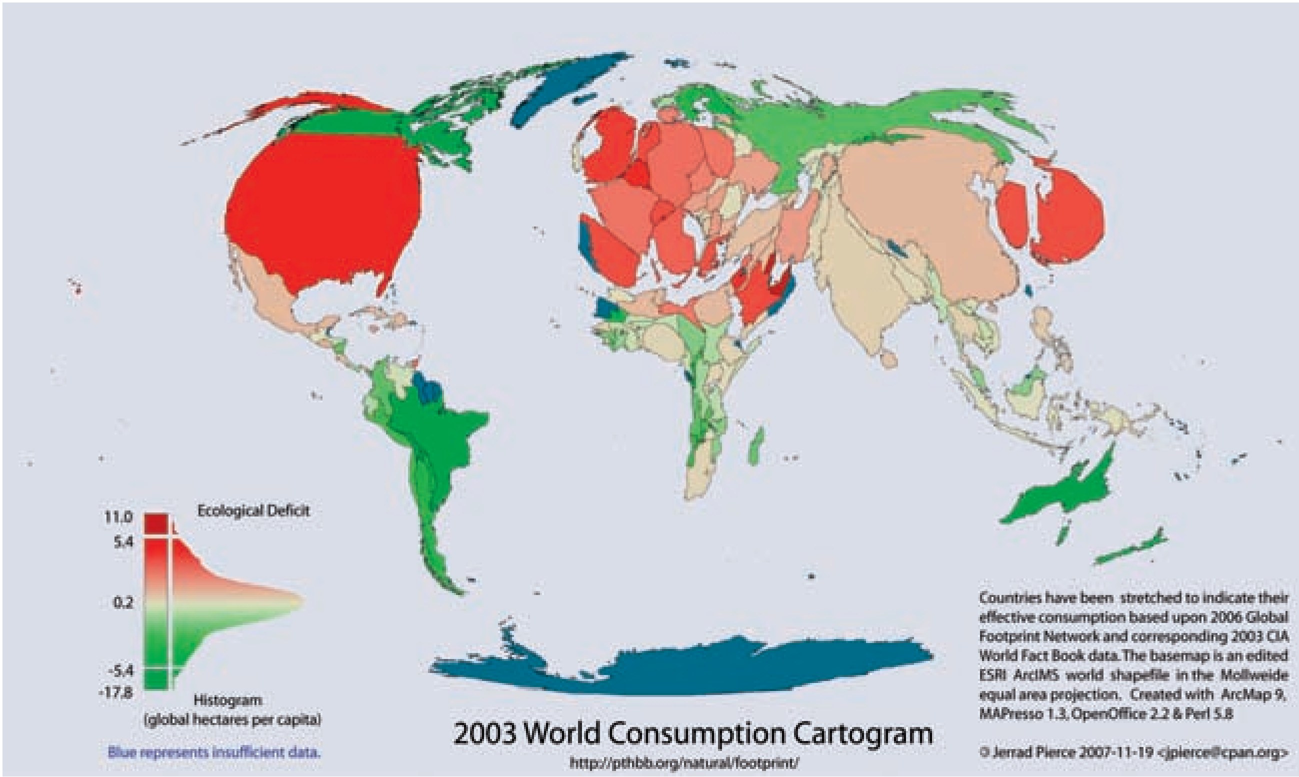

FIG. 124. MODERN WORLD CARTOGRAM OF OUR ECOLOGICAL FOOTPRINT BY JERRAD PIERCE, 2007.

1949, the three western sectors emerged as the Bundesrepublik Deutschland (BRD, Federal Republic of Germany, known as West Germany), and the Soviet sector east of the Oder-Neisse Line became the Deutsche Demokratische Republik (DDR, German Democratic Republic, known as East Germany). This division was underscored during the Cold War by West Germany's membership in NATO (North Atlantic Treaty Organization) and East Germany's alignment with the Soviet Union and the seven other Communist states in Central and Eastern Europe in the Warsaw Pact. It also had a marked impact on civilian mapping in East Germany, where the Soviet penchant for cartographic secrecy led to separate sets of military and civilian maps, with the former classified and closely guarded and the latter deliberately distorted to confound or mislead NATO intelligence analysts.

East Germany's duplicative sets of topographic maps attest to prevailing Soviet beliefs in both the importance of geographic information and the presumed effectiveness of large-scale falsification as a means of defending it. This endeavor, which included geologic and agricultural mapping as well as commercial cartographic products, was the theme of a conference held in Berlin in 2001, eleven years after German reunification, and sponsored by the Bundesbeauftragte für die Unterlagen des Staatssicherheitsdienstes der ehemaligen Deutschen Demokratischen Republik. A collection of papers arising from the conference was edited by Dagmar Unverhau and published in German in 2002 and in English in 2006. The collection's multiple appendixes include declassified reports, directives, and excerpts from editorial specifications that document the extent and method of the deception.

During the 1950s, when intensive remapping was essential to an orderly rebuilding of the war-torn country, tension developed between Soviet authorities, who favored secrecy and the suppression of detail, and East German cartographic officials, who wanted the mapping to be more appropriately accurate and available. A 1965 decree by the Nationaler Verteidigungsrat der DDR, apparently under Soviet pressure, called for increased secrecy in map content as well as greater control over printing, storage, and distribution. Archivist Dagmar Unverhau (2006a, 43) identified a "set-up phase" during the 1950s and early 1960s, which included the renunciation and recall of earlier topographic maps and their replacement, under strict monitoring, with new maps produced by the cartographic arm of the ministry of state security, Ministerium für Staatssicherheit, a

FIG. 125. DETAIL FROM TOPOGRAPHISCHE KARTE (AS), 1:100,000. Sheet M-33-28 Dresden, current to 1984, 1986 edition. Compare the detailed information about structures and transport lines inside the red circle near the center of the excerpt with the comparatively generalized features in the same part of figure 126. Size of the entire original: 35 × 39 cm; size of detail: 6 × 13.5 cm. Image courtesy of the Staatsbibliothek zu Berlin–Preußischer Kulturbesitz; Kartenabteilung.

FIG. 126. DETAIL FROM TOPOGRAPHISCHE KARTE (AV), 1:100,000. Sheet 1209 Dresden, current to 1983. Size of the entire original: 44.1 × 37 cm; size of detail: 6 × 13.5 cm. Image courtesy of the Bayerische Staatsbibliothek, Munich. Permission courtesy of the Staatsbetrieb Geobasisinformation und Vermessung Sachsen 2014.

massive bureaucracy that included the infamous secret police, the Stasi. From 1966 through 1990, topographic maps were produced in two separate editions: a comparatively detailed state edition (AS, for Ausgabe Staat) framed by a Soviet datum and including grid lines and a wide range of features relevant to national defense (fig. 125), and the relatively sparse national economy edition (AV, for Ausgabe für die Volkswirtschaft), with a less dense grid and coordinates for another ellipsoid (fig. 126). On neither map sheet is the coordinate system or reference ellipsoid identified. Academic cartographer Wolf Günther Koch (2006, 76) identified two phases of cartographic secrecy: a period of "heavily simplified map contents and a kind of generalisation bordering on schematisation, particularly of the built-up areas" extending from 1966 through 1978, and a more relaxed period after authorities recognized the need for "maps of better quality with more detailed content in different scales" and a geodetic framework.

Falsification was more a matter of suppression or "camouflaging" than of gross geometric distortion, according to archivist Roland Lucht and his colleagues, who scrutinized AS and post-1978 AV editions for several areas and concluded, "The content-related alterations cannot be justified with the kind of military secrecy practised more or less everywhere or with the goal of generalisation—they go too far: They are falsifications" (Lucht, Henkel, and Scholz 2006, 132). Even so, archival research revealed a preference for modest amounts of displacement. According to 1965 guidelines, a 1:200,000 base map intended "as source material for . . . products for the general public [was] to be edited in such a way that, as a result of irregular scale and directional distortions, topographic objects are represented with an inaccuracy of up to ± 3 km" (Unverhau 2006b, 246), while "principles of camouflage" released in 1986 sanctioned deliberately displacing symbols for key features 1.5–2.5 mm at 1:10,000 and 0.5–1.5 mm at 1:50,000 (Unverhau 2006b, 276).

East Germany's cartographic duplicity is unique only in the attention afforded by the 2001 Berlin conference: similar practices occurred in Czechoslovakia and Poland (Koch 2006, 73) and perhaps elsewhere in the Eastern Bloc. Although Soviet control accounts for much of the intense secrecy, public and civil authorities in East Germany were no doubt conditioned by the cartographic restrictions during the Nazi era (Monmonier 2005). Particularly intriguing was the absence of "a reasonably complete set" of AV maps, an apparent victim of the cartographic purge that accompanied reunification (Koch 2006, 84).

MARK MONMONIER

SEE ALSO: Administrative Cartography; Akademie für Raumforschung und Landesplanung (Academy for Spatial Research and Planning; Germany); Bundesamt für Kartographie und Geodäsie (Federal Office for Cartography and Geodesy; Germany); Cold War; Geopolitics and Cartography; Military Mapping by Major Powers: Germany; Public Access to Cartographic Information; Sources of Cartographc Information; Topographic Mapping: Eastern Europe; Wayfinding and Travel Maps: Indexed Street Map

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Cartographic Journal, The. In June 1964, *The Cartographic Journal* became the first general distribution English-language journal in cartography. (A rival claimant to this distinction is the *Cartographer*, predecessor of *Cartographica*, which emerged in 1965 with a date of 1964 on the cover of its first issue.) The journal's prominence as a peer-reviewed publication of the British Cartographic Society (BCS) is reflected in its diverse coverage of the science and technology of presenting, communicating, and analyzing spatial relationships by means of maps and other geographical representations, including remote sensing, geographic information systems, the Internet, Global Positioning Systems, and mobile mapping. Although the journal's commentary has focused on the United Kingdom, scholars in North America, continental Europe, and elsewhere have contributed many of its articles.

The journal is nearly as old as the BCS, which was first proposed at a cartographic symposium in Edinburgh in 1962 and established formally the following year. The society's first council, which included G. R. Crone, D. H. Maling, and other leading British cartographers and geographers, appointed J. S. Keates as editor and in November 1963 adopted the title *The Cartographic Journal*. The first edition carried a foreword by the new society's chairman, Brigadier D. E. O. Thackwell (1964, 2), who announced the intention "to give news of all general cartographic activities, to include reports of symposia, meetings, and of their discussions, to publish articles of cartographic interest, and to review maps, atlases and books on cartography."

The society's role includes appointing the editor, normally an academic at a British university with a special interest and involvement in cartography, and the journal's content includes BCS activities. Each year's final issue includes the society's annual report and financial statement as well as the awards presented at the annual symposium. Since 1975 a special award has honored the author of the most outstanding article in the journal, as judged by the editorial board.

The journal's contents have reflected salient change in the impact of mapping on society as well as the evolution of mapping technology, including the advent of digital media and dynamic mapping. J. C. Robertson's 1967 paper on SYMAP is emblematic of a broad range of articles exploring innovative topics such as computational approaches to map projection, alternative generalization algorithms, and mapping for users with specific needs. Other articles have examined customized content and the changing landscapes of commercial and academic cartography. In addition, obituaries have commemorated the accomplishments of notable mapmakers and cartographic scholars, while regular nonrefereed sections have identified recent additions to the cartographic literature; reviewed textbooks, technical manuals, and scholarly monographs; and reported new map accessions to the Royal Geographical Society's library.

Except for occasional special issues, such as the comprehensive overview of British commercial and academic cartography prepared for the Ninth General Assembly of the International Cartographic Association (ICA), held in Bournemouth in 1991, the journal was published semiannually until 2003, when the frequency increased to three issues per year; quarterly publication was introduced in 2008. The journal's distinctive A4 (21 × 29.7 cm) format has remained unchanged since its first issue, and full color became standard in 1999. Since 2009 *The Cartographic Journal* has been recognized as an affiliated journal publication of the International Cartographic Association.

KENNETH S. FIELD

SEE ALSO: Journals, Cartographic; Societies, Cartographic: Cartographic Societies in Western Europe

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Cartographic Practice, Modes of. See Modes of Cartographic Practice

Cartographica. The journal *Cartographica* was founded and edited by Bernard V. Gutsell as a private venture in 1964 under the name *Cartographer* (Castner 1997, 4). A semiannual publication, the *Cartographer* was intended as an outlet for original research in cartography. Prior to the 1960s no journals specifically served the cartographic community, either in Canada or elsewhere. Researchers in cartography, therefore, had to publish their work in journals of cognate disciplines such as history, geography, and surveying, which had only a marginal interest in cartography. In 1965 the journal received support initially from the National Research Council and the Canada Council. Grants have continued from the Social Sciences and Humanities Research Council of Canada.

In 1968 the name was changed to the *Canadian Cartographer*. Three years later Gutsell introduced the separate monograph series *Cartographica*, with three issues per year, as an outlet for book-length manuscripts. From the very beginning, the primary objective of the journal and its monograph series was to publish the results of Canadian research together with the work of international scholars, thereby combining wider exposure for Canadians with increased knowledge of activity beyond Canada. That the percentage of published articles by authors outside North America increased from 19 percent for 1980–89 to 36 percent for 1990–99 attests to the practicability and importance of this dual objective.

The journal received global recognition in 1980, when the International Cartographic Association bypassed other journals in selecting *Cartographica* for distribution to its member countries, partly because abstracts of articles were published in Canada's official languages, English and French, as well as in German and Spanish. In 1977, two years after its creation (in which Gutsell played a major role), the Canadian Cartographic Association (CCA) designated the *Canadian Cartographer* and the supplementary monographs *Cartographica* as its official journal. The title page of the journal notes that it is "an official journal of the International Cartographic Association/Association Cartographique internationale and the Canadian Cartographic Association/Association canadienne de cartographie."

Ownership of the journal and monograph series was transferred to the University of Toronto Press in 1980 and combined into a single quarterly serial with the common name *Cartographica*. Gutsell remained as editor until 1994, when he relinquished the position to Michael R. C. Coulson, who served until 1999 and was succeeded by Brian Klinkenberg.

During its early years (1964–67, as the *Cartographer*) the journal's content focused on map production, history of cartography, and cartographic education. While the interest in map history remained strong throughout the middle period (1968–79, as the *Canadian Cartographer*), articles on automated cartography, generalization, and geographic information systems (GIS) (e.g., Douglas and Peucker 1973; Boyle 1974) were prominent along with those on cartographic communication, symbolization, and map design.

In 1980, when the journal expanded to four issues per year (as *Cartographica*), the history of cartography was again a regular subject (Blakemore and Harley 1980), while automated cartography was equally prominent. Generalization, education, map design, symbology, projections, and cartographic communication were recurrent themes. In the late 1990s rising interest in "critical GIS" and the social aspects of cartography joined the list of frequent topics.

CLIFFORD H. WOOD

SEE ALSO: Journals, Cartographic; Societies, Cartographic: Cartographic Societies in Canada and the United States

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Cartometry. Cartometry consists of taking, analyzing, and using measurements directly from maps. Maps have long been seen as models of reality after application of scale, projection, and generalization transformations. An important assumption is that the map inherently stores the geographical and spatial properties of its mapped region. Accordingly, elements on the map can be observed and measured as a substitute for the same measurements in the real world, with the proviso that the transformations built into the map must be inverted first. These measures then become surrogates for real-world measurements that may be too costly, dangerous, or impossible to make in reality. Examples include measuring the length of a river, the area of a forest, or the directional trend of geological faults.

Map measurements are subject to the errors and tolerances used in the initial mapping and subsequent cartometry, and these are amplified by measurement error and conversion back through scale and projection. While direct map measurement remained an important part of cartography throughout the twentieth century, the digital cartographic transition after about 1960 led to the substitution of algorithms and formulas for mechanical instruments and the adoption of estimation as the preferred method for cartometric evaluation. By the end of the century, widespread use of the Global Positioning System (GPS) and remote sensing had tipped the balance back to directly measuring the earth and its properties in the field, as had been the case in nineteenth-century geodetic, land, and topographic surveying. Nevertheless, these new technologies have reinvigorated cartographic interest in cartometry—by geometry and computation rather than by measurement and estimation.

While the first use of the term *cartometry* is lost to history, there is little doubt that the term was in common use in cartography by the mid-1960s. The word appeared as "cartometric scaling" in the 1967 edition of the U.S. Defense Intelligence Agency's *A DOD Glossary of Mapping, Charting and Geodetic Terms*, which defined it as "the accurate measurement of geographic or grid coordinates on a map or chart by means of a scale" (31). Cartometry first entered the Library of Congress vocabulary of scientific terms in 1986, following its use in journal publication titles in English by 1981 (Ley 1981). Applied prior to the twentieth century to instruments (cartometers) for measuring the areas or perimeters of lakes and other features on maps, and later to software that could do the equivalent from digital files, the term was first given a succinct meaning in the International Cartographic Association's (ICA) *Multilingual Dictionary of Technical Terms in Cartography* (1973) as "measurement and calculation of numerical values from maps, together with their graphic presentation" (353). D. H. Maling used the term in the title of his book *Measurements from Maps: Principles and Methods of Cartometry* (1989), which first popularized the field. Maling echoed the ICA definition but deemphasized the graphic presentation component since it was part only of the English-language definition. Noting that methods in cartometry dated back to at least the sixteenth century, he also stressed the need to bring together cartometric methods across the mapping sciences and forestry with those sciences working on making measurements from photographs and images, in particular via microscopes and using stereo views.

Maling provided a framework for defining the scope of cartometry by noting the four measurements possible: counting occurrences, and measuring distances, directions, and areas. These measurements are closely embedded within map geometry: occurrence implies position and coordinates; distances are calculated between coordinates by the Pythagorean theorem or spherical geometry, or along vectors defined by points; and areas can be bounded by points or lines. Maling noted that these elements could be combined to build derived measures. For example, the number of occurrences within an area gives a density. Other derived measures listed by Maling include volume and slope, or gradient. Maling stressed that quantitative characterization of these measures allows objective map description, map comparison, and an analysis of map accuracy. He emphasized further that his treatment of cartometry did not assume the measurements only characterized maps; they were generic to the analysis of images, pictures, and satellite data. Maling suggested that the scope of interest in cartometry should encompass science, navigation and route finding, and administration. Scientific use lies in comparison, analysis, and hypothesis testing in cartography, photogrammetry, resource inventory, and biology. Navigational uses include route finding, dead reckoning, estimating times, and computing distance along a specific path. In administration and government, Maling pointed to many uses in planning, water resources, flood mapping, real-property assessment, and cadastral mapping. Cartometry's value in following and making tractable the modifications to the Law of the Sea, an international issue in the 1980s, was explored with an administrative case study, which included computing the Exclusive Economic Zone of proximal nations.

In spite of the almost complete conversion during the twentieth century from analog to digital cartometric methods, some mechanical methods have remained robust. Maling listed eight "classical" methods for computing distance and seventeen for area. To these he added five probabilistic methods for distance and five for point counting. Mechanical devices include: paper strips; measuring wheels; thread; grids and dots printed on acetate; the parcel, polar, polar disk, rolling disk, and Hatchet planimeters (fig. 127); cut-and-weigh; and the densitometer. Some of these devices remain in production and use in the early twenty-first century, and have been converted to high-precision digital instruments, based on the simple principles of their ancestors. Among the probabilistic methods are Buffon's needle, the longimeters of Julian Perkal and Lars Håkonson, and Matérn's method. For example, the Steinhaus longimeter, patented by mathematician Hugo Steinhaus in the 1930s (fig. 128), measures the lengths of curved lines on maps by estimation. Three transparent grids with cells of 3.82 millimeter spacing are each rotated 30 degrees, and the number of times the curve crosses a grid line provides an estimate of the length of the curve in millimeters. Subsequent research has examined analytical equivalents of these statistical methods and conducted coding of their experimental algorithms using numerical approximation (Goodchild 2008).

Two key turning points in the development of cartometry during the twentieth century were the widespread use of the tablet digitizer, which made the direct capture of data from maps accurate, simple, and cost-effective, and the use of digital imagery, first in remote sensing and then in air photos, which made large amounts of map data available in formats suitable for automated processing. In both cases, digital cartometry required algorithms for the accurate georectification and projection of the data. In tablet digitizing, paper map sheets or mylar separations were often digitized by taping the map to a sensitized tablet surface, carefully digitizing reference points with known coordinates that were separately entered into the software, and then tracing the map features layer by layer and point by point using the same software. The entire process has been described and

FIG. 127. POLAR PLANIMETER, MADE BY G. CORADI, ZURICH, CA. 1937. The circular weight to the upper right is static while the user traces the figure with the circular magnified cursor, accumulating the area on the scale on the "elbow" via a roller in contact with the surface. Length of lower arm: 22 cm. Image courtesy of Daniel Toussaint, Aulnay-sous-Bois.

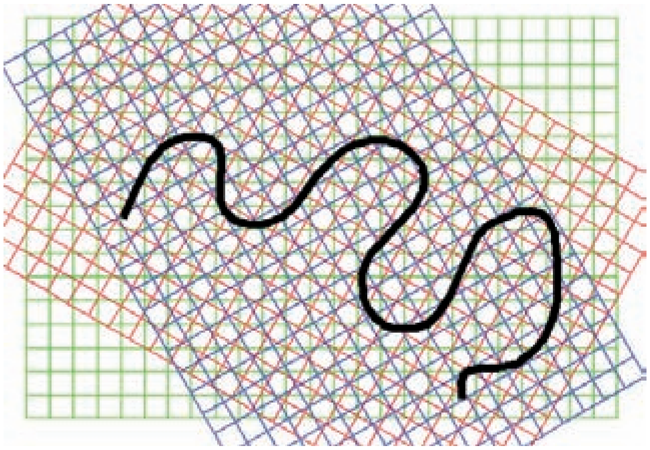

FIG. 128. PRINCIPLE OF THE STEINHAUS LONGIMETER. 3.82 millimeter cells at 0 degree, 30 degrees, and 60 degrees are overlain onto a line. The line's length is determined by the number of crossings of the line with the grid.
Image courtesy of Keith C. Clarke.

FIG. 129. AN OPISOMETER, ALSO CALLED A MEILOGRAPH OR MAP MEASURER. The instrument is used for measuring the lengths of arbitrary curved lines.
Image courtesy of Frank C. Müller.

discussed along with some of the errors to be expected when maps are captured in this way (Clarke 1995). Conversely, while data from remote sensing instruments are already in digital format, there are a host of issues relating to georectification, atmospheric correction, and projection that can have major implications for cartometry (Steinwand, Hutchinson, and Snyder 1995). Maps and images when projected must always include scale distortions that significantly affect measures of length, direction, and area. Much of cartometry assumes a flat surface and Euclidean geometry, but many methods (even the mechanical) allowed calculation on the sphere (but not on the ellipsoid or geoid). Maling (1989) discussed various issues concerning projection distortion and reviewed studies that had tested national map coverages for "deformations of the medium" attributable to map projection and properties of map paper, such as grain direction and expansion with increase in relative humidity. He also discussed the impact on basic measurements of the choice of datum and spheroid.

An examination of textbooks in cartography and photogrammetry shows that Maling's list of methods was an abridgement of a larger set in common use. John Campbell (1991, 177–92), in his text on map use, included the following as examples for direction finding: inspection and resection, the compass, astronomical observation, radar, radio direction finding, Loran (long-range navigation), and GPS. David P. Paine (1981, 84–90), in his text on air photo interpretation, included computing orientation angles from air photos. For distance measurement, Campbell used as examples scaling with paper strips, the opisometer (fig. 129), the digitizer, and the Pythagorean theorem; his examples of area measurement methods included scaling and computation, the polar planimeter, grid squares, the dot planimeter, division into strips, division into regular polygons, and digitizing (Campbell 1991, 104–14). Most texts in photogrammetry devoted space to using the dot planimeter (e.g., Lo 1976, 124–25), and gave more extensive coverage of distortions due to the operation of the aircraft and nature of the imagery. Paine (1981, 92–93) included weight apportionment, similar to dasymetric mapping. Few texts devoted much space to measures of accuracy other than the root-mean-square measure and issues of the National Map Accuracy Standards (Thompson 1988, 102–7).

Applications of cartometry reflect Maling's sense that combinations of measures of occurrence, direction, distance, and area can produce statistics that are both descriptive and analytical. Campbell (1991, 191–97) gave examples of direction measurement in dead reckoning and flight planning. He also provided many examples of the use of derived measures in geographic study. Distributions (repeat occurrences) can be examined by quadrat analysis, the variance-mean ratio, and the nearest neighbor statistic, while the correspondence of distributions, termed "map comparison" by geostatistician John C. Davis (1973, 390–407), is illustrated using quadrat analysis, overlay computation, chi-squared, and Yule's *Q*. Networks are analyzed by associated number, diameter, connectivity index, and symmetry. Branching networks are discussed with Strahler order and the bifurcation ratio. Photogrammetric scientist C. P. Lo (1976, 87–92) added to the network values the computation of drainage density (length of streams divided by area) and to the directional measures the azimuth-frequency (and radial plot). Campbell (1991, 115–20) considered shape separately and provided examples for the shapes of polygonal features using the Miller, Bunge, and Boyce-Clark methods.

Later treatments of cartometry rarely use the term, referring more generally to spatial or geographical measurement (e.g., Longley and Batty 1996) as a prerequisite to spatial analysis. Measurement was seen as necessary for transformation, description, optimization, and hypothesis testing, and no distinction was made between exact and approximate methods. Some new measures were introduced, such as mean distance from a centroid (dispersal), the weights matrix for similarity of distributions, *K*(*d*) or the expected number of points in a distribution at distance *d* (clustering), and Moran's *I* for spatial autocorrelation.

A later addition to the cartometric measurements in common use was the fractal, fractional, or Hausdorff–Besicovitch dimension (*D*). This single value can be computed for lines or areas, and for surfaces. Nina Siu Ngan Lam and Lee De Cola (1993, 23–40) gave four methods for computing *D*, one of which, the walking-divider method, has clear origins in cartometry and the earlier work of the mathematician Lewis Fry Richardson (1961). Other methods were the area-perimeter ratio, equispaced polygon method, and cell counting. Using fractal measurement on city outlines, mountains, and many other natural features became common and led to important theoretical and empirical advances.

Cartometry also proved useful in analyzing patterns of distortion on historical maps. M. J. Blakemore and J. B. Harley (1980) reviewed the use and potential of cartometry in historical cartography and archaeology. Subsequently, many studies have appeared (and continued into the twenty-first century) that compare the location or configuration of features on ancient maps with their current-day counterparts (e.g., Kelley 1995). In 2007 the Institut für Kartografie at Eidgenössische Technische Hochschule (ETH) Zürich released MapAnalyst, a free software package for the visual analysis of distortion on old maps (Jenny, Weber, and Hurni 2007). The rediscovery of cartometric analysis through historical cartography was at last exploiting what Maling had called a "neglected discipline" (Maling 1977).

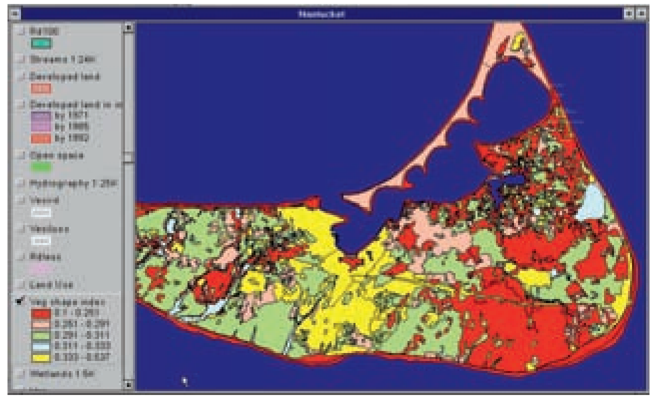

FIG. 130. COMPUTER SCREENSHOT SHOWING FRAGSTATS DATA. This ArcView screen display shows vegetation data computed by the FRAGSTATS spatial landscape metrics program.
Image courtesy of Keith C. Clarke.

During the late twentieth century, cartometry also flourished in ecology, particularly in the subfield of landscape metrics. Landscape metrics came about as air photos, remote sensing, and GIS expedited the mapping of plant and animal communities. A key to the rise of landscape metrics was the availability of the computer program FRAGSTATS. This software program was designed to compute a wide variety of landscape metrics for categorical map patterns (fig. 130). The original software was released in the public domain during 1995 in association with the publication of a U.S. Department of Agriculture's Forest Service General Technical Report (McGarigal and Marks 1995). This software derived statistics for individual polygonal areas on a map, for single categories, or for whole maps, using the term *patch* for polygon. Able to compute an extraordinary number of statistics, the program has been used to study habitat fragmentation, biodiversity, the impact of humans on environments, plant succession, and many other spatial processes. It has been used in geography and planning, especially for studies of land use.

Although Maling's vision of cartometry as excluding visual displays of derived statistics and relating purely to media-based renderings of maps might have seemed highly dated at the beginning of the twenty-first century, several factors contradict this assessment. First, instruments for cartometry have survived—some might say prospered—into yet another century and remained in demand. These instruments, while based on those developed in the nineteenth and twentieth centuries, added new digital equivalents to reach unprecedented levels of accuracy. Second, while the computer and digital cartography moved cartometry toward analytical and precise solutions, interest in statistical cartography or probabilistic cartometry also remained strong. Indeed, these methods found new life in numerical methods and approximation and became natural starting points in the late twentieth century for advanced research in cartographic uncertainty. Third, new software placed cartometric tools in the hands of anyone interested in maps, freeing them from the tedium of direct measurement and achieving much of the interdisciplinarity called for in Maling's landmark book. And finally, the emerging field of visual analytics, which applies intensive computing to the visual aspects of maps and images, promises to keep the methods of cartometry alive and well throughout the coming decades.

KEITH C. CLARKE

SEE ALSO: Accuracy in Mapping; Analytical Cartography; Electronic Cartography: Electronic Map Generalization; Maling, D(erek) H(ylton)

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Cartoons, Maps as Political. See Political Cartoons, Maps as

Cave Map. A cave map is a cartographic representation of a natural subsurface cavity. Cave maps commonly are drawn in plan view with generalized walls shown as solid lines. Internal features, such as floor slopes, ceiling geometry, water, and speleothems, are represented by a variety of specialized symbols standardized by the Union of Internationale de Spéléologie (UIS) in 1999 (Häuselmann 2002) (fig. 131). Despite their three-dimensional nature, until the last part of the twentieth century, cave

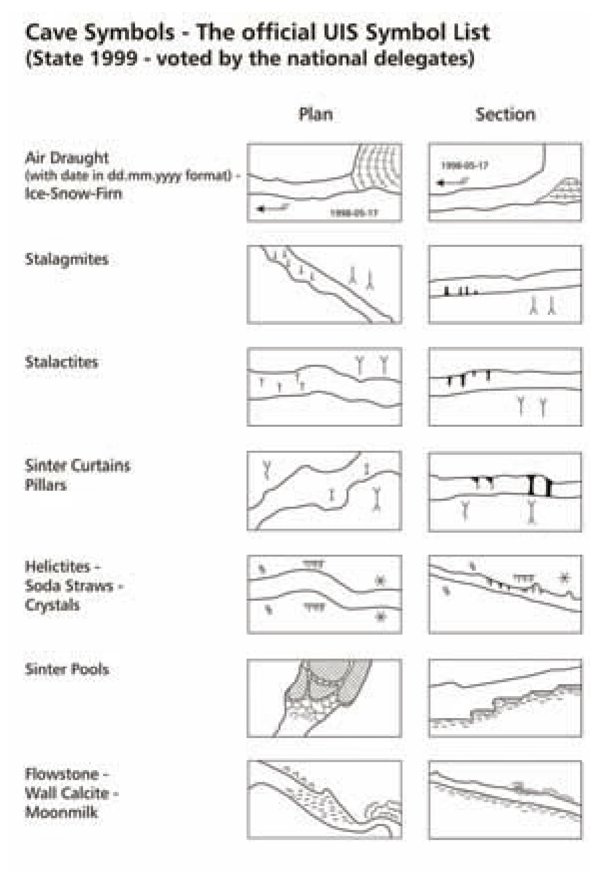

FIG. 131. STANDARD CAVE SYMBOLS, 1999. Examples of cave symbols for underground mapping that were voted on and accepted by national delegates of the UIS.
From *Cave Symbols: The Official UIS List*, 1999, online publication, 4.

maps seldom included a fully developed, corresponding profile view. Instead, the maps usually possessed a series of passage cross-section drawings of wall and ceiling geometry. These cross-sections provide a more immediate navigational aid for in-cave use than an entire cave profile. Many caves have passageways that cluster around a finite number of elevations. Cartographic methods to address these multilevel caves include introducing a lateral offset and offering separate plans for each level, marking levels with different colors, and using symbols such as hatch lines to represent underlying, nonintersecting cave passages.

Because caves are hidden from view, direct field survey remains the only reliable method for mapping them. Cave exploration and mapping have been closely coupled since the 1800s (Shaw 1992); to map a cave, it must be explored, and vice versa. Before World War II, cave mapping was typically undertaken by engineers for property and natural resource assessment. During the 1800s and early 1900s, particularly in the United States, caves were assessed for minerals and chemicals like nitrates used in fertilizers and explosives (Wookey 2004, 715). Worldwide exploration by scientists and amateurs began in the late 1940s. At the same time, governments began shifting from mineral assessment to studies on cave water supplies.

The technique for cave mapping appears to have remained relatively unchanged since the end of the eighteenth century (Wookey 2004, 715). The first detailed description of modern cave survey technique was written by E.-A. Martel (1894, 24–28) in France. The core of a cave map is the measurement of a survey line along the length of a cave's passageways. The survey starts at the cave entrance, where a first survey station is set. The mapping team proceeds into the cave and sets another survey station as far away as possible while maintaining line of sight with the original station. The party measures azimuth, distance, and inclination from the first station to the second. The data are recorded in a notebook with written or symbolized observations about the walls, ceiling, floor, and other features. Then the surveyors set a third station farther down the passageway within line of sight to the second station. The team measures and collects data for those stations and continues the process until the entire cave is mapped.

The construction of a final cartographic product occurs by plotting the assemblage of stations on paper or a computer screen. The process is conducted either graphically using azimuths and scaled distances to position the stations or using trigonometry to obtain coordinates. Before computers and calculators aided in deriving and drawing coordinates, many cave surveys either ignored inclination or endeavored to create in-cave surveys with inclinations of either 0 or 90 degrees. Computers also permitted the use of error detection and correction algorithms. Once the survey stations are plotted, walls and other features are drawn manually. Starting in the 1990s, graphics software allowed cave maps to be produced entirely in digital form. A key incentive for fully digital cave maps is the integration of data into a geographic information system. Although cave map data can be imported into mainstream spatial analysis software, visualizing, relating, and analyzing caves' spatial data in a larger environmental context remains an ongoing research issue in hydrogeology and geographic information science.

For the first half of the century, the Brunton Pocket Transit compass (a handheld compass and clinometer) was the primary device for cave surveying. Beginning in the 1960s, the aluminum-shelled Suunto sight compass and clinometer became standard. Similarly, fiberglass tapes replaced the metal tapes and chains used earlier in the century. For entirely underwater caves, standard cave survey techniques are modified to include the dive computer for elevation data and a wrist- or slate-mounted compass for azimuths (Wookey 2004, 716–17). End-of-century technologies that have changed the nature of cave mapping include semiautomated data-logging compass/clinometer/range finders and scanning laser arrays for producing cave geometry point clouds (Sluka 1999). Experimental work also has been underway to detect and map caves from above ground. Geophysical techniques, including electrical resistivity, ground penetrating radar, and microgravity, have offered some success in detecting caves from the surface, but generally only for near-surface or large voids.

J. ALAN GLENNON

SEE ALSO: Geologic Map; Navigation; Terrain Analysis and Cartography; Wayfinding and Travel Maps: Mobility Maps

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Celestial Map. See Astrophysics and Cartography; Lunar and Planetary Mapping; Star Chart

Census Mapping. As an official enterprise focused on counting people, cattle, manufacturing plants, and other entities relevant to governmental administration, a census agency uses maps in three principal ways. Before an

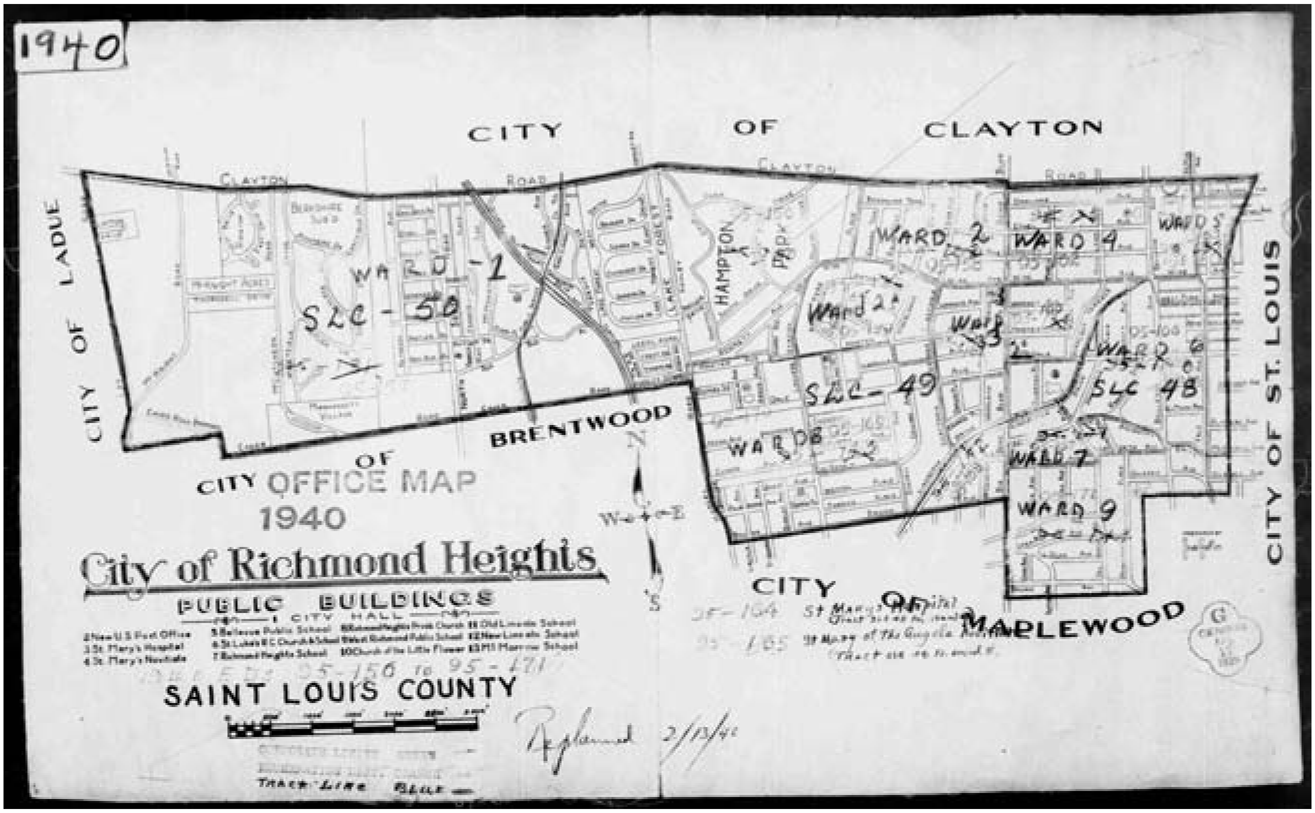

FIG. 132. 1940 U.S. CENSUS ENUMERATION MAP, RICHMOND HEIGHTS, ST. LOUIS COUNTY, MISSOURI. This is a copy from microfilm, the original has been destroyed (common practice after the completion of the census and the microfilming). Below the map scale are references to the color used in the marking of boundaries on the original: corporate limits green; enumeration district orange; trace line blue.
Image courtesy of archives.com and the U.S. National Archives, Washington, D.C.

enumeration can be undertaken, the agency uses large-scale maps to identify households, farms, and firms that a census taker needs to visit or to which a questionnaire might be mailed (fig. 132). Once the raw data have been gathered, the agency uses geographic information—electronic, analog, or both—to aggregate the data into counts for geographic units useful to planners and other administrators as well as to social scientists and marketing firms. These geographic units are typically part of a hierarchy within which counts for small areas like neighborhoods or city blocks can be aggregated for cities, counties, provinces, regions, and the entire country. In the final phase, a census agency publishes these counts in specialized tables and portrays some of its aggregated data on small-scale maps that are disseminated to other governmental units and the public. Small-scale census maps have been distributed in various ways: as appendices or supplements to tabular census reports; as parts of national, thematic, and school atlases; as illustrations for press releases, news articles, and scholarly publications; and in the final decades of the twentieth century, on the census agency's website.

Census maps produced in 2000 were little different in appearance or concept from those created a hundred years earlier. Most apparent is the sustained prominence of choropleth maps, the surficial similarity of which obscures a broad range of technological developments, including overhead imaging and photogrammetry, which increased the timeliness and geometric reliability of large-scale topographic maps used in precensus planning, and photographic image-transfer methods, which lowered the cost of adding color to postcensus cartographic summaries. But no single development was as important as electronic computing, which by the end of the century pervaded all phases of conducting a census and disseminating its results. This extensiveness began with electronic maps of individual residences that yield the electronic address lists used in printing and mailing self-administered questionnaires, followed by the automated scanning of returned questionnaires, the "first count"

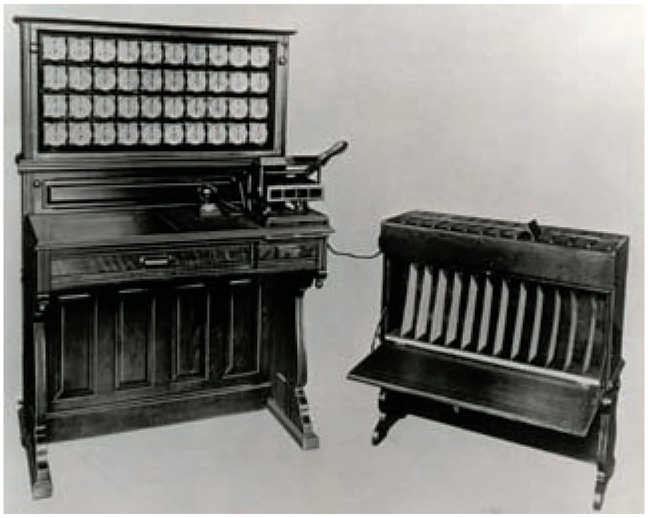

FIG. 133. HOLLERITH TABULATOR (LEFT) AND SORTER (RIGHT). This machine was used by the U.S. Census Bureau for the 1900 population census. A punch card representing a household's characteristics was placed in the card-reading station on the right-front of the tabulator, and when the handle was pulled down, the information encoded by the punched holes was registered on the appropriate counters and an electrical signal to sorting box opened the appropriate compartment so that the operator could put the card in the appropriate bin. Image courtesy of the U.S. Census Bureau, Public Information Office (PIO).

tabulation that supports legislative reapportionment and political redistricting, subsequent summary counts that inform demographic analysis in both government and the private sector, and the automated generation of maps that are printed and posted electronically.

Electronic processing of census data evolved from punch cards on which punch positions arranged in rows and columns afforded the numerical coding of information about households and their residents. The Hollerith card was the invention of Herman Hollerith, who in the 1880s also devised a machine (fig. 133) for punching the cards and a tabulating machine for counting the number of cards with selected characteristics (Truesdell 1965). Although electromagnets were used to read the punches, the early tabulating machines were essentially mechanical. The U.S. Census Bureau, which used Hollerith's system to expedite and improve the accuracy of tabulations for its 1890 censuses of population and agriculture, fostered several enhancements. Although Hollerith was a poor salesman, his design took hold, and shortly after the turn of the century census agencies in several European countries were using similar tabulating machines (Heide 2008). His firm became the seed for IBM (International Business Machines) Corporation, and punch cards became known as IBM cards.

Electronic computing based on magnetically stored information had its roots in the ENIAC (Electronic Numerical Integrator and Computer), a massive machine with vacuum tubes and hand-soldered connections developed in the United States by the War Department in the 1940s. Faster computers led to the emergence of a civilian market, and the Census Bureau quickly became a prime customer. A UNIVAC I (Universal Automatic Computer) acquired in 1951 was used to process part of the 1950 population census and all of the 1954 censuses of agriculture and manufactures, and a more powerful UNIVAC configuration was acquired for the 1960 population census. Digital technology diffused quickly to European countries, including Norway and Sweden, where population registers provide continuous socioeconomic information. Generally the U.S. Census Bureau was somewhat ahead of its British counterpart, which converted from manual to digital data encoding in the 1960s, from manual to digital geography encoding in the 1980s, and from manual to digital "geography design" in the 2000s (Martin 1998, 674–76).

Digital geography was based on Dual Independent Map Encoding (DIME), a topological data structure that treats a small areal unit like a city block as a polygon surrounded by a chain of straight lines (street segments usually) joined at nodes (usually street intersections). Each polygon is assigned a unique number, as are the lines and nodes. In addition, each of the polygon's lines (sides) is assigned a particular direction, usually the direction in which house numbers increase, and any line lacking house numbers is arbitrarily assigned the direction from an arbitrarily chosen "low node" to the "high node" at the far end. Each line can then be represented by a DIME record, which relates the low and high nodes to the polygons on the left and right (see fig. 227). The term *dual* reflects a topological notion whereby a line "bounded" by its low and high nodes is also "cobounded" by its left and right polygons. This relationship is important because a computer algorithm can check the consistency of a DIME file, thereby making certain that, among other things, each polygon is surrounded by a unique sequence of lines and nodes. The DIME framework was devised in the late 1960s by James P. Corbett, a mathematician working at the Census Bureau (Cooke 1998).

Plans for the 1970 U.S. census integrated the DIME concept with an address coding guide (ACG), which lists several pieces of information for each street segment, namely, the street name, the street type (e.g., avenue, drive, street, road), the low and high house numbers on each side of the street, and the numbers of the small areal units (census blocks and census tracts) on each side of the street. Because ACGs had been used for the previous census to relate individual house numbers to a specific block and tract, an ACG file could be converted to an ACG/DIME file by assigning unique node, line, and polygon numbers. When the database includes geographic coordinates for the nodes, cartographic software can draw the street network, plot the boundaries of census tracts, shade the interiors of blocks or tracts with a particular characteristic (for instance, areas in which most median household income is below a given threshold), and even estimate geographic coordinates for households that did not return the census questionnaire—although nondisclosure rules preclude publishing maps showing individual households, these plots could help local field personnel plan a recanvass.

For its 1990 enumeration the Census Bureau developed an upgraded version named TIGER (Topologically Integrated Geographic Encoding and Referencing), which allowed more detailed representations of winding streets and curved boundaries between polygons (Marx 1990). The ACG/DIME system used for the previous census had treated curved features relatively clumsily by adding additional nodes so that what had been a single straight line was now represented by a several straight-line segments. By contrast, features in TIGER were comparable in geographic detail to features on 1:100,000-scale topographic maps, which the U.S. Geological Survey (USGS) had been producing in a digital format. Partnerships with USGS and the U.S. Postal Service yielded a TIGER database with updated road names, postal codes, and other information useful not only for conducting a census and mapping its results but also for finding and following minimum-distance routes between points. Census mapping thus played an important role in the late 1990s in the development of online mapping services like MapQuest and early in the next century in the proliferation of commercial GPS navigation systems for motorists and delivery services (Cooke 1998).

Electronic cartography also fostered the automated or interactive design of new geographies based on census data. The most conspicuous of these new geographies emerged in the United States after the 1990 census when political cartographers crafted state-level redistricting plans designed to promote the election of nonwhite candidates as well as enhance the strength of the majority party. In states with a history of unconstitutional racial discrimination, the Department of Justice pressured redistricting officials to create districts in which a supermajority of African-American or Hispanic voters could elect one of their own with comparative ease. The result was a spate of noncompact districts with bizarre shapes denounced in the media with names like "pair of earmuffs" (Monmonier 2001, 49–73). This kind of fine-tuned racial gerrymandering would have been difficult (if not impossible) without the block-level census tabulations intended to help states address a Supreme Court mandate to minimize differences in population size among congressional districts. Redistricting software designed to maximize automatically the dominant party's electoral strength quickly added geometric indexes useful for avoiding controversial shapes.

Other designed geographies served a wider range of users by eliminating disparities in area among conventional geographic units like counties and provinces. In 1960, for instance, Sweden addressed the problem of area disparity with a population map based on square-kilometer grid cells aligned to the national coordinate system established in 1938 and readily related to existing topographic and economic maps (Claeson 1963). Compiled from the official population register, the map showed population distribution on 1 November 1960, the official date of Sweden's 1960 census (fig. 134). Britain aggregated data from its 1971 census to one- and ten-square-kilometer grid cells, which provided a convenient base for point-symbol maps, surface maps, and flow maps as well as for more conventional choropleth maps (Rhind 1983). Although grid cells were uniform in size, they were not readily related to the viewer's existing mental map of places and regions. This difficulty was partly addressed in the 1990s, when efficient methods for constructing area cartograms afforded customized solutions to the MAUP (modifiable areal unit problem) (Dorling 1993).

New geographies designed to accommodate advertisers and marketing firms led to tabulations of census data by postal code. These tabulations address inherent differences between block data, which represent the interior of a block, and postal codes, which reflect the routes of letter carriers. An example is the summary statistics tabulated by nine-digit ZIP code for the 2000 U.S. census. Because existing cartographic data could not support reliable mapping of these tabulations, the Census Bureau created new geographic databases for ZCTAs (ZIP Code Tabulation Areas). By the end of the century experimenters not content with existing geographies were using census data to automatically define socially homogeneous "output areas" for planners and social scientists (Martin 1998, 678–82).

Census agencies have occasionally taken the lead in developing innovative designs and mapping techniques. Prominent additions to the innovations already mentioned include use of a high-resolution imagewriter to produce color separations for two-variable "cross-maps" (Meyer, Broome, and Schweitzer 1975) and a land use filter to control the automatic placement of dots on statistical maps. The U.S. Census Bureau has used cross-

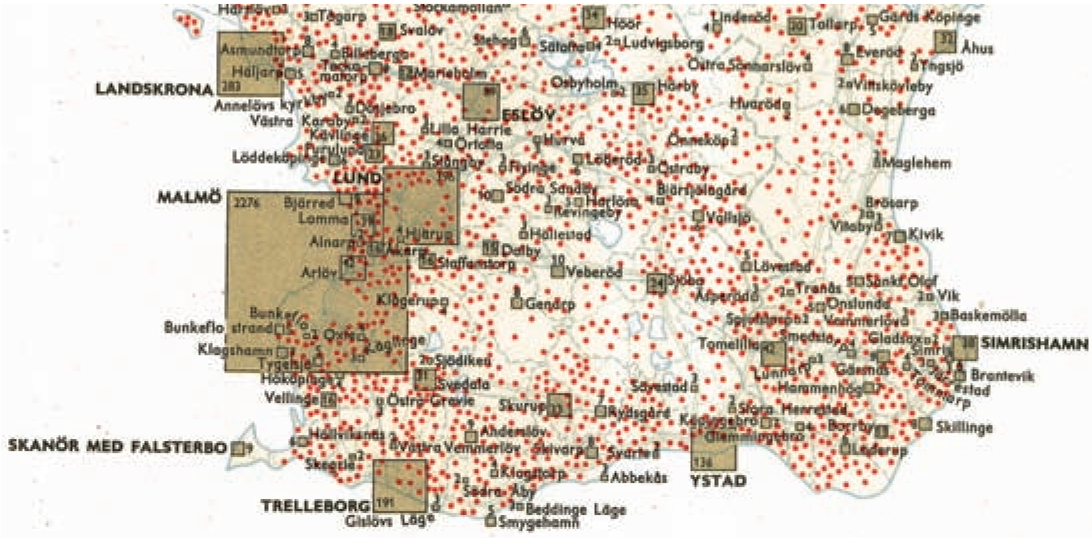

FIG. 134. DETAIL FROM THE *BEFOLKNINGENS FÖRDELNING 1960 I SVERIGE = DISTRIBUTION OF POPULATION IN SWEDEN 1960*, 1:1,000,000, 1964. Each dot represents 100 rural inhabitants. The squares represent urban population; the numbers inside each box indicate the urban population in hundreds. The map was prepared in two sheets by Olof W. Hedbom, G. Norling, and E. Pålsson; this detail is from the southern sheet.
Size of each sheet: 83 × 69 cm; size of detail: 7.2 × 14.5 cm.
Image courtesy of the Earth Sciences and Map Library, University of California, Berkeley.

maps to enhance a variety of publications, most notably the urban atlases produced from the 1970 enumeration for the sixty-five largest Standard Metropolitan Statistical Areas (SMSAs). And starting with the 1969 Census of Agriculture, the bureau has enriched its quinquennial Graphic Summary with numerous computer-generated dot maps for specific crops, livestock, and farming operations. These maps had been produced manually for earlier agricultural censuses, but detailed electronic data and display hardware already in place allowed a dot-placement algorithm to save time and money.

Census agencies in developing nations benefited greatly from technology transfer orchestrated by the United Nations (UN) and the International Geographical Union (IGU). The UN vigorously promoted technology transfer through regional seminars on sampling methods and statistical analysis and, in cooperation with the IGU, fostered the adoption of modern census methodology in many developing nations. The *Census Mapping Survey* published in 1984 for the IGU Commission on Population Geography is particularly useful to map historians and other scholars because it includes state-of-practice reports for twenty-one nations, mostly in Africa, Asia, and Europe (Nag 1984). In the early 1960s, when the commission issued recommendations for map scale and symbols, its members were still debating the relative merits of dots and spheres for representing numbers of persons on small-scale maps (William-Olsson 1963). In addition, the International Cartographic Association (ICA), founded in 1959, has occasionally established a working group or commission focused on census cartography.

MARK MONMONIER, WITH ADDITIONAL INFORMATION PROVIDED BY ROBERT W. MARX

SEE ALSO: Administrative Cartography; Demographic Map; Electoral Map; Statistical Map; Urban Mapping

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Central Intelligence Agency (U.S.). See U.S. Intelligence Community, Mapping by the

Central Research Institute of Geodesy, Air Survey, and Cartography (Russia). See Tsentral'nyy nauchno-issledovatel'skiy institut geodezii, aeros"yëmki i kartografii

Centrography. In geography, centrography refers to the methods of descriptive statistics that allow the determination and mapping of measurements of central tendency in spatial distributions, including points, lines, and surfaces, whether or not weighted by an additional variable. Its essential goal is to locate the center (center of gravity, the median center, or any other type of center) of a distribution of geographic objects of the same nature (e.g., cities or villages in a given region; nodes within networks, cultivated surfaces, or clearly identified populations; landmasses). The notion of center can also be extended to variables that are attributes of these objects. Applications would include finding, for example, the central location of a particular type of agricultural production, the center of a given region's wealth, or the most accessible node in a communication network. Moreover, maps showing the movement of these centers over time can provide concise, highly generalized descriptions of long-term trends.

The first graphic application of centrography appeared in the nineteenth century in a map by the French engineer Charles Joseph Minard (1865), who established the center of gravity for the Parisian population. Several plates of the *Statistical Atlas of the United States* (1874), published as a supplement to the 1870 U.S. census, applied a suggestion by J. E. Hilgard (1872) for describing the westward shift of the center of the American population between 1790 and 1870 at ten-year intervals. Before World War I, several physicists attempted to determine the "center of the continental hemisphere" using experimental methods based on direct calculation from a terrestrial globe and a world map cast on an equidistant projection. In 1898 the German Hermann Beythien placed this center near the Atlantic coast of France. In 1913 Alphonse Berget located it more precisely on the isle of Dumet, to the north of the mouth of the Loire.

Centrography flourished between the two world wars with the work of a group of geographers in Leningrad led by E. E. Sviatlovsky. This school defined and graphically represented a great variety of centers, including static or dynamic centers. It collaborated with Soviet officials for planning and statistics, and its work resonated strongly with core members of the International Geographical Union. Nevertheless, Sviatlovsky's laboratory was suppressed by the Soviet government in 1934.

Centrography experienced a resurgence starting in the 1950s during academic geography's quantitative revolution, which eventually led to the field of spatial statistics. Several geographers took up the idea of producing in two dimensions what statisticians had accomplished in one (Hart 1954). The two-dimensional center provided a useful descriptive (rather than predictive) statistic for summarizing complex spatial distributions. Calculations assumed a data set of point coordinates (x, y), each associated with a weight or "mass" such as population, aggregate wealth, or the amount of production. The mean center (also called the barycenter, centroid, or center of mass) can thus be calculated by multiplying each coordinate value by its associated weight, summing these weighted values separately for each coordinate, and dividing each by the sum of the weights. The median center, first presented as the point dividing the distribution of weighted points into quadrants separated by two perpendicular axes and equal in total weight, was later defined in a more rigorous fashion as the location that minimizes the sum of the distances to all points, earning it the name "center of convergence" or "minimum aggregate travel point" (Porter 1963) (fig. 135).

All these notions appeared rather early, but it took geographers awhile to rediscover methods for their correct determination, which had in some cases been perfected by mathematicians as early as the seventeenth century (Porter 1963, 229n16). Although almost all centrographic studies treated the points as lying on a flat plane, distance calculations based on a spherical surface afford a more accurate treatment of large territories such as Canada (Kumler and Goodchild 1992). Finding the geographic center of the world's landmasses raises the greatest difficulties in calculation (Affholder 1991). The precision depends not only on underlying scale or resolution of the data but also upon the nature of the cartographic representation employed, the effect of which becomes perceptible because of the curvature of the earth (fig. 136).

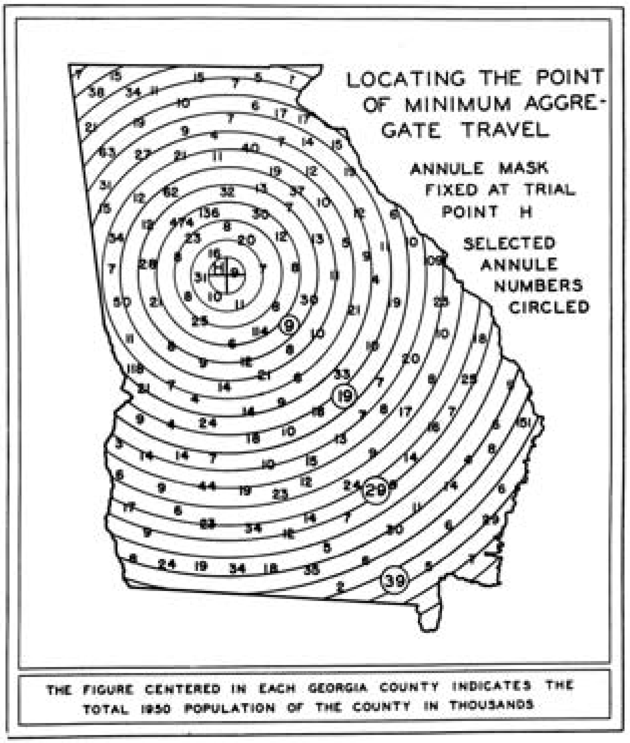

FIG. 135. POINT OF MINIMUM AGGREGATE TRAVEL, BASED ON 1950 POPULATION DATA OF GEORGIA.
Size of the original: 15.1 × 12.8 cm. From Hart 1954, 57 (fig. 4). Copyright © 1954 Clark University, Worcester.

Indicators of dispersion supplemented centrographic cartography. Roberto Bachi (1957), who considered a single numerical indicator useful for describing the overall dispersion of weighted points around their center, introduced a standard distance similar in principle to the standard deviation used in one-dimensional statistics but based on each point's mass as well as its squared distance from the center. Proportional point symbols sized to represent standard distance were proposed as an informative enhancement of maps depicting multiple centers. A similar but more revealing indicator was the dispersion ellipse, the major axis of which represented the direction of greatest dispersion. On a map depicting multiple distributions or a single phenomenon for different times, dispersion ellipses varying in size, elongation, and orientation afforded a concise comparison of differences or trends in overall dispersion and directional bias.

The visual effectiveness of these maps relies on the notion of the central point as a meaningful representation of a broader spatial distribution. For spatial-temporal phenomena like migration and diffusion, a historical sequence of representative centers provided straightforward, more or less intuitive generalizations at geographic scales between those of the whole world and the local community. In addition, this notion of meaningful centers is related to the principle of distance decay, whereby the attractiveness of a central location generally declines with increased distance from the center. Gravity and potential models, which rely on distance decay to characterize the cumulative effects of concentrations of population or wealth around multiple centers, helped researchers construct maps of surfaces showing spatial variation in attractiveness and accessibility. Distance decay is also apparent in Johann Heinrich von Thünen's theory of land rent, developed in the early nineteenth century; Walter Christaller's theory of central places, from the 1930s; various generalized surfaces describing population density around cities, from the 1920s onward; and gravity models of migration, principally in the 1960s and 1970s.

Centrography has been used in a variety of ways. The calculation of a center can suggest a dominant or privileged position, which can have social significance of local importance. Even in one of the most anodyne of cases, that of the simple determination of a geometric center, the locale designated as the center of a country, a region of the world, or the whole world often exploits this position to promote tourism, recalling the myth of the center or navel of the world illustrated, for example,

FIG. 136. CENTER OF THE LAND HEMISPHERE ON THE LORGNA PROJECTION. The determination made by Berget (1913) is shown in yellow; that of the Institut géographique national de France (1989) in red.
Diameter of the original: ca. 15 cm. From Jean-Georges Affholder, "Une nouvelle détermination du pôle des terres émergées," *Le Monde des Cartes* 173–74 (2002): 43–58, esp. 51 (fig. 1).

by the city of Delphi in ancient Greece. Several communities that considered themselves the center of France or of Europe have constructed monuments that proclaim their centrality.

Although the map is not an essential element of centrography, graphic depiction adds an expressive and often spectacular dimension to the numerical results. This effect is particularly apparent when the simultaneous representation of several centers highlights relationships among the distributions of different variables, or when the displacement of a phenomenon's center of gravity is depicted over time. In this way V. P. (Benjamin) Semënov-Tyan-Shanskiy portrayed the territorial development of the Soviet Union with the movement of the center of population from 1500 to 1926 (fig. 137). Later work by Sviatlovsky and his American collaborator Walter Crosby Eells (1937) described the shift toward the south and the east of economic activity in the Soviet Union between 1858 and 1932.

Despite the comparative rarity of centrographic maps at the end of the twentieth century, centrography had gained acceptance in criminology as a numerical technique for analyzing mobility triangles relating the location of a crime to the addresses of the victim and the offender. Dispersion ellipses and other techniques of centrographic cartography, while too complicated for general audiences, served crime analysts as an exploratory tool for generating hypotheses about major crimes like serial rape (LeBeau 1987).

GILLES PALSKY AND DENISE PUMAIN

SEE ALSO: Raisz, Erwin (Josephus); Statistical Map; Statistics and Cartography

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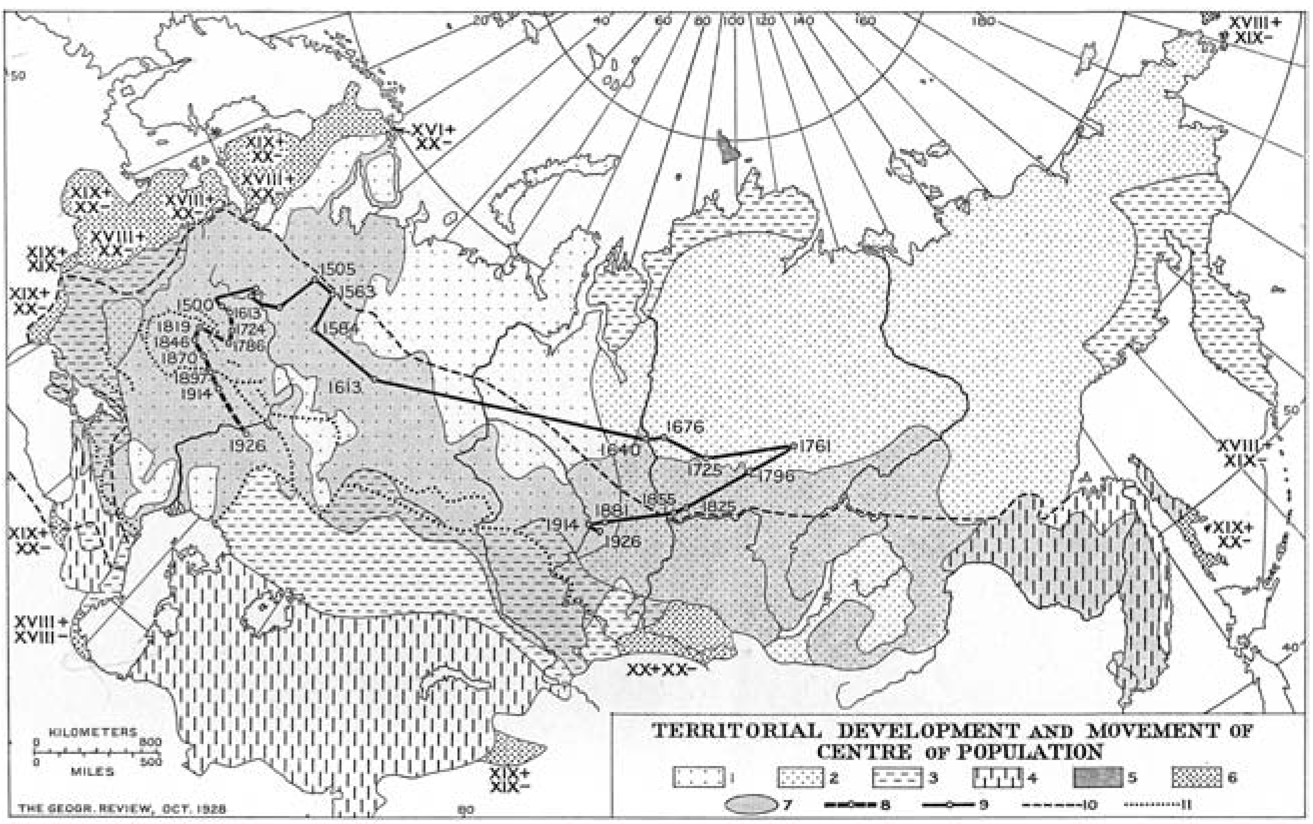

FIG. 3—Historical development, compiled by B. Semenov-Tian-Shansky. Territory acquired by Russia in: 1, sixteenth century; 2, seventeenth century; 3, eighteenth century; 4, nineteenth century; 5, twentieth century; 6, lost territories; 7, over 50 per cent Slavs in the population (twentieth century); 8, movement of center of territory from 1500 to 1926; 9, movement of center of population; 10, northern and western boundaries of the Mongolian-Tatar dominion of about 1300; 11, defensive lines against nomads and Caucasian mountaineers in sixteenth to eighteenth century.

FIG. 137. *TERRITORIAL DEVELOPMENT AND MOVEMENT OF CENTRE OF POPULATION*, 1928.
Size of the original: 11.5 × 18.7 cm. From V. P. (Benjamin) Semënov-Tyan-Shanskiy, "Russia: Territory and Population, A Perspective on the 1926 Census," *Geographical Review* 18 (1928): 616–40, esp. 622 (fig. 3). Permission courtesy of the American Geographical Society, New York.

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CERCO (International). See Comité Européen des Responsables de la Cartographie Officielle (European Committee of Representatives for Official Mapping; International)

Chen Shupeng **陈述彭.** Chen Shupeng, Chinese cartographer, and an academician of the Zhongguo kexueyuan 中国科学院 (Chinese Academy of Sciences; CAS) was born in February 1920 in Pingxiang, Jiangxi Province, China. He graduated from the Shi di xue xi 史地学系 (Department of History and Geography) at Zhejiang daxue 浙江大学 (Zhejiang University) in 1941 and served as an assistant and then lecturer of cartography at Zhejiang University, focusing on land use survey and mapping and topographic analysis. In 1957, he published *Zhongguo dixing niaokan tuji* 中国地形鸟瞰图集 (Bird's-eye view atlas of topography in China). He was honored with the O. M. Miller Cartographic Medal, awarded by the American Geographical Society, in 1998.

In his six-volume work, *Dixue de tansuo* 地学的探索 (Exploration in geoscience), he plotted many field sketches and block diagrams. In the compilation of the *1:400 wan zhongguo dishitu* 1:400万中国地势图 (1:4,000,000 scale relief map of China) (1958), he introduced zoning criteria utilizing drainage density, layer tints, and contour line reconstruction based on geotectonic features to enhance the visualization of the regional characteristics of the relief map of China. In the 1950s, he became a member of the Guojia da dituji bianzuan weiyuanhui 国家大地图集编纂委员会 (Compilation committee of the national atlas) and served as its academic secretary. Later, as the deputy director of its editorial department, he was responsible for the compilation of the general design specifications and the editing and publication of the physical atlas. *Zhonghua renmin gonghe guo ziran ditu ji* 中华人民共和国自然地图集 (Physical atlas of People's Republic of China) [1965], which introduced more than twenty kinds of new thematic maps and modernized eight key methods relating to map compilation and printing, set a high standard for national and regional atlas compilation in China. This work won the Guojia keji jinbu jiang 国家科技进步奖 (National significant science and technology achievement prize) in 1977.

In the early 1960s, Chen organized several mapping experiments that resulted in a large-scale thematic map series of Hainan Island based on aerial photos. In the mid-1970s, he initiated Landsat image applications and published the *1:400 wan he 1:250 wan zhongguo weixing yingxiang tuji* 1:400万和1:250万中国卫星影像图集 (1:4,000,000 and 1:2,500,000 scale satellite image atlas of China), and edited *Ludi weixing yingxiang zhongguo dixue fenxi tuji* 陆地卫星影像中国地学分析图集 (Atlas of geoscience analyses of Landsat in China). Also during this period, he coauthored the textbook *Yao gan di xue fen xi* 遥感地学分析 (Geoanalysis with remote sensing), and gave lectures at Beijing daxue 北京大学 (Beijing University) and the Zhongguo wenhua daxue 中国文化大学 (Chinese Culture University). He helped Nanjing daxue 南京大学 (Nanjing University) to establish a cartographic major and organized the research and development of mapping equipment in the CAS, exploring the new fields of remote sensing and computer-assisted mapping.

He successfully organized several remote sensing application experiments on resources, energy, and the urban environment and published the *Tengchong hangkong yaogan shiyan tuji* 航空遥感图集 (腾冲试验区) (Atlas of airborne remote sensing [in the Tengchong study area]) (1985) and *Tianjin shi huanjing zhiliang tuji* 天津市环境质量图集 (Atlas of environmental quality of Tianjin City) (1986). He won the Chen Jiageng diqiu kexue jiang 陈嘉庚地球科学奖 (Tan Kah Kee award in earth sciences) in 1999. Two publications, *Taihu dongxi dongtingshan jingguan tuji* 太湖东西洞庭山景观图集 (Atlas of Taihu Lake landscape) and *Guilin qixingyan kasite dongxue dimao tu* 桂林七星岩喀斯特洞穴地貌图 (Graphic illustration of Qixingyan cave system, Guilin), have been translated into Russian and German and won the Contribution Prize from the International Karst Society in 2001. Also in 2001, he was honored with the Mannerfelt Medal, the highest award given by the International Cartographic Association (ICA).

At the end of the 1990s, he advocated the concept of *diqiu xinxi kexue* 地球信息科学 (geoinformation science), committing himself to the use of *wangge ditu* 网格地图 (grid mapping) and research on the cartographic methodology called *dixue xinxi tupu* 地学信息图谱 (geoinformation tupu) (Chen 2001b). He promoted the fusion and complementarity between Eastern and Western cultures and stimulated the integration of remote sensing, Global Positioning System (GPS), and geographic information systems (GIS) based on network communication. Chen Shupeng died on 25 November 2008 in Beijing.

HE JIANBANG 何建邦

SEE ALSO: Zhongguo kexueyuan (Chinese Academy of Sciences)

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Chief Administration of Geodesy and Cartography (Russia). See Glavnoye upravleniye geodezii i kartografii

Children and Cartography. Children in literate Western societies have long been inspired to make maps by seeing map illustrations in children's literature. Two paradigms stood out in the twentieth century as representative of their genres. Ernest H. Shepard's map for A. A. Milne's *Winnie-the-Pooh* (1926) exemplified a popular type of pictorial map for printed children's books at the start of the century. The Marauder's Map introduced in J. K. Rowling's *Harry Potter and the Prisoner of Azkaban* (1999), which showed all the characters in Hogwarts Castle as moving dots, was familiar to children from their virtual gaming environments at the century's close. Furthermore, map drawing exercises were variously incorporated within primary education throughout the century. Twentieth-century academic studies of children's mapmaking capabilities collected examples of maps made by children. Although persistent as an academic field of study, particularly in the United Kingdom, it remained an emerging discipline characterized by diverse scholarship scattered across multiple literatures (Anderson 1995).

Beginning in the 1930s, U.S. educators promoted map sketching as a simple, flexible, and inexpensive baseline test for diagnosing students' map comprehension (McNee 1955). However, aside from occasional reports by social studies teachers of successful implementation in their classes, student-drawn sketch maps remained an undervalued and neglected educational tool in the United States. A marked decline in map-based instruction occurred in elementary schools as geography was increasingly subsumed under the rubric "social studies." The deleterious results were reflected in the consistently low scores of U.S students on international geographic location tests.

Lucy Sprague Mitchell, an early advocate for progressive education in the United States, pioneered age-appropriate geography instruction for children. In contrast to the painstaking copy work favored in nineteenth-century pedagogy, Mitchell's 1934 teacher's guide, *Young Geographers*, emphasized the creative process. Mitchell recommended different types of maps for each age level, beginning in nursery school with protomaps or incipient map-like forms utilizing toy blocks. As children's comprehension of symbols matured from pictorial to abstract, they progressed to three-dimensional clay or sandbox models or large floor maps painted on oilcloth. The reissue of Mitchell's book in 1963 led the then-emergent human ecology movement to discover her ideas. Proponents of community-based environmental education shared her small-world view and encouraged children to draw things of emotional importance in their neighborhoods. In place-based education and ecological literacy programs, Mitchell's approach of engaging children in fieldwork helped to instill ecological concepts through hands-on production of desktop terrain models, three-dimensional wall murals, and collage maps of their environment (Sobel 1998). In a similar manner, the Parish Maps movement in England, a community manifestation of the local conservation movement during the mid-1980s, integrated contributions by young children into large-scale, multimedia map productions.

Formal academic study of children's mapmaking capabilities was greatly stimulated by the English edition of *The Child's Conception of Space* (1956) by Jean Piaget, a Swiss clinical psychologist, and Bärbel Inhelder. The resultant research literature was highly interdisciplinary, somewhat controversial, and widely dispersed across the fields of child development; neuropsychology; social, environmental, and cognitive psychology; art education; and geography and cartography. Geographers and psychologists in the Place Perception Project at Clark University, the Mapping Project at Pennsylvania State University, and the Sheffield Research Program took the lead in researching children's mapping abilities in the United States and the United Kingdom. Most studies documented experiments focusing on discrete skills in cognitive mapping abilities and spatial cognition of preschool children. Research on older children (six to twelve years old) emphasized map-reading skills for route learning or wayfinding. While art educators and developmental psychologists extensively documented the gradual progression of children's figure drawings, comparable work on the development of mapmaking and model building by children was lacking. Designed as a teaching guide, Patrick Wiegand's *Learning and Teaching with Maps* (2006) provides a thorough overview of academic research literature about children and cartography from the 1950s onward.

Educators quickly adopted Piaget's classification scheme of four developmental levels: sensorimotor, preoperational, concrete operational, and formal operational. Map instruction was commonly delayed until age eight, when children attain Piaget's concrete operational stage. However, a key tenet of Piaget, that map comprehension is a late and hard-won achievement, was challenged in the 1970s by the nativist theory claiming that innate core spatial knowledge develops at an early age. A heated debate between James M. Blaut and the neo-Piagetians Lynn S. Liben and Roger M. Downs ensued and was documented in a series of articles in the *Annals of the Association of American Geographers* (2003). As Piaget's influence continued to wane, most educators accepted that spatial reasoning was fully functional by preschool age and accordingly began map instruction at age five in kindergarten. Developmental psychologists speculated that, just as preschool children's exposure to richer linguistic environments contributes to the eventual acquisition of advanced language skills, understanding of spatial representations would be enhanced through parent-child interaction while viewing various visual media: drawings, paintings, photographs, models, graphs, and maps. For example, parents reading aloud should direct the child's attention to depictions of space in picture books, such as Jean de Brunhoff's *The Travels of Babar* (1934), by noting that distant things appear smaller (Liben 1999, 316). Books illustrated with panoramic views, such as Peter Spier's *The Fox Went Out on a Chilly Night* (1961), and oblique views, such as Gail Hartman's *As the Crow Flies* (1993), would be easier than plan views for young children to comprehend and would allow the reader to trace the story within the landscape. Denis Wood's analysis of picture-book illustrations (1984) made the case that prevalent depiction of hills in profile, as in Tibor Gergely's illustrations for *The Little Red Caboose* (1953), was teaching children to represent hills in the same manner in their own drawings. Exposing children to a variety of landscape forms and different types of maps in books would expand their environmental experiences. That activity could be reinforced by asking children to create drawings based on stories, thereby enhancing their ability to understand and interpret external spatial representations (Wiegand 2006, 104).

Geography educators in the United Kingdom believed that essential understanding of map conventions could best be taught by having children draw their own sketch maps based on field observations (Bailey and Fox 1996). Also referred to as freehand, free recall, or diagrammatic mapping, sketch maps were considered the ideal vehicle for training students to translate spatial concepts into the graphic language of maps. Despite the field-map tradition and the emphasis on graphicacy as a distinctive form of communication in U.K. school curricula, a noticeable decline occurred between 1974 to 1999 in student sketch maps (Wiegand 2006, 2).

There is, of course, a fundamental difference between cognitive mapping and wayfinding on the one hand and mapmaking and map reading on the other. The distinctive graphic visual system of a map features a mix of abstract symbols. Studies have revealed a logical progression in the way children draw maps (fig. 138). Before age eight, children tend to draw pictorial maps with elevation views of buildings. They then transition to combining pictorial and plan elements within the same map. By age ten they begin to draw more abstract plan views and introduce cartographic symbols (Neperud 1977), although cross-cultural studies in developing countries reported greater reliance on pictorial mapping among older students (Wiegand 2006, 50). Since children routinely scribble or draw before they learn to read and write, drawing pictorial maps was regarded as a developmental stage preliminary to mastering conventional mapmaking (Matthews 1986).

In his seminal field study in a New England town, Roger A. Hart analyzed how children represent spatial arrangements of places in their everyday home environments. He asked students, aged four to nine, to first create room-sized models of their home area with three-dimensional clay figures and then trace their shapes to create the map. Significantly, the extent of their mobility in town was a better indicator of map quality than age or IQ score (Hart 1981). Subsequent studies conducted

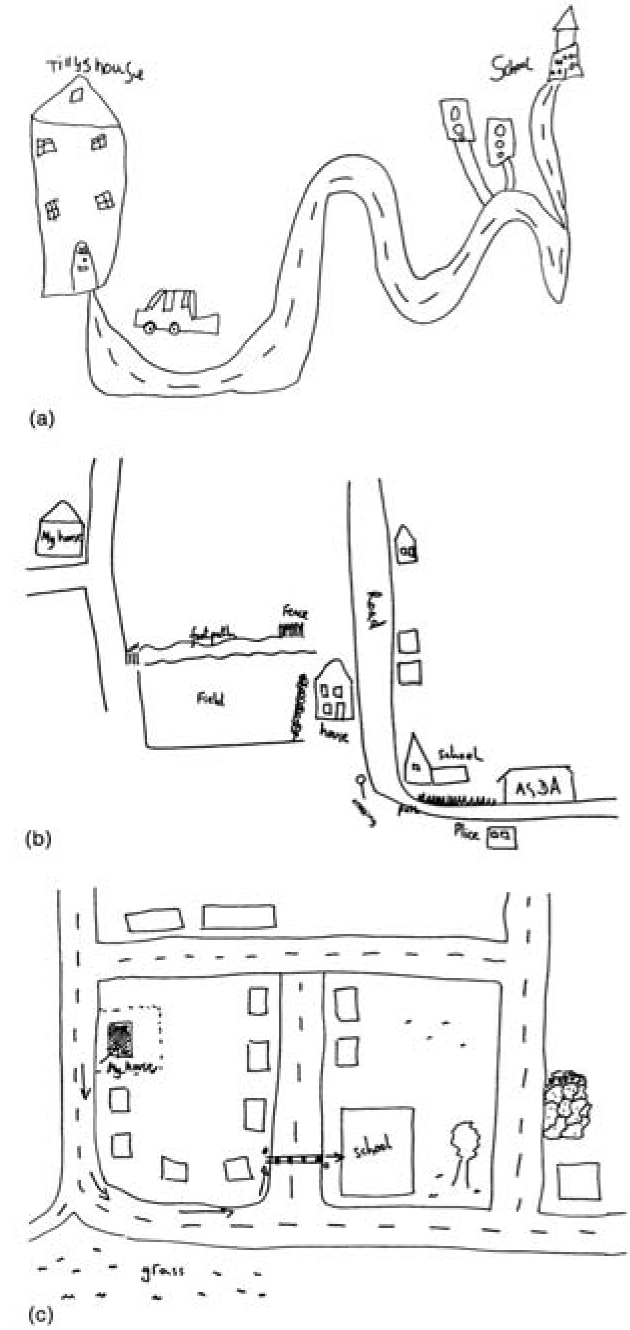

FIG. 138. LARGE-SCALE EXAMPLES OF CHILDREN'S JOURNEYS FROM SCHOOL TO HOME. Examples mapped by children show the three stages through which children generally evolve as they learn to master technical mapping conventions for depicting their environment: (a) pictorial (generally under eight years old); (b) hybrid form combining pictorial and plan (generally between eight and ten years old); (c) plan (generally over ten years old).
From Wiegand 2006, 49 (fig. 6.1). Reproduced by permission of Taylor & Francis Books U.K.

in Canada and the United Kingdom replicated the correlation between greater mobility, defined as free range, and increased accuracy in mapping their neighborhood (Wiegand 2006, 46).

In the mid-1990s Wiegand and others undertook several studies in the United Kingdom to evaluate children's understanding of the configuration of the earth's landmarks based on previous exposure to maps in school atlases. Researchers employed the free recall method for drawing country and world maps (Wiegand 2006, 69–74). The children's maps revealed an Anglocentric bias, depicting the British Isles most accurately while exaggerating the size of Europe and underestimating the size of Asia and Scandinavia. Students were better at showing location and size than shape in world maps. Their maps displayed a systematic distortion, also common in adult sketch maps, by centering city locations and aligning continents according to vertical and horizontal lines. Other researchers found student's freehand sketch maps useful for identifying the blind spots, biases, and misconceptions in students' mental pictures of the world (figs. 139 and 140).

The question whether children's sketch maps improve with increased opportunities for travel and media exposure was the focus of an international study conducted with ten-year-old children from eight European and American countries. The results of the free map drawing exercises supported previous findings of gender differences in map quality resulting partly from different levels of experience and exposure. Schools could mitigate such disparities by incorporating virtual travel experiences on the Internet (Schmeinck and Thurston 2007).

Based in part on Lev Vygotskiy's cooperative learning model, educators undertook collaborative mapping projects with favorable results. Teamwork to produce large-scale maps increased the cognitive demand on the participants by requiring explanation or justification of their ideas during the mapping process. The group dynamic also encouraged students to set their own standards for completing and evaluating the task (Leinhardt, Stainton, and Bausmith 1998). In some communities collaborative mapping supported the research of urban planners and designers who enlisted children to map spaces and hidden environments in their neighborhood (Halseth and Doddridge 2000).

Issues of cartographic literacy and children's relationship with maps received official recognition in 1995 when the International Cartographic Association (ICA) formed its Cartography and Children Working Group, with the mandate of introducing children to the power of maps. Four years later it became the Children's Commission. In 1993 the ICA had successfully created a biennial international map competition for students under fifteen (later sixteen) years of age. Titled "Children Map the

FIG. 139. SMALL-SCALE WORLD SKETCH MAP DRAWN BY A CHILD (AGE TEN TO ELEVEN) BEFORE INSTRUCTION. Compare figure 140.
From Doug Harwood and Kay Rawlings, “Assessing Young Children’s Freehand Sketch Maps of the World,” *International Research in Geographical and Environmental Education* 10, no. 1 (2001):20–45, esp. 26 (fig. 2). Reproduced by permission of Taylor & Francis.

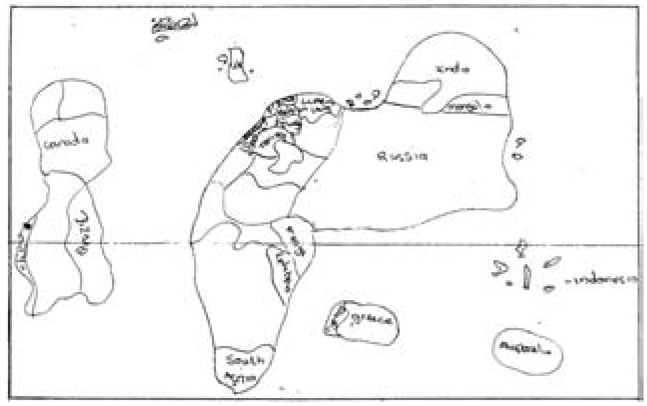

FIG. 140. SMALL-SCALE WORLD SKETCH MAP DRAWN BY A CHILD (AGE TEN TO ELEVEN) AFTER INSTRUCTION. This resulted in significant improvements in the freehand sketch map and also revealed typical misconceptions about the shape, size, and location of continents (compare fig. 139). From Harwood and Rawlings 2001, 27 (fig. 3). Reproduced by permission of Taylor & Francis.

World,” the competition was established as a memorial to Barbara Bartz Petchenik, a past ICA vice president. As a cartographer and lifelong advocate for age-appropriate map design, Petchenik asserted that making a map is a far more valuable learning experience than looking at dozens of maps during social studies instruction, and that the ability to make maps nearly guarantees the ability to read them (Bartz 1970, 24). Tens of thousands of children from ICA member countries have since participated in the competition. Their submissions provide an ongoing resource for analyzing children’s understanding of map elements and map creation (fig. 141).

Cartographic literacy and children’s ability to evaluate and assess maps have become critical with the proliferation of digital technologies, and research has embraced children’s relationships to digital maps. While computer mapping plays an increasing role in education, the act of drawing a map with pencil and paper is still needed to bridge the gap between what young children see and the abstract mapping concepts hidden in electronic systems (Castner 2000). Whether the sketch map tradition survives in the twenty-first century remains to be seen, but its advocates have made a solid case for maintaining this skill in the school geography curriculum.

YOLANDA THEUNISSEN

SEE ALSO: Atlas: School Atlas; Education and Cartography: Teaching with Maps; Perception and Cognition of Maps; Petchenik, Barbara B(artz)

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FIG. 141. KEVIN WU, *SAVE THE WORLD* (2007). Age nine, Walton Elementary School, Coquitlam, British Columbia. An example of a child's world map from the International Cartographic Association's Petchenik competition established in 1993 to promote "children's creative representation of the world." The competition offers a venue for children to demonstrate their knowledge, ability, and creativity in constructing maps based on themes selected by the organizers. From Temenoujka Bandrova et al., eds., *Children Map the World: Selections from the Barbara Petchenik Children's World Map Competition, Volume 2* (Redlands: ESRI Press, 2010), 28. Permission courtesy of the Commission on Cartography and Children, International Cartographic Association.

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Chinese Academy of Sciences (CAS). See Zhongguo kexueyuan

Chorley Report (1987). See Report of the Committee of Enquiry into the Handling of Geographic Information

Choropleth Map. After initial experimentation with a variety of thematic map symbols in the early nineteenth century, choropleth map symbols became the most widely used form for thematic maps by the time modern census taking was established in most principal European countries toward the end of the century. The choropleth method is usually employed to display quantitative data corresponding to bounded enumeration areas, such as counties or census divisions. Each enumeration area is assigned a uniform area symbol, typically a color, which represents the quantity occurring within the enumeration area. Usually each color represents a range of data values, with the darker color corresponding to greater magnitude.

In 1827 Baron Charles Dupin, a French educational reformer, published the first known choropleth map titled *Carte figurative de l'instruction populaire de la France* (Robinson 1982, 156–57). The map shows the number of persons per male child at school for each *département* of France. Dupin's map does not include a legend, but rather the actual numeric data value has been written in each area, and the attempt has been made to give each area a tint corresponding to its actual value (a technique later referred to as classless choropleth mapping). The map was highly influential among members of intellectual society concerned about the negative effects of rapid industrialization and was quickly followed by other choropleth maps depicting themes of the social and economic environment. For example, in 1829 Adriano Balbi and A.-M. Guerry published three choropleth maps showing the incidence of various types of crime in France. In 1836 sixteen choropleth maps published by Adolphe d'Angeville covered the realm of what were then referred to as "moral statistics," themes related to social problems such as crime, illiteracy, poverty, and disease. Another early map of note was Henry Drury Harness's 1837 map of population density in Ireland, a variant of the choropleth map (a type later known as a dasymetric map) (Robinson 1982, 115–18, 156–63). When compiling a dasymetric map, the cartographer could vary the extent of the symbol within an enumeration area where it was known, for example, that the phenomena did not occur.

The surge of thematic mapping activity in the early to mid-1800s was stimulated by innovations in the social sciences and printing technology as well as by increased government concern with economic, demographic, and health conditions. European countries began to conduct national censuses, providing a wealth of statistical information for defined administrative areas. By the time of Great Britain's comprehensive census in 1851, thematic maps, including many choropleth maps, typically accompanied census reports. Advances in mathematical probability and statistics provided ways of processing the quantitative information collected, although some statistical conventions had yet to be established. For example, d'Angeville's 1836 maps of crime depicted the number of persons per crime, in contrast to the later practice of mapping the number of crimes per 100,000 persons. Finally, the introduction of lithography and color printing facilitated production of area tints and patterns in a sequence of tones or hues for choropleth area symbols.

By 1860 choropleth mapping was well established as a functional thematic mapping method, and its use and design continued essentially unchanged until the mid-twentieth century. However, the term *choropleth*—combining the Greek words for *choro* (area or place) and *plethos* (a great number or multitude)—was not adopted until 1938, when John Kirtland Wright proposed it (1938, 4). The label became fixed when Erwin Raisz's textbook *General Cartography*, also published in 1938, utilized the term, although he warned that "such a map will not give a true picture of distribution, because in most cases it is not at the county or township line where the value changes" (1938, 246). Despite that cautionary note, choropleth maps continued in common use by cartographers, especially for census data (fig. 142). Although choropleth map compilation changed little, the reproduction of choropleth maps did change, facilitated during the first half of the twentieth century by new printing technology, especially photolithography combined with tint screens and four-color process printing.

A more significant development in the history of thematic mapping began in the 1960s with the introduction of digital technology for producing maps. Choropleth maps were among the first thematic maps to be automated. When examining early choropleth maps created using dot matrix printers and software programs, such as SYMAP and CALFORM, it is easy to understand why cartographers were often highly critical of early attempts at automated mapping (fig. 143). A brief but curious stage in choropleth map research involved designing area symbols in differing shades of gray by overstriking certain letters on the keyboard, for example, H, I, X, and O to produce a 65 percent black (Groop and Smith 1982, 19–20). Computer mapping programs did not use the term choropleth; instead, software developers referred to "graduated color" maps or "range-fill" maps.

Not only were new production technologies emerging during the 1960s, but a paradigm shift was occurring within the scholarly discipline. The new research paradigm no longer envisioned mapping as an end in itself with the map as a static final product, but rather as part of a dynamic communication process whereby spatial information was transmitted from the mapmaker to the map user via the map. With the communication model came a shift of focus to the map user. Interest grew in understanding the tasks for which choropleth maps were used and how to effectively design maps to facilitate those tasks. During the last several decades of the twentieth century researchers delved into every aspect of the use and design of choropleth mapping.

A seminal paper by George F. Jenks and Fred C. Caspall in 1971 outlined much of the research agenda.

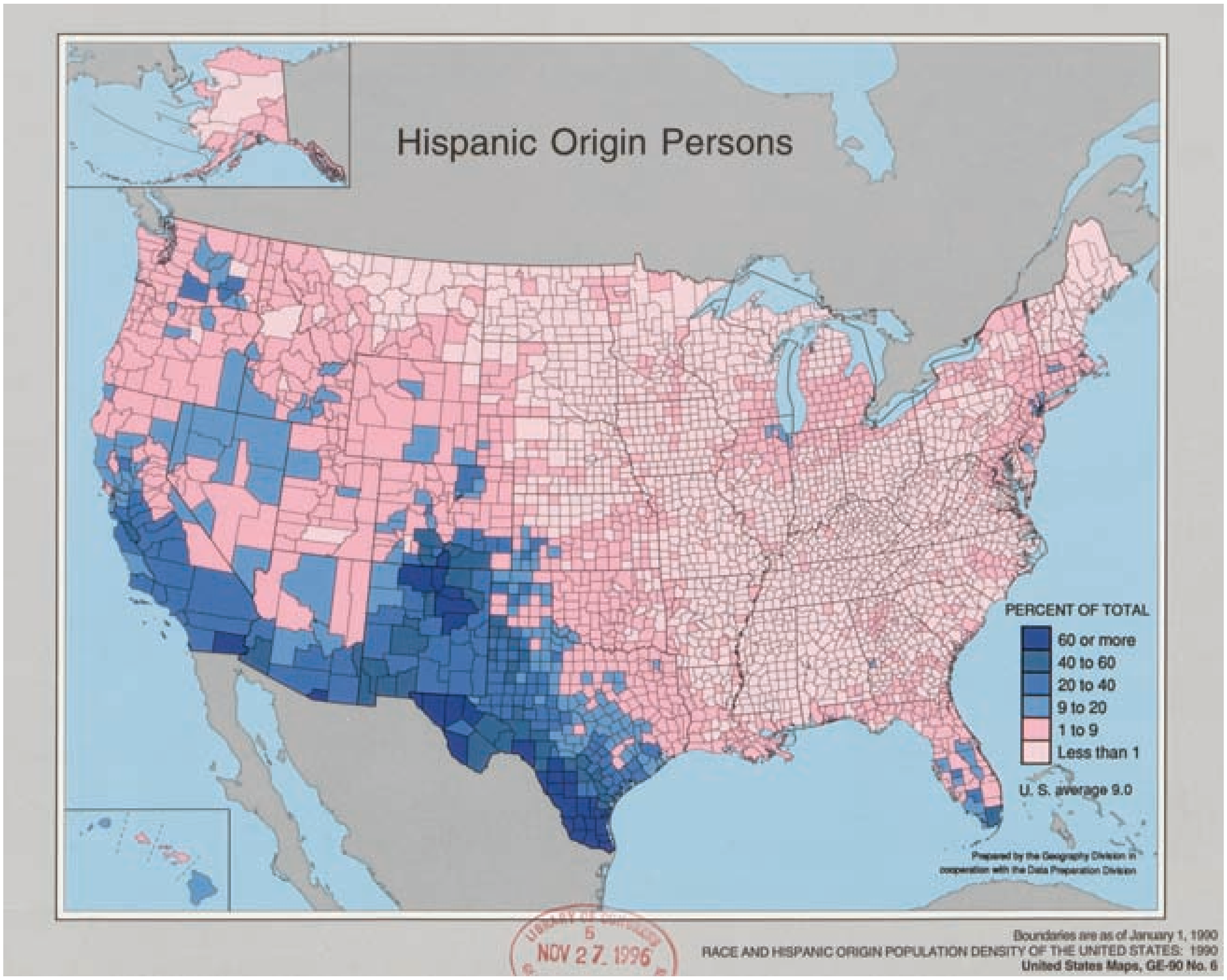

FIG. 142. U.S. BUREAU OF THE CENSUS, *HISPANIC ORIGINS PERSONS*, 1990. One of four maps on the sheet *Race and Hispanic Origin Population Density of the United States: 1990*. This color choropleth map on an Albers equal-area projection typifies those produced by many national government agencies to accompany census reports. Size of the entire sheet: ca. 47.2 × 53.3 cm; size of this map: ca. 18.7 × 23.6 cm. Image courtesy of the Geography and Map Division, Library of Congress, Washington, D.C.

Recognizing that a classed choropleth map is a generalization of the actual distribution depicted, they focused on strategies to measure and reduce error. Framed within the communication paradigm, three choropleth map uses were recognized: to provide an overview of the spatial distribution, to convey specific information about particular locations, and to show visually prominent boundaries that the user could then relate to other maps. The success with which the user could perform those tasks would be influenced by the design of the choropleth map, including the number of data classes, the method used to divide the data into classes, and the symbols used to portray each class. Each of those design variables, and the relationships among them, generated considerable research in the following several decades.

Numerous studies looked into the selection of an effective sequence of gray area symbols for a black-and-white choropleth map. The difficulty lay in a visual phenomenon, the fact that tint screens printed in progressive percentage increments (i.e., 10%, 30%, 50% 70%, 90%) are not perceived as equal steps of blackness by the map reader. The quantitative relationship between printed and perceived gray values was defined by a curve of the gray spectrum. George F. Jenks and Duane Sidney Knos (1961) compared four grayscale curves that had been developed in other disciplines, whereas the experimental design by A. Jon Kimerling (1975) produced a new

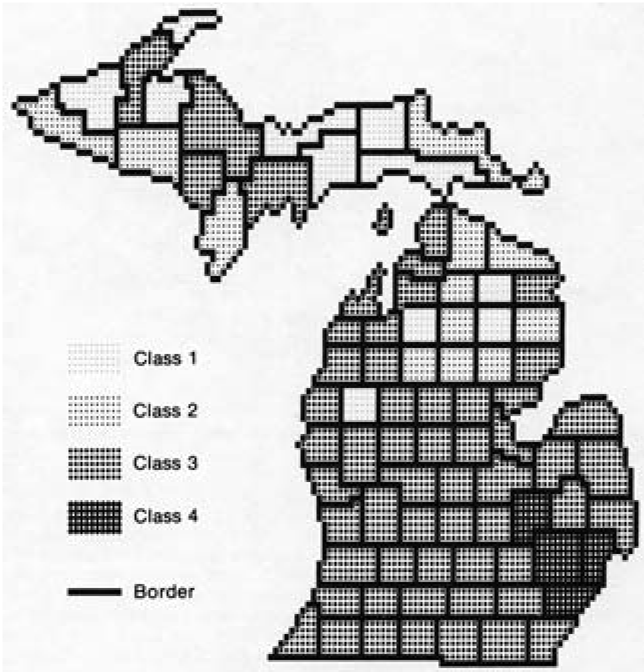

FIG. 143. UNTITLED CHOROPLETH MAP OF MICHIGAN, 1982. This early example of an automated choropleth map was produced on a printer intended for printing text (Printronix 300 Dot Matrix Printer). The map symbols were created by darkening some of the dots in the 9 × 6 dot array making up each character.
From Groop and Smith 1982, 22 (fig. 3). Reprinted by permission of Taylor & Francis.

curve. Although such psychophysical research, which attempted to quantify the relation between actual (measurable) and perceived map symbols, had run its course by about 1990, the issue continued to be discussed in later cartographic texts.

Color choropleth maps presented other design challenges. Researchers, including Janet E. Mersey (1990) and Mark Harrower and Cynthia A. Brewer (2003), studied the problem of selecting an effective sequence of colors for a choropleth map. Mersey's map user study concluded that the choice of an optimum color sequence needs to consider how the map will be used and the number of classes it will employ. Harrower and Brewer devised an online program, ColorBrewer, to assist in selecting a series of colors appropriate for sequenced or diverging categories on a choropleth map. A sequenced series refers to data that increases from low to high values, whereas in a diverging series, values increase both above and below a central value.

Other research focused on methods for dividing data into classes. Methods based on simple rules, such as putting an equal number of observations into each class (quantiles) or having each class span the same data range (equal interval), were known to often yield poor results, as they did not account for the actual variation in the raw data. With computer technology came the ability to devise more mathematically sophisticated methods. Jenks and Caspall (1971) presented an iterative statistically optimal method based on minimizing the sum of the deviations about class means. That method and slight variants of it were quickly adopted for many mapping software programs. Richard M. Smith (1986) compared traditional and optimizing methods and concluded the latter gave more accurate and reliable results.

The optimizing measures provided a statistical means of quantifying one type of choropleth map accuracy based on the number of map classes and the class interval method. Alan M. MacEachren (1985) investigated the influence of three additional factors, the spatial variation of the surface and the size and compactness of the enumeration areas, on choropleth map accuracy. He found spatial variation of the data to be especially significant, results that led to interest in determining a single statistic to characterize choropleth map complexity. Mark Monmonier (1974) had compared five complexity measures based on statistical indices and graph theory, while a later study by MacEachren (1982) had found that users' subjective notions of map complexity were highly correlated with objective graph theory measures.

Since choropleth maps are often produced in a series and compared visually by map users, researchers explored the factors affecting that task. Judy M. Olson (1972) studied the relationship between class intervals and statistically measured map correlation, while Theodore R. Steinke and Robert Lloyd (1983) found that map users' subjective measures of map similarity corresponded to objective measures. A method developed by Jacek Pasławski (1982) included spatial proximity of areas in the classification method.

Studies were also performed on the design of classless and bivariate (showing two distributions) choropleth maps, two variants easily created with the computer. The dasymetric map, a modified form of choropleth map giving a more detailed spatial view of the distribution, largely fell out of favor due to the challenge of automating the method.

By the year 2000 choropleth mapping could be automated readily and with excellent results. In fact, with vector-based geographic information systems (GIS), which store attribute data in a spreadsheet format keyed to map areas, choropleth mapping became more pervasive than ever. By that time the communication model had evolved into a paradigm of geographic visualization, which recognized the important role of mapping in interactive data exploration. GIS facilitated direct interaction between the user and the spatial information,

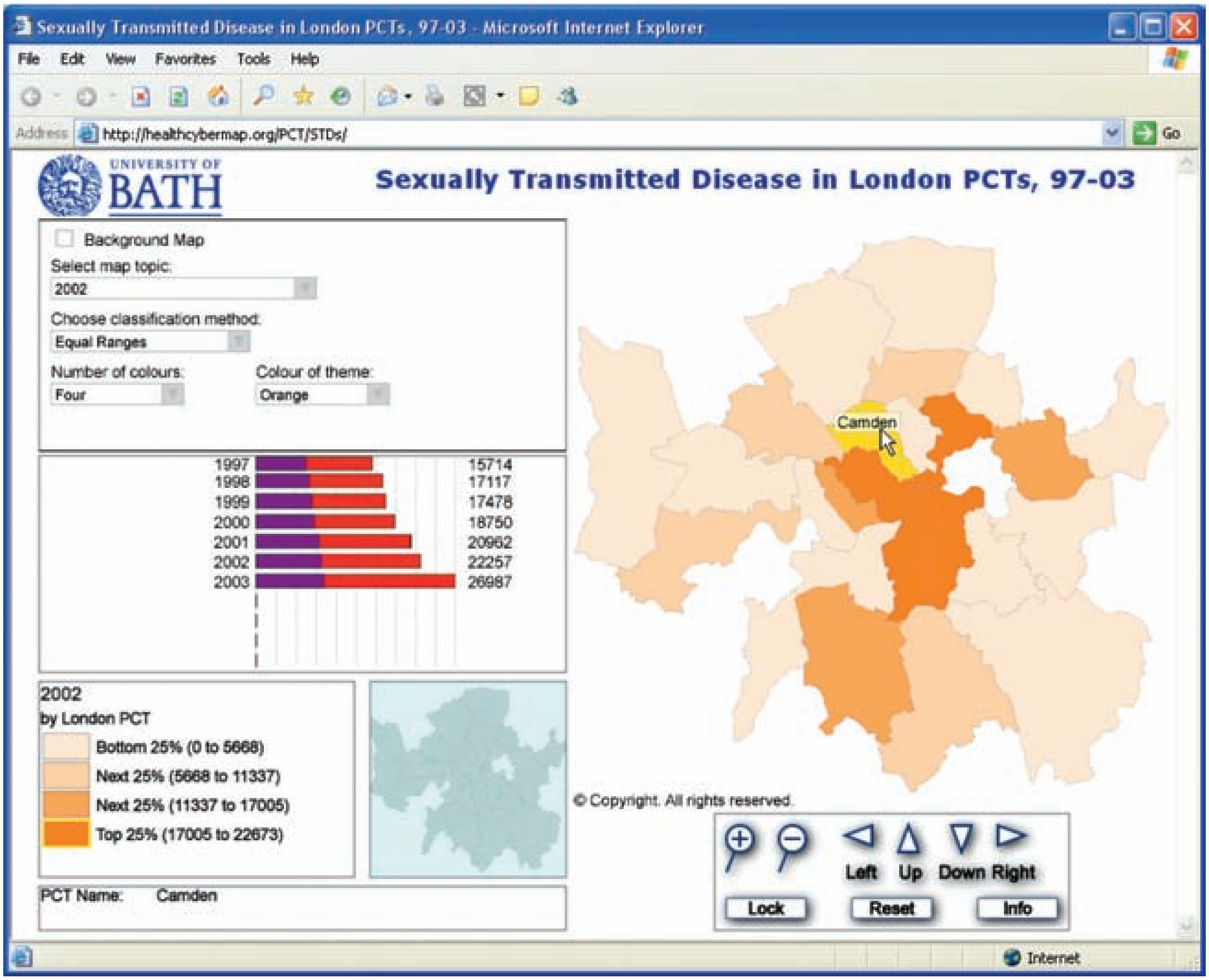

FIG. 144. *SEXUALLY TRANSMITTED DISEASE IN LONDON PCTs, 97-03*, 2005. Screen capture of an online interactive choropleth mapping tool used to display health-related statistics in England.

From Kamel Boulos, Russell, and Smith 2005, fig. 1.

which was increasingly available in digital format from government agencies. The incredible rise in popularity of the Internet at the turn of the century led to the design of web-based tools for creating choropleth maps. Interactive web-based choropleth maps were made to display the incidence of sexually transmitted diseases in England (Kamel Boulos, Russell, and Smith 2005). Users could access the website and select the data they wished to map, the number of classes, the classification method, and the map colors (fig. 144). Although the technology used to create choropleth maps had changed radically, it is noteworthy that over 150 years after d'Angeville's maps choropleth maps were still a prevalent means of displaying health-related statistics, along with other categories of information.

JANET E. MERSEY

SEE ALSO: Bivariate Map; Census Mapping; Statistical Map; Thematic Mapping

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FIG. 145. DEMONSTRATION OF CHROMA KEY. A student learns to coordinate movements with a map on the monitor while standing in front of a blank chroma key wall. Digital photograph taken in June 2006 at Illinois State University. Image courtesy of James R. Carter.

Chroma Key. Many television pictures that viewers see are composites of two or more images. Over the years various techniques have been employed to composite multiple images into single pictures. In the 1950s NBC developed Chroma-Key, a technique based on using a unique color as a backdrop to a foreground image (Bretz 1962, 281–83). In chroma keying, a mixer deletes the unique color from the foreground image and cuts the remaining image into the background image. The term *chroma key* has evolved into a generic name. The process is also known as chrominance keying and color separation overlay and is used commonly in commercials, newscasts, sporting events, and weather broadcasts (Millerson 1999).

Blue or green is normally employed as the chroma key backdrop because these colors are most dissimilar from skin tones. It is important that the backdrop color not appear anywhere in the desired foreground image, or that portion of the image will be deleted and the background image will be displayed. There have been many instances where viewers have seen a map appear on the body of the presenter (Henson 2010, 101–3). When analog maps were used, a single camera was usually employed to capture the on-air person interacting with the map while standing in front of that map. With the advent of computer graphics in the 1980s, chroma key became an important tool to permit an individual to interact with a suite of maps generated in a computer.

Computer graphics and chroma key have become the standard for the presentation of weather maps on television (Henson 2010). For example, a weathercaster stands in front of a blank wall of blue or green, far enough away to cast no shadows on the wall (fig. 145). The weather maps and satellite images that have been prepared beforehand are stored in a computer under control of the weathercaster, who normally has a computer-control device in hand. The camera focuses on the weathercaster, creating the foreground image. The weathercaster brings up the weather maps on the computer to create the background images. To the side and off-camera is the composite image of the weather map with the image of the weathercaster cut into the map. The weathercaster interacts with the maps by coordinating movements with the composite image on the screen while telling the weather story (Carter 1998). Adept presenters, moving in front of a blank wall, trace out the motion of fronts and air masses on animated maps and satellite images (fig. 146).

JAMES R. CARTER

SEE ALSO: Television and Maps; Weather Channel, The (U.S.); Weather Map

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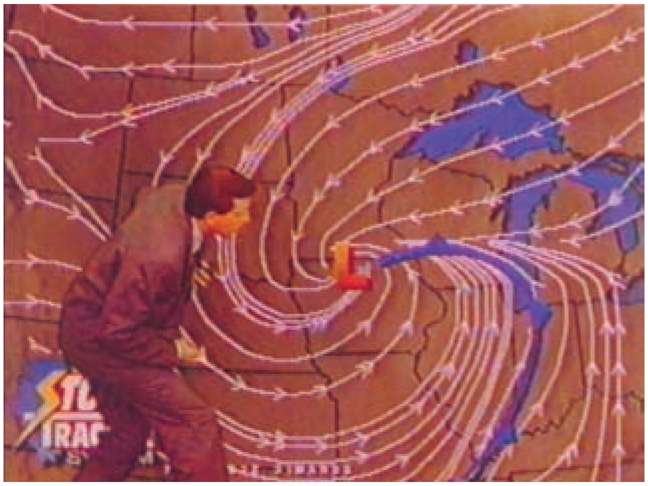

FIG. 146. PRESENTING TELEVISION WEATHER. Weathercaster standing in front of a chroma key backdrop with the map generated by computer. Mike McClellan, WMBD-TV, Peoria, Illinois, uses his whole body to show how winds are spiraling counterclockwise around a center of low pressure over northern Iowa. Photograph taken in 1997.
Image courtesy of James R. Carter.

Henson, Robert. 2010. *Weather on the Air: A History of Broadcast Meteorology*. Boston: American Meteorological Society.

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Cinema and Cartography. The history of the relationship between cinema and cartography began with the invention of cinema. Since the end of the nineteenth century, maps appeared in films as props, often hanging on walls or actively used by explorers and gangsters. The presence of these everyday artifacts on the silver screen was soon supplemented by the emergence of maps specifically designed for and by cinema. These cinematic maps—or "cinemaps"—have been created throughout the twentieth century, often foreshadowing the functions and technological development of contemporary dynamic cartography. Caquard (2009) provides a detailed discussion of the examples presented here.

The first animated maps appeared in movies in the 1910s. One of the oldest was created for a docudrama titled *Among the Cannibal Isles of the South Pacific* (directed by Martin E. Johnson, 1918). In this very early example the animation was quite rudimentary: a simple line unfolding on a static map outlined a journey. In the 1920s, cinemaps became slightly more sophisticated with the representation of a rotating earth (e.g., *Dreams of the Rarebit Fiend: The Flying House*, Winsor McCay, 1921) and animated symbols (e.g., *Le Tour de la France par deux enfants*, Louis de Carbonnat, 1923).

The sophistication of cinematic maps increased substantially in the 1930s. In the German film *M* (Fritz Lang, 1931) a cinemap shows concentric circles drawn on a map montage representing the investigative process used by the Berlin police to find clues regarding a serial killer (fig. 147). In a scant eighteen seconds, this cinemap portrays several elements of contemporary digital maps. First, it combines both sound and image, and thus may well be the first audiovisual map ever created. Second, the map overlays photography onto a conventional topographic map, thereby anticipating the combination of cartographic signs with satellite images in digital cartography. Third, it provides two perspectives of the same map—one oblique and one perpendicular—a practice not common in cartography until the advent of virtual globes. Finally, the drawing of concentric circles, which resemble geographic information system (GIS) "buffer zones," foreshadows the use of digital technologies for automated spatial measurements.

In the 1940s, zooming capabilities, so popular in contemporary virtual globes, appeared in cinema. *Casablanca* (Michael Curtiz, 1942) opens with a cinemap that takes the audience through multiple scales from the entire spinning globe, to Paris, then to the Mediterranean Sea, and finally ending up on a busy street of Casablanca, the setting of the film (fig. 148). This map integrates all of the zooming capabilities available in virtual globes at the beginning of the twenty-first century. Thus, by the 1940s many of the functions available in contemporary digital cartography had already been imagined and represented in film. At the time, academic cartog-

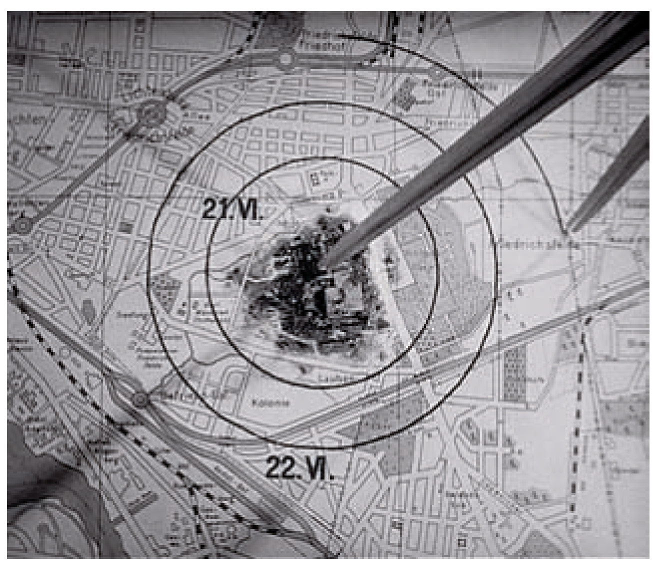

FIG. 147. MAP FROM *M* (FRITZ LANG, 1931). This cinemap portrays several elements of contemporary digital maps such as the use of sound, combination photography/map, and automated spatial measurements.
Copyright 2006, Janus Films.

FIG. 148. MAP FROM *CASABLANCA* (MICHAEL CURTIZ, 1942). This cinemap integrates all of the zooming capabilities currently available in virtual globes.

raphers started to express some interest in the animated maps produced in cinema (Speier 1941; Boggs 1947). It was only in the 1950s that professional cartographers began to develop animated maps using cinematographic techniques (Thrower 1959).

In the 1960s, another important step foreshadowing contemporary cartographic practices was achieved in cinema. Filmmakers developed cinemaps representing the use of real-time data as illustrated by those found in two films: *Dr. Strangelove* (Stanley Kubrick, 1964) and *Goldfinger* (Guy Hamilton, 1964). Both films included cinemaps displaying real-time data, which could be considered a precursor of GPS tracking systems. In the 1970s satellite images at multiple scales appeared in movies such as *Powers of Ten* (Charles Eames and Ray Eames, 1977), which portrays a very realistic continuous zoom across multiple satellite images from the universe to the molecule. Interestingly, this movie inspired the development of Keyhole, the company that developed the software used to create Google Earth (Crampton 2008). By the end of the 1970s, most of the contemporary capabilities of virtual globes had been conceptualized in cinema. It took a few more decades to turn them into the fully operational and interactive cartographic applications in wide use at the end of the century.

This brief and selective review of some of the major cinemaps of the twentieth century represents only one dimension of the historical relationship between cinema and cartography. Many other forms of visual, audio, and conceptual maps have been used by cinema for a range of purposes, including narrative and symbolism as well as to provide emotional, poetic, and political overtones (Conley 2007). Looking at the relationship between cinema and cartography is not only a way of anticipating future cartographic functions. It can also serve as a basis for reflecting on the ethical, political, and narrative dimensions of past, present, and future cartographic practices.

SÉBASTIEN CAQUARD

SEE ALSO: Animated Map; Literature and Cartography; Narrative and Cartography

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Climate Map. As the visual realization of systems of climate classification fashioned from multidecade sequences of meteorological data, climate maps portray regimes produced by different combinations of temperature, precipitation, altitude, latitude, distance from the ocean, and other variables. Throughout the nineteenth century and most of the twentieth century, climatology was a descriptive science; with few exceptions, climatic cartographers used the occurrence of different suites of vegetation as the criterion by which to identify and delineate different climates. In the era of imperial expansion, Europeans seeking overseas territories reinforced this approach with a strong interest in the kinds of crops that might flourish in their new lands. In the late twentieth century, concern about global climate change awakened considerable interest in maps of current, past, and likely future climates.

Since climates, their vegetation markers, and the weather that produces them are generally transitional from one region to another, the placement of boundaries on a climate map will vary from one classification scheme to another. That two different climate maps draw a boundary in different places generally reflects the different criteria used to construct the climate system on which the map is based as well as the relative weights and mathematical relationships of different climate elements within the system.

There have been many systems of climate classification from the 1880s onward, but almost all of those in use at the end of the twentieth century were descended from the system first developed by Wladimir Peter Köppen in 1884 and modified continuously by him and his coworkers until his death in the 1940s (fig. 149). C. W. Thornthwaite produced highly influential versions of this system in the 1930s and 1940s, and Glenn Thomas Trewartha introduced further modifications in the 1950s and later. Most global climate maps in printed atlases intended for general use still follow the outlines of Köppen's highly evolved scheme.

An examination of Köppen's climate classification system thus provides the most informative entry point into the study of twentieth-century climate maps. As a young scientist thinking about the mapping the earth's climate in the 1870s and 1880s, Köppen's first intuition was to represent vegetation differences as a series of zones of latitude in a Eurasian climate system. Although equating climate with latitude goes back to Greco-Roman antiquity, Köppen's work gave this qualitative notion a quantitative basis.

The system that Köppen chose began from the observation that the northernmost latitude for the growth of trees is well defined by the temperature of the warmest month. Where the warmest mean monthly temperature is 10°C or less, trees cannot grow. Moreover, definable suites of vegetation show up where the mean monthly temperature remains above 10° for one, four, and twelve months. Equally well-defined suites of vegetation show up where the mean monthly temperature remains above 20°C for one, four, and twelve months. Köppen mapped temperature distributions by drawing isotherms (lines of equal temperature) for 10° and 20°. Isotherms for periods of one, four, and twelve months thus produced a system of climate zones covering the entire globe.

Köppen worked continuously to refine the system. In 1901 he borrowed botanical and zoological names for various climates—arctic fox climate, birch climate, baobab climate, liana climate, and so on—and in still further modifications took into account the amount and seasonal distribution of precipitation. The mature climate system had six climate types (five based on temperature, one on aridity) identified by capital letter: A, tropical rain climates; B, dry regions; C, generally warm rain climates; D, boreal climates; E, cold climates beyond the tree line; and F, frost climates without vegetation.

Refinements included the addition of lowercase letters following the capital letter defining the climate type. Thus, what Köppen originally called the beech climate became Cfb, where "C" indicates that the coldest month is between 18°C and –3°C, "f" reflects continual precipitation (sufficient rain or snow to avoid dry conditions in all months), and "b" means that the mean temperature of the warmest month is below 20°C while the mean temperature is above 10°C for at least four months of the year.

The standard climate map based on the Köppen system is a multicolored depiction of bounded regions of climate, generally structured by lines of latitude but modified by topography (interior continental, coastal, mountainous) and further subdivided according to the alphabetic system described above. The colors originally chosen by Köppen were suggestive of vegetation, and changed in different editions. Late twentieth-century atlases typically used colors suggestive of temperature: polar regions appear in light blue and mauve, temperate regions in shades of green and gray, steppes in yellow, deserts in orange, and the tropical areas of the Pacific, Africa, and South America in pink and red. A roughly similar color scheme was common in newspaper and online weather maps.

While global climate maps based on the Köppen system are useful for pedagogic purposes, deficiencies in spatial resolution and key details—largely a consequence of covering vast areas on small-scale, page-size maps—have limited its value in scientific reference material for general readers. Seattle, Washington, typically designated Cfb—Köppen's original beech climate but labeled marine west coast climate in later versions—illustrates the problem of insufficient spatial resolution. On most climate maps this region stretches along the coast from southeastern Alaska to northern California. While Seattle marks the midpoint of the north-south range of this region, the marine west coast designation is a poor descriptor of Seattle's climate. In a Cfb climate, there must be sufficient moisture in all months of the year, but because Seattle is located in the rain shadow of the Olympic Mountains to the west, it actually has a Mediterranean climate, coded Csb, with the "s" indicating a dry season in summer. In fact, in spite of Seattle's reputation for rain, native vegetation in the area uniformly reflects its drought tolerance for the three to four months a year with almost no precipitation.

As another example of this problem of spatial resolution, mapping Australia according to the Köppen system at an equatorial scale of 1:85,000,000 yields roughly ten climate zones. By contrast, at the more detailed scale of 1:65,000,000, the cartographer must attempt to integrate nine zones of precipitation, which are not coextensive with the climate zones, and fifteen different kinds of vegetation zones, which are much more finely subdivided than either the climate map or the precipitation map (*Times Atlas of the World* 1967, xxix and pls. 4 and 5). Here as in most areas of scientific endeavor, the author of a climate map must balance scope and precision and constantly play off information content against legibility. There is no firm convention to guide the cartographer here, and different maps will reflect the skills, connoisseurship, and conceptual orientation of different makers, often to a striking degree.

Frequent reference within large climate schemes to the existence of highly varied microclimates points to the difficulty of balancing scope and precision in the cartographic representation of climates. The accuracy of climate maps is also limited by the number of isolines (representing different variables) that may be placed on a single map without making it cluttered and unreadable. A usefully comprehensive description of average atmospheric conditions within a region requires many such lines: isotherms, isobars, contour lines of equal altitude, lines of equal mean annual precipitation, lines delineating equal evapotranspiration rates, lines showing seasonal prevailing winds, lines delineating zones of vegetation, lines delineating similar soil groups, and many other aspects of climate. Individual maps, rather than a single integrated map of climate, might be the best strategy.

A typical solution appeared in *The Times Atlas of the World*, which addressed world climate with a collection of successive maps at scales between 1:65,000,000 and 1:85,000,000 of *World Climate and Food Potential*, *World Oceanography*, *Mean Annual Precipitation*, and *Types of Natural Vegetation*, as well as smaller and less resolved maps of sea surface temperature, ocean salinity, atmospheric pressure, mean annual evaporation, January and July temperatures, different soil groups, and so on (1967, xxviii–xxix and pls. 3–5). While the presentation of atmospheric data on successive maps, one step at a time, clearly expands the reader's awareness of world climate, the inability of even the most imaginative viewers to hold much of this information in mind simultaneously when viewing it on successive maps underscores the genius and utility of the Köppen system, which is, one might say, the *least unsatisfactory* scheme of climate representation ever developed.

In the 1990s, when the cartographic presentation of climate data shifted from the printed map and paper atlas to interactive, Internet-based multimedia presentations, the cartographic conventions and the ability to summarize and portray climate globally became less clear. In the last decade of the twentieth century and the early years of the twenty-first century a number of promising electronic resources for mapping global climate were developed by national governmental organizations like the National Climatic Data Center in the United States, international governmental organizations like the Food and Agricultural Organization of the United Nations (in concert with the International Water Management Institute), and commercial information providers like Google Earth.

The National Climatic Data Center, which had published bound collections of maps summarizing climatic data for several decades, introduced an online *Climate Atlas of the United States* in 2002. Though constrained by the short time series of its data (1961–90) and its limited area (less than 2 percent of the earth's surface), the center's electronic atlas has the great strength of allowing viewers to select and integrate different combinations of climate factors as layers on a single interactive map—an approach that avoids the clutter of conventional climate maps overloaded with isolines.

In 2009, the International Water Management Institute published a software product with a geographic scope and historical depth far exceeding that of the *Climate Atlas of the United States*. The institute's Synthesizer program for their *World Water and Climate Atlas*, enhanced by CD-ROM databases of gridded global climate data extending back to the beginning of the twentieth century, lets the user explore the progress of climate change in great detail.

Google Earth, an Internet-based application released in 2005, provided a "virtual globe" onto which users could add and thus disseminate their own data. This capability inspired a number of intriguing climate maps, including a joint initiative of Google and the Hadley Centre for Climate Prediction and Research, a component of Britain's meteorological office (Met Office), to make climate change maps available through Google Earth. The cartographic conventions of paper maps and the Köppen system also appeared on Google Earth, including an updated version of the Köppen-Geiger classification portrayed on a map uploaded in 2006 by the Global Precipitation Climatology Centre and the University of Vienna (fig. 150).

The ready ability to generate flexibly layered climate maps for the earth as a whole (rather than just a few regions) on a timescale of centuries (rather than a few decades) is an inevitable joint legacy of climate research, the Internet, and electronic cartography. Even so, no general system of classification and mapping had emerged during the twentieth century to unseat the Köppen system and its many descendants from their leading role in climate cartography. Despite the system's insufficient resolution of climate regions and inability to present much information simultaneously, its single-map overview could prove a useful complement to highly interactive tools for exploring the growing trove of climatic data.

MOTT T. GREENE

SEE ALSO: Biogeography and Cartography; Meteorology and Cartography; Weather Map

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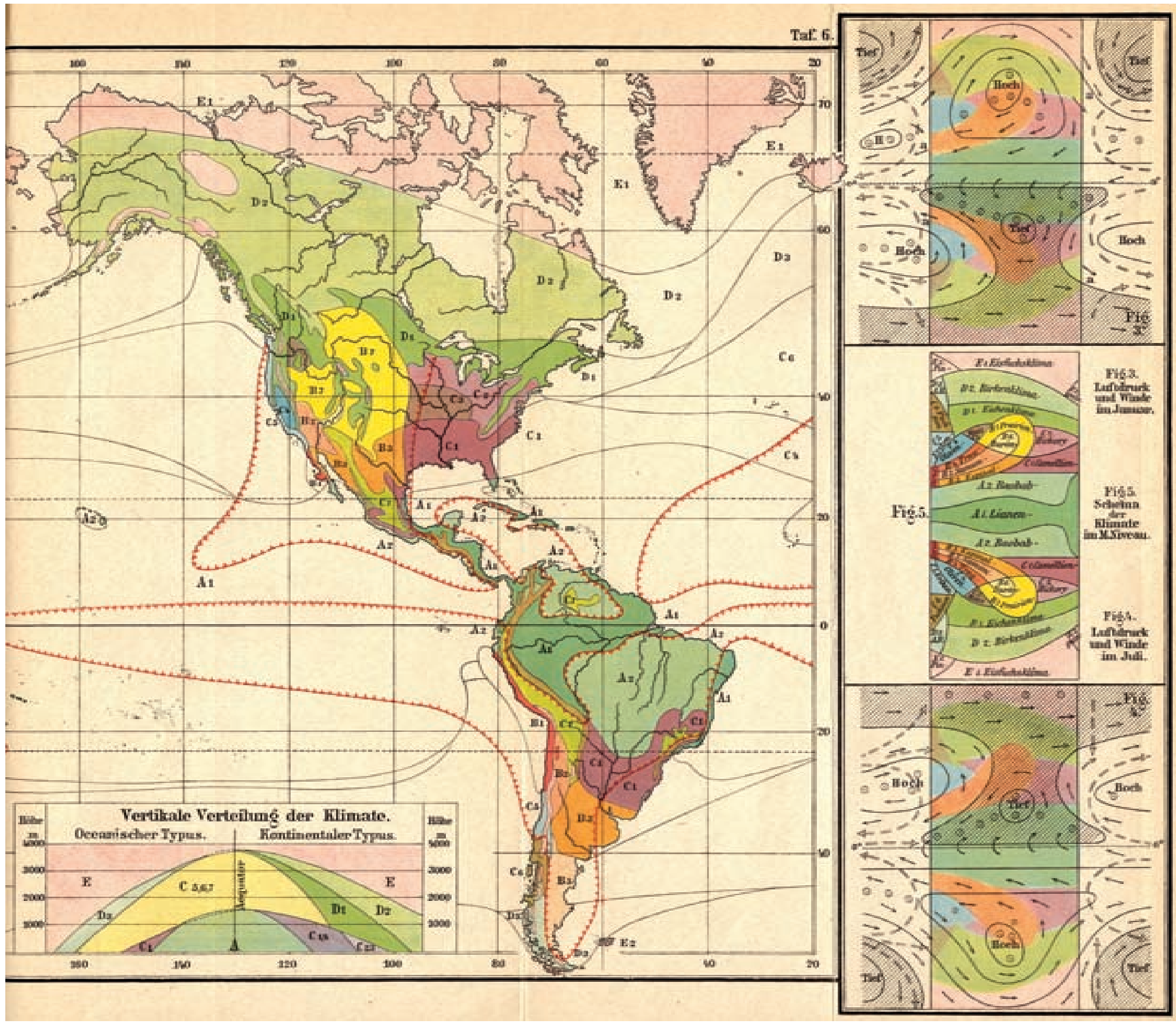

FIG. 149. THE AMERICAS PORTION OF KÖPPEN'S CLIMATE MAP, 1901. Note that climatic regions extend into oceanic areas, and that Köppen indicated the contrasting differentiation of climate with altitude in "oceanic type" and "continental type" climates. The figures on the right margin from top to bottom are the air pressure field for January, the botanical names for the different climate regions, and the air pressure field for July.
Size of the original: 22.4 × 26.4 cm. From Köppen 1901, endpaper, Tafel 6 and figs. 3, 4, and 5.

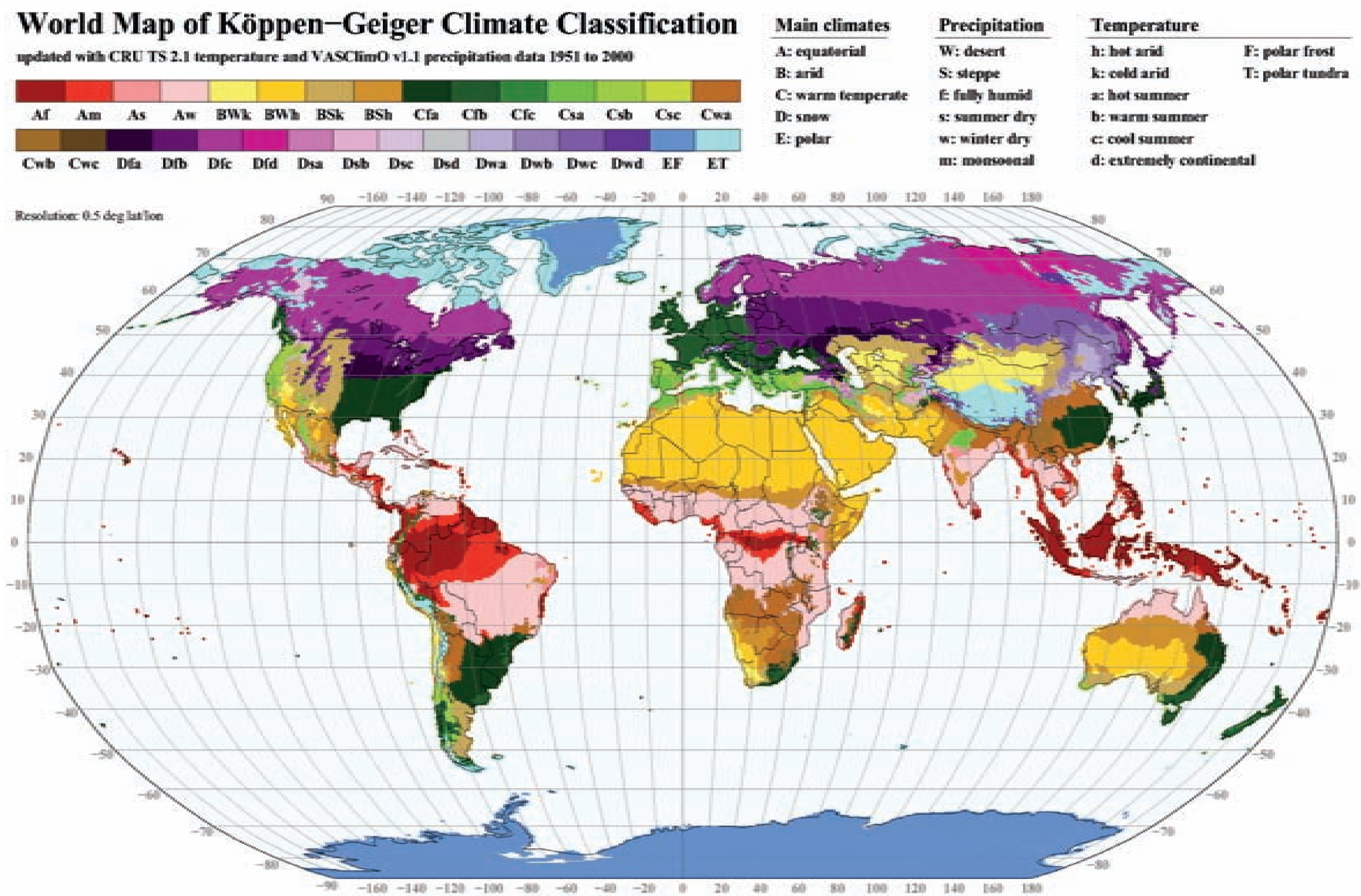

FIG. 150. *WORLD MAP OF KÖPPEN-GEIGER CLIMATE CLASSIFICATION*, 2006. The Köppen classification employing the standard three-letter classification system. While the details differ from figure 149, there is no greater resolution of climate areas than the map produced a century before; this is not for lack of data, but a concession to readability.
Size of the original: ca. 17.1 × 25.4 cm. From Kottek et al. 2006, 261. Permission courtesy of E. Schweizerbart Science Publishers, Stuttgart.

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Close (Arden-Close), Charles Frederick. Charles Frederick Close, who changed his legal surname to Arden-Close in 1938, was born in Jersey, Channel Islands, on 10 August 1865 (O'Brien 2002). He entered the Royal Military Academy, Woolwich, in 1882, and graduated in 1884, with a commission in the Royal Engineers. He spent time at the School of Military Engineering, Chatham, before serving in Gibraltar and again at Chatham. Posted to India for five years, starting in 1890, he was greatly impressed by the Survey of India's methods, which he introduced later, at Chatham, where he was appointed chief inspector of surveying. Seeking to serve in Africa, he was employed on boundary surveys, including that between British Central Africa, Rhodesia, and German East Africa. Contacts with David Gill and Cecil Rhodes at Cape Town influenced his ideas about mapping the continent. A brief posting to the South African War in 1900 saw Close carry out the first survey, including compiling a map for the campaign and printing it in the field in color. By 1902 Close was back at the School of Military Engineering, Chatham, where he found time to write the *Text Book of Topographical and Geographical Surveying* (1905). In 1904 he represented the War Office at a major conference, in Cape Town, on the topographic survey of South Africa, and in 1905 he was appointed to head the Topographical (later Geographical) Section, General Staff. Seizing the opportunity, he had set up the Colonial Survey Committee, whose reports reveal much of the uneven progress in mapping colonial lands between 1906 and 1913.

Close was appointed director general of the Ordnance Survey (OS) in 1911, and served with great distinction until 1922. During that period he pushed forward creation of the International Map of the World at 1:1,000,000. Although determined to reinvigorate OS mapping, especially at small scales aimed at both the general public and the military, he reluctantly accepted postwar retrenchment, which thwarted his efforts to restore scientific research to the OS, strengthen its archaeological work, and provide Britain with up-to-date modern maps and plans. Knighted for his work in World War I, Close was elected a fellow of the Royal Society in 1919.

After retirement, Close attended international meetings and served as secretary of the International Geographical Union (IGU) from 1922 to 1928 and as its president from 1934 to 1938. Between 1937 and 1942 he chaired the British National Committee for Geography, set up for the IGU by the Royal Society. During this period he supported the Palestine Exploration Fund, the English Place-Name Society, and the Geographical Association. Having initiated some early work on the history of the OS when he was director general, he published some of this research in *The Early Years of the Ordnance Survey* (1926) as well as many shorter reminiscences collected as a fifty-year retrospective in the *Empire Survey Review* (1932–34). Close died at Winchester on 19 December 1952. Published bibliographies (de Graaff-Hunter 1953; Freeman 1985) list most, but not all, of his publications.

CHRISTOPHER BOARD

SEE ALSO: International Map of the World; Ordnance Survey; Royal Geographical Society

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Cloth, Maps on. Maps were inscribed on cloth as early as the second century B.C. The earliest known cloth maps were military maps drawn on silk by the Chinese. Since that time many cultures have drawn, painted, stitched, and printed maps on silk, linen, cotton, agave cloth, rayon, and microfiber fabric.

Mapping surface and printing methods influence the appearance of a map and the amount of detail that can be shown. Printing maps on fabric is particularly challenging insofar as different fabrics have different textures. For example, silk is usually a finer weave and texture than cotton or linen, which tend to be coarser and thus less able to support a detailed cartographic image. What's more, the texture is dictated by the fineness of the threads and the number of threads per inch. Cloth was used before paper had been invented, but in the twentieth century, fabric was used because it is lightweight, durable, easily folded and concealed, and water resistant.

During the twentieth century maps printed on cloth were often dismissed as mere curiosities because many of them were intended as novelties or decoration rather than as spatial tools usable for wayfinding. In contrast to maps on clothing or home furnishings, which are clearly decorative, military maps and tourist maps rendered on cloth served more traditionally functional cartographic applications.

Military maps, especially the well-known escape maps of World War II, have been the most thoroughly studied. World War II–era escape maps are often called silk maps because they were first produced on silk. Great Britain was the first to employ escape maps, but Germany and the United States produced them as well (Doll 1999, 9). In the United States these maps were usually printed on rayon, a semisynthetic fiber made of cellulose. The maps were lithographed on both sides by mounting the fabric on a paper backing and, after printing one side, stripping the paper and repeating the process for the second side.

Maps on scarves and bandannas date from the nineteenth century, when maps such as the well-known Mitchell map were printed on silk or linen as well as on paper. The Smithsonian Institution has a collection of souvenir bandanna maps of the District of Columbia printed in 1933 by F. Schumacher & Co. and designed by Mildred G. Burrage. These bandannas were sold to raise money for the George Washington Parkway (Collins 1979, 427). In the mid-twentieth century, silk maps of individual states of the United States were sold as souvenir headscarves (fig. 151), and later in the century cloth maps designed for wayfinding were sold to tour-

FIG. 151. SOUVENIR SILK SCARF MAP OF OHIO FROM THE 1950s. Size of the original: 79 × 85 cm. Image courtesy of Judith A. Tyner.

ists. These fabric maps can also be considered decorative maps because they were advertised as maps that could be worn. The first examples of this genre were silk scarves marketed as a convenient way to carry a map without being obvious. The fact that they were easily compressible was an advantage because they could be packed or stuffed into a pocket. Tasaram, a major producer of these scarves, stated that they were inspired by the World War II escape maps (Plous 2003). These scarves were produced by a number of companies, and most focused on world cities popular with tourists, notably London, Rome, Paris, Washington, and New York. Two sizes were produced, 34 × 34 inches and 22 × 22 inches. Crumpling was not encouraged for long, thin versions produced as neckties.

A second type of tourist map was the fabMAP, introduced by Rand McNally in the early twenty-first century. Unlike the silk-scarf maps, these were smaller, measuring approximately 8 × 11 inches, and made of microfiber. Like the scarves, they highlighted tourist venues, in this case those in the United States such as the Las Vegas strip, Hollywood, and Waikiki (fig. 152). Advertised as serving the dual purpose of map and lens-cleaning cloth for digital cameras or eyeglasses, the fabMAPs were printed on both sides and included a legend and bar scale demonstrating that they were designed as maps, not curiosities. In preparing the images, Rand McNally used its own data as well as information from the spatial data supplier Navteq.

Bandanna maps, screen printed on cotton, were the third type of cloth-based tourist map in the late twentieth century. Unlike earlier bandanna maps, areas shown were primarily recreational areas, especially national parks and monuments, and the maps were marketed to outdoor enthusiasts, who could use them for wayfinding or—soaked in water and wrapped around the head or neck—a means of cooling off on warm days (fig. 153). Although contours were marked as well as roads, campgrounds, and other points of interest, they included a legend, but no scale, perhaps to discourage distance estimation, as cotton distorts when pulled. (A caveat printed on the maps warned that they were not to be used for compass navigation.) In addition, the relative coarseness of the fabric did not permit fine detail. The Printed Image, a Chico, California, company that specialized in printing maps on clothing, including tee shirts and tote bags, licensed the map images used for the bandannas from Tom Harrison Maps, another California firm.

Maps on cloth in the twentieth century have been little studied. With the exception of World War II escape maps, relevant information is found largely in advertisements for scarves and bandannas.

JUDITH A. TYNER

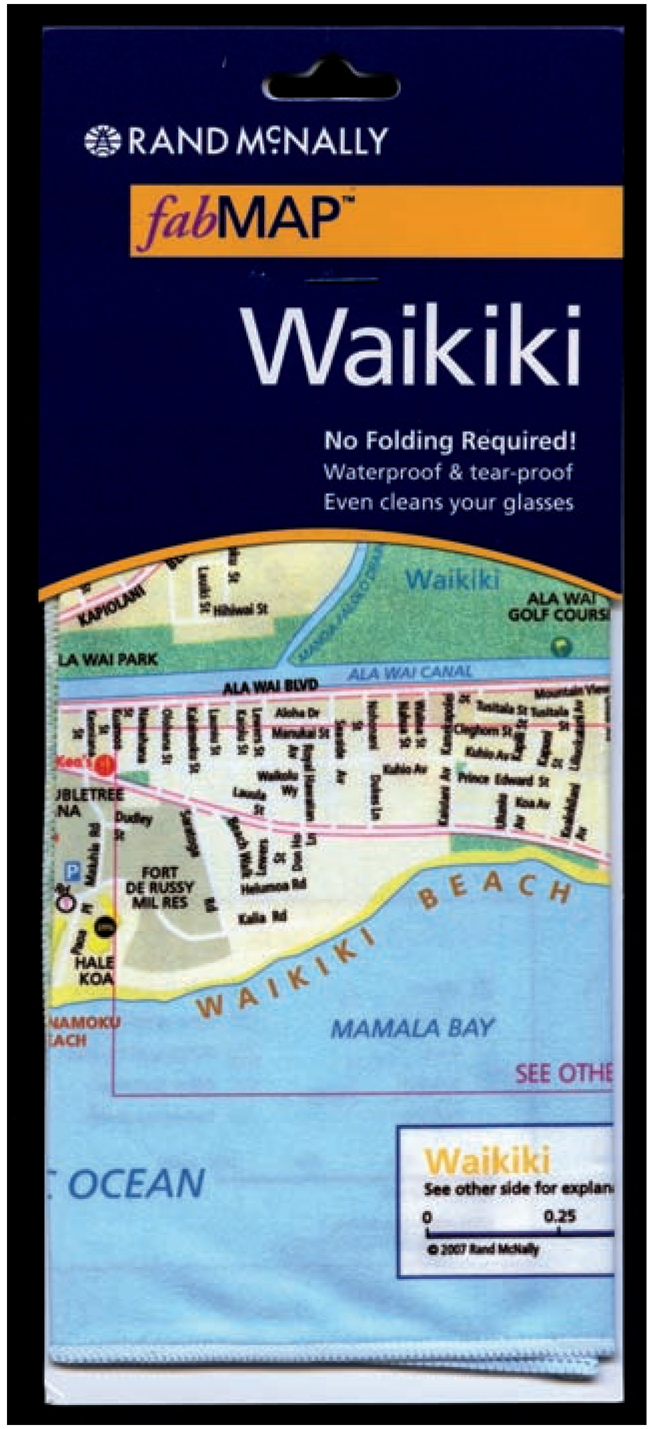

FIG. 152. WAIKIKI FABMAP BY RAND MCNALLY, 2007. Size of the map unfolded: 20.7 × 30.2 cm. Map © Rand McNally; R.L. 11-S-001.

SEE ALSO: Decoration, Maps as; Map: Printed Map; Wayfinding and Travel Maps: Escape and Evasion Map

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FIG. 153. DETAIL FROM LATE TWENTIETH-CENTURY BANDANNA MAP OF JOSHUA TREE NATIONAL PARK, 1991. Designed by Tom Harrison and sold by Nature Facts Bandanas, Chico, California.
Size of the entire original: 54.3 × 54.3 cm; size of detail: 14.5 × 14 cm. Permission courtesy of Tom Harrison Maps, San Rafael.

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CNIIGAiK (Russia). See Tsentral'nyy nauchno-issledovatel'skiy institut geodezii, aeros"yëmki i kartografii (Central Research Institute of Geodesy, Air Survey, and Cartography, Russia)

Coastal Mapping. Cartographic coverage of the world's coastlines, including areas immediately onshore and offshore, expanded appreciably between the years 1900 and 2000 in both areal extent and level of detail. This expansion reflected technological advances, particularly in the use of aerial imagery and acoustic sounding; increased recognition of coastal areas as hazard zones and fragile environments; and sustained interest in maritime safety and military planning. Motivated by imperial ambition or geopolitical anxiety, Great Britain, Japan, the Soviet Union, and the United States, among others, mapped their own coasts as well as more distant shorelines along which military action was plausible if not anticipated.

As in the nineteenth century, the coastline itself was mapped in different ways by topographers and hydrographers, who usually employed separate vertical datums, which resulted in at least slightly dissimilar land-water boundaries. Throughout the early decades of the twentieth century, a topographic survey party moved along the coast on foot, describing and mapping the apparent high-water shoreline with a sketchbook, plane table, and telescopic alidade. The plane table included a drawing board with spirit levels at right angles and a tripod with a ball-and-socket mechanism for leveling the drawing board. In plotting the shoreline on a field sheet affixed to the drawing board, the topographer relied on a graduated straightedge aligned with the alidade's telescope and a stadia rod with uniformly spaced divisions. To estimate distance to the stadia rod, held vertically several hundred feet away, he counted the number of divisions between thin horizontal stadia hairs ground into the top and bottom of the sighting glass. Using the straightedge, he added the scaled distance to the cumulative traverse on the field sheet and sketched in noteworthy departures from a straight line. Taking additional sightings, he sketched in roads, fences, significant buildings, and other notable features. When the traverse neared the edge of the paper, he started a new sheet, which could be integrated with the other field plots to produce a composite map of shoreline topography. To fit the map into a proper cartographic framework, the topographic party periodically tied its shoreline traverse to triangulation stations with comparatively accurate known locations established earlier by a geodetic survey.

To complete the coastal survey, a hydrographic party probed offshore waters for channels and hidden dangers by running soundings outward from the shore along evenly spaced straight lines, typically parallel to each other but often configured in a rectangular system when the chart included a harbor or small embayment. Shallow depths could be measured with a graduated pole, whereas deeper waters required a lead line, marked in feet or fathoms and drawn downward by a heavy weight. Each sounding was plotted on a boat chart at a position estimated using a sextant to measure the angles between lines of sight to prominent landmarks or special signals erected onshore at known locations on the topographer's map. After one assistant used the sextant to measure the angles between sight lines to three successive signals, another aide transferred the resulting two angles to a three-arm protractor called a station pointer; by aligning its three arms to the known locations, he quickly plotted the sounding's position on the boat chart. Prominent buoys tied into the topographic survey were also used for triangulation.

A close survey with soundings every ten yards along sounding lines twenty yards apart generally guaranteed an adequate map of the seafloor in troublesome areas in which a lead line might easily miss a coral reef, pinnacle rock, or isolated boulder. But even a close survey could occasionally miss a thin hazard rising sharply from the seafloor. To ensure safe navigation and identify areas requiring a close survey, hydrographers sometimes supplemented their soundings with a wire-drag survey, in which a wire 3,000 to 12,000 feet long, supported by a chain of buoys and weighted down to a specific depth by sinkers, was dragged slowly through the water between two boats (see fig. 385). While careful observation of the intermediate buoys would indicate an obstruction extending above the set depth, the wire drag provided no other information about the elevation or configuration of the seafloor (Weber 1923, 20).

Designed to warn of submerged dangers, soundings are logically referenced to a low-water tidal datum, rather than to the high-water line surveyed by coastal topographers. Development of the clock-driven recording tide gauge in the mid-nineteenth century fostered careful calibration of sounding datums, and the construction of an analog tide predicting machine by William Thomson, Baron Kelvin, in 1873 led to reliable local tide tables with which mariners could relate a ship's draft to charted soundings. U.S. Coast and Geodetic Survey (USC&GS) charts issued in 1900 referred soundings along the Atlantic and Gulf Coasts to mean low water (the average of all low waters) but referenced soundings along the Pacific Coast to mean lower low water (the average of the lower of each day's two low tides) because successive low tides there often differed by three feet or more. In 1980, the National Ocean Service (NOS)—the agency was renamed in 1970—further standardized its charts by adopting mean lower low water as the tidal datum for the Atlantic and Gulf Coasts, while Great Britain and many other nations continued to relate their soundings to the lowest astronomical tide, which the International Hydrographic Organization recommends and the American military prefers. (Because severe weather can produce a tide lower than forecast, the predicted lowest astronomical tide is hardly foolproof.) The U.S. Geological Survey further complicated matters by taking the mean high-water line shown on USC&GS charts as the coastline for its large-scale topographic quadrangle maps but using mean sea level as the vertical datum for contour lines and other onshore elevations.

In integrating the efforts of coastal topographers and hydrographers, early twentieth-century American navigation charts could accommodate only a sampling of the latter's soundings—typically the lower (shallower) soundings, which represented the more hazardous waters in their immediate vicinity—while the landward portion of the chart focused on features of importance to mariners and rarely depicted areas more than a mile inland (fig. 154). And because rigidly uniform, geographically complete coverage was not essential, government agencies and private firms producing coastal charts not only allowed significant overlap among adjoining charts but also employed a wider variety of scales and sheet sizes than those used for topographic quadrangle maps.

World War I made coastal charting agencies aware of the promise of overhead imagery, but serious experimentation did not begin until the 1920s. The USC&GS established a photogrammetry unit in 1922, and became strongly committed after a resurvey of the Florida coastline later in the decade demonstrated that aerial imagery could capture topographic detail for a significant area at a cost no greater than the ground survey of a much narrower band along the shoreline (fig. 155). Experimentation led to the development of a nine-lens camera that could photograph a strip 11 miles (18 km) wide on a roll of film 23 inches (58 cm) across (Reading 1935). The camera, which weighed 300 pounds (140 kg), was no less important than its associated "transforming printer," which could combine all nine images onto a single composite photograph 35 inches (89 cm) on a side. The eleven-mile strip was sufficiently broad to encompass a generous ribbon of mainland and most coastal islands in a single flight. Because of the resulting cost savings, photogrammetry and tide-coordinated air photos, carefully timed to capture the high-water line, displaced the plane table during the 1930s and 1940s.

Remote sensing claimed a wider role in the late 1950s, when color photography afforded more revealing images of shallow water. A decade later color infrared imagery supported special projects focused on currents, seafloor habitats, or land cover, and in the 1980s the NOS began to rely heavily on orthophotographs (displacement-free areal images). By the late 1990s terrestrial lidar, a computationally intensive imaging technique using pulsed light beams fired from an airplane, was mapping coastal terrain with elevations accurate to within 15 cm (6 inches). Although high resolution satellite imagery was occasionally used for coastal cartography, cost considerations favored conventional aircraft. Even so, satellites play an important role in lidar, which uses Global Positioning Systems (GPS) to estimate the aircraft's exact position.

In much the same way that aerial imagery enhanced the accuracy and cost effectiveness of topographic mapping, acoustic sounding (also known as sonar, for sound navi-

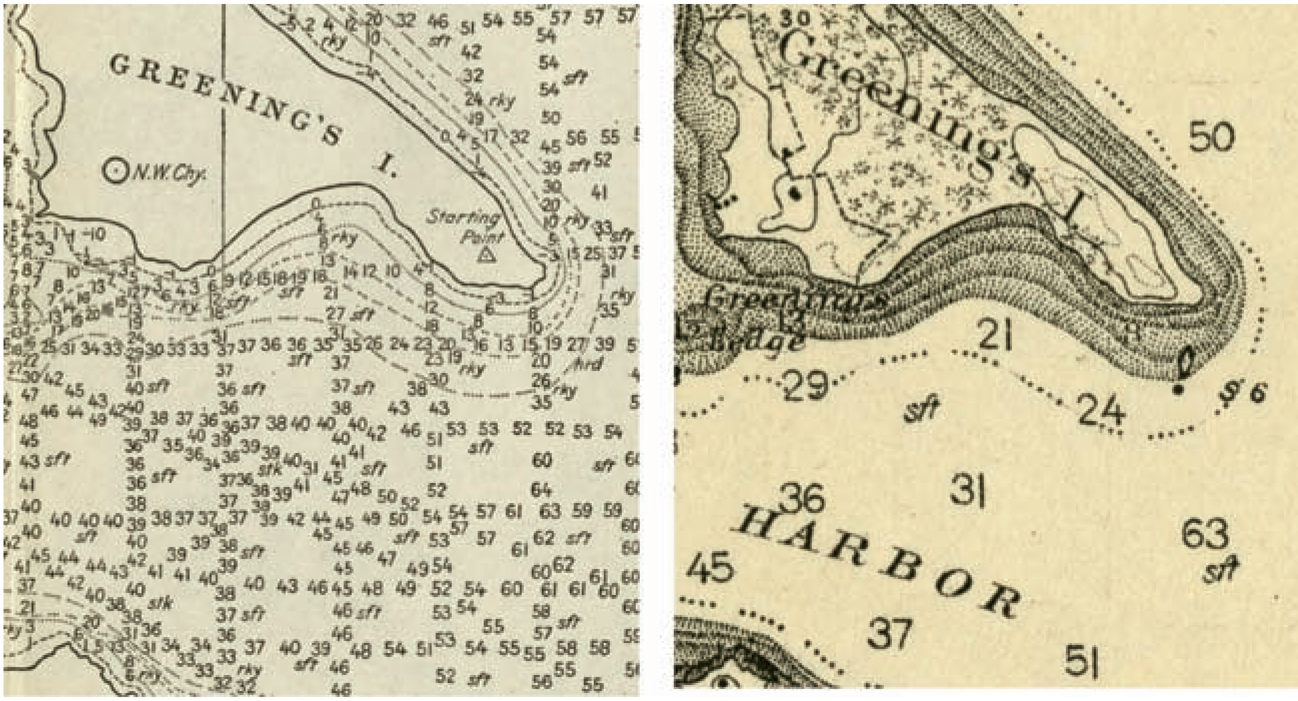

FIG. 154. COMPARISON OF HYDROGRAPHIC SURVEY WITH NAUTICAL CHART. An early twentieth-century hydrographic survey (left) and the corresponding portion of a completed nautical chart (right) for waters near Mount Desert Island, Maine. The finished chart is more enlarged here for ready comparison.
Size of the originals: 19.5 × 23.2 cm (left) and 19.6 × 22.6 cm (right); size of details: 7.2 × 6.6 cm (left) and 3.6 × 3.3 cm (right). Composited from Jones 1916, figs. 22 and 31.

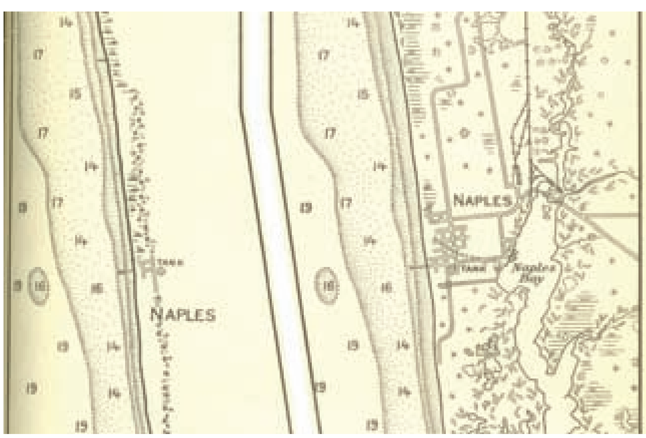

FIG. 155. COASTAL CHART COMPARISON. Corresponding portions of a coastal chart for an area near Naples, Florida, using a limited ground survey (left) and aerial photography (right).
Size of the entire original: 17.6 × 11.5 cm; size of detail: ca. 7.7 × 11.5 cm. From *Annual Report of the Director, United States Coast and Geodetic Survey to the Secretary of Commerce for the Fiscal Year Ended June 30, 1930* (Washington, D.C.: U.S. Government Printing Office, 1930), facing 18.

gation and ranging) revolutionized hydrographic surveying during the twentieth century. With roots in antisubmarine sensors developed toward the end of World War I, sonar measures distance from the water surface to the seafloor—or to a school of fish or other reflective object in the water—by generating an acoustic signal and timing its return. Hydrographic surveys began using acoustic sounding to map in deep water during the 1920s and in shallow water in the 1930s. Systems that transmitted and received signals from a "towfish" attached to the hydrographic vessel by a cable and towed at depth near the seabed could capture a detailed image of the ocean floor. Electronic computing greatly improved the efficiency of these systems, which were largely classified until the 1970s. A more recent technology is bathymetric lidar, developed to map relatively shallow water from an aircraft. Similar to terrestrial lidar, it works only in clear water, by comparing elevations captured using red beams, which are reflected from the water surface, and green beams, reflected from the seafloor. Filtering algorithms designed to remove structures and vegetation yielded the bare earth images and elevation models sought by coastal topographers.

Like other cartographic genres, coastal charts reflect improvements in reproduction technology, particularly the wider use of color printing, which enhanced the contrast between land and water, highlighted the area between low- and high-water shorelines, and underscored key bathymetric contours. Toward the end of the century, electronic technology promoted the timely delivery of revised charts, which could be reproduced at marine supply dealers on large-format one-off color printers or displayed onboard as an electronic chart transmitted over the Internet. Although electronic charts held the promise of automatically correlating shallow water and submerged hazards with a ship's position, estimated to within a meter or less by differential GPS, their bathymetric lines and hazard symbols were typically captured from existing charts and thus hampered by uncertainties on the order of 30 and 120 meters for scales of 1:20,000 and 1:80,000, respectively. Navigation expert Nigel Calder (2003, 41) underscored the dangers of overzooming an electronic display to an appropriately large scale and cautioned that "the user of any chart should not be lured into a false sense of security about its accuracy." While some maritime nations were reluctant to sacrifice their traditional chart symbols, electronic charting stimulated increased collaboration on international standards.

The latter half of the twentieth century witnessed the emergence of two new cartographic shorelines, supplementing the high- and low-water lines reported on marine charts. Although all four delineations depict coastal hazards, they address different concerns and rarely share the same map. The third shoreline, which depicts likely inundation from storm surge, informs flood insurance maps, evacuation plans, and land use restrictions; the fourth shoreline, representing the plausible rise in sea level associated with climate change, is used to compare approaches to wetlands management and to rally support for reducing carbon emissions (fig. 156). Heavily

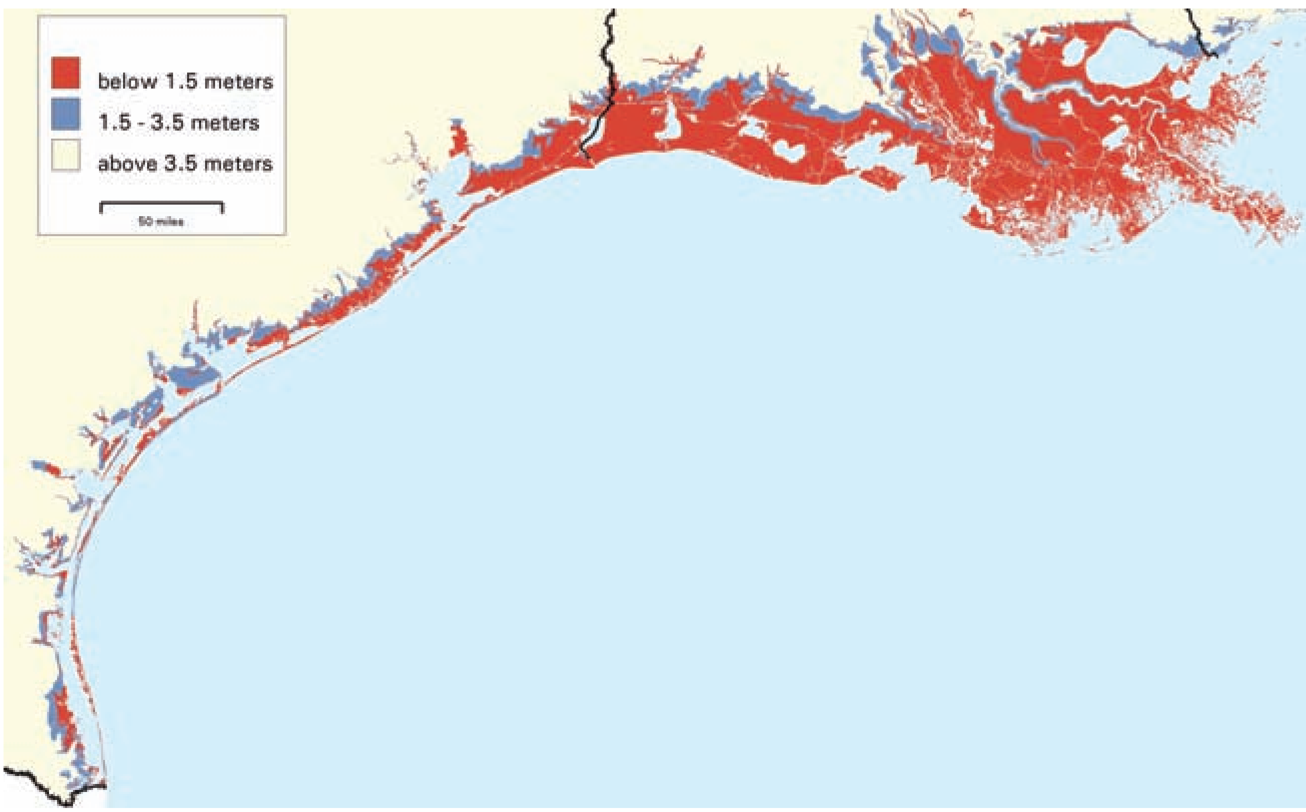

FIG. 156. LANDS CLOSE TO SEA LEVEL RISE ALONG THE WEST GULF COAST OF THE UNITED STATES. Accompanying the map on the EPA website was a carefully worded explanation: "This map is based on modeled elevations, not actual surveys or the precise data necessary to estimate elevations at specific locations. The map is a fair graphical representation of the total amount of land below the 1.5- and 3.5-meter contours; but the elevations indicated at particular locations may be wrong. Those interested in the elevations of specific locations should consult a topographic map. Although the map illustrates elevations, it does not necessarily show the location of future shorelines. Coastal protection efforts may prevent some low-lying areas from being flooded as sea level rises; and shoreline erosion and the accretion of sediment may cause the actual shoreline to differ from what one would expect based solely on the inundation of low land. This map illustrates the land within 1.5 and 3.5 meters of the National Geodetic Vertical Datum of 1929, a benchmark that was roughly mean sea level in the year 1929 but approximately 20 cm below . . . sea level [in 2001]." Enlarged excerpt from Titus and Richman 2001, 217 (fig. 4).
Image from the U.S. Environmental Protection Agency, Climate Change website.

dependent on numerical modeling and evolving scientific understanding of physical processes, these two new land-water boundaries exemplify the emergence of time as a cartographic frontier in the nineteenth and twentieth centuries, when earth system forecasting became an important mapping application.

MARK MONMONIER

SEE ALSO: Hydrographic Techniques; Law of the Sea; Lidar; Marine Charting; Photogrammetric Mapping: Aerial Photogrammetry and Cartography; Plane Table; Topographic Mapping

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Cognition of Maps. See Perception and Cognition of Maps

Cold War. The Cold War (1945–91) was a continuous international military and economic conflict waged primarily between the United States and the Soviet Union. Though mutual animosity separated the two nations since the early 1920s, they nevertheless cooperated to crush fascism during World War II. With fascism defeated, the United States and the Soviet Union renewed their differences. The two superpowers clashed over the rebuilding of Europe, the legitimacy of new postwar states, nuclear arms proliferation, the space race, industrial resources, and the fate of many underdeveloped, nonaligned (Third World) nations. Virtually all Western European–style capitalist democracies sided with the United States, including the British Commonwealth, France, West Germany, Italy, Japan, and most of Latin America. The Soviet Union controlled Eastern Europe and struck close relations with communist nations including North Korea, Mongolia, China (by 1949), Cuba (by 1959), and North Vietnam (Vietnam by 1975).

State propaganda, espionage, and the international media were especially important in this war as both sides sought dominance in nonaligned nations. The Cold War ended in late 1991 with the internal collapse of the Soviet planned economy, the breakup of the Soviet Union itself, and the subsequent mass immigration of thousands of Eastern Europeans to Western Europe.

The Cold War had a monumental impact on cartography. New aerial photography and land-measurement technology, developed as tools for the Cold War, allowed for more accurate and comprehensive mapping projects. The north and south polar regions were directly mapped for the first time in human history. The space age, with its satellite technology, ushered in the modern era of space-based geodesy and mapping on a truly global scale. Cold War geopolitics promoted the use of specific kinds of map projections—both new and old. But while the Cold War fostered new mapping technology, it also prioritized cartographic information as a military resource. Cutting-edge Cold War cartographic information was normally the sole domain of the superpower governments and was usually out of civilian hands. Thus, cartographic secrecy was a major by-product of the Cold War.

From the end of World War II to the 1960s Cold War cartographers were heavily influenced by the air age. Though man achieved powered flight in the 1920s, the air age (and air-age mapping) reached its climax in the first two decades of the Cold War. The rapid development of military aircraft and remote sensing technologies during and after World War II greatly increased the accuracy of government and civilian maps. The greatest airplane-based remote sensing developments occurred in the fields of photogrammetry and radar mapping.

The earliest remote sensing technology was photogrammetry, which used aerial photography to measure distance and elevation. The idea of using photography to create more accurate maps dates to the early nineteenth century. However, from the end of World War II to the late 1950s aerial photography and mapping were exceptionally useful to Cold War cartographers. In addition, the U.S. Geological Survey used aerial photographs as the basis for its standard quadrangle maps, and photogrammetric maps, that is, maps made directly from aerial photos and measurements, became popular in the U.S. press shortly after World War II.

The use of radio detection and ranging, or radar, to assist in mapmaking began during the Cold War. Land-based radar was experimental in World War II and lacked the power and resolution to be used for terrestrial surveys and mapmaking. In the early 1960s the U.S. Air Force developed the first airborne radar technology, called side-looking airborne radar (SLAR), which could detect enemy aircraft in any weather. The declassification of SLAR in 1970 signaled a wave of radar-generated mapping projects in the private sector. Since radio waves pass through clouds, SLAR allowed cartographers to accurately map the many tropical and polar regions frequently covered by clouds. In the 1970s SLAR maps provided the first accurate views of Central America, the Amazon River Basin, Central Africa, and Antarctica.

Geodesy, the science of measuring the earth, was indispensable to both superpowers during the Cold War. Geodetic surveys provided more precise visions of the earth's features—visions that featured strongly in Cold War military and political ideology—and promised the accurate destruction of targets by missiles launched from another continent. The United States based its Cold War air and space defense networks on military-sponsored geodetic survey data. Similarly, the Soviet Union developed its own geodetic measuring system, which helped unify the Eastern Bloc and the space race between the superpowers brought modern geodesy into the space age.

Both superpowers conducted international geodetic surveys of lands in and around their respective nations in the 1920s and 1930s. The North America Datum of 1927, which framed topographic and military mapping in the United States, was too outdated and imprecise to be useful in Cold War defense planning. By the late 1950s the advent of guided missile technology required a more precise system of land survey data. In 1959 the U.S. Air Force ordered a geodetic survey of the Cape Canaveral area of Florida, where many missile-tracking stations were located, to get more exact locations of the stations. The survey, which benefited from a relatively new light-wave-based Geodimeter, resulted in an accuracy factor of 1 part in 1,000,000. Previously, the most accurate survey data were accurate only to about 1 part in 50,000.

In 1961 the U.S. Department of Defense funded a similarly accurate survey of all of North America, called the High-Precision Transcontinental Traverse (HPTT), to more precisely locate new satellite-tracking stations across the Eastern Seaboard. Notably, the HPTT was the last major land-based survey in the United States. By the mid-1960s cutting-edge geodesy had entered the space age.

Though the science of geodesy dates back to the ancient Greeks, the exact shape of the earth (also called the figure of the earth) was not known when the Cold War began. Until the advent of satellite technology, geodetic measurements could be made only on land. Land-based surveys could not directly measure the majority of the earth's surface—the oceans. Also, earthbound scientists could not factor differences of terrain into larger models of geodetic theory. The greatest leaps in Cold War geodesy were made with the aid of space-age satellites, which could, for the first time, view and measure the earth's features from very high altitudes.

The very first artificial satellite, the Soviet Union's Sputnik, launched in 1957, proved that satellites could benefit geodesy in two ways. First, deviations in satellite orbital paths could be measured to learn more about the shape of the earth. American scientists, who were intently tracking Sputnik for signs of aggression, recorded strange dips and rises in its orbital path that revealed variations in the earth's gravitational field. This was convincing evidence that the planet was not a neatly rounded ellipsoid (a sphere flattened at the poles). The National Aeronautics and Space Administration's (NASA) tracking of its Vanguard satellite in 1958 proved the earth was not ellipsoidal as previous theories held, but pear shaped. Radio Doppler tracking technology of the 1960s and laser tracking technology of the 1970s culminated in maps of the earth's surface accurate within 10 centimeters, which better-defined earth's bumps. The "bumpy pear" image of the earth revealed by Cold War satellites forever changed the highly symmetric nondimpled model of the planet.

Second, Sputnik proved that satellites could be reliable platforms for radio traffic and hence for radio triangulation from space. Although the Soviet Union had been the first to place a satellite in orbit, the American government made fuller use of satellite triangulation for Cold War military purposes than its competitor. In the 1960s NASA launched dozens of navigation satellites, and by 1970 a constellation of NASA satellites allowed the U.S. Navy to use satellite triangulation to track and direct its ships with greater precision than ever before. Later the Air Force used satellite navigation for cruise missiles and other long-range weapons. Although developed for the military, satellite triangulation would find its greatest use many years later in the civilian sector (see below).

The Soviet Union prioritized the gathering of geodetic information throughout its history. In 1919 Vladimir Il'ich Lenin brought state cartographic and geodetic projects together in a new agency called the Vyssheye geodezicheskoye upravleniye (VGU). This agency became a state ministry in 1938 and was renamed the Glavnoye upravleniye geodezii i kartografii (GUGK, see table 18). During the Cold War this national ministry's authority was extended into the Eastern European nations. Until the mid-1960s the most accurate state geodetic survey data and topographic maps were classified. However, workable topographic maps were available to military and civilian sectors for general construction and survey projects. In 1965 in response to American advancements in global satellite geodesy, the Soviet Union upgraded the secrecy of geodetic information. At a 1965 conference of the heads of geodetic services of socialist states, virtually all state geodetic and cartographic information became strictly classified (Brunner 2006, 160). For the duration of the Cold War this excessive state secrecy made it very difficult for the Eastern Bloc nations to carry out state construction projects.

The Global Positioning System (GPS), which uses many satellites to determine a user's location on the earth at any time of the day or night, was a product of Cold War–era U.S. military technology. Though NASA satellites dominated earth's orbital space by 1970, U.S. military leaders recognized the vulnerability of the satellites to breakdown and enemy attacks. To address this problem, in 1973 the U.S. Department of Defense began design work on a new system called Navstar GPS. The first satellite was launched in 1978, and by 1993 the complete constellation of twenty-four satellites, including three working spares, was in place. Each satellite orbits the earth twice a day at an altitude of 20,200 kilometers and is always in contact with at least three other satellites in the system. Each satellite broadcasts a signal that identifies its instantaneous location and includes the current time. Because these timed radio signals arrive more quickly from a satellite that is relatively close, a GPS receiver can be used to calculate the user's position from differences among the signals from several visible satellites.

For the first ten years of GPS operation, only the U.S. military was allowed access. GPS technology was top secret, and the necessary equipment was too costly for the civilian market. Demand for commercial access increased, and in 1988 the government made GPS broadcasts selectively available for commercial use by introducing a blurred time signal that allowed the instantaneous calculation of horizontal position accurate to about thirty meters. NASA reserved the higher accuracy channels for official government use until the end of the Cold War. In 1991, during the First Gulf War, U.S. troops used hand-held GPS receivers in combat for the first time. By the early 1990s the ready availability of inexpensive, hand-held GPS satellite receivers in the private market caused an explosion of commercial GPS mapping and survey projects all over the world. It is hard to imagine a handier device for terrestrial explorers, surveyors, and mapmakers. Following removal of the Selective Availability constraint in May 2000, GPS receivers proliferated in cell phones, vehicle navigation systems, and location-tracing devices for monitoring parolees and sex-offenders.

In terms of projections, the Mercator, which had dominated global mapping since the late sixteenth century, was very popular throughout the Cold War, as were other equatorial projections with less distortion near the poles. The wide spaces between landmasses on Mercator maps allowed the United States and the Soviet Union to express differences between the capitalist West and the communist East. American maps, centered near the Chicago meridian, often devalued the Soviet Union by dividing the Eurasian landmass and placing the two halves at opposite sides of the map. American news journals regularly used Mercator maps to defend the Monroe Doctrine, especially during the Cuban Missile Crisis of 1962. Soviet Mercator maps, with the Moscow meridian near the center, portrayed the United States as a meddling interloper in Eurasian affairs from across the wide Atlantic and Pacific Oceans.

Much has been made of the distortions of the Mercator projection, but these distortions helped keep the projection popular throughout the Cold War. The Mercator projection's exaggeration of area in higher latitudes was exploited by both superpowers in cartographic propaganda. Since the earliest years of the communist government, the Soviet Union recognized the projection's propaganda value. Lenin ordered Mercator maps for state-sponsored atlases after World War I (fig. 157). The exaggerated size of the Soviet Union—often over 200 percent larger than normal on the Soviet state's Mercator maps—bolstered national pride throughout the Cold War. Andrei Gromyko, Soviet foreign minister from 1957 to 1985, decorated his study with a large Mercator map, which he claimed reinforced his ideas of Soviet dominance of Eurasia.

The United States used Mercator maps to argue for the containment of the hulking Soviet empire. The containment policy (1947), whereby American-led capitalist nations sought to physically surround the Soviet Union and, after 1949, communist China as well, was effectively illustrated with Mercator maps in news journals and state documents. On these maps, European nations in the Marshall Plan, the British and French colonies of the Middle East and Southeast Asia, and American military bases in the Far East formed a continuous barrier around menacing communist Eurasia. In addition, the North Atlantic Treaty Organization (NATO) often used Mercator maps in its publications and press releases.

Cold War cartographers frequently used other projections that emphasized the roundness of the earth. The air age allowed man to see and map the earth from great heights for the first time. Innovative cartographers began to reject the flat plane of the Mercator projection and other equatorially centered frameworks in favor of projections that related the perspective of air pilots. These were called perspective maps or airman's view maps. The greatest proponent of airman's view maps was the American civilian cartographer Richard Edes Harrison.

FIG. 157. EARLY SOVIET MAP ON THE MERCATOR PROJECTION, *THE ANNIHILATION OF KOLCHAK AND HIS FOLLOWERS, SEPTEMBER 1919–1922*. Size of the original: 13.7 × 21.6 cm. From "What Business with Russia?" *Fortune* 31, no. 1 (1945): 153–57, 195–202, esp. 157 (bottom).

Working for American national news journals, including *Fortune* and *Life* in the mid-1930s, Harrison became dissatisfied with the inaccuracies of Mercator maps. He criticized the cartographic profession for allowing these inaccuracies to distort public perceptions of geography. Harrison's maps sought to portray the roundness of the earth as seen from very high altitudes. Moreover, Harrison frequently departed from a North Pole orientation for his maps, favoring oblique orientations used by commercial and military pilots.

One of the most popular types of airman's view projections popularized by Harrison during the Cold War was the polar projection. Polar projection maps (maps centered on the polar regions) date to antiquity. They are zenithal maps, also called azimuthal maps, which attempt to portray the round surface of the globe. Mercator maps often included a pair of insets covering the polar regions with polar projection maps—a useful enhancement because the increasing north-south scale of the Mercator framework precludes showing the two poles. But until man began to fly, Mercator's flat projection, so favored by maritime navigators, dominated Western global cartography. Harrison's polar projection maps, which gained favor as the air age matured during World War II, were popular throughout the Cold War.

The north polar region and north polar projection maps factored heavily in Cold War geopolitics (fig. 158). For Americans, the Cold War meant that the greatest military threat, the Soviet Union, was uncomfortably close across the Arctic Circle and the Bering Strait. The progressive technology of airplanes, radar, missiles, nuclear weapons, submarines, and satellites made the air space over the north polar region a centerpiece of U.S. Cold War strategy. In the U.S. press, north polar projection maps were the standard for illustrating national and international polar defense networks ringing the Arctic Circle from the Aleutian Islands to Greenland. Although the secrecy of Soviet state maps precludes an assessment of the importance of polar projections in the Soviet Union, Soviet use of north polar projection

FIG. 158. ANTICOMMUNIST POLAR PROJECTION MAP, *TWO WORLDS, 1950*, BY ROBERT M. CHAPIN. Size of the original: 27.7 × 38 cm. From *Time* magazine 55, no. 1 (2 January 1950): 34–35.

maps was surely necessary for the Arctic war games conducted throughout the Cold War. Moreover, the use of north polar projection maps in Soviet political cartoons criticizing American military actions above the Arctic Circle suggests that the projection was widely recognized throughout the Eastern Bloc.

Cold War international interest in Antarctica inspired comparatively few south polar projection maps, most notably among nations with territorial claims on the southern continent. U.S. Navy Admiral Richard Evelyn Byrd's second flight over the South Pole in 1946 (his first was in 1929) was celebrated in the nation's press with numerous polar projection maps. Even so, American interests in Antarctica were largely scientific, and the federal government had not recognized any nation's territorial claims there since the 1920s. By contrast, Britain had several territorial claims in or near Antarctica, which were challenged by Chile and Argentina. British political atlases published in the 1950s featured large polar projection maps, which included the Falkland Islands as a crown colony and validated British scientific and territorial claims while they omitted competing claims such as Argentina's lust for the Islas Malvinas (as the Falklands are known in Spanish). Norway and the Soviet Union also had claims in Antarctica but, like the United States, they were preoccupied with the North Pole throughout the Cold War.

The south polar region was never as important to the Cold War superpowers as the north polar region for several reasons. First, it was the North Pole that separated the two superpowers, not the South Pole. The various Cold War polar defense and warning networks established by both sides in the Arctic were absent in Antarctica. Second, regular commercial air traffic, which was established over the Arctic Circle in the 1950s, was never established over Antarctica. Third, the continent of Antarctica was established as a "global wilderness" by the superpowers in a 1959 international treaty, which suspended indefinitely any territorial claims to the region. For the rest of the Cold War period, the southern continent was viewed by all industrialized nations as an international scientific zone. From 1960 to the end of the Cold War, cartographic attention to the region decreased dramatically.

Cold War geopolitics of the 1960s and 1970s influenced the creation of two new map projections. In 1963 University of Wisconsin cartographer Arthur H. Robinson devised the Robinson projection to more accurately represent landforms in the higher latitudes. The projection was, no doubt, partially inspired by the American need to shrink the size of the Soviet Union on maps. His elliptical projection reduced the exaggeration of the Soviet Union from over 200 percent on Mercator and Van der Grinten projections to less than 20 percent. The roundness of the earth was seen best at the edges of the map. Robinson projection maps became popular in American classrooms in the 1970s and 1980s. At the height of the projection's popularity in the late 1980s, the National Geographic Society replaced the Van der Grinten projection normally used for its world atlas maps with the Robinson projection.

The rise to prominence of equatorial Third World nations in Cold War geopolitics in the late 1960s and early 1970s compelled many mapmakers to rethink the European focus of widely used projections. In 1973 the German historian Arno Peters devised the Peters projection to counter what he called the Eurocentric bias of projections popular in Western colonizing nations. Because his projection is essentially identical to an equal-area cylindrical projection secant at 45° introduced in the mid-nineteenth century by James Gall, it became known in many circles as the Gall-Peters projection. To more accurately portray the relative sizes of nations near the equator, the land areas in the higher latitudes were deformed and squashed (e.g., Greenland and Antarctica were thin, horizontal bands). Elsewhere the world's landmasses appeared to be stretched from north to south, which emphasized the continents of South America and Africa as well as India and China. Though not well received by cartographic scholars, the Gall-Peters projection was popular during the Cold War era among many international organizations, including the World Council of Churches and the United Nations.

It is not surprising that both the United States and the Soviet Union practiced cartographic secrecy during the Cold War. The United States had a long history of omitting important military installations on topographic maps before World War II. During the Cold War, the government routinely omitted federal military sites including Camp David in Maryland, "Area 51" in Nevada, and the North American Aerospace Command (NORAD) in Colorado. And as previously noted, GPS radio signals were prioritized for military use while civilian users were provided less accurate signal frequencies. Even so, the U.S. government was far more open about cartographic information than was the Soviet government.

The Soviet Union had practiced map secrecy since the 1930s, but the Cold War triggered a surge of secrecy not seen in Europe since the Enlightenment. After World War II Soviet citizens were denied access to large-scale maps of any kind. Smaller-scale maps were subject to misinformation and omissions. Not only did important government sites disappear from public maps, so did dozens of Soviet cities. In the mid-1960s, in response to the new satellite-based American geodetic surveys, the Soviet Union decided to completely classify almost all state cartographic information. The 1965 conference of the heads of the geodetic services of socialist states severely restricted public access to recent geodetic surveys and topographical maps. Even small-scale maps on the order of 1:2,500,000 were withheld from the public. All the nations of communist Eastern Europe were ordered to uphold the same levels of map secrecy.

The new level of map secrecy was especially problematic for Communist Bloc countries. Official state maps now had to be processed twice—once for accuracy and once for secrecy—which severely delayed the production time of reliable maps. Public works projects in Eastern Europe ordered from Moscow were severely delayed due to a lack of accurate geodetic information. By the same token, international survey and construction projects within the Eastern Bloc were severely hampered because maps made for public use were purposely distorted. East German citizens were particularly victimized by this state secrecy insofar as accurate Soviet maps of the West German border were not available to the public until the 1990s.

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SEE ALSO: Air-Age Globalism; Geodesy: Geodesy and Military Planning; Geopolitics and Cartography; Harrison, Richard Edes; Radó, Sándor (Alexander Rado); Robinson, Arthur H(oward); U.S. Intelligence Community, Mapping by the

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Collecting, Map.

CANADA AND THE UNITED STATES
EUROPE

Map Collecting in Canada and the United States. It was only in the later nineteenth and twentieth centuries that map collecting became relatively popular in North America. A more general interest in old maps among historians and collectors began to emerge in the mid-nineteenth century, when the use of lithography to reproduce old maps became widespread. The quadricentennial of Columbus's discovery of the continent provided an important impetus to the study of American cartography, and books by historians Justin Winsor (1884–89), Henry Harrisse (1892), and John Boyd Thacher (1896), among others, offered numerous reproductions of important maps to a wide public. The bibliography of cartography compiled by Philip Lee Phillips (1901), first superintendent of the Hall of Maps and Charts at the Library of Congress, is an excellent guide to the resources available to map collectors at the turn of the new century.

All the great nineteenth-century collectors of Americana, many of whose libraries would become important institutional collections, actively acquired maps and atlases. For examples, see the entries in Donald C. Dickinson (1986) for William Loring Andrews, Edward Everett Ayer (collection acquired by the Newberry Library, Chicago), Hubert Howe Bancroft (University of California, Berkeley), Samuel L. M. Barlow, John Carter Brown (Brown University), Elihu Dwight Church (Huntington Library, University of California, Los Angeles [UCLA]), Wymberley Jones De Renne (University of Georgia), Wilberforce Eames, Peter Force (Library of Congress [LC]), Henry Harrisse (LC), James Lenox (New York Public Library), and John Boyd Thacher (LC).

For maps as well as books, these collectors had to rely largely on European dealers, among whom Frederic Muller of Amsterdam, Henry Stevens of London (although he was an American by birth), and Ludwig Rosenthal of Munich were the leading vendors of maps and atlases and remained active well into the twentieth century. Also, beginning in the late nineteenth century, a steady growth in the publication of cartobibliographies and map catalogs began to provide the tools that would support cartographic connoisseurship in the twentieth century.

Among the collections built largely in the first half of the twentieth century, maps formed an important component in the libraries of Frederick W. Beinecke (Yale University), James Ford Bell (University of Minnesota), Alfred Clark Chapin (Williams College), William L. Clements (University of Michigan), William Robertson Coe (Yale), Robert E. Cowan (UCLA), Templeton Crocker (California Historical Society), Everette DeGolyer (Southern Methodist University), Melville Eastham (LC), William McIntire Elkins (Free Library of Philadelphia), John Work Garrett (Johns Hopkins University), Thomas Gilcrease (Gilcrease Museum), Everett D. Graff (Newberry Library), Archer M. Huntington (Hispanic Society of America), Henry Edwards Huntington (Huntington

Library), Woodbury Lowery (LC), Tracy W. McGregor (University of Virginia), Philip Ashton Rollins (Princeton University), Henry Raup Wagner (Pomona College), and Carl I. Wheat (Bancroft Library and Harvard University).

George H. Beans, who would form one of the most distinguished map collections of the twentieth century, began collecting in the early 1920s and found it a lonely activity; in a classified ad he declared "collector of old maps desires correspondence with others similarly interested" (*New York Times* [*NYT*] *Book Review and Magazine*, 12 June 1921, 28). Beans was clearly on the leading edge of a trend because it was during the 1920s that the notion of collecting old maps began to take hold more widely. Two London firms issued their first catalogs devoted solely to maps in the 1920s: Maggs Brothers in 1921, and Francis Edwards in 1929 (Hirsch 2006, 47). The Boston firm of Goodspeed's published what may be the first real map collector's manual in 1925 (Holman 1925), an enlarged edition the following year, and its first all-map catalog in 1929. A large display ad for Lord & Taylor advertised "Antique Maps By the Celebrated Cartographer Guiljelmus Blaeuw" and went on to comment on "the increasing vogue for old maps" (*NYT*, 2 Apr. 1925, sec. 1, 10). Several New York antiquarians began to take out small classified ads for old maps (e.g., *NYT*, 19 July 1925, BR 22; 28 Mar. 1926, BR 30; and 23 Jan. 1927, sec. 7, 13) and Macy's announced that "a recent display of old maps held in the Picture Department on the sixth floor . . . aroused so much interest that the department has been searching ever since for more unusual ones" (*NYT*, 16 Jan. 1927, sec.1, 11). In 1926 an Illinois librarian writing in *Publishers' Weekly* observed,

> The vogue of the old map has greatly increased in the last half dozen years. The second-hand bookshops and cartographer's shops in Paris and London have been thoroly [*sic*] ransacked in search of treasures. The dealers say that the Americans started the craze. Now, at least, it takes a fortune to start a fair collection. . . . Old maps are quite a factor in modern interior decoration . . . .They are especially adapted to the decoration of offices, directors' rooms, or studies. Aldous Huxley has suggested that the walls of a study be decorated with modern topographical survey maps instead of wall paper. Scraps of mutilated maps are economically made into lampshades, screens and other decorative articles. One of the modern women's magazines even offers instructions in embroidering maps for wall decoration (Herron 1926, 1258–59).

Emerson David Fite and Archibald Freeman's *A Book of Old Maps* came out in 1926 and was still in print in the 1970s.

The vogue continued throughout the 1930s. Collecting old maps was a hobby for film star Richard Barthelmess (*NYT*, 8 July 1934, sec. 9, 2); Macy's advertised a "Sale of rare decorative 17th Century Maps, 99¢ to 24.89" (*NYT*, 5 June 1935, sec. 1, 4); and a brief article was headlined "Collectors Seek Early Maps" (*NYT*, 28 Feb. 1937, sec. 12, 10). The publication of Lloyd A. Brown's *Notes on the Care & Cataloguing of Old Maps* in 1941 is further evidence of both private and institutional interest in map collecting on the eve of World War II, and on the fatal Sunday of 7 December 1941, the Argosy Book Stores and the Rand McNally Map Store in New York were suggesting old maps as Christmas presents (*NYT*, 7 Dec. 1941, BR 60).

As in so many other aspects of cartography, World War II certainly spurred the collecting of maps, if not as antiques, as aids to understanding current events. In the fall of 1941, the Rand McNally Map Store in New York reported "a boom in maps," with a popular item being the "London Daily Telegraph's map of the front in Russia, mounted and framed, and fixed with a finish so you can mark it up with oil-base crayons according to the headlines" (*NYT*, 19 Oct. 1941, D4).

Sources for old maps in the years between the wars included, as we have seen, department stores, book and map stores, and a few specialized dealers. English dealers were, and remain, very important to the antiquarian map trade in North America, both as direct suppliers and as wholesalers. R. V. Tooley joined the London firm of Francis Edwards in 1919 and began to make his name as the most prolific and influential dealer and authority on old maps in the twentieth century. He became the grand old man of map dealers, breaking atlases, sorting the maps into geographical piles, coloring them with water colors when necessary, and generating business, much of it with American dealers and collectors. His book *Maps and Map-Makers*, a history-cum-collector's guide, first appeared in 1949 and has never been out of print. From 1963 to 1975, Tooley's Map Collectors' Series published 110 lists of maps tailored to collecting areas and was an important stimulus to the field.

In North America, Goodspeed's in Boston remained a prime source of maps, as were the Old Print Shop and the Argosy Gallery in New York City. H. P. Kraus issued several very important catalogs devoted solely to maps in the 1950s and 1960s. Kenneth Nebenzahl, who opened his shop in Chicago in 1957, published an illustrated catalog the *Compass for Map Collectors* from 1961 to 1988. The "vogue of the old map" mentioned in the 1926 *Publishers' Weekly* article took on new force in North America during the 1970s. A number of new dealers specializing in maps got their starts in that decade including Kitt S. Kapp (1968), Richard B. Arkway (1969), Walter Reuben (Tejas Gallery, 1972), Jo Ann and Richard Casten (1972), Richard Fitch (1973), High Ridge Books (1975), George Ritzlin (1977), and Thomas Suarez (1978).

One index of growth in the map collecting community can be gleaned from published directories. The first edition of the *World Directory of Dealers in Antiquarian Maps* listed 278 dealers who did at least some business in old maps; 104 of them were in the United States, 17 in Canada. Three years later the revised edition listed over 500 dealers, of whom 143 were in the United States and 20 in Canada (Ritzlin 1977; 1980). The International Map Collectors' Society's *Directory of Members* for 1983 listed 79 North American members; in the 1999 directory there were 179 North American members (IMCoS 1983; 1999). Table 11 is a selective list of collectors active primarily in the second half of the century (only those whose collections have found an institutional home are listed).

Finally, a word about map prices. It is a commonplace to remark on the high cost and appreciation value of antiquarian maps. In the 1926 article quoted earlier, we read that "it takes a fortune to start a fair collection." The 1969 books *Investing in Maps*, by Roger Baynton-Williams, and *Maps and Prints for Pleasure and Investment*, by Douglas Charles Gohm (2d edition 1978), point to what was presumably a relatively new motivation for at least some collectors. Numerous magazine and newspaper articles and a few dealers in the last decades of the twentieth century have emphasized the investment value of old maps, and in 2009 the website of Barry Lawrence Ruderman Antique Maps, Inc., stated that "in recent years, the number of 'investor collectors' has increased significantly." As a baseline of prices and inflation, figure 159 compares the Consumer Price Index (CPI) between 1900 and 1999 with a corresponding index calculated from the list price of forty-three sales of the America map from Ortelius's *Theatrum orbis terrarum* offered for sale between 1909 and 1999. Both series use an index value of 100 to represent average prices for the period 1982–84, which allows a comparison of map prices, which ranged from $2.50 in 1909 to $9,750 in 1994, with the average price of all consumer goods. It's clear that while the CPI rose steadily in the last three decades of the century, map prices were comparatively volatile.

Although forty-three sales of one map is an admittedly tiny sample, and the data do not reflect variation in condition, edition, or state, the graph suggests that map prices may not, in fact, have risen faster than those of other commodities and might even have failed to keep up with inflation.

ROBERT W. KARROW

SEE ALSO: Antiquarian Maps and Grand Larceny; Libraries and Map Collections, National; Tooley, R(onald) V(ere)

TABLE 11. Selected list of Canadian and United States map collectors

American Museum (Bath, Eng.)	Dallas Pratt
Boston Public Library	Norman B. Leventhal
Davidson College	William Patterson Cumming
Harvard University	Bohdan Krawciw
John Carter Brown Library	George S. Parker
Library and Archives Canada	Trevor Lloyd
	Alexander E. MacDonald
	Coolie Verner
Library of Congress	Ethel M. Fair
	Janet Green
	Arthur W. Hummel
	Jay Kislak
	Shannon McCune
	Muriel H. Parry
	Alan M. Voorhees
Library of Virginia	Alan M. Voorhees
Maryland State Archives	Russell Morrison
McGill University	Alfred J. Pick
	William H. Pugsley
Memorial University of Newfoundland	Fabian O'Dea
Newberry Library	Roger Baskes
	Martin M. Cassidy
	Gerald F. Fitzgerald
	Wright Howes
	Andrew McNally III
	Hermon Dunlap Smith
New York Public Library	John H. and Flora Levine
	Lawrence H. Slaughter
Queen's University	Albert H. Ruddell
Spertus Institute of Jewish Studies	Seymour H. Yale
Stanford University	David Rumsey
Tampa Bay History Center	J. Thomas Touchton
Trent University	Robert Lloyd Hunter
University of Southern Maine	Peter M. Enggass
	Harold L. Osher
	Lawrence M. C. and Eleanor Houston Smith
University of Texas at Arlington	Virginia Garrett
University of Virginia	Seymour I. Schwartz
Virginia Historical Society	Alan M. Voorhees
Yale University	Jonathan T. Lanman
	Paul Mellon

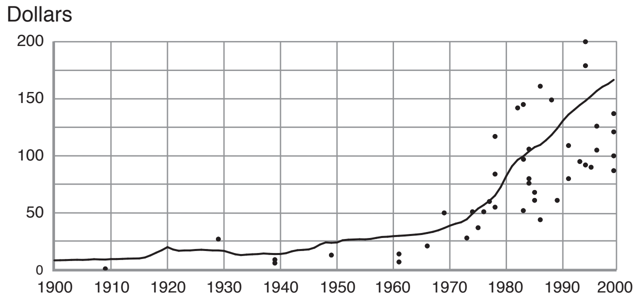

FIG. 159. COMPARISON OF THE LIST PRICE FOR THE AMERICA MAP FROM ORTELIUS'S *THEATRUM ORBIS TERRARUM* WITH THE AVERAGE PRICE FOR ALL CONSUMER GOODS. Graph shows forty-three sales of the map compared to average of consumer goods as measured by the U.S. Consumer Price Index. Both series use an index of 100 to represent average price for the period 1982–84.

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Map Collecting in Europe. The twentieth century witnessed a dramatic increase in the collecting of antique maps theretofore accumulated largely because of their relevance to more contemporary concerns like geopolitics, commerce, or self-promotion. By contrast, the twentieth-century collector aspired, at least on an individual basis, to collect maps as antiquarian objects, with the decorative elements often as important as the mapmaker, the region, or the significance of the map itself. As a reconfiguration of the much older map trade, map collecting as an avocation or hobby reflects the emergence of an artificial market driven by dealers who promoted the sale and collection of maps created for other purposes.

At the dawn of the century, map collecting was largely the preserve of institutional collections, many of which were still actively filling gaps in their holdings at the century's end. For private individuals, the principal focus was on atlases and books with maps; of lesser importance were separately published maps, acquired mainly to complement a collection of atlases. Perhaps the most conspicuous collector was Sir James Caird, whose personal collection became the basis of the library at Britain's National Maritime Museum in Greenwich. The well-established auction houses, Sotheby's and Christie's, were prominent, but much of the market was dominated by the great book-dealing firms, such as Henry Stevens, Son & Stiles; Rosenbach Company; Maggs Bros.; Quaritch; and Francis Edwards.

In the first years of the twentieth century there were few committed collectors as well as a considerable oversupply, particularly of lesser-quality material. Obsolete atlases were considered of little or no value, and all too often they were simply thrown away or used as coloring books for children. In extreme cases, individual maps—particularly the decorative double-hemisphere worlds of the seventeenth century—were used to decorate lampshades, wastepaper baskets, trays, and place mats, while the rest of the atlas was discarded.

In England, at least, this situation changed after Lawrence Baynton-Williams, based in Guildford, Surrey, realized that individual atlases (and also plate books) had a greater potential value as the sum of their parts rather than as a complete entity. Baynton-Williams started in business in 1923, selling individual map sheets to local bookshops and antique shops as wall decorations (fig. 160). He subsequently expanded the business by selling directly into the private market from retail premises, notably on the Old Brompton Road (fig. 161), and then on Lowndes Street in London. Removing individual plates for separate sale has been criticized by modern purists, who consider its sacrilegious to "break" a book. It also became apparent that coloring the sheets, to make them more visually appealing to the buyer, greatly enhanced their value. This, too, became a contentious issue.

In Europe records of private collections are scanty because, unlike in the United States, there are few tax advantages to donating a map collection. Consequently, many collections were developed and subsequently dispersed in relative secrecy. Noteworthy exceptions include the László Gróf's Carta Hungarica Collection and the various gifts from the Tomasz Niewodniczański Collection—both donated for reasons of heritage—as

FIG. 160. LAWRENCE AND ROGER BAYNTON-WILLIAMS (THE LATTER WITH HIS BACK TO THE CAMERA) AT A COUNTY FESTIVAL WITH MOBILE DISPLAY.

Image courtesy of Ashley Baynton-Williams.

well as Albert Ganado's collection of maps of Malta and the Bank of Cyprus's collection of maps of that island. Typically a collection was assembled and sold in one generation or sold off by the original collector's heirs because the passion—obsession?—is not as easily transmitted through the generations as the items themselves. And in only a few cases, notably R. H. Johnstone's collection of large-scale county maps, Joel Tabor's collection of London maps, and Christopher Henry Beaumont Pease, Lord Wardington's atlas collection, was a catalog produced for a complete collection at the time of sale. Many more collections were quietly assembled and equally quietly dispersed, through trade or auction, leaving behind little more than folktales or rumors.

At the end of World War II, amid the general economic recession, the book trade was faced with a dramatic increase in material in circulation, but a diminished marketplace. The trade in separate maps reemerged as dealers returned from the war. In England that group included Lawrence Baynton-Williams and R. V. (Ronald Vere) Tooley, head of the map department at the London booksellers Francis Edwards. In France, Louis Loeb-Larocque emerged at the center of the Paris map and atlas trade.

Sometimes referred to as "the effective founder of the antiquarian map trade" (Campbell and Kay 1987, 80), Tooley was an active researcher and writer on old maps. He was the author of *Maps and Map-makers* (1949), the first general reference book aimed at the map collector, and *Tooley's Dictionary of Mapmakers* (1979), although he was once famously told by R. A. Skelton, then head of the Map Library of the British Museum (now British Library), that reference books were the preserve of librarians, and that he (Tooley) should stick to dealing.

FIG. 161. THE BAYNTON-WILLIAMS GALLERY ON THE OLD BROMPTON ROAD. The Baynton-Williamses were the first dealers in England to open retail premises devoted to maps and prints.
Image courtesy of Ashley Baynton-Williams.

Indeed, Tooley was to be author (oft-times hidden by pseudonym) of a substantial proportion of the first generation of cartographic reference books, most notably as editor (and chief writer) of the Map Collectors' Circle series of 110 monographs published from 1963 to 1975. While few have stood the test of time, Tooley saw his task to be getting research material into print rather than aiming for bibliographic completeness, and there is no question of the important role his cartobibliographies played in bringing on contemporary collectors.

It is worth noting that the next generation of reference books were written by the collectors themselves, frustrated by the lack of material on their subject and resolved to address that deficiency—Andreas Stylianou and Judith A. Stylianou (Cyprus), Rodney W. Shirley (the British Isles and world maps), Christos G. Zacharakis (Greece and Crete), Lajos Szántai (Hungary), Roberto Borri (Italy), and so on.

While Tooley was responsible for helping form some of the most well-known collections of the twentieth century, the principal role of the map department at Francis Edwards was as a clearing house or conduit for new material into the wider trade, both in England and on the European continent, but, most important, into the American trade, supplying the first generation of American dealers, such as Kenneth Nebenzahl, the Old Print Shop, the map department in the New York department store Altman's, and Richard B. Arkway.

The 1960s was the first decade of growth of avid collecting of sheet maps. The 1960s, 1970s, and even the recession-struck 1980s were probably the golden era; material was plentiful, and there was little competition for all but the most collectable material. In this time of plenty, the dealers were encouraged to educate their clients, reasoning that an informed buyer would be a long-term customer, and this is reflected in the many great collections of the period.

In 1969 Roger Baynton-Williams published *Investing in Maps*, the first readable beginner's guide and the introduction to antique maps for many a collector. Although not intended to promote maps as an investment—it was part of a series on investing in antiques, and the title was necessary for publication—the book was to set a trend in the following decade.

The 1970s saw a further growth in the market with rapid price rises across most areas in turn leading to a rush of new dealers into the trade. The most high-profile of them, Mapsellers (the map department of the leading stamp dealers Stanley Gibbons), treated map collecting as an investment business at a time of increasing uncertainty in stock and currency markets. One London-based dealership, Mappamundi, even produced an investment brochure demonstrating that antique map prices had increased 14,000 percent in fewer than ten years, far outstripping comparable gains with stocks and shares.

However, the momentous addition to the trade was the American dealer W. Graham Arader III. A controversial figure, Arader single-handedly transformed the market, promoting antique maps as investment-quality but undervalued collectables. His undeniable marketing skills brought maps to the attention of an affluent American clientele, and this marks the transition from a regional cottage industry and hobby to an international profit-driven industry.

European collectors were drawn mainly from less affluent social strata, as there were plenty of collectable areas for the wealthiest collectors. America, with its shorter heritage, has fewer choices for, and less material available to, the wealthy would-be collector. With a higher disposable income than their European rivals, Americans came to dominate the map market to the extent that, inter alia, the most important private collections of maps of the British Isles, Scotland, Norway, Corsica, and Tuscany; British large-scale maps; Italian Lafreri-type maps; and wall maps of European countries are found in the United States.

Across Europe, map collecting had an uneven appeal, which is hard to explain. Maps of affluent regions have been more highly collected—for example, London—while the Warsaw Pact countries of the Soviet era were all but unsellable, as were France and many of its regions. Demand for other areas had fluctuated with the regional economies, with prices for maps of Germany, Luxembourg, and Switzerland never regaining the heights reached in the 1980s. Regions with strong regional or political identities, such as Cyprus, Malta, and Catalonia, have long been popular, as have Italy and its towns and provinces, particularly helped by the extraordinary number of cartobibliographies available to the collector.

The last years of the twentieth and the first of the twenty-first century have seen the opportunities for the collector increase dramatically as the Internet has increased accessibility not only to the world trade but also to institutional catalogs, references sources, and the like. This has been a double-edged sword, in that anyone can establish themselves as a map dealer and, if they are computer-savvy enough, appear to rank with the established names of the trade, particularly on Internet auction sites. For the knowledgeable collector, this access has been of considerable benefit; for the inexperienced, the introduction to the trade via the Internet has too often proved an unsatisfactory experience and may be one facet of a general failure to bring in new collectors, much evident since the beginning of the 1990s.

There has also been an increasing dominance of the auction house, once wholesalers to the trade, but using their marketing machine and high profile to reach out to the private market. In this Sotheby's has been very much the leader, dominating the map auction market from London. This ascendancy has been confirmed in three particular sales: "Important Atlases and Cosmographies," "The Wardington Library Important Atlases & Geographies," and "The Library of the Earls of Macclesfield . . . Part Nine: Voyages, Travel and Atlases." Considered with the Christie's New York sale, "The Frank Streeter Library," these sales were astonishing financial successes.

In the past, these sales would have been dominated by map dealers. Unexpectedly, perhaps, the major buyers were a new generation of collector affluent enough to collect atlases in their own right and book dealers targeting that market. One consequence is that as atlases in general are again worth more than the sum of their contents, the supply of individual maps fresh to the market has markedly declined, discouraging new map collectors and leading to a much diminished market for maps removed from books and atlases but also an accompanying boom in map thefts from libraries.

With map collecting focused again on atlases and rare separately published maps and largely consolidated in the hands of the international book trade, collecting has come full circle, very much to its position at the start of the twentieth century.

ASHLEY BAYNTON-WILLIAMS

SEE ALSO: Antiquarian Maps and Grand Larceny; Libraries and Map Collections, National; Tooley, R(onald) V(ere)

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Collections, Map. See Libraries and Map Collections, National

Colonial and Imperial Cartography. Cartography, and geographical science more generally, was central to the creation and extension of the colonial empires of industrial states during the eighteenth and nineteenth centuries. As J. B. Harley (1988, 283) pointed out, maps were a commodity and a proxy for territory, and the livelihoods of millions who lived under colonial rule could be dictated by the stroke of a pen. In the twentieth century, the content of this cartography changed along with the philosophies undergirding the project of empire, but Harley's basic observation still held true. Before 1900, imperial and colonial cartography tended to be more tentative and explorative, and scientific associations and geographical societies created and published a significant proportion of maps while extolling the virtues of the explorer (Driver 2001). But in light of the changing relationship between imperial powers and the dependencies they claimed toward the end of the nineteenth century, the agents and purposes involved with imperial and colonial cartography shifted (Stone 1995). Such changes were not uniform in tempo or in application and varied depending on the colonial power and the colony in question, but the general tendencies were shared.

In the wider historiography of imperialism and colonialism the question remains open as to just where those two terms' definitions end historically and ontologically, even in respect to one another. From a political standpoint, imperial and then colonial rule, which are contingent on progressively more invasive and direct administration over territory (though not always so directly over the political organization of people), terminate with the colony's political independence. This view also restricts consideration to overseas possessions, though the cartography of far-flung continental territories of states like Russia or the United States certainly shares some aspects. Yet even with these delimitations, many cases exist (e.g., Egypt, Vietnam, and Southern Rhodesia/

Zimbabwe) in which the distinctions between colonialism, imperialism, and independence were at best exceptionally grainy. Imperial and colonial mapping likewise made fluid transitions from a cartography attendant upon imperial expansion and administrative establishment into a cartography of development, and ultimately this trend continues in the era of independence, further complicating any effort to compartmentalize empires, colonies, and their cartographic output or to relegate them to the past.

Within the colonial empires of industrial Europe, the United States, and Japan, we may posit a distinction between colonial cartography (maps of varying sorts used in immediate administration within a dependency) and imperial cartography (maps used to create an image of the empire as a legitimate entity and articulate a claim on territory). Some discussions of the progression of cartography characterize "imperial" cartography as explorative or appropriative mapping that preceded "colonial" cartography for exploitation in any given territory, though the latter certainly did not extinguish the former in the twentieth century. The existence of imperial and colonial cartography as a distinct category is, however, arguable insofar as the imperial nature of the map is dependent upon the context in which it is deployed and understood and not upon anything innate to the cartographic enterprise, which itself developed in response to the idea of empire (Edney 2009).

In the context of the colony, maps were vital elements in the creation of administratively "legible" entities from the end of late nineteenth century onward, if not the central ones (Bell, Butlin, and Heffernan 1995; Cohn 1996; Scott 1998). For this purpose, simple schematic cartography was often all that was required, as Stone (1995, 120) points out in the case of Northern Rhodesia (Zambia). However, any desire for comprehensive and multivariate cartographic coverage ran headlong into efforts to run empire "on the cheap," given that systematic surveying and map compilation were enormously expensive (fig. 162). Imperial governments were therefore unlikely to make an investment, though they occasionally provided survey parties for high-level trigonometric and topographical survey; colonial governments were generally poorer in financial resources and therefore even less likely to invest in precise and comprehensive survey and mapping projects as long-term investments. Cartographic projects at the colonial level were therefore almost always understaffed and unfunded by any central treasury. Under these great constraints, the patchy cartography that a variety of private individuals and officials produced varied wildly in purpose and quality. Even intensified efforts after World War I to standardize data collection were fraught because surveyors and instruments were relatively scarce, and concordance between survey authorities was often lacking.

Colonial maps of whatever type (topographical, cadastral, geological, hydrographic, and various thematic maps) were therefore generally created only as needed, when the collection of data could be economically added to existing survey operations, or when it was usefully undertaken by some private party or scientific organization. Rebellions or colonial wars, tourism, taxation, development schemes, and the like stimulated the creation of colonial maps. Rarely did colonial cartography precede some pressing need unless, as in India, a detailed surveying framework was already in place through the efforts and needs of prior administrators or the work could be carried out during the pursuit of other activities. Colonial boundaries (especially between European colonizers), coastal areas, areas of dense settlement (e.g., Java or many regions of India and Egypt), resource-rich areas (such as the mines of Namibia or the Witwatersrand, or the railway lines servicing them), and regions of conflict (such as Kenya in the 1950s, the South African Highveld between 1900 and 1902, and the Philippines during the same period) produced far more detailed map coverage than other areas less important to the maintenance of colonial control or the collection of revenue (fig. 163).

Another variable in colonial cartography was found in its basic practitioners, the surveyors. In most colonies, surveyors were really private contractors and fairly scarce on the ground. After the 1910s, however, an increasing—though generally still small—number of surveyors were employed full-time by colonial authorities, though standards were often uneven. The major exceptions to this paucity of technicians were well-established colonies such as India, Canada, New Zealand, Australia, South Africa, and their predecessors, where significant numbers of survey technicians were trained or employed locally before 1900. All of these colonies in fact provided surveyors and map production services for other colonies with insufficient resources, and the resulting bootstrap nature of survey employment before 1945 is well documented by C. G. C. Martin (1980) in the case of Nyasaland (Malawi). For the most part, funding for colonial cartography before World War II remained the province of private individuals and local governments, most of whom did not have any local apparatus for printing maps. Indeed, colonial survey departments were often themselves established only in response to demonstrated need for sustained mapping (Stone 1995).

Thus, it often fell to poorly trained colonial administrators or professionals outside of survey organizations to collect and compile raw geographical information into manuscript maps. Well after 1920, and sometimes as late as the 1950s, this form of ad hoc cartography was still fairly common in so-called "native" areas, where communal land distribution was the norm. Aerial photography and technical improvements in data compilation eased the provision at least of topographical

FIG. 162. *PROVISIONAL MAP OF EAST AFRICA PROTECTORATE*, 1:1,500,000 (SOUTHAMPTON: ORDNANCE SURVEY, 1910). Characteristic of the transitional form of cartography shortly after formal colonization, this map includes little detailed relief, shows settlements only along lines of communication, and indicates administrative boundaries that are "not to be taken as strictly accurate."

Size of the original: 69.5 × 68.5 cm. Geographical Section, General Staff, War Office, United Kingdom (GSGS no. 2542). Image courtesy of the American Geographical Society Library, University of Wisconsin–Milwaukee Libraries.

maps in the colonies, but maps of human geography and property still languished if they were not seen as a necessary investment for revenue collection or other state purposes. In the case of South Africa, for example, crude schematics drawn by local headmen or agents had sufficed to indicate spatial order and the presence of structures in many areas under communal tenure before 1994, because state revenue was not based on the individual ownership of alienable property in those areas. Indeed, early in the twenty-first century the South Af-

FIG. 163. *OVERZICHTSKAART VAN DE RESIDENTIE DJOKJAKARTA* [YOGYAKARTA], 1:250,000 (BATAVIA [DJAKARTA]: TOPOGRAPHISCHE INRICHTING, 1921). This colonial reference map of a district on the valuable, long-occupied (and therefore surveyed) Dutch island of Java firmly locates all settlements and includes an inset showing lines of communication between major centers with distances.
Size of the original: 45 × 44 cm. Image courtesy of the Donald W. Hamer Maps Library, Pennsylvania State University, State College.

rican government was still spending large sums to conduct surveys in such regions as part of comprehensive land reform. Such cartographic gaps continue to exist in various parts of the formerly colonized world.

Imperial cartography in its twentieth-century iteration differed from the appropriative mapping of the period culminating in Europe's scramble for the tropical world in the late nineteenth century. In the twentieth century, imperial cartography moved from a more aggrandizing form of territorial depiction to one that included more elements of thematic cartography, mirroring concerns over economic integration and the reform of imperial systems in the wake of the European devastation of World War I. The development of this new focus for imperial cartography accompanied resurgent efforts to coordinate colonial mapping by successive bodies within European states. These included the Colonial Survey Committee, the Directorate of Colonial Surveys, and the Directorate of Overseas Surveys in the United Kingdom; the Service géographique de l'armée, Institut géographique national, and ORSTOM (Office de la recherche scientifique et technique d'Outre-Mer) in France; the Istituto Geografico Militare in Italy; the Junta de Investigações do Ultramar in Portugal; and a variety of colonial and military offices and geographical societies in all of the imperial states. Such military and political organizations struggled against official parsimony to advocate standardization and central coordination for cartographic output, built on a strong foundation of geodetic and first-order trigonometric control, to overcome problems of expediency that drove up the ultimate cost of mapping and resurveying in the colonies by requiring repeated resurvey to settle disputes and correct errors (Hailey 1938).

That said, during the twentieth century broader changes in the philosophy of colonialism did have a growing effect on the nature and volume of cartographic output. The experience of World War I encouraged European states to pursue greater economic integration within their colonial empires, leading to a vast number of schemes aimed at improving communications and health, along with agricultural, mining, and eventually even some manufacturing output. Detailed cartography showing specific features and the evaluation of their economic potential was integral to this kind of large-scale planning for land use and exploitation (fig. 164). Noninvasive technologies such as photogrammetry, aerial survey, and, later, remote sensing made any precision required affordable, and refined methods of color lithography pioneered during the world wars ensured better distribution. The correspondence between the maps produced and what they portrayed on the ground may have been questionable, but the impression of knowledge at least was not.

Europe's colonial powers extended their operations further even as the imminent political independence of most colonies became clear after 1945, still in the interests of "development" along imperial lines, and intended to continue beyond independence (McGrath 1983). Such mapping was not unique to formal imperial powers; hegemonic ones like the United States and the Soviet Union were eventually also involved in expansive articulations of geographical conceit and indeed "global" cartography can be seen as the ultimate articulation of the scientific optimism associated with imperialism (Smith 2003; Bell, Butlin, and Heffernan 1995). In some cases, the onus for overseas mapping changed hands along with global hegemony—especially toward the United States government and its Army Map Service (later NIMA [National Imagery and Mapping Agency], and later still the NGA [National Geospatial-Intelligence Agency]), which flew aerial surveys over many areas before decolonization.

Imperial and colonial maps did not end their relevance and reach with the end of the political arrangements that created them. The new states and leaderships that succeeded colonial rule after 1945 in turn inherited these geographical archives and their cartographic legacy, which had de jure relevance if not de facto application on the ground. The "decolonization" of geographical science, and therefore cartography, in order to correct the hegemony of colonialist presumptions is a nascent and difficult project (Crush 1994). The cartography of empire and colony, and their ontological nebulosity, therefore continue both in spirit and in substance in the postcolonial world.

LINDSAY FREDERICK BRAUN

SEE ALSO: Boundary Disputes; Indigenous Peoples and Western Cartography; Geopolitics and Cartography; Nation-State Formation and Cartography; Projections: Cultural and Social Significance of Map Projections; Race, Maps and the Social Construction of

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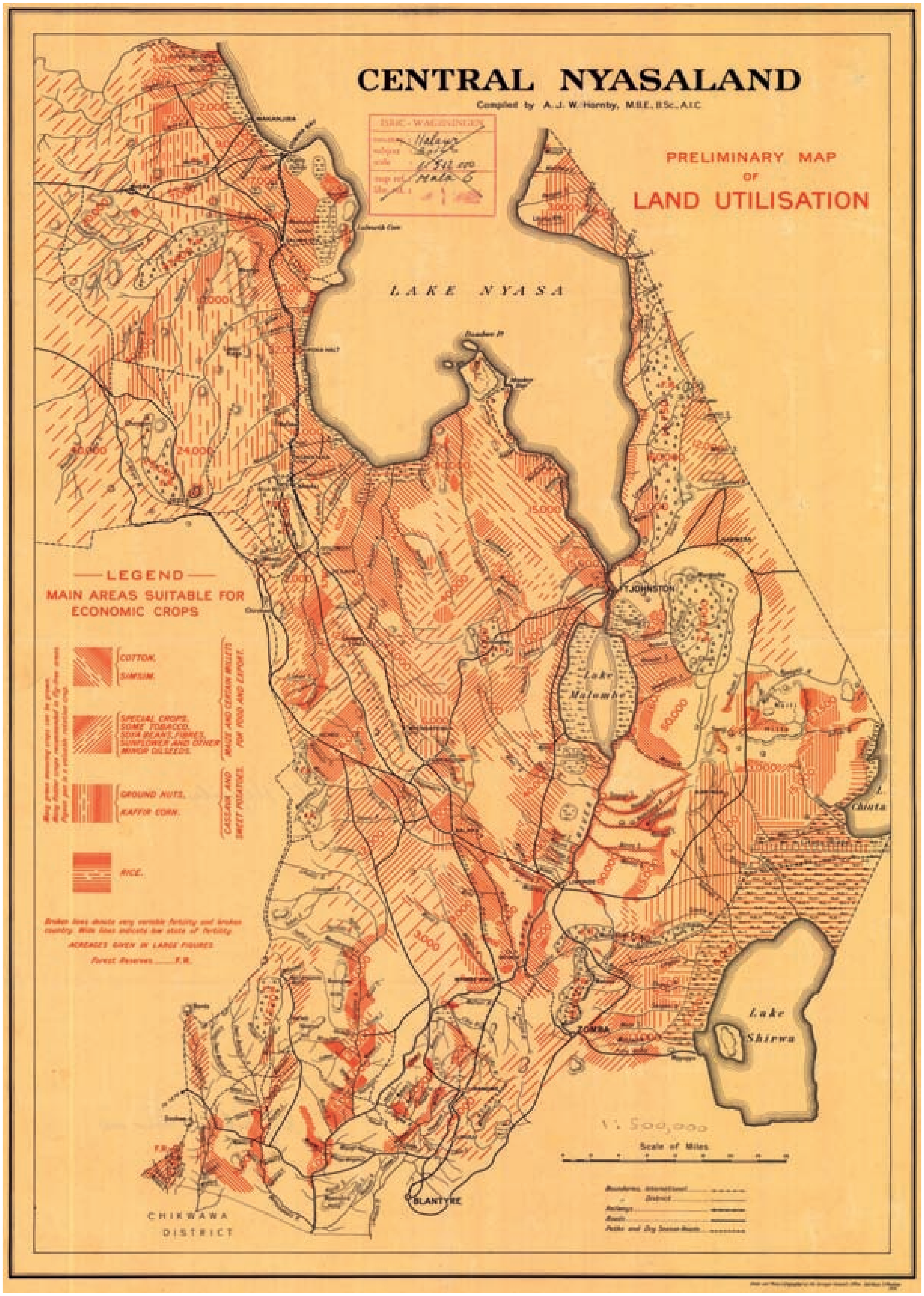
Color and Cartography. The twentieth century experienced profound changes in the use, understanding, and technology of maps displayed in color. Previous



CENTRAL NYASALAND
Compiled by A. J. W. Hornby, M.B.E., B.Sc., A.I.C.
PRELIMINARY MAP
OF
LAND UTILISATION
ISRIC - WAGENINGEN
Malawi
1:500,000
LAKE NYASA
Lake Malombe
Lake Shirwa
L. Chiuta
FT. JOHNSTON
ZOMBA
BLANTYRE
CHIKWAWA
DISTRICT
— LEGEND —
MAIN AREAS SUITABLE FOR ECONOMIC CROPS
COTTON,
SIMSIM.
SPECIAL CROPS, SOME TOBACCO, SOYA BEANS, FIBRES, SUNFLOWER AND OTHER MINOR OILSEEDS.
GROUND NUTS,
KAFFIR CORN.
RICE.
MAIZE AND CERTAIN MILLETS FOR FOOD AND EXPORT.
CASSAVA AND SWEET POTATOES.
ACREAGES GIVEN IN LARGE FIGURES
Forest Reserves.......F.R.
Scale of Miles
Boundaries, International
Railways
Roads
Paths and Dry Season Roads
40,000
24,000
50,000
15,000
3,000

centuries had witnessed the inventions of printing, color printing, and photography, and the articulation of basic color theories, all of which continued to advance. However, computer technology after the midcentury transformed the making of colored maps from a specialized craft into the ubiquitous and flexible generation of readily available maps that could be displayed on virtually any computer anywhere.

By 1900 hand painting of watercolors onto published maps had given way to color printing, still relatively arduous and expensive but yielding more consistent results. Map products meant to last for many years and be seen by masses of people, mainly geological and topographic map series, atlases, and wall maps, were worth printing in color. In addition to flat solid colors, their makers employed sophisticated techniques including patterns of dots or lines to produce varying tints of an ink color and overprinted inks for additional hues (fig. 165).

A few journals included color maps. *National Geographic Magazine*, more scholarly than popular at its inception, included limited color in its first volume (1888), and the first color map supplement appeared in the second (1889). The early issues, however, were not the colorful photo- and map-rich productions that came later. The cartography division of National Geographic Society (NGS) was formed in 1915. In May 1918 a map

(*Facing page*)

FIG. 164. *CENTRAL NYASALAND, PRELIMINARY MAP OF LAND UTILISATION*, CA. 1:500,000 (SALISBURY [HARARE]: SURVEYOR GENERAL'S OFFICE, 1935). The colonial fixation on central planning and imperial economic integration in the mid-twentieth century emerges clearly on this agricultural map of central Nyasaland (Malawi), which indicates the location of soils most "suitable for economic crops," including both those economically beneficial on an imperial scale (such as tobacco and cotton) and on a more local, intracolonial scale (such as corn and rice). Furthermore, the map includes notes on the ecology of the area, in particular the presence of tsetse and optimal rotation crops, which presumably are intended for faraway administrators and potential European entrepreneurs. Similar kinds of overlay maps served the purposes of geological exploration and valuation.
Image courtesy of the European Digital Archive of Soil Maps.

FIG. 165. DETAIL FROM *GEOLOGIC MAP OF THE ARKANSAS VALLEY IN SOUTHEASTERN COLORADO*, BY NELSON HORATIO DARTON (BALTIMORE: A. HOEN & CO., 1905), 1:380,160. Printed by lithography; line symbols are black, blue, and brown, but the main message about the extent of different rock types is conveyed by area symbols created by printing red, orange, blue, and green inks individually as flat solid colors, as fine line patterns, or as overprinted solids or patterns to create additional hues.
Size of the entire original: 65 × 78 cm; size of detail: 18.4 × 33.7 cm. From Nelson Horatio Darton, *Geology and Underground Waters of the Arkansas Valley in Eastern Colorado* (Washington, D.C.: Government Printing Office, 1906), pl. VI.

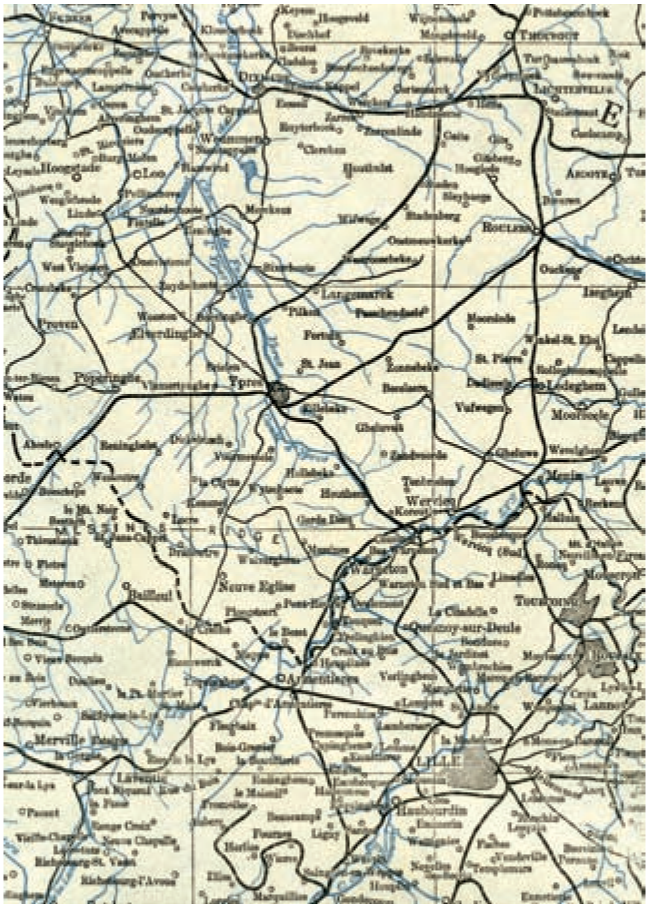


FIG. 166. DETAIL FROM *MAP OF THE WESTERN THEATRE OF WAR*, 1:458,124, BY ALBERT H. BUMSTEAD, CARTOGRAPHER. The town symbols and names printed in black on this map, intended to help Americans follow the events of World War I, are its dominant feature compared to the light blue rivers, and their importance is also indicated by the advertisement, printed beneath the title (not shown), offering an alphabetical index of all names for 25 cents.
Size of the entire original: 66.2 × 78.7 cm; size of detail: ca. 13 × 9.3 cm. From *National Geographic Magazine* 33 (1918), issued as a separate map supplement.

with limited use of color (fig. 166) portended the highly detailed maps that would become signature NGS productions. A map published later that year (fig. 167) foretold of the colorful nature of maps to come (fig. 168).

As the century progressed, a wider range of maps appeared in color. Highway maps, for example, became common as mass marketing of the automobile enabled more people to travel longer distances into unfamiliar territory. The advent of route recommendations and highway numbering systems necessitated differentiation of roads on those maps. Free road maps given out by oil companies aided travel and boosted gasoline sales. Advertising via road maps used color to attract attention and inspire movement via automobile for decades (figs. 169 and 170).

Changes in printing technology enabled those developments in color map production. Shortly after 1900 the introduction of offset printing made lithography more efficient. Offsetting or transferring the printing image from the metal printing plate onto a rubber cylinder, from which the image was printed onto paper, produced a clearer, sharper image than direct printing from the plate. It also meant that the image on the printing plate was right-reading and thus easier to check and correct. Offset lithography also facilitated adjustment of the printing press to register or align different colors of ink, each requiring a separate printing plate and pass through the press. By midcentury, continuing advances in photomechanical techniques meant that five or more inks on maps were beginning to give way to process color with standard yellow, magenta, cyan, and black inks that, when used in varying combinations, can produce a very large number of colors. It was also common to print pictorial photographs in process color, which meant that maps and photographs could be printed together on the same presses.

Nevertheless, color printing costs remained high enough to keep even newspapers with large circulations, and their map illustrations, monochrome until near the end of the century. Similarly, geographers and other academic researchers had limited opportunity to illustrate their works with color printed maps and photographs. Through midcentury most maps in journals and books published for the modest academic market were monochrome. Academic cartographers had little access to color technology for producing maps or for teaching students how to execute maps for reproduction in color. Student exercises in classes required hand coloring of maps, usually with colored pencils.

There was little research on color in mapping during the first half of the century, either to devise new methods of representing information or to evaluate the effects of color on map users. One reason was that cartography was not yet a recognized academic field of study; another was that mapmaking was primarily done by government mapping agencies and commercial map publishers. Also, standardization of color specification into the Commission international de l'éclairage (CIE) system was not formalized until the early 1930s (Wyszecki and Stiles 1967, 238–39). Color measurement equipment was highly specialized and not yet widely available, color proofing methods were inadequate, and color printing was still expensive and difficult to control. Without color measurement to assure consistency of test materials, it was difficult to make color the subject of research in any field. Access to technology, both for map production and color measurement, improved later in the century, espe-

FIG. 167. DETAIL FROM *MAP OF THE RACES OF EUROPE AND ADJOINING PORTIONS OF ASIA AND AFRICA*, EDWIN A. GROSVENOR AND GILBERT HOVEY GROSVENOR (DRAWN UNDER THE DIRECTION OF) AND ALBERT H. BUMSTEAD, CARTOGRAPHER (DRAWN BY). The nineteen area symbols showing racial affinity with shades of brown, yellow, red, green, blue, and purple were created by overprinting a smaller number of ink colors as fine dot patterns that blend visually.

Size of the entire original: 49.9 × 60.8 cm; size of detail: ca. 11 × 18.4 cm. From Edwin A. Grosvenor, "The Races of Europe: The Graphic Epitome of a Never-Ceasing Human Drama; the Aspirations, Failures, Achievements, and Conflicts of the Polyglot People of the Most Densely Populated Continent," *National Geographic Magazine* 34 (1918): 441–536 (map supplement).

cially in the 1960s through 1980s. Until then color remained an intellectual rather than practical or research interest in cartography (Robinson 1952, 1967).

Selected editions of cartography textbooks show how growing attention to color reflected the changing technology of map production and reproduction. Erwin Raisz's 1938 *General Cartography* covered color printing on four pages in the chapter on "Methods of Map Reproduction," with additional mentions elsewhere. The first edition of Arthur H. Robinson's *Elements of Cartography* (1953) devoted almost six pages to the subject under the headings "Color in Cartography" and "Choice of Color" and under topics such as printing, lettering, and terrain representation. In *Principles of Cartography* (1962), Raisz still covered color printing in four pages under "Map Reproduction" but also added six pages that included "Physics of Color," "Choice of Colors," and "How to Paint an Area Evenly." He closed the section with exercises in map coloring by painting with watercolors or applying colored-film cellotints. Neither those textbooks nor the next two editions of Robinson's *Elements* (1960, 1969) used colored inks or inserts. By contrast, Werner Witt's German text, *Thematische Kartographie* (1967), had forty tipped-in color illustrations, including two folded color charts. By the mid-1990s, the text section on color in the sixth (and last) edition of *Elements* (Robinson et al. 1995) had expanded to three full chapters (over sixty pages) covering "Color Theory and Models," "Color and Pattern Creation and Specification," and "Color Pattern and Use" as well as a small signature of process-color illustrations. The fifth edition of Borden D. Dent's *Cartography: Thematic Map Design* (1999) included a chapter on color plus a small color signature. The first edition of Terry A. Slocum's *Thematic Cartography and Visualization* (1999) included a thirty-two-page signature of full-color illustrations plus two chapters and two appendixes on color. Shortly after the turn of the century, color maps, photos, and graph-

FIG. 168. DETAIL FROM *SOUTH AMERICA*, BY JOHN F. SHUPE, 1:11,890,000. This example of a highly developed printing practice employed yellow, cyan, magenta, black, a special blue, and grayish brown inks printed, singly or in combination, solid or screened, to create the various outlines of the countries, relief, line symbols, and lettering with precision and clarity.
Size of the entire original: 68.8 × 49 cm; size of detail: ca. 10.6 × 9.8 cm. From *National Geographic* 182 (1992), issued as a separate map supplement. Permission courtesy of the National Geographic Society, Washington, D.C.

ics appeared throughout cartography textbooks, following the practice in geography and other textbooks with higher sales.

Textbooks also reflected the development of consumerism (consumers preferred color). By late century, even newspapers commonly incorporated color maps, with *USA Today* (founded in 1982) leading the way. In addition, television (though still in the limited-resolution NTSC [National Television System Committee standard) had long displayed color maps, especially in weather reports, for millions of viewers every day.

The most far-reaching technical development of the last half of the century, the computer, caused profound changes in color usage on maps. It not only affected printing and television but also introduced new ways of conceiving, constructing, and displaying maps.

By the year 2000, memory had faded that early direct use of computers in mapping had been controversial, largely because output limitations degraded map aesthetics. Most early computer maps from the late 1960s and early 1970s were composed of machine-printed characters. Although series of characters could be printed on separate sheets, photographed, and exposed to printing plates, forming crude color illustrations, they hardly merited the expense. The development of line plotters improved output quality, but inked lines on paper were of little use as separations for color printing. Line plotters with multiple inks soon enabled direct output of colored lines in various patterns, generated one line at a time for each copy. Quality was still far inferior to printed maps. Meanwhile, cartography's focus was shifting from communicating with many people by means of the printing press to reaching individuals and small groups with the cruder but still useful paper computer output. Computer users could see data of interest in spatial context, generate hypotheses, and make decisions—activities that remained part of the broad spectrum of map use as highly flexible electronic mapping developed.

Equipment for high-quality output did exist in the

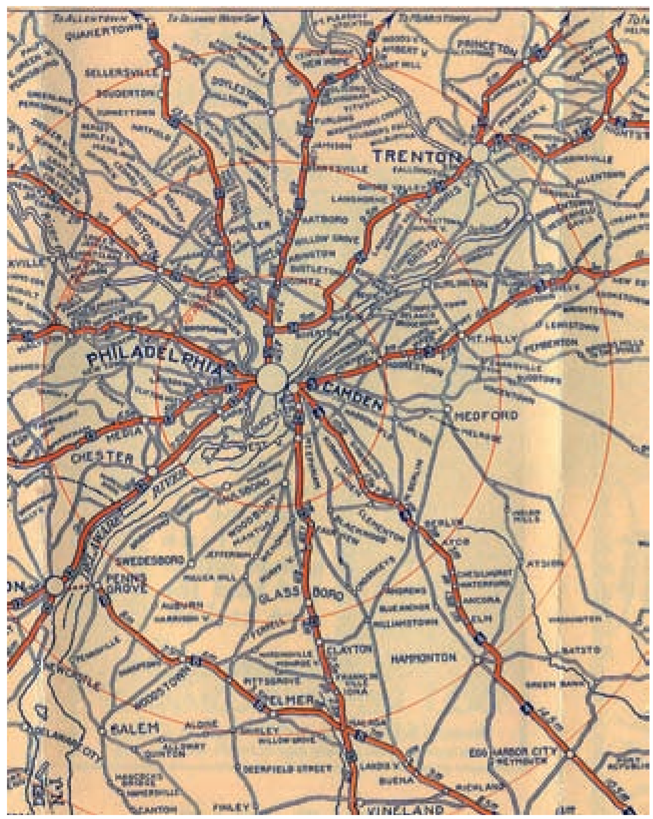


FIG. 169. *BLAZED TRAILS 60 MILES FROM PHILADELPHIA* (CHICAGO: RAND MCNALLY FOR GULF OIL REFINING CO., [1922?]). A pioneering road map publisher of the automobile era, Rand McNally combined advertising and wayfinding by showing both Gulf Oil stations (on the inset map of the city, not shown) and major roads (on the main map showing the city and surroundings) in eye-catching red.
Size of the entire original: ca. 20.7 × 28.2 cm; size of detail: ca. 15.9 × 12.6 cm. Image courtesy of Harold Cramer, Historical Maps of Pennsylvania. Map © Rand McNally; R.L. 11-S-001.

FIG. 170. DETAIL FROM *PENNSYLVANIA ROAD MAP*, SOLD BY EXXON OIL COMPANY, 1996. Oil company road maps changed with the technology and cartographic practices over the century. They were rarely offered and virtually never free in the last two decades of the century, but Exxon offered this map at very low cost (suggested retail price was 49 cents).
Size of the entire original: ca. 28 × 61 cm; size of detail: 14.5 × 10.7 cm. Image courtesy of Harold Cramer, Historical Maps of Pennsylvania.

early days of computer mapping. The quality of color maps produced by the Experimental Cartography Unit (ECU) of the Royal College of Art in London was remarkable for that time, but high cost made it impractical. Some government agencies and private firms also experimented with high-quality printable computerized maps in the late 1960s and early 1970s. The Ontario Department of Transportation and Communications reported that its fine 1971 topographic map *City of Peterborough, Ontario, and Environs* was "'untouched-by-human-hands' except for the peel coats used for the areas covered by vegetation and water bodies" (quote in map legend; see fig. 981). The concept was demonstrated, but production was not yet cost effective. Instead, production units adopted computers only for processes that machines could perform better and faster than humans. The U.S. Central Intelligence Agency used plotters to produce map projections, previously a time-consuming and tedious task. A plotter with a scribing head in place of a pen could make linework negatives automatically. Later a lighthead replaced the scriber and exposed photographic negatives. The process was much the same as an ordinary plotter, but the dimensionally stable materials yielded negatives suitable for printing high-quality maps with precisely registered colors (fig. 171). Taking a different approach, the U.S. Bureau of the Census used a high-resolution black-and-white monitor and a camera to produce a black-and-white 35-millimeter negative of the image associated with each map color. They subsequently enlarged the negatives to a size suitable for contact exposure to printing plates, screened appropriately (fig. 172). Direct exposure of plates as computer output was still several years away.

Early uses of computers in mapmaking included storing and manipulating data, printing names on stick-up material, and producing separations on paper for guiding the manual construction of usable color separations. All such uses helped cartographers reach the goal of a high-quality printed map in color. During that experi-

FIG. 171. DETAIL FROM *ANHWEI* (PROVINCE), 1975. This map was scribed automatically using a projection program, with color separations prepared by exposing peelcoat material and manually removing areas to produce open-window negatives through which photographic tint screens could be exposed.
Size of the entire original: 25.8 × 22.2 cm; size of detail: 16.1 × 17 cm. From *Peoples Republic of China Administrative Atlas* ([Washington, D.C.]: Central Intelligence Agency, 1975), 13.

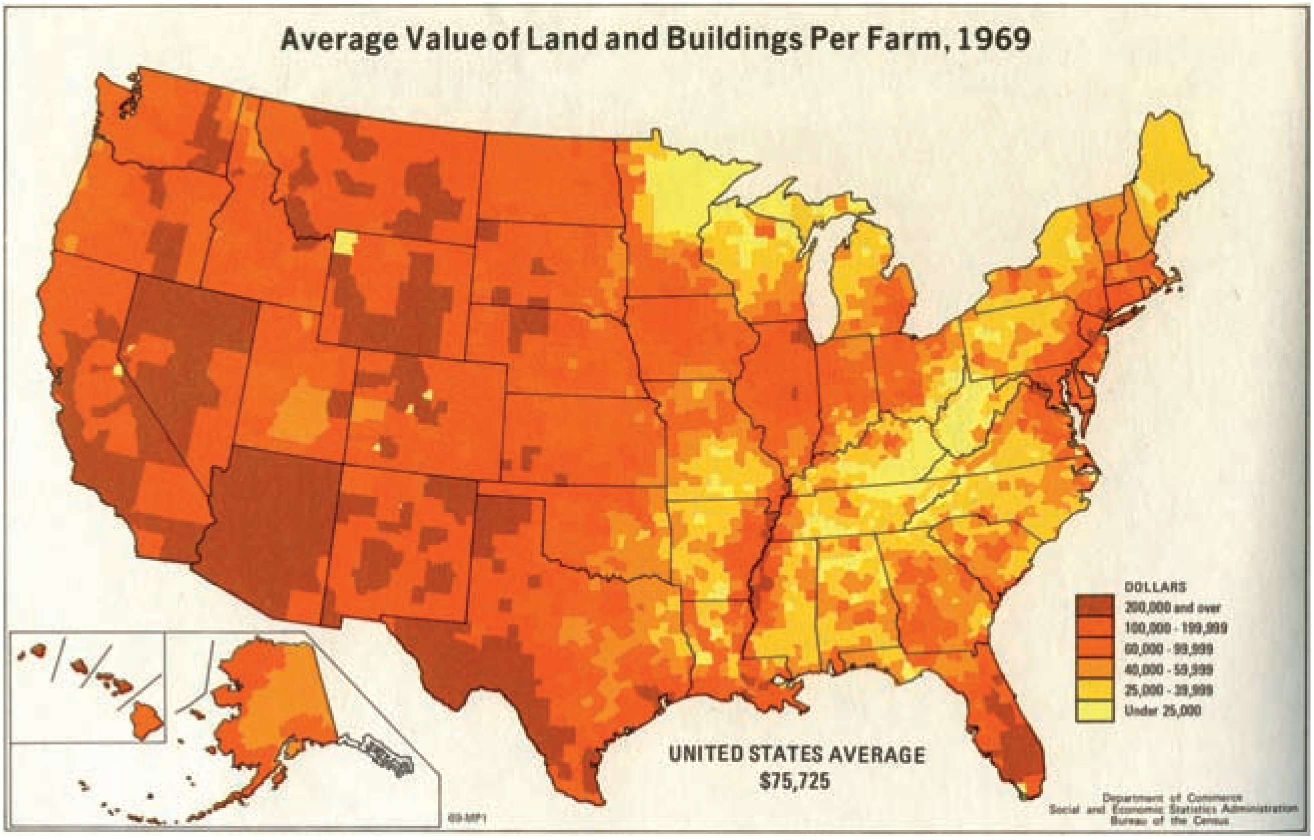


FIG. 172. *AVERAGE VALUE OF LAND AND BUILDINGS PER FARM, 1969*. The image for each color was displayed on a black-and-white monitor, photographed onto 35 millimeter film, enlarged, and exposed to composite negative(s) for the relative ink color(s) with screens as needed. Size of the original: 12 × 19 cm. From U.S. Bureau of the Census, *1969 Census of Agriculture*, vol. 5, Special Reports, pt. 15, Graphic Summary (Washington, D.C.: U.S. Department of Commerce, 1973), 20.

mental period output devices were used to expose color photographic material and make high-quality one-off copies of maps and graphs, generating a short-lived production industry employing specialized professionals. A stronger trend, however, was toward democratization of the making of maps and graphs. By the early 1980s, computers with color monitors, albeit mainly in laboratories and offices, could display large numbers of colors from a color palette of millions. High-quality, relatively detailed color maps could be displayed on the screen by the mapmaker for the map user, the two often being the same person. Although limited by display resolution to the equivalent of a few square inches of a paper map, in research such computer maps were replacing hand-constructed, color-penciled manuscript maps and even paper output from computers.

After color monitors became available, a multi-agency project in the United States foreshadowed some of the systems that would later develop. The Domestic Information Display System allowed the user to access and map statistical data as an electronic display. Allowing some choice of colors and class intervals, it was capable of overlaying two variables and even animating change over time. Intended for use in decision making, it was a stunning system when it first appeared in 1978. Limited to choropleth mapping and a central database, however, it lacked flexibility. Also, the decision makers were not accustomed to using computers, much less using them to explore data on maps. Even worse, users could not integrate their own data sets. An expensive system, it did not attract widespread use (Cowen 1983).

By the mid- to late 1980s, computer-graphics software (e.g., FreeHand and Illustrator) allowed the development of color illustrations, including maps, for printing. Mechanical construction of separations was no longer required, nor were large-format cameras and proofing devices needed to make negatives and combine them into a proof copy to preview the map and its colors. Registration marks could be inserted by selecting that option, and screened patterns would be angled correctly, with registration of patterns and linework automatic and precise. Producing a color map using a computer was a far less abstract experience than previous methods (to students especially) because the map was visible, with all its component parts, in color, while the work progressed. Colors on a computer screen differ somewhat from those printed on a map because colors on the screen are additive, not subtractive like printing inks, and are larger in gamut than printed colors. Nevertheless, the use of computers to render maps was a significant change that expanded the activity to a wider range of people than those specifically trained in specialized, time-consuming techniques.

The emergence of smaller desktop computers enabled adoption for home use, as well as in laboratories and offices. New software allowed a widening range of people to make maps. Available computer mapping programs tended to limit output to straightforward quantitative maps, in contrast to the variety produced in the broader mapping industry. The graphics software used to produce high-quality color separations and negatives could not link to data sets and did not lend itself to home use. Instead, software with "friendly" interfaces offered collections of maps, including road and street maps (forerunners of the more flexible Internet street maps that emerged later and found wider use) and more limited-interest thematic and other atlases.

Meanwhile, geographical information system (GIS) software was being developed to link data sets, conceived as layers, for producing a wide variety of maps, qualitative as well as quantitative. Early versions of GIS were frustrating to cartographers because of the limited graphics choices, but by the 1990s those systems could produce high-quality color maps for monitor display, either directly or on the Internet. There were sufficient design choices to facilitate either traditional high-quality printing or the new trend toward on-demand printing on high-resolution raster color output devices. Cartography and GIS were merging, and software was becoming a powerful tool for map construction as well as analysis.

As the World Wide Web developed and computers became ubiquitous, the computer screen became the map display of choice. Dissemination of geographic information required new skills to construct web pages and produce interactive tools allowing users to choose what to see and sometimes even the colors to be displayed. Reproduction of maps on paper shifted, in some cases, from huge numbers of copies produced on printing presses to print-on-demand using a high-resolution color output device. The shift meant higher per-copy cost than with traditional large print runs, but the advantages included no need to store map inventories, the opportunity to obtain up-to-date copy, and, in the case of topographic maps, the ability to print the exact geographic area desired rather than a predetermined sheet.

Cartography was more than a passive beneficiary of the widespread technological changes occurring during the twentieth century; it helped to drive them. The need for spatial intelligence during the two world wars and others following gave impetus to such innovations as aerial photography, associated stereoscopic instruments for extracting information for mapmaking, and plastic media for producing color separations for maps. Later in the century, military needs stimulated the development of digitizers, plotters, and systems for direct collection of spatial digital data, including remote sensing and Geographical Positioning Systems.

The detection systems developed during the twentieth century resulted in huge data stores. Remote sensing repositories, census files, and other systematic collections of spatial data caused cartographic thinking to shift away from the inference associated with sparse data to the extraction of information from a plethora of data. New cartographic products resulted, ranging from image maps of the physical earth to complex maps of multiple variables. Color was an integral part of the symbol systems used for displaying information on those new cartographic products, just as it had been in the geological and other complex maps employing color in the previous century (figs. 173 and 174).

Color research was also partly driven by cartography because the map is a form of graphic display that makes huge demands on symbol systems and calls for the use of color. In North America color research emerged in cartography during the last three decades of the century. By the 1980s technological advances allowed researchers to present maps with specifiable colors to human subjects, and not long after, answers to questions and response times were being recorded automatically.

The use of color in cartography developed intellectually during the twentieth century, especially as the notion of color logic gained increasing attention. Max Eckert (1908) had called for logic in the selection of map colors, referring to such principles as the use of colors similar to the natural color of the object or phenomenon being mapped, shades of a single color to represent similar things, and consideration of the context of use (wall maps vs. maps observed close up). He also saw the spectrum as a logical color scheme, apparently because of its physical scientific basis. Intellectual attention to color in the United States increased after World War II. In *The Look of Maps* (1952), a treatise developed largely from Robinson's cartographic work at the Office of Strategic Services during the war, a quarter of the text was devoted to color. Eckert's writings figured prominently among Robinson's references, with few others from the geographic or cartographic literature. Robinson referred to the significant achievements in color mapping in Europe during the nineteenth century and noted that, by comparison, that avenue of development

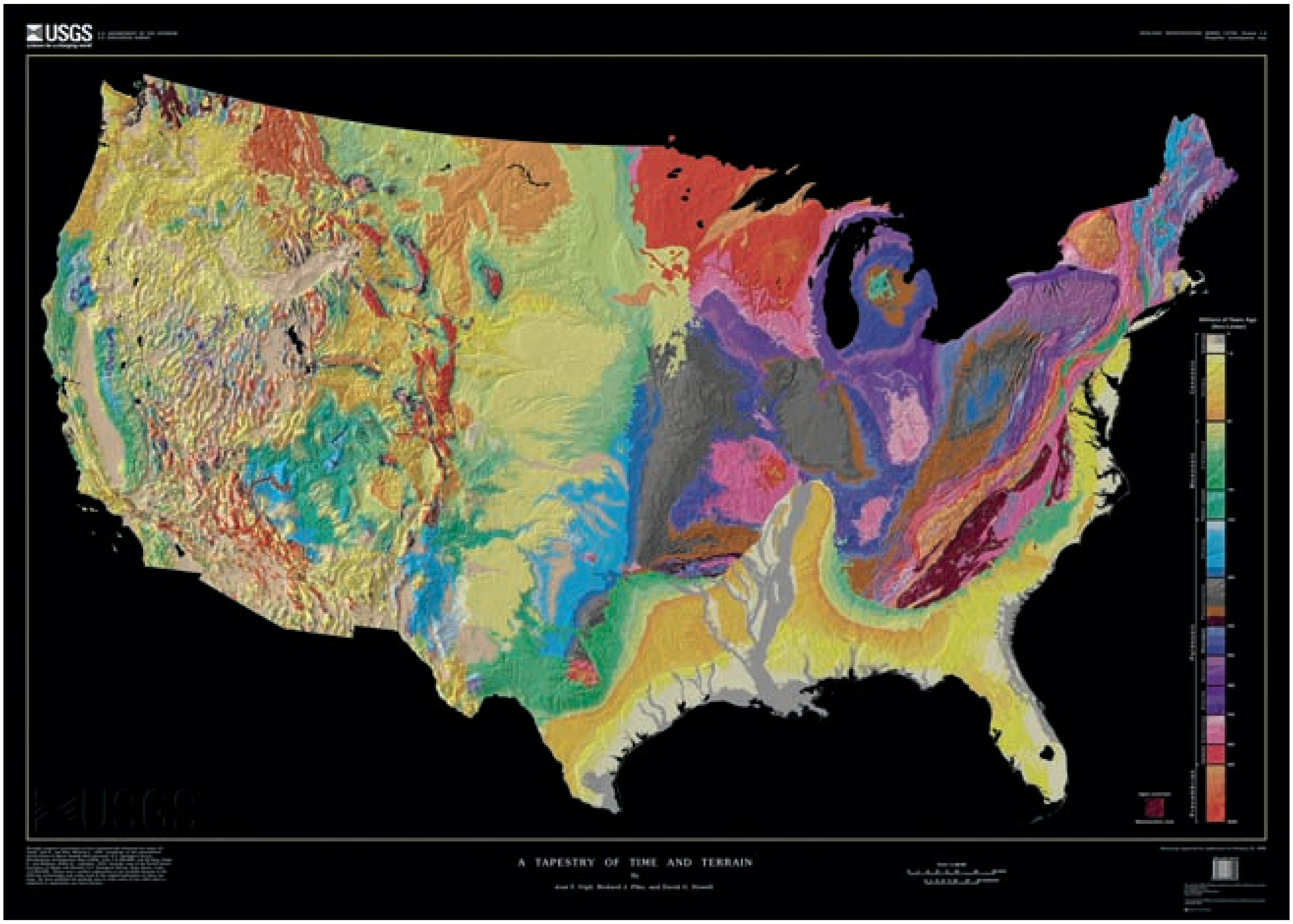


FIG. 173. *A TAPESTRY OF TIME AND TERRAIN*, BY JOSÉ F. VIGIL, RICHARD J. PIKE, AND D. G. HOWELL, 1:3,500,000 (RESTON: U.S. GEOLOGICAL SURVEY, 2000). Geologic Investigations Series 2720. This brilliantly colored computer-produced map stands alone as a paper-format poster but was also available in various electronic formats presenting the map as the centerpiece of linked interactive features that explain and build upon it.
Size of the original: 101 × 141.6 cm. Image courtesy of the U.S. Geological Survey, Denver.

had been "forgotten, at least in American cartography" during the first half of the twentieth century (78). He foresaw no abatement of the costs of color reproduction and predicted (correctly for a few decades) that most cartographers would not be closely involved in color map production. His insistence on the importance of understanding color principles and techniques tacitly drew cartographic research toward the study of maps and map users.

The shift of emphasis in geography, starting in the 1950s, away from description and regional studies to quantitative analysis and thematic specialties such as economic, physical, cultural, population, and transportation geography, stimulated interest in maps of quantitative information. Such thematic maps became increasingly dependent on color to convey primary map information. They also became a prime subject for research in cartography, although the earliest studies employed black ink only.

By the 1970s, the two-variable choropleth maps produced by the U.S. Bureau of the Census made it obvious that logical color schemes were important (Meyer, Broome, and Schweitzer 1975). Ensuing arguments over the readability of such maps inspired studies and led to various color schemes, along with a more nuanced understanding of their meaning to users (Mersey 1980; Olson 1981). With access to color printing, color schemes on maps could be subjected to experimental study. It was becoming worthwhile to develop tools and understanding of color systems for use in cartography. CIE color specifications were analytically calculated for the printing ink combinations commonly used in mapmaking (Kimerling 1980) and the Munsell color-order system was translated to printing ink combinations (Brewer

1989). The logic of spectral schemes on maps had been questioned for decades, and it was the increasing flexibility of color choices afforded by platemakers in university cartographic laboratories, plastic media (including screens) in the production system, and better access to printing that led young researchers to investigate the effects of these and other color schemes, along with such variables as numbers of classes and classing systems, on the ability of readers to answer questions about maps (Mersey 1990; Brewer 1996, 1997; Brewer et al. 1997). Efforts were made to categorize color schemes in some logical manner, relating them to measurement type (quantitative, qualitative) and conceptual nature of data being displayed (Olson 1987; Olson and Brewer 1997; Harrower and Brewer 2003).

Cartographers had long been concerned about users with color-impaired vision (colorblindness), a condition affecting roughly 6 percent of the general population. In the 1980s, changing attitudes toward physical impairments as well as better technology set the stage for opening the issue. Research showed that users with color impairments could be accommodated by appropriate selection of colors (Olson and Brewer 1997).

Cynthia A. Brewer synthesized various threads of color research into recommendations of color schemes for maps (Brewer 1996). By the end of the century she was working on an interactive color selection tool (Harrower and Brewer 2003). Within a few years, ColorBrewer, a freely accessible Internet tool, was enabling users to select from several predefined color sets (for three categories of color schemes and for various numbers of classes) and see the resulting color scheme displayed on a prototype choropleth map. The display indicated the suitability of the selected colors for people with certain color-vision impairments as well as the feasibility of projecting, laser printing, or offset printing the colors. Designed for cartography, the tool was available to anyone attempting to select colors. Such work in cartography influenced other fields in which color was an issue.

In sum, color was already used as a powerful representational tool in the nineteenth century. Yet the state

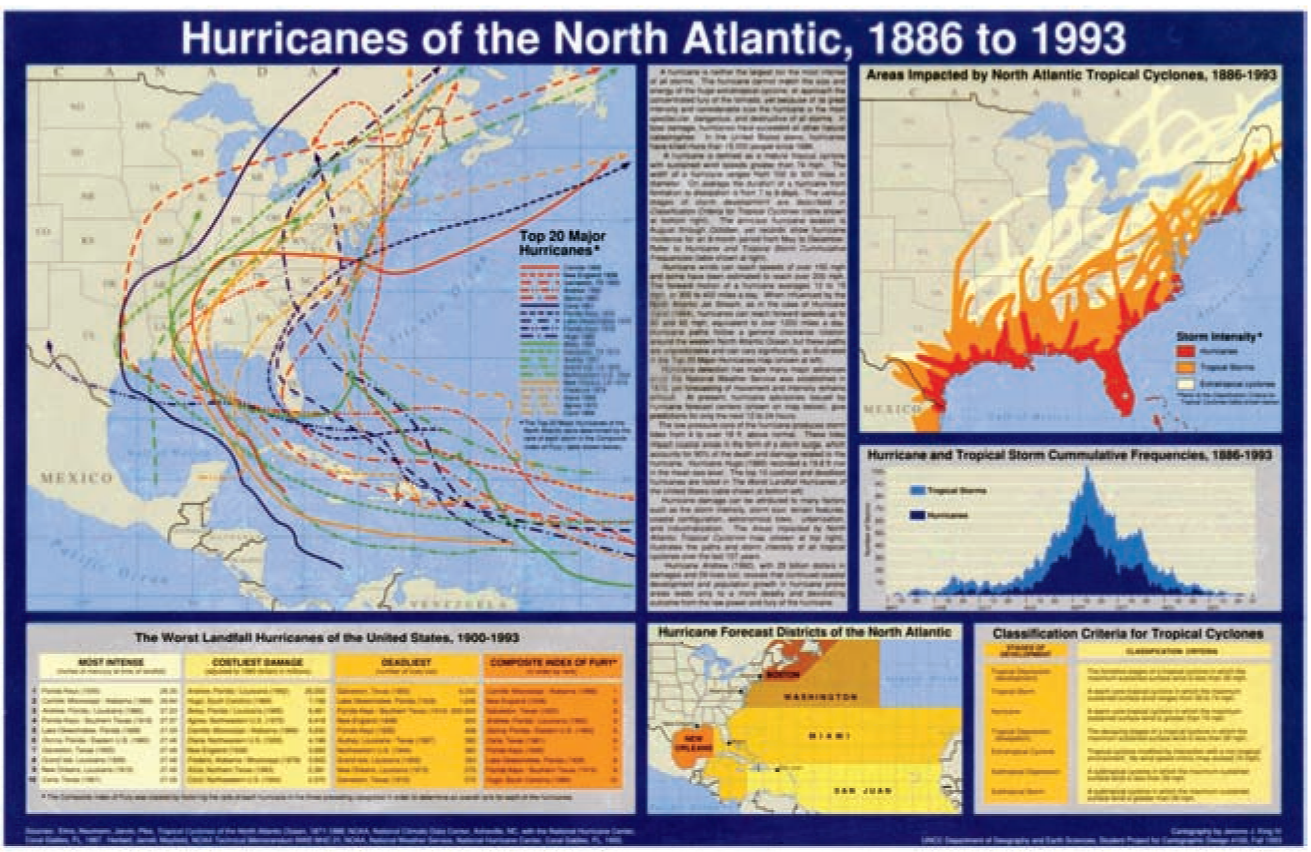


FIG. 174. *HURRICANES OF THE NORTH ATLANTIC, 1886 TO 1993*, BY JEROME J. KING IV. ACSM Map Competition, Best Map Design, Student Category, 1993. Designed as a poster, this computer-produced display of complex phenomena unites maps and text and uses color to differentiate qualitative distinctions such as regions as well as to show hurricane intensity.
Image courtesy of the Geography and Map Division, Library of Congress, Washington, D.C.

of color in cartography had altered greatly by the end of the twentieth century. The most imaginative futurist could not have foreseen the transition from paper to predominantly electronic media and the changing ways in which color would be employed on maps, ubiquitously and flexibly, with mapping both benefitting from and contributing to technological and intellectual developments in color.

JUDY M. OLSON

SEE ALSO: Art and Cartography; Perception and Cognition of Maps; Photography in Map Design and Production; Reproduction of Maps: (1) Color Reproduction, (2) Reproduction, Design, and Aesthetics

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Comité Européen des Responsables de la Cartographie Officielle (European Committee of Representatives for Official Mapping; International). The Comité Européen des Responsables de la Cartographie Officielle (CERCO) was active in Europe between the late 1970s and the year 2000. The organization's initiator was René Mayer, director of France's Institut géographique national. In 1979 Meyer invited the heads of neighboring national mapping agencies (NMAs) to a meeting in Paris to discuss possible European collaboration initiatives in the field of cartography (Anonymous 2005, 5). CERCO was officially formed a year later in Madrid. The first members of the organization were the heads of the NMAs of France, Spain, Belgium, and Germany, but membership rapidly increased in the following years and grew to almost forty by 2000.

At the Madrid meeting participants agreed on a set of bylaws and defined CERCO's objective as "mutual information, consultation and co-operation in the field of cartography as defined by the United Nations, with the exception of military mapping and hydrography" (Luzet 1999, 2). A key element of CERCO's mission was to help members meet national and European needs for mapping and geospatial information. The main strategic objectives of the organization included promoting the role of NMAs within the European Union, raising awareness among the public and legislators of the role and needs of NMAs, defining and adopting standards, and helping its members develop a European geographic information industry. CERCO members were grouped into four categories according to their financial contributions; potential new members were accepted as observers for two years before being accepted as full members.

CERCO was composed of three main bodies. The General Assembly was the main decisional body and met at least once a year. The Executive was composed of a president, whose role was mainly honorific and rotated among members every two years; a management board; and a secretary-general. The latter held the position for five years and was responsible for the administration of CERCO, the coordination of the activities, and the organization of the annual meetings. At the core of CERCO were the Working Groups (WGs), in which most cartographic-related activities actually took place. Several WGs were established over the years, but particularly active (Luzet 1999, 4) were the WGs for data quality, updating databases, copyright and relation with the private sector (the first established), and geodesy and GPS.

In 1993 CERCO established the Multipurpose European Ground-Related Information Network (MEGRIN), a separate organization intended to undertake the management of pan-European projects that CERCO could not undertake because of its limited resources and lack of legal status (Leonard and Luzet 2001). MEGRIN's achievements in the following years included the creation and updating of the Seamless Administrative Boundaries of Europe (SABE) at the scales of 1:100,000 and 1:1,000,000, and the implementation of the Geographical Data Description Directory (GDDD), an Internet-based metadata service containing a descriptive listing of all principal geographical databases available from European NMAs.

In 2000 CERCO and MEGRIN merged to form EuroGeographics, which counted forty-one members in 2006. EuroGeographics' mission and objectives are similar to CERCO's.

ALBERTO GIORDANO

SEE ALSO: Accuracy in Mapping; European Union; Geographic Information System (GIS): Metadata; Standards for Cartographic Information

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Community Mapping. Community mapping refers to the use of mapping by members of a geographic community for their own empowerment for various reasons, including their need for geospatial information as a foundation for rational decision making, or their need for maps either to arouse public awareness locally or to publicize their concerns more widely (Crampton and Stewart 2004). During the twentieth century, community mapping has been shaped by historical and political events as well as by theoretical shifts in the disciplines of geography, cartography, and planning, and, since the 1970s, by technical developments in cartography and geographic information systems (GIS). Embracing a philosophy of local empowerment through local knowledge, community mapping became more potent throughout the twentieth century, gaining momentum at the end of this era with the development of geospatial technology, especially geographic databases and interactive mapping software.

Antecedents of community mapping are clearly evident in the mapping efforts of Jane Addams, founder of Hull House in Chicago. A social activist working in Chicago in the late 1800s, Addams frequently spoke on behalf of the poor and marginalized in that bustling city as it moved beyond its starring role in the World's Fair (World's Columbian Exposition) of 1893. While highlighting Chicago's coming of age, the World's Fair also pointed to the gap between rich and poor, calling for a remedy. But a remedy could not come without first shedding light on the poverty of Chicago's South Side. Seeking a means to tell this important story to the larger world, Addams recognized the value of maps. She created a series of maps of her neighborhood in Chicago based on a survey called "A Special Investigation of the Slums of Great Cities," which was undertaken by the U.S. Department of Labor in 1893, along with additional conversations with neighborhood residents. These maps identified the location of ethnic neighborhoods and included rich written descriptions of the poverty that gripped area residents (Addams 1899, 1960). In form, content, and spirit, these maps ushered in the twentieth century's community mapping efforts.

City planning and the planning profession were other important influences on the evolution of community mapping in the twentieth century, along with new tools and motivation for community mapping use. Inherently interested in maps at the neighborhood level, city planners were among the first to combine themes from multiple maps, giving rise to the concept of map layers, which led to the electronic GIS. As early as 1912, Düsseldorf, Germany, and Billerica, Massachusetts, were mapped using the multilayer method; and by 1929, New York was also overlaying thematic maps to provide a richer understanding of the area (Clarke 2003, 8–9). By 1950, Jacqueline Tyrwhitt used map layers on transparent overlays, and in 1969, Ian L. McHarg's *Design with Nature* solidified the concept and practice. For example, McHarg's thematic layers for Staten Island (1969, 105–14) include geology, hydrology, vegetation, tidal interaction, soils, and scenic value. These efforts hardly reflect the notion of community mapping as a grassroots endeavor inasmuch as urban planning is an official duty of cities, and much of the community mapping associated with urban planning has represented an official view rather than the view of those who live in the communities or who might have been marginalized. Even so, this assessment is moderated by two factors: (1) the professional mission of planners, which is to seek outcomes that optimize the needs of various communities (with some of these needs competing), and (2) the formalization of public input as an element in the final designs of public planning agencies.

Developments in cartography and computer-assisted mapping at the end of the 1950s provided a foundation for later progress in community mapping. The crucial innovation that has come to be known as "map in, map out" (MIMO) made it possible to convert maps into a computer-readable digital format and set the stage for the development of GIS (Tobler 1959). (While the phrase "map in, map out" has been attributed to Waldo R. Tobler, he suggests that the term came after publication of his groundbreaking work, possibly from a colleague in Britain [personal correspondence, 2013].) It took many more years before the technology became available commercially, and even longer until its price, power, and ease of use evolved to a point at which GIS became a viable tool for marginalized people to use to empower themselves in policy deliberations. Yet without this technological development, the evolution of community planning as it entered the twenty-first century would not have been possible.

The 1960s saw tremendous social upheaval and technological advancement in the industrialized countries of North America and Western Europe. In the United States, the civil rights movement of African Americans, with its demonstrations and persistent efforts to gain power in the public sphere, set a tone that continues to find life in community mapping. Other movements, including opposition in the United States to the war in Vietnam and the women's rights movement, similarly encouraged the powerless to take power, partly by challenging authority. This era and its momentum spawned intellectual debate and inspired social activism within the discipline of geography.

During the 1960s, geographer William Bunge developed a model for community mapping that continues to inspire community mappers. By 1968, as the social upheaval in the United States was reaching its zenith, Bunge joined Gwendolyn Warren in undertaking the Detroit Geographical Expedition. The objective of this initiative was to put a human face on Detroit's inner city problems, using maps as well as what social geographer Andy Merrifield (1996, 332) called "evocative photographs" in an atlas format with large pages. Subsequent generations of community mappers adopted Bunge's pioneering strategy in which professional geographers worked with members of residents' associations, community activists, socially responsible citizens of all stripes, and others with extensive local knowledge (including taxi drivers). Bunge emphasized the importance of ensuring that the people being studied have the final say regarding crucial aspects of the study (Merrifield 1996, 333). Thus, in the spirit of the Hull House maps, Bunge's study of Detroit, Michigan, provided a modern framework for community mapping in the latter years of the twentieth century.

By the late 1980s, technological developments in GIS had begun to pave the way for the commercialization and wider implementation of GIS technology. The National Center for Geographic Information and Analysis (NCGIA), created by the National Science Foundation in 1988, provided additional momentum for this expansion by actively encouraging exploration of community mapping through several of its ongoing small-group workshops, known as "research initiatives." The NCGIA also helped popularize another name for community mapping: public participation GIS.

The phrase "public participation GIS" (PPGIS) originated within the planning profession, and its introduction to the cartographic and GIS communities dates from the middle 1990s, when Harlan Joseph Onsrud, Paul Schroeder, and Xavier R. Lopez met to organize an NCGIA workshop devoted to improving access to GIS as a tool of empowerment for groups that had historically been underrepresented in public policy decisions. It was Lopez who suggested using the phrase in the workshop's title, in part because of its use among planners, who (as noted) have played a significant role in community mapping as well as in the development of GIS.

At the heart of the debate regarding PPGIS was the question of whether geographic information systems were more likely to be a democratizing force or a disenfranchising force within the public policy process. A number of scholars noted in the 1990s that many groups were poorly represented in the evolution of GIS, and that the use of the technology by public organizations made it more difficult for average citizens to participate in ongoing policy debates. This occurred because GIS simplifies spatial analysis and the creation of persuasive maps by those in power, putting community groups without this technology at a distinct disadvantage. As J. B. Harley suggested, "maps can reinforce and legitimate the status quo" (1996, 442). The opposing argument held that as barriers to the use of GIS fall, community groups and other marginalized peoples will also gain access to this powerful technology.

A series of gatherings in the 1990s served to build a permanent community of activists and researchers devoted to the goals of community mapping. The first of these was the "GIS and Society" workshop, organized by Thomas K. Poiker (formerly Peucker), sponsored by the NCGIA, and held at Friday Harbor, Washington, in November 1993. In 1995 a special issue of *Cartography and Geographic Information Systems* (vol. 22, no. 1) featured articles written by participants at that workshop. In spring 1996, the University of Minnesota hosted another NCGIA meeting at Koinonia, Minnesota, to develop a research agenda under the "GIS and Society" rubric. One of the breakout groups at that meeting focused explicitly on PPGIS. This led to a workshop on PPGIS hosted by the University of Maine in the summer of 1997. In 1998, *Cartography and Geographic Information Systems* published a special-content issue on PPGIS (vol. 25, no. 2).

Several of the participants in these workshops were already actively engaged in community mapping around the world, often in service to marginalized groups. Epitomizing this practice is the work of Daniel Weiner and Trevor M. Harris and their colleagues, who discussed the "multiple realities of resource access and use represented within the Kiepersol [South Africa] GIS" in their effort to "contribute to democratic decision making for land and agrarian reform" (Weiner et al. 1995, 30). Others have followed this example, and a thriving long-term commitment to community mapping using GIS persists into the twenty-first century.

Conferences and workshops designed to develop such relationships and to transmit technological skills to community groups became a regular feature of the community mapping and PPGIS communities in the waning days of the twentieth century. These efforts ultimately resulted in the creation of formal networks linking community mappers and proponents of PPGIS around the world. Specifically, the creation and evolution of the Internet and its listservs and virtual meetings has made it possible for community mappers to stay in touch on a daily basis.

The creation of Integrated Approaches to Participatory Development (IAPAD) has provided a virtual meeting place for anyone interested in community mapping. IAPAD offers numerous resources, including a PPGIS listserv, bibliographies, and links to numerous other resources for community mappers. Moreover, the IAPAD website provides opportunities for the PPGIS community to describe their own projects and share them with others. As proclaimed on its website, IAPAD is "dedicated to assuring grassroots' participation in the project cycle (design, appraisal, implementation, monitoring and evaluation)," and "committed to facilitating the interaction of less favored groups of society with local government institutions and donor agencies."

Community mapping initiatives have developed throughout the world. For example, in Chicago, the Cabrini Connection reported on its website the use of "GIS computer technology to guide volunteers, donors and business partners to tutor/mentor locations around Chicago." The Common Ground mapping project in Victoria, British Columbia, Canada, has used mapping as a tool for a variety of community initiatives in the area, and IAPAD has identified additional ongoing projects in Fiji, Nepal, India, Ecuador, Thailand, Sri Lanka, and Vietnam.

As the twentieth century came to a close, the PPGIS and community mapping movement coalesced with tremendous momentum, keeping alive the content, form, and spirit of Jane Addams' Hull House maps and the cartographic products of William Bunge's Detroit Geographical Expedition. Expanding far beyond the confines of urban areas in developed regions, community mapping grew to include initiatives around the world, many of them in developing countries. If its history over the twentieth century is any indication, community mapping will continue to evolve, incorporating new technologies and strategies in the interest of improving neighborhoods for those who live there.

NANCY J. OBERMEYER

SEE ALSO: Boundary Disputes; Crime Map; Counter-Mapping; Environmental Protection; Indigenous Peoples and Western Cartography; Planning, Urban and Regional; Public Access to Cartographic Information

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Computer, Digital. A computer is a machine that manipulates information according to programmed instructions. The term *computer* originally denoted any person or machine that performed numerical calculations, but it has become synonymous with the digital computer, which uses software (stored programmed instructions) to control hardware (physical electronic components).

Digital computers debuted in the 1940s in large part as aids to wartime cryptographic, manufacturing, and logistical efforts. Early computers were generally limited to institutional settings such as government agencies and research laboratories. These computers were constructed from electrical relays or vacuum tubes, but by the 1960s electronic transistors had replaced these technologies and allowed computers to become inexpensive enough to be offered commercially. From the 1970s onward, most computers were powered by microprocessors that combined millions of transistors and other electronics on a single integrated circuit. Advances in the speed and affordability of microprocessor technology from the 1980s onward and the growth of the Internet in the 1990s spurred individual ownership of computers to the point where they became commonplace in much of the developed world.

Digital computing defined much of the scientific and technological context of twentieth-century cartography. Cartography became dependent on software for visualization and display, data capture and management, image processing and spatial analysis, and design. Despite the importance of this software to cartography, human expertise remained vital. For example, computing had a mixed impact on map aesthetics because digital data and design software offered trained cartographers unparalleled latitude in map composition while allowing neophytes to easily create conceptually flawed maps that were visually appealing. Automated tasks such as label placement and line generalization similarly addressed long-standing cartographic challenges but rarely replaced the need for human intervention.

Computer hardware also affected cartography. Computer displays offered on-screen viewing and manipulation of cartographic data and output. Printing technology such as pen plotters and printers afforded advantages in speed and availability over manual cartography or printing presses. Digital computers were essential to the scanning technology that undergirds many forms of remote sensing and allows rapid capture of analog documents such as maps. Computer-based digitizing and photogrammetric devices similarly permit human operators to acquire data from a variety of analog sources.

Beyond the use of hardware and software in cartography, digital computing had societal dimensions for mapping and related activities. Computers allowed cartographers to readily update the data underlying maps with techniques ranging from the automatic capture of large data sets by scanning to the interactive processing of existing data. The increasing availability of data and maps via the Internet and other digital media promoted the wide use of customized maps created by people with little cartographic training. Computing also expanded the use of mapping in governance because the smallest, or most, local of agencies could afford digital cartographic tools. In terms of the long-standing relationship between cartography and warfare, digital computers lie at the heart of technologies such as the Global Positioning System, geographic information systems, and remote sensing. In sum, digital computing became an essential aspect of twentieth-century cartography but also emphasized the continuing role for human judgment in mapping.

STEVEN M. MANSON

SEE ALSO: Digital Library; Electronic Cartography; Geographic Information System (GIS)

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Conformality. The concept of conformality as applied to cartography refers to a geometrical transformation between the set of coordinates on the spheroid of the earth and those on a map that is angle preserving. In its simplest form, "angle preserving" means that the lines drawn on the surface of the earth will intersect at the same angles on the flat map, thereby conveniently reducing constant compass headings on the earth's surface to straight lines—a property particularly valuable when maps were used for navigating open water or aiming long-range artillery. Because they preserve angles, conformal maps also produce low scale distortion over local areas and can be manipulated to produce very accurate large-scale geographic mapping. This preservation of angles forms the basis of conformal map projections, which since the time of Gerardus Mercator have occupied an important place in cartographic history. During the course of the twentieth century conformal projections became mathematically very complex and were created for reasons that ranged from mere mathematical curiosity, like the orthoapsidal projections thought up by Erwin Raisz (1943), to the more important and practical applications, such as the Space Oblique Mercator projection, which was critical in the early development of satellite mapping and remote sensing.

A conformal projection or mapping can be mathematically expressed by any number of functions using either differential geometry or the algebra of complex numbers. No matter how it is functionally defined, the geometrical transformation between the coordinates on the sphere (u, v) and those found on the map (x, y) must meet the conditions set out by the Cauchy-Riemann equations:

$$\frac{\partial u}{\partial x} = \frac{\partial v}{\partial y} \text{ and } \frac{\partial u}{\partial y} = -\frac{\partial v}{\partial x}$$

This pair of equations shows in differential form the conditions for any projection to be angle preserving when the coordinates of one surface are transformed to another. During the twentieth century cartographers found that a wide range of mathematical functions could be made to conform to these conditions, and the number of conformal projections multiplied, especially with the advent of computers and the invention of faster numerical methods for solving differential equations.

The derivation of conformal projections as a mathematical exercise led to interesting insights into the behavior of projections in general and to speculation on the infinite variety of forms that these geometric and algebraic transformations could take. Among the most complex of the mathematical derivations attempted were those based on elliptic functions.

An elliptic function is a mathematical mapping from one set of numbers to another that is defined on the complex plane and is periodic in two directions. Most projections are differential and algebraic equations that are defined over the real number plane. Elliptic functions expand this definition by defining functions over the complex plane, which includes *i*, the square root of −1. The fact that these functions are doubly periodic means that the coordinates involved in the transform can be varied independently, allowing great variety in the schemes by which latitude and longitude can be transformed from the surface of the earth to a planar map.

Oscar S. Adams, in a short 1925 book, was the first to exploit the doubly periodic nature of elliptic functions to produce conformal projections. Adams's work is densely packed with mathematics that had never before been applied to cartography, and the concept of conformality was an integral part of the derivations. Adams called upon a wide range of mathematics, including the theory of Abelian functions and Jacobian and Dixon elliptic integrals, to create conformal projections of the sphere within a six-pointed star, the surface of the earth within an ellipse, and other peculiar mappings with little practical application.

Based on Adams's work, L. P. Lee (1976) adopted an integral form of elliptic equations that was first discovered by Hermann Amandus Schwarz in 1864:

$$w = \int_0^z (1 - z^n)^{-2/n} dz$$

Using this integral, Schwarz (1869) showed that the interior of a circle with radius z could be conformally represented by the interior of a regular polygon w of n sides. Expanding on Schwarz's work, Lee used elliptic equations to develop a series of projections that conformally mapped the earth onto the faces of all of the platonic regular polyhedra. Although Lee's work has never been used for actual mapping applications, it was a remarkable mathematical achievement that opened new possibilities for the use of complex analysis in the development of conformal map projections (fig. 175).

More practical uses of the concept of conformality can be found in projections developed using polynomial series expansions of complex numbers. This ability to expand algebraic transformations using complex numbers allowed the creation of specialized projections for large-scale conformal mapping, exploiting the fact that

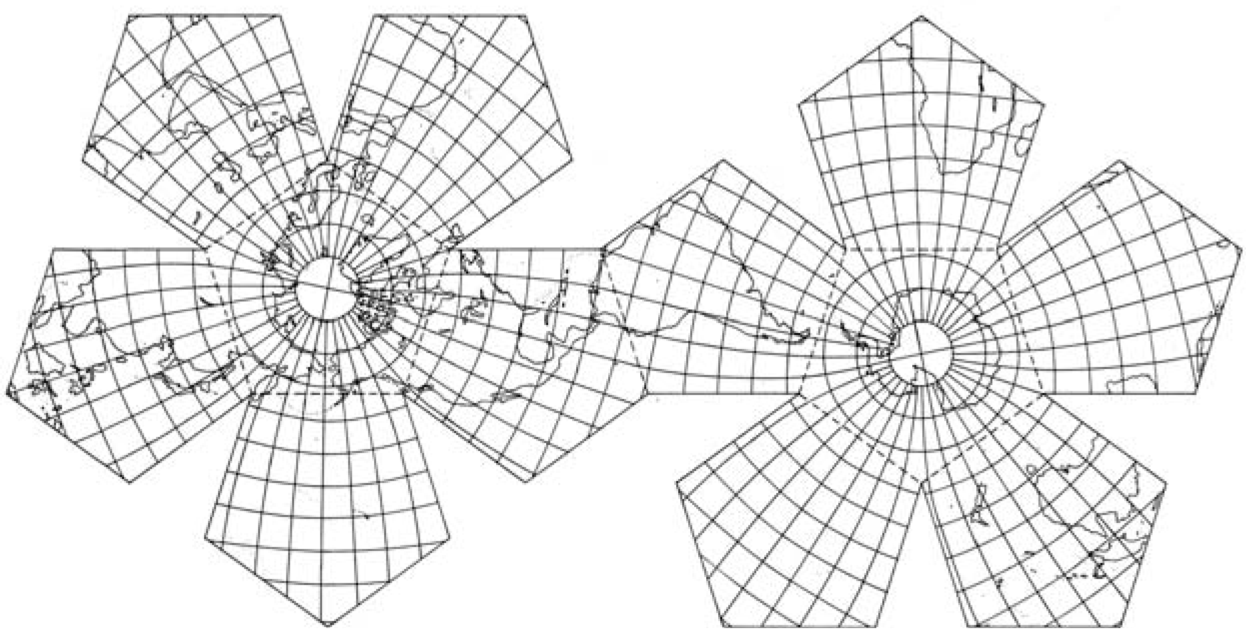

FIG. 175. LEE'S CONFORMAL PROJECTION OF A SPHERE. Here the earth is projected onto Plato's dodecahedron using elliptic functions.
Size of the original: 9.6 × 19.7 cm. From Lee 1976, 103 (fig. 47) (DOI: 10.3138/FQ88-5827-6550-4144). © University of Toronto Press, 1976. Reprinted with permission from the University of Toronto Press.

in many cases the benefits of conformality can only be preserved locally. The most common expansion of this type was first developed by Ludovic Driencourt and Jean Laborde in 1932:

$$x + iy = \sum_{j=1}^{n} (A_j + iB_j)(x' + iy')^j$$

This equation, which allows an exactly conformal projection to be drawn for specific geographic areas that are irregularly shaped, was used by Laborde for a map of Madagascar and later in the 1970s by John Parr Snyder for his conformal map projection of the fifty United States called the GS50. The procedure uses an already existing conformal projection and adapts it to a particular area in order to reduce scale distortions in regions bounded by closed curves. In theory, this type of expansion appears to allow one to determine an *A*, *B*, and *n* to fit almost any shaped region and to make the scale factor follow almost any prescribed pattern. In practice, however, the polynomial expansion is soluble only in special cases and was difficult to manipulate before the age of computers. Snyder, in his GS50 projection (fig. 176), was able to determine coefficients that allowed a region around the fifty states to have nearly zero scale distortion at the cost of the surrounding areas having very high error.

There are two other important applications of the concept of conformality to modern cartography. The first is its role in the early development of satellite mapping and remote sensing. The Landsat 1 satellite, launched in 1972 as ERTS 1 (Earth Resources Technology Satellite 1), was programmed to fly in an orbit with a satellite ground track that proceeded essentially along an oblique circumference of the earth approximately nine degrees off the poles. In order to make maps from the images that the satellite was producing, Alden P. Colvocoresses, cartographic coordinator for earth satellite mapping at the U.S. Geological Survey, defined a new type of projec-

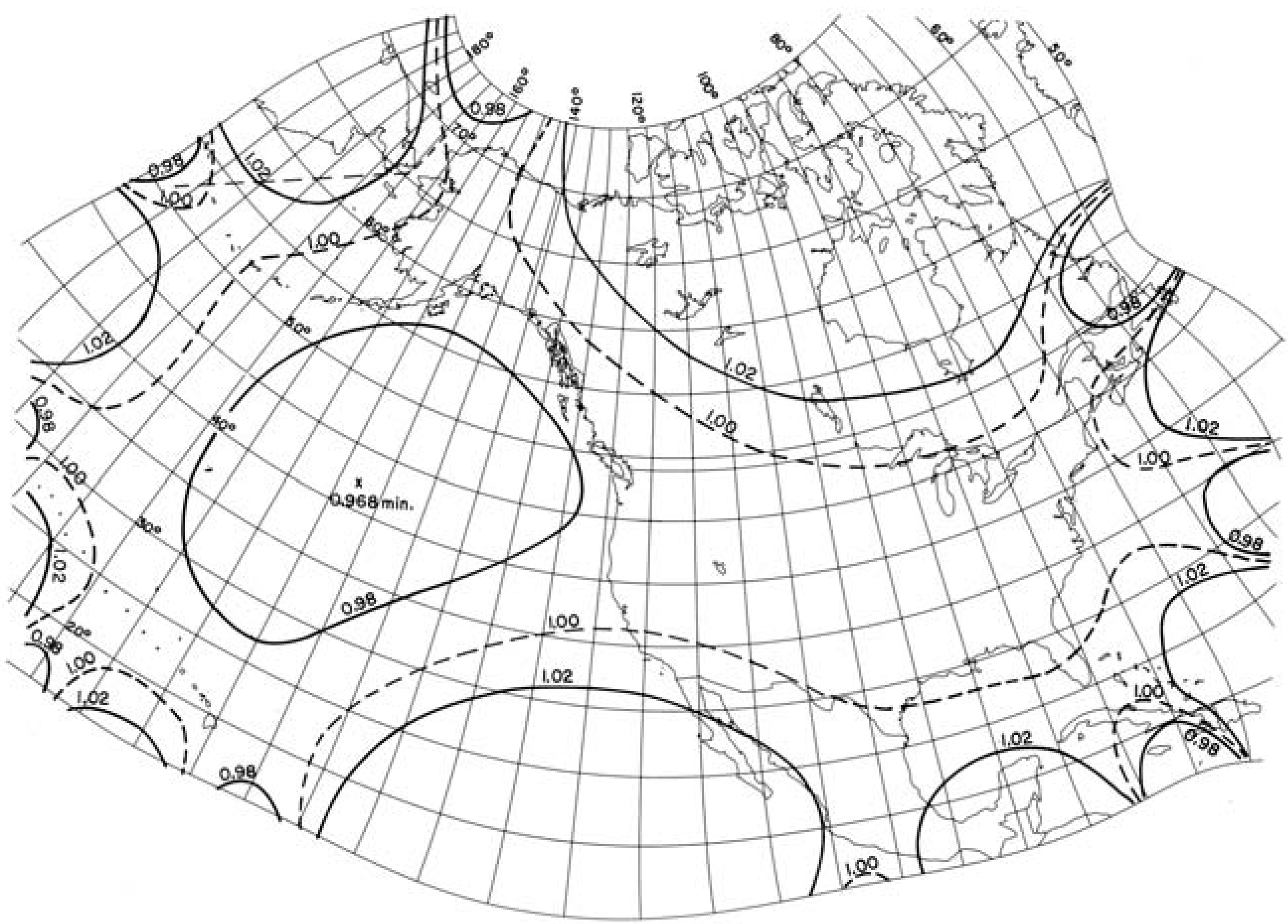

FIG. 176. SNYDER'S GS50 PROJECTION OF THE FIFTY UNITED STATES. Created with the Driencourt-Laborde expansion, note the area of zero scale distortion that surrounds the continental United States.

Size of the original: 14.1 × 19.9 cm. From Snyder 1984, 32 (fig. 4). Reproduced by permission of Taylor & Francis.

tion that would allow the mapping, conformally at the correct scale and with minimum scale variation, of the swath of the earth's surface that was scanned continuously throughout the orbit's cycles. Colvocoresses defined the projection as conformal as an a priori condition due to the geodetic conditions produced by the satellite orbit and accuracy considerations and in his paper (Colvocoresses 1974, 922–23) stated: "The projection could have any one of several characteristics, but precise map makers generally consider the characteristic of conformality as dominant. Conformality retains equal scale locally in all directions and preserves angular relationships." The actual equations describing the projection would not be developed until several years later, by Snyder (1981).

The second application of conformality can be found in development and adoption of the Universal Transverse Mercator (UTM) coordinate system by the U.S. military in the 1940s. The UTM system is not a single conformal projection, but like so many of the other innovations concerning the concept of conformality in the twentieth century, it is defined by customizing and mathematically modifying other forms of conformal projection. In the case of the UTM a secant version of the Mercator projection is applied to the surface of the earth that has been divided into sixty zones, 6° wide. Between 80°S to 84°N these sixty zones cover the surface with low-scale-distortion projections that reflect the increased importance of large-scale mapping for both civilian and military uses. (Polar areas are covered by the Universal Polar Stereographic coordinate system, also based on conformal map projections.) Like conformal projections based on polynomial expansions, the UTM exploited the areas of low scale distortion that are locally defined in each of the sixty zones. Because the sixty projections overlap, the areas of low scale distortion near the center of each zone can be utilized while the more distorted areas beyond the zone boundaries are ignored.

JOHN W. HESSLER

SEE ALSO: Coordinate Systems; Mathematics and Cartography; Projections: Projections Used for Military Grids; Tissot's Indicatrix

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Control Survey. See Photogrammetric Mapping: Geodesy and Photogrammetric Mapping

Conventions, Cartographic. The process of symbolization is inherent to mapmaking and involves the selective generalization and abstraction of features. Cartographers employ conventions to regulate this process and to facilitate the identification and recognition of features by the user. Cartographic conventions extend from metadata, projection systems, toponyms (place-names), and general color schemes to the more detailed characteristics of symbology, lineweights, and typefaces used in labeling specific types of features. Conventions may apply within a single map, within and among map series of identical or different scales, and among maps produced by different organizations or individuals. Some conventions have evolved over time as best practice, such as the use of blue for depicting hydrological features, orientation toward north, and the use of darker shades to denote higher values (as in choropleth maps, for example). Other conventions are more deliberately introduced, for example, the particular symbology adopted in specialized maps such as aeronautical and marine charts, which follow internationally agreed conventions and standards to ensure a degree of uniformity, upon which the safety of users relies.

Following the development of the lithographic printing press in the early nineteenth century, the enhanced possibilities of color printing brought through the later innovations of photolithography, cerography, and rotogravure allowed greater uniformity in the appearance of the finished map. The introduction of offset lithography resulted in sharper and faster printing, allowing the standardized reproduction of more detailed symbols and graphically sophisticated maps. This development was particularly useful in the production of topographic and general reference maps, which utilize homogeneous styles of cartography. In 1911, the first sheets of the International Map of the World (IMW)—a global series of maps at the 1:1,000,000 scale that had been proposed by German geomorphologist Albrecht Penck at the Fifth International Geographical Congress in 1891—were published. The project relied on the establishment and implementation of an internationally agreed series of conventions, ratified in 1909 and confirmed in 1913, including a bilingual legend comprising a standard set of symbols (fig. 177). Contemporary lithographic presses enabled exact specifications of the size, shape, and color of

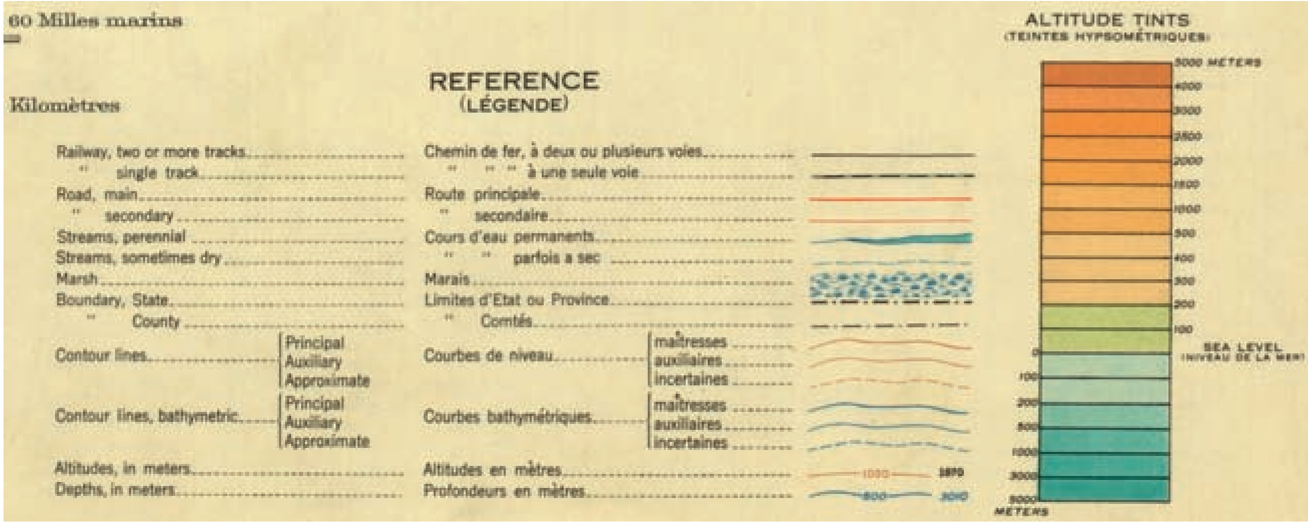


FIG. 177. LEGEND DETAIL FROM *MT SHASTA*, INTERNATIONAL MAP OF THE WORLD, 1:1,000,000, 1949. The IMW was a bold attempt to create, through international collaboration, a global series of maps at the 1:1,000,000 scale utilizing a standard symbology, as illustrated here. Published Washington, D.C.: U.S. Geological Survey (sheet N.K-10).

Size of the entire original: 58.9 × 54.2 cm; size of detail: 7.8 × 19.7 cm. Image courtesy of the American Geographical Society Library, University of Wisconsin–Milwaukee Libraries.

symbols and lettering to be implemented and reproduced by the respective national mapping agency responsible for each sheet, yielding a standardized result.

Inevitably, the advent of war stimulates the birth and death of cartographic conventions. The utilization of portable offset presses to produce the trench maps of World War I involved overprinting detailed topographic information with the positions of the opposing armies in color. However, by early 1918, the British convention of depicting friendly forces in red and the enemy forces in blue had been reversed to conform to the French style of trench mapping.

Standards in printed color reproduction continued to improve after World War I, and some contemporary observers noted the homogenizing effect of cartographic conventions, particularly in national topographic mapping series: "Nowadays, to the map-maker's eye, all water is blue. Even the Avon at Bristol, the Mersey at Liverpool, the Thames at Waterloo Bridge, and the very mud which, during most of the day, fringes the rivers, all are as blue as a Mediterranean seascape" (Jervis 1936, 40). By World War II, most medium-scale topographic map series had adopted a four-color scheme of blue for water features, green for vegetation, brown for contours, and black for planimetry, which was later termed the "classical style" by J. S. Keates (1996, 256). Indeed, W. W. Jervis (1936, 146) had observed: "The new countries of Europe have failed to avail themselves to the full of the manifold aids which modern colour-printing has placed at their disposal in map-production." In their survey of topographic maps published during World War II, however, Everett Claire Olson and Agnes Whitmarsh (1944, 160) point out that in some cases, the use of color "has apparently been dictated by the desire to produce a striking design rather than a practical map," which at least implies a degree of innovation. Their wartime text provided a series of tables that allowed a straightforward comparison of nationally adopted symbologies (fig. 178), especially highlighting the degree of convention exhibited in the design of point symbols.

In the postwar period, the IMW lost momentum, and its demise was partly because of the absence of a strong central body to direct the project and promote uniformity. But a major problem of the series was the difficulty in creating symbols that were equally applicable to all parts of the world (Thrower 1999, 168). The disappointing outcome of the project did not, however, signify the end of international cooperation in efforts toward the standardization of cartographic symbols. Following the formation of the International Civil Aviation Organization (ICAO) in 1944, a World Aeronautical Chart (WAC) series evolved to meet the increasing needs of aircrews. Being derived in the early stages from U.S. Army Air Force material, the charts were produced at 1:1,000,000, had clear functional objectives, and were specially designed to meet the needs of a particular user group. As these users do not require the same diversity of information as befitted the inventory of the landscape

FIG. 178. TABLE ILLUSTRATING MAP SYMBOLS USED BY DIFFERENT COUNTRIES. This table shows the representation of buildings adopted in topographic mapping by a range of countries and illustrates how they can exhibit considerable similarity (e.g., triangulation points) and difference (e.g., lighthouses). Size of the original: 13.3 × 11.4 cm. From Olson and Whitmarsh 1944, 150 (fig. 10).

approach of the IMW, fewer design decisions were required. By conforming to a series of specific internationally agreed conventions, the ICAO series succeeded in its aims of meeting the specialized needs of its users.

The emerging cartographic legacy of the Soviet Union (Collier et al. 1998; Postnikov 2002) has also highlighted the extent to which cartographic conventions can be successfully applied toward the creation of a global mapping program. This involved the production of detailed topographic maps at a wide range of scales (from 1:2,500,000 to 1:10,000) to standard specifications by (and incorporating) a number of Eastern Bloc countries. In Romania, for example, following the Conference of East European Cartographic and Geodetic Services held at Sofia in 1952, new topographic series were initiated according to the Soviet 1942-System (Parry and Perkins 2000, 842). While civilian maps were produced, these usually represented areas in poor detail and official maps were not generally available to the public.

Modern lithographic color printing offers a full range of color and tone, providing a freedom of expression to affect the content, methods of representation, and aesthetic appearance of printed maps (Keates 1996, 254). Makers of thematic maps have tended to take advantage of these developments, largely because they are usually produced as individual maps or as a series within an atlas that follows a publisher's own house style. Conversely, topographic mapmakers, usually following established organizational procedures, have been less free to experiment. However, the series of papers instigated by David Forrest, Alastair W. Pearson, and Peter Collier (1996) demonstrated how various topographic mapping organizations treat different phenomena, such as the coastal environment (Forrest, Pearson, and Collier 1997), vegetation and rural land use (Collier, Pearson, and Forrest 1998), and relief (Collier, Forrest, and Pearson 2003). These studies examined maps produced by commercial and state mapping organizations at different scales and found little evidence of convention among mapmaking organizations. The extent of stylistic diversity among European state topographic maps was further demonstrated by Alexander J. Kent and Peter Vujakovic (2009), whose analysis of 1:50,000 mapping revealed strong national differences among a sample of twenty countries (fig. 179).

Cartographic conventions that govern the portrayal of place in modern state topographic mapping can lead to the homogenization of landscape. As J. B. Harley (1991, 12) remarked: "The U.S. Geological Survey is developing a national cartographic data standard. Yet is this entirely a step forward? It could result in a further narrowing of the ways in which the diversity of local landscape is mapped and it is saying, in effect, that there is only one way of showing a particular geographic feature despite any potential insensitivity to social and environmental issues in that form of representation." This homogenization might suggest a lack of authenticity and sensitivity to local distinctiveness, leading to social resistance and the questioning of the authority of state topographic maps and the relevance of cartographic conventions. While the coupling of desktop publishing software with inkjet printing in the early 1990s, enabling users to create digital maps and print them out in color, was the first step toward the democratization of cartographic conventions, counter-mapping initiatives began to emerge in the United Kingdom in the early 1980s. These sought to democratize the power of mapping through the creation of maps of a local area by the local community, e.g., the Common Ground Parish Maps Project (fig. 180), or of anywhere by a wider user community online, e.g., OpenStreetMap, founded in 2004. Here, cartographic conventions are approved by the community, as opposed to the institution.

The advancement in geographical information tech-

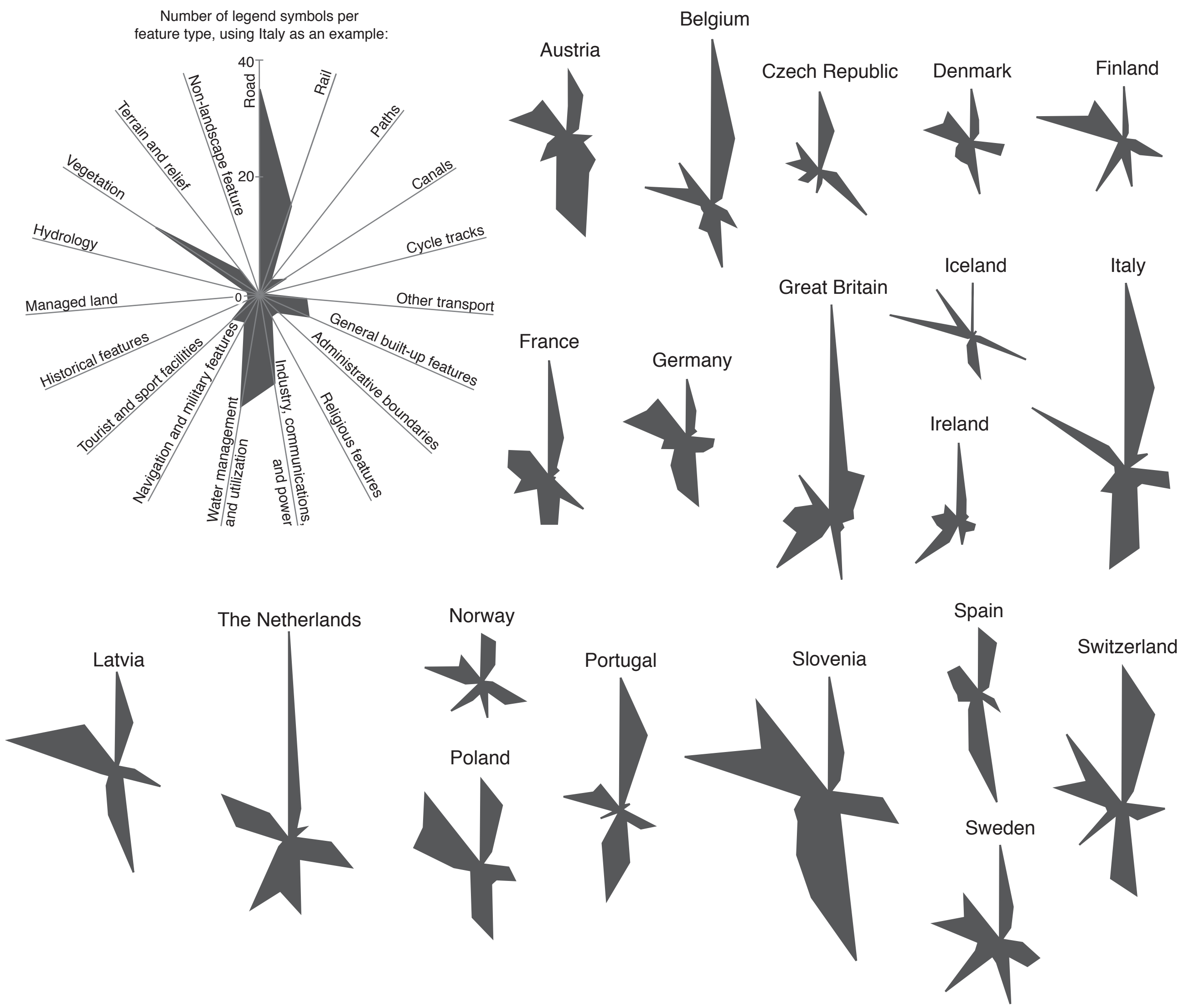
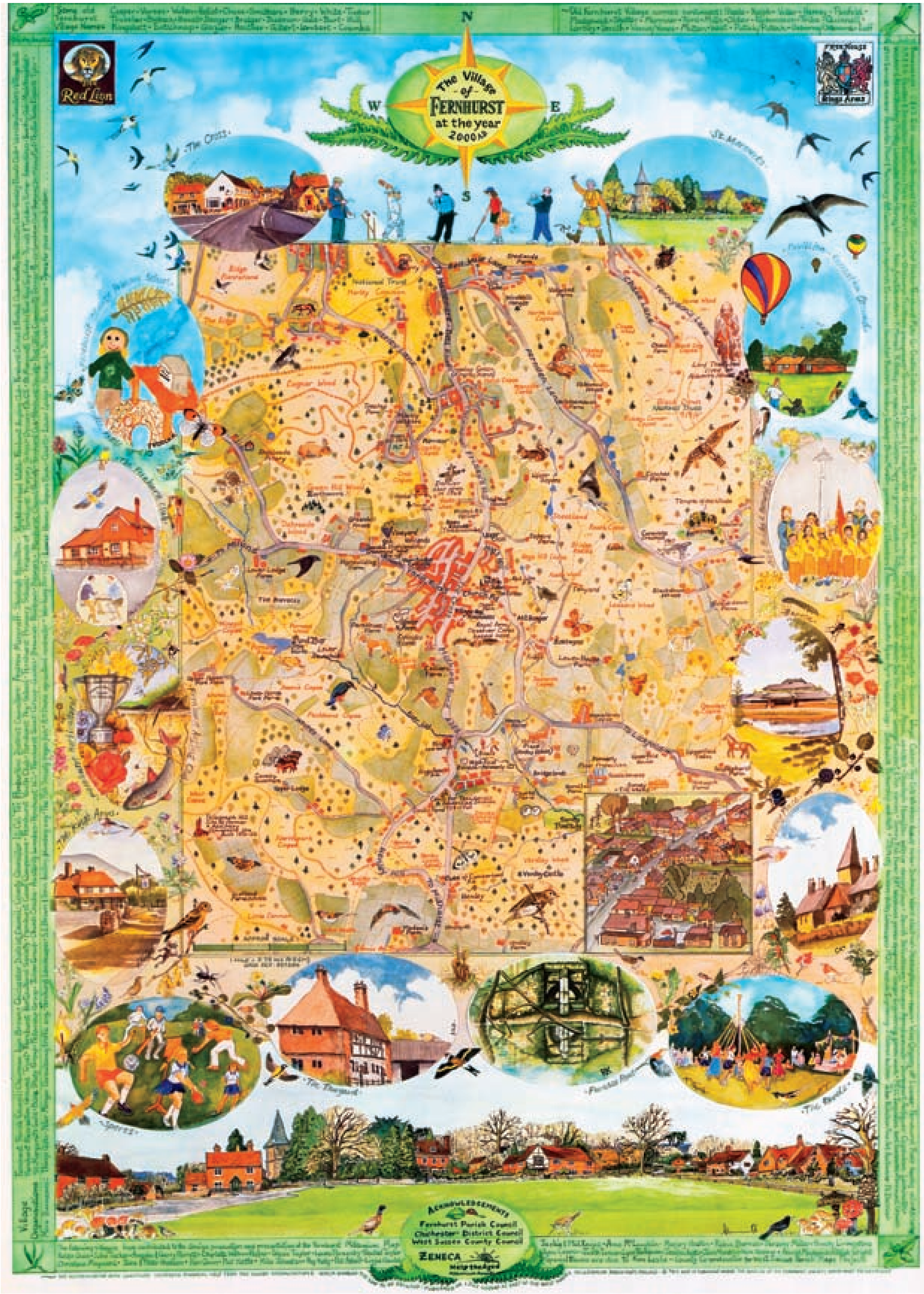


FIG. 179. NATIONAL TRENDS IN EUROPEAN MAP SYMBOLIZATION. Star plots indicating the number of discrete graphical legend symbols devoted to the representation of particular types of features in European 1:50,000 state topographic map series, illustrating stylistic diversity. Despite other pan-European initiatives for standardization, national traditions of cartography persist.
After Kent and Vujakovic 2009, 201, 202.

nology since the IMW was proposed in 1891 has been substantial. A total transformation in the way information can be gathered, stored, displayed, and shared has significant implications for the nature of cartographic conventions that would seem to raise the possibility of a successful new initiative in global mapping. Such advances, however, do not eliminate the associated problems of international cooperation. Aspirations for a new era of global cooperation in the new century (therefore echoing Penck) have been expressed by David Rhind (2000, 295), who refers to topographical mapping as "the geographical framework used to underpin many activities of the state and of business." Rhind uses the term "harmonization" (as opposed to "standardization"), perhaps to acknowledge the unlikelihood of resolving differences between countries in terms of the portrayal

(*Facing page*)
FIG. 180. *THE VILLAGE OF FERNHURST AT THE YEAR 2000 AD*, CA. 1:16,900, 2000. Counter-mapping initiatives challenge cartographic conventions, particularly the homogenization of landscape through state topographic mapping. In this example of a parish map of Fernhurst, West Sussex, England, the local community aimed to capture the local distinctiveness of the place for the new millennium.
Size of the original: 55.7 × 39.6 cm. © The Fernhurst Society. Image courtesy of the Fernhurst Society, West Sussex.


The Village of Fernhurst at the year 2000AD
N
W
E
S
Red Lion
Kings Arms
The Cross
Acknowledgements
Fernhurst Parish Council
Chichester District Council
West Sussex County Council
Zeneca

of features through cartographic symbology. Indeed, the vision of EuroGeographics (a not-for-profit organization formed in 2000) is to achieve the interoperability of European mapping and other geographical information data within ten years. This would be achieved primarily through the standardization of the referencing and coding of information, based on ISO (International Organization for Standardization) 19115, which refers to quality in the provision of metadata such as language, date, and character set, rather than the construction of a standardized portrayal through conventions regarding symbol design. Indeed, the INSPIRE (Infrastructure for Spatial Information in the European Community) directive of 2007, which aims to create a spatial data infrastructure for all European Union countries by 2019, relates to the classification of geographical information rather than its portrayal.

The dawn of the twenty-first century saw a decline in traditional lithographic press printing of large numbers of map sheets in favor of on-demand printing via large-format inkjet printers based in retail outlets. This led to national mapping organizations developing new symbologies to suit this means of production and consequently a narrower topographic symbology comprising a suite of less intricate point symbols (e.g., Natural Resources Canada). Moreover, with the availability of on-demand mapping via online servers, users can also exercise some choice over what features to show and how to show them. Some national mapping organizations allow users to create a topographic map sheet centered on an area of their choice (e.g., Ordnance Survey, Great Britain), while others are experimenting with new color schemes based on artists' palettes (Institut géographique national, France).

Although cartographic conventions ensure mutual understanding through the portrayal of features, freedom from static media such as paper and the one-solution map has changed the way they function. It is likely that with greater user customization, the future implementation of cartographic conventions will be less visible, and conventions relating to the portrayal of features will be the preserve of specialized mapping, such as demining (the removal of land mines) (Kostelnick et al. 2008), rather than of general reference or topographic mapping.

ALEXANDER J. KENT

SEE ALSO: Customization of Maps; International Map of the World; Metric System; Scale; Standards for Cartographic Information; Styles, Cartographic; Topographic Map; Wayfinding and Travel Maps: Road Symbols

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Coordinate Systems. Coordinate systems come in several varieties. In cartography two types are especially important: a two-dimensional Cartesian coordinate system useful on the plane (a flat map), and a two-dimensional spherical coordinate system useful on the surface of a sphere. This latter type is based on the geographic coordinate system—latitude and longitude—where latitude, φ, measures angular distance north and south along a meridian of longitude, and longitude, λ, measures angular distance east and west along a parallel of latitude. The former consists of a rectangular system, or grid, of two sets of parallel straight lines oriented at right angles to one another. The coordinates are identified as x and y, with x measuring distance horizontally and y measuring distance vertically. In using a rectangular grid, it is assumed to be attached to a point on the globe and the other points on the globe have been projected onto the grid according to some map projection system.

Hipparchus of Rhodes, in the second century B.C., is generally credited with describing the theoretical foundations of the geographic coordinate system of latitude and longitude. René Descartes, a French mathematician, is given credit for defining the Cartesian coordinate system in 1637. Since Descartes provided the first systematic link between Euclidean geometry and algebra, these systems have become more precisely defined mathematically and coordinates more accurately measured, making them even more useful to the map user. Cartesian coordinates are the foundation of analytic geometry and provide geometric interpretations for many other branches of mathematics, such as linear algebra, complex analysis, differential geometry, multivariate calculus, and group theory, and, of course, for cartography.

The twentieth century probably incorporates both the maximum use and the beginning of the demise of the use of Cartesian, or rectangular, coordinate systems in cartography. Rarely has a technique gone from becoming nearly mandatory on all maps to becoming nearly useless in such a short span of time. Near the beginning of the century users began asking cartographers to supply rectangular grids on maps because Cartesian coordinate systems were expedient methods for individuals to calculate and communicate distances and directions between positions on the earth. The degree of precision could be made to conform to the needs of the situation. Increasing in sophistication and use until the last two decades of the century, these Cartesian grids became de facto mandatory features on maps, particularly in the military.

A Cartesian coordinate system is a manmade rectangular grid system overlain on a flat map as shown in figure 181. Although planar coordinate systems are of two basic types, rectangular and polar, the overwhelming majority of those used in cartography are rectangular. The planar polar systems are most often used in conjunction with maps of either the north or south polar regions, or airport vicinities. The more commonly used rectangular system allows the map user to calculate distance and direction between two points on the map using equations that are markedly simpler than those used to calculate distances and directions using geographic coordinates (Robinson 1995, 50, 52, 99).

During the more than 2000 years of existence of coordinate systems, many specialized systems have been developed for specific uses with maps. The use of coordinate systems for the purposes of ground partitioning by the Etruscans, the Chinese, and the Japanese provide early evidence of the usefulness of ground-based rectangular coordinate systems with recordation on maps. In the twentieth century, astronomically based systems became practical and it was therefore not surprising that a large number of regional grid systems were put into use. The gradual perfection in the methods for use and in the accuracy and the subsequent increased utility of these systems can be traced in United States history, through the specification and use of the Public Land Survey System (PLSS) (see figs. 750 and 751). The PLSS, still in use, was initially devised to distribute western land in the United States (Pattison 1957). Most of the United States outside of the original thirteen colonies and the states of Kentucky and Tennessee utilized this ground-based coordinate system for legal property descriptions beginning in the early nineteenth century and continuing throughout the twentieth century. A similar area referencing coordinate system was devised and used in Canada.

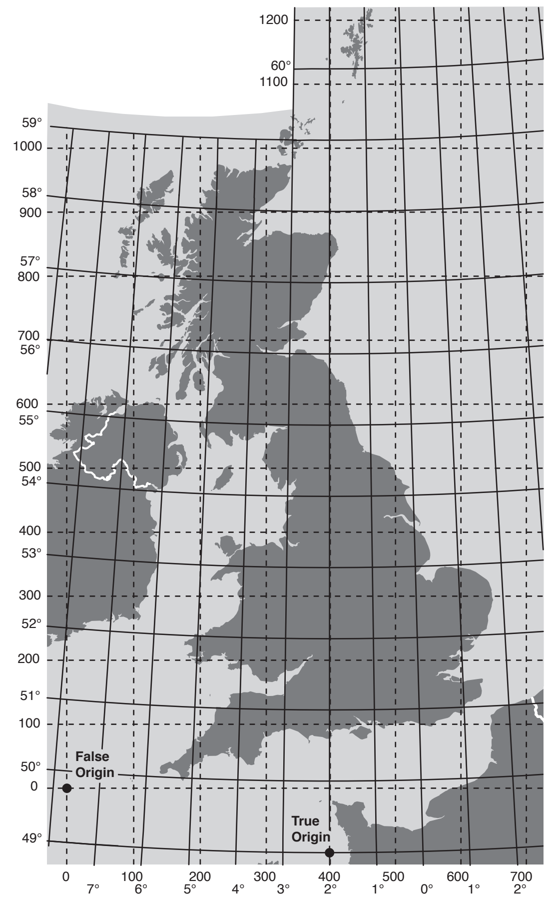

FIG. 181. THE RELATIONSHIP BETWEEN A RECTANGULAR GRID AND GRATICULE. The rectangular grid (dashed lines) is drawn here at every 100 kilometers, and the graticule of meridians and parallels (solid lines) is drawn at 1° intervals of latitude and longitude. The origin, the point of coincidence between the curved earth surface and the flat grid system, is shifted from latitude 49°N, longitude 2°W (true origin) to the northwest on the map (false origin) to avoid negative grid coordinates in Great Britain.
After Maling 1992, 32 (fig. 2.02).

Internal contradictions in the PLSS were of little concern at first. However, by the fourth decade of the century the description and use of the PLSS system in the United States was resulting in numerous lawsuits due to the densification of the population (living on smaller land parcels) and to the inherent logical flaws in its definitions. Legally it became more efficient to replace the PLSS with the State Plane Coordinate (SPC) system, a point-defining system, lending further evidence of the ease of use of a Cartesian grid (Mitchell and Simmons 1974). The SPC system divides each state into one or more rectangular coordinate zones for the specification

FIG. 182. ZONES OF THE STATE PLANE COORDINATE SYSTEM.
After Muehrcke 1978, 90 (fig. 3.5).

of property boundaries (fig. 182). As with Britain's National Grid (figs. 181 above and 186 below), coordinates are referenced to a false origin outside the zone, to the southwest, and positions are measured in feet. In the PLSS, the central meridian is accorded an east coordinate of 500,000 feet (fig. 183). The rectangular grids are placed over either a transverse Mercator or a Lambert conformal conic projection of a state or portion of a state designed to minimize the total number of zones while maintaining an accuracy such that distances calculated using SPC and distances on the sphere calculated using latitude and longitude do not differ by more than one part in 10,000. This reproducible system was then incorporated into state laws such that it could be an alternative to the PLSS (defined on the ground only) for legal property boundary description. Although the foregoing discussion has concentrated on the use and explication of point and area defining coordinate grid systems in the United States, rectangular coordinate grid systems were widely used internationally, especially during the second half of the century.

To further understand the rapid rise in requirements by users for coordinate systems on maps during the twentieth century, an example of the existing external conditions for the detailed use of maps at the beginning of the century is useful. By the end of the nineteenth century warfare and specifically armaments had progressed to the point that opposing forces could be separated by distances greater than the human eye could see. Also within the first fifteen years of the century, the airplane was invented and quickly found a role in warfare. Both ground and air forces required methods to aim artillery at an enemy without being able to see the target. This inability to find targets visually meant that trajectories had to be calculated from map information in real time during field operations. Calculations involving latitude

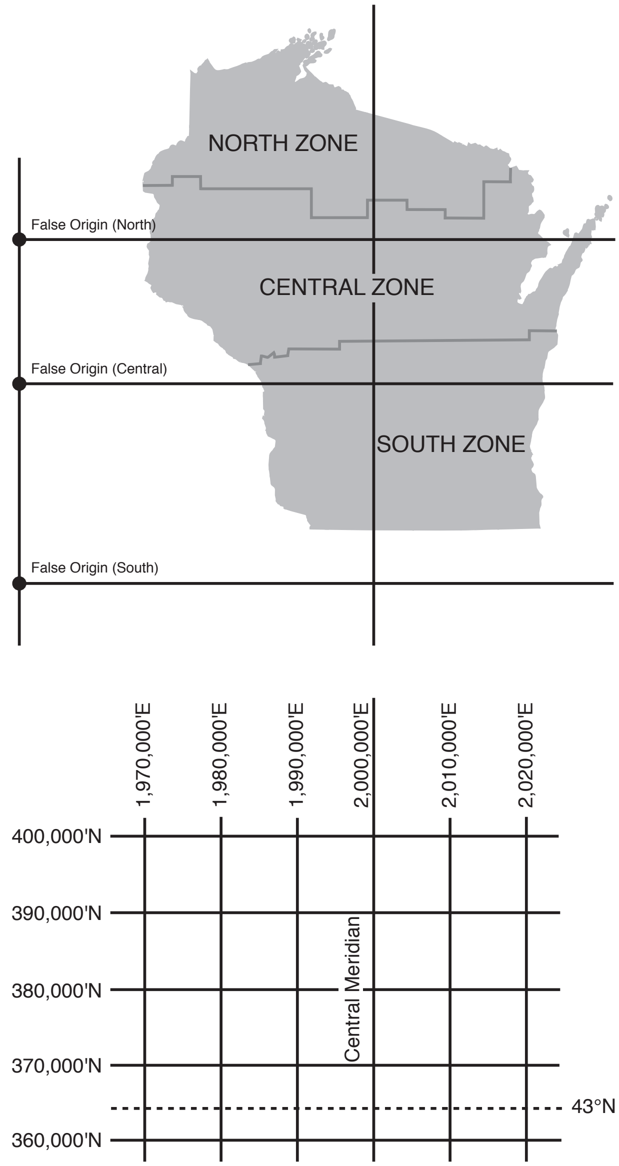

FIG. 183. STATE PLANE COORDINATE (SPC) SYSTEM FOR WISCONSIN. Each zone in the SPC has an origin to the southwest of the area it covers. A point in the center of the area of coverage is usually given an arbitrary value of 2,000,000 feet east, and 500,000 feet north. All references therefore are positive numbers from a false origin to the southwest. A standard reference would be the state name and zone (Wisconsin South Zone), easting (*x* value in feet), northing (*y* value in feet).
After Muehrcke 1978, 90 (fig. 3.6).

and longitude were too involved for real time field use by humans.

In order to make these trajectories accurate, the map base had to maintain basic angular and distance relationships, a set of criteria that could not be met overall. The French were among the first to address this problem. Their displeasure with their topographic map series appeared after the Prussian defeat of the French in 1870–71. During battles in Lorraine and Alsace all the deficiencies for the military of the then current French maps were revealed. The effectiveness of the artillery was limited by an absence of a network of points of precisely predetermined coordinates. The charts of the territory were insufficient in number, and production could not keep up with the demand of the soldiers serving on the ground forces. Soon after the war, in 1887, the French created the Service géographique de l'armée (SGA) by decree. World War I combatants had a need for charts at 1:10,000 or 1:20,000, which could be used to aim artillery accurately. The French were ready due to their newly created SGA, an efficient cartographic war machine. The modernization of cartographic production and institutions clearly had begun. The French simplified the problem by constructing a series of local planar coordinate grids on their maps. Their success quickly led other nations to follow, and between World War I and World War II many systems of planar coordinates were devised for military use.

World War I, World War II, the Cold War, the Korean War, Vietnam, Algeria, Israel/Palestine, and the First Gulf War, not to mention numerous other regional conflicts during the century, made warfare increasingly dependent on maps and coordinate systems. For strategic mapping purposes, after World War II the United States and United Kingdom agreed to divide the areas of the earth and to produce maps for future use of utility to both. As part of this agreement a major coordinate system, the Military Grid Reference System (MGRS), was devised and made mandatory on all defense-related maps. The MGRS offers an excellent and unique way to bring map information to the map user quickly with an accuracy of one part in 2,500. Using the meter as the unit of measure, the MGRS employs an alphanumeric system for communicating Universal Transverse Mercator coordinates (UTM, covering 84°N to 80°S latitudes) or Universal Polar Stereographic coordinates (UPS, covering polar areas north of 84°N and south of 80°S). Figure 184 explains the system's zones and belts, and figure 185 describes the system used to identify 100,000 squares within each 6° × 8° quadrilateral. The system provides a unique set of coordinates within one meter accuracy for any location on earth. All military maps at a scale of 1:1,000,000 or larger contain the MGRS. For maps at scales smaller than 1:1,000,000 scale, GEOREF (World Geographic Reference System) was devised to supplement the MGRS. GEOREF is an area-referencing system highly useful for large military operations, allowing areas theoretically as small as one meter square to be referenced quickly and uniquely for any spot on the earth's surface.

This success also spilt over into civilian uses of map information. In the United States, the U.S. Geological Survey (USGS) modified MGRS for its topographic maps. This simplification removed the use of the 100,000 meter squares of the MGRS and simply required the use of the UTM zone number and the x and y coordinates of the point. In 1974, the USGS stated that all of its civilian maps would show latitude and longitude, UTM rectangular coordinates, SPC, other plane rectangular coordinate systems that are mathematically relatable to geodetic positions via defined map projects, and the PLSS. It further stated that "the Geological Survey intends to encourage the adoption of the Universal Transverse Mercator system as the basic reference for use with the products of the National Mapping Program" and advocated that "the UTM reference system be used to the maximum extent feasible on maps made by other organizations, and for data collections which are related to maps" (Thompson 1987, 231). So the United States adopted a world coordinate grid system for use both internally and for its mapping of other places in the world.

There also exist good reasons for smaller than world grid systems. As already mentioned, one example is the SPC system used in the United States to gain accuracies to one part in 10,000. Another good example is the United Kingdom's National Grid. Devised by the Ordnance Survey solely for Great Britain and its nearby islands, this system can provide results with submeter accuracy (fig. 186).

Other subcontinental and localized systems came into use. By the mid-1980s, the Library of Congress had cataloged over 650 map series produced during the twentieth century at scales larger than 1:20,000. In an unpublished study that examined a sample of eighty-nine of these map series, the depiction of coordinate grid systems was included on seventy of the series. There were three primary ways of symbolizing the system: (1) sets of parallel lines drawn over the entire map surface, (2) the use of ticks along the edges of the sheets with cross hairs indicating intersections on the map itself, and (3) the use of ticks only along the edges.

Series at a scale of 1:10,000 tended to use the first system; at 1:5,000 the series were fairly equally divided among the three systems. As scales decreased, the use of latitude and longitude became more conspicuous. Clearly the use of coordinate grid systems was a standard feature of large-scale mapping. Sixteen of the series covered areas in North America, while thirty-two covered parts of Europe. Both Africa and Asia contributed sixteen of the series (but the influence of European colonial mapping was evident, or a residual, in many of the African series). Six series covered areas of South America while three were from Australia. The age of the series inspected is also of interest. Forty-seven percent

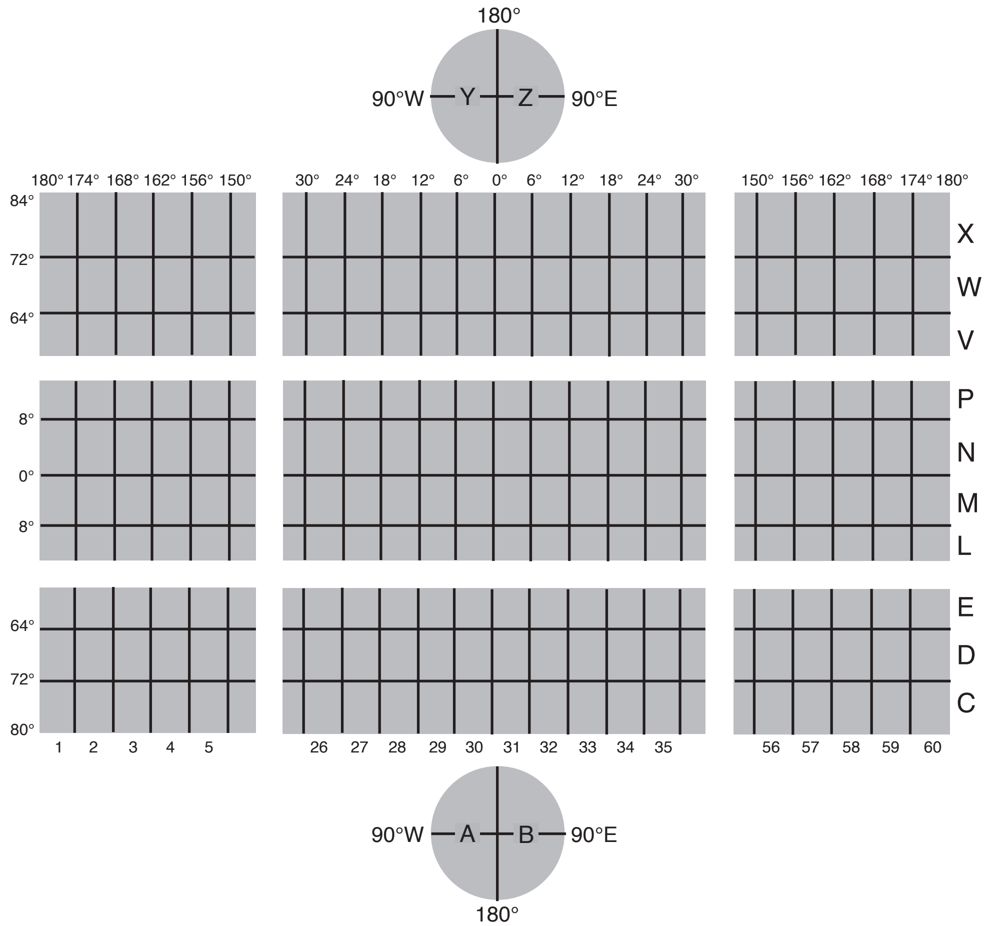

FIG. 184. THE MILITARY GRID REFERENCE SYSTEM (MGRS). This worldwide system appears complex, but its use is fairly simple. The world, except for the two polar regions, is divided into 60 zones of 6° of longitude and 20 belts of 8° of latitude. The zones are numbered consecutively from 1 thru 60 proceeding eastward along the equator from the 180th meridian. The belts are lettered from 80°S to 84°N latitude by the alphabet beginning with the letter C (omitting I and O). Zones A and B are used for the southern polar region (from 80°S latitude), and Zones Y and Z are used for the northern polar region (from 84°N latitude). Each 6° × 8° quadrilateral is divided into 100,000 meter squares (Zone X is an exception and covers 12° of latitude).
After Robinson et al. 1995, 102 (fig. 6.10).

of the series were from the 1960s, with an additional 34 percent dating to the 1970s. Fifteen percent were dated to the 1950s, while the remainder were earlier in the century. The years 1958 through 1974 saw the creation of over 70 percent of the series. That time period may represent the apex of the use of coordinate grid systems on nonmilitary maps.

Although coordinate grid systems are still shown on maps, their inclusion is significantly different from what it was during the period specified above. Until the mid-1970s coordinate grid systems were an essential element of the usefulness of a map, and the mapmaker carefully symbolized them on maps. During the 1970s the increasing awareness of the benefits of automation in cartography first made the portrayal of coordinate grid systems on maps easy for the maker while retaining the usefulness for the user. The depiction of coordinate grid systems became a "cheap" feature to be added to maps by mapmakers and a desirable feature for the map user: a dream for map marketers. With the ease of electronically drafting the grid lines on virtual or printed maps, the use of rectangular grid coordinates will be with us for some time even though the new measurements and calculations may be made using latitude and longitude values. Also the extant records using coordinate grid systems for definition remain an important, often legal, factor especially in systems for property management.

After the introduction of the Global Positioning System (GPS) during the last quarter of the century, the use of latitude and longitude became as easy as, or easier than, the use of rectangular coordinate grid systems. This led to a rapid increase in government, military,

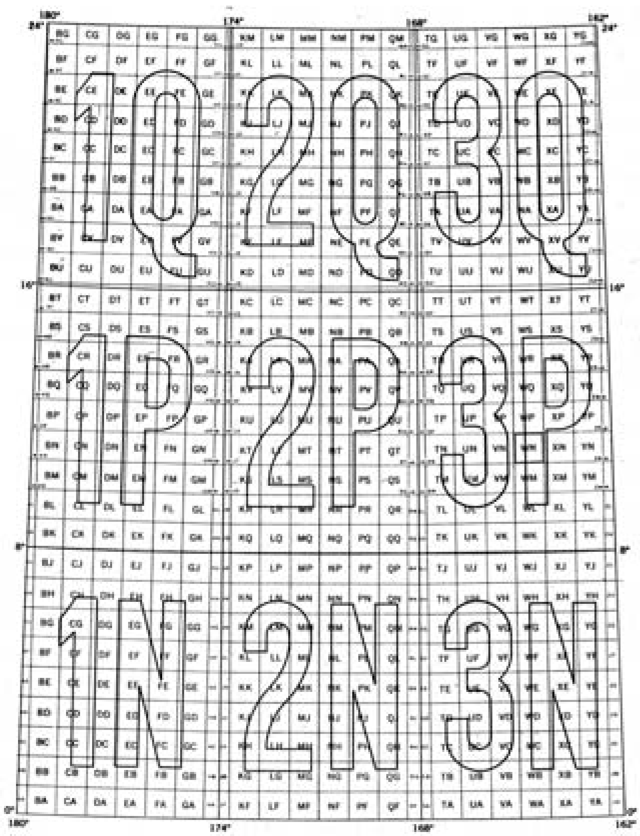

FIG. 185. MGRS 100,000-METER-SQUARE IDENTIFICATIONS. Squares 100,000 meters on a side with each quadrilateral labeled, both north-south and east-west, by letters of the alphabet in a scheme that prohibits a two-letter combination from recurring within 18 degrees of latitude or longitude. Each 100,000 meter square is then subdivided by 10s, both north and south and east and west into 10,000 meter, 1,000 meter, 100 meter, 10 meter, and 1 meter squares. Therefore the southwest corner of every square meter of the earth's surface can be referenced by an alphanumeric similar to 2P KQ033757, which would represent a 100 meter square.
Size of the original: 14.5 × 11.2 cm. From United States, Department of the Army, *Map Reading* (Washington, D.C., 1965), 24 (fig. 21).

and public use of GPS that by the end of the twentieth century had changed the use of grid systems dramatically. GPS became readily available commercially during the last decade of the century, and by embedding GPS technology into other electronic devices, all citizens became capable of tracking locations (static or moving) in real time by exact geographical coordinates with the complex calculations accomplished internally by these electronic devices. Simply stated, one could use geographical coordinates to gain more precise information more quickly than by the use of rectangular coordinates. The basic reason for rectangular coordinates had been eclipsed.

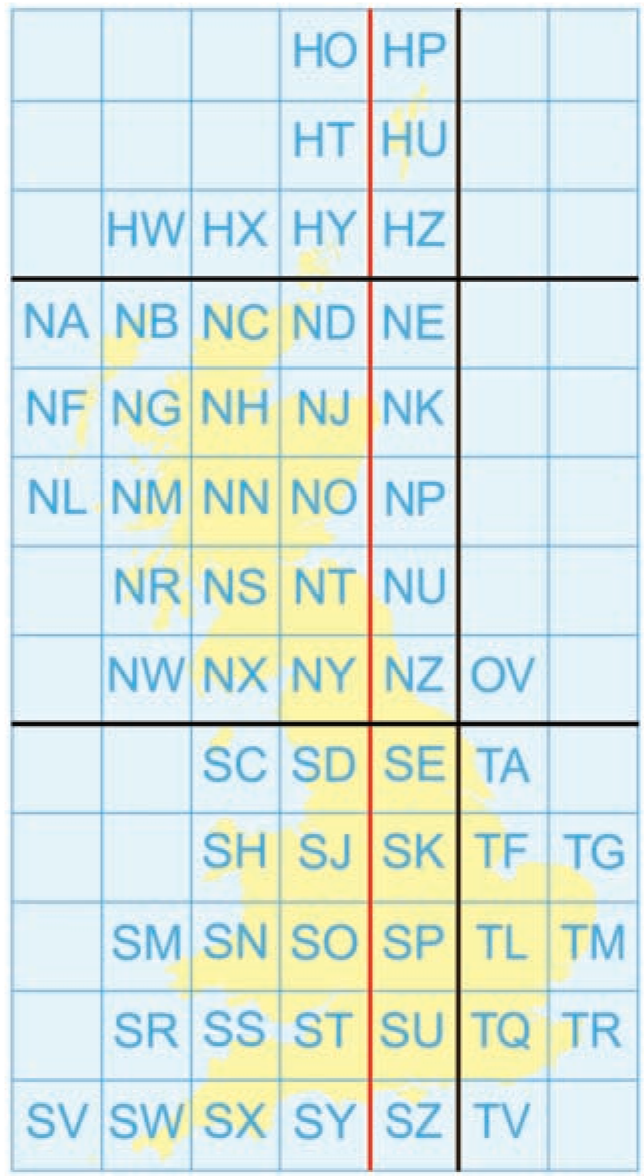

FIG. 186. THE NATIONAL GRID FOR GREAT BRITAIN. An example of a regional point-based rectangular coordinate grid system. For the first letter, the grid is divided into squares 500 × 500 kilometers. There are four of these that contain significant land area within Great Britain: S, T, N, and H, outlined with black lines. For the second letter, each 500 kilometer square is subdivided into 25 squares 100 × 100 kilometers, each with a letter code from A to Z (omitting I) starting with A in the northwest corner to Z in the southeast corner. These squares are outlined in blue on the map (those containing land are lettered). The central (2°W) meridian is shown in red. Within each square, eastings and northings from the origin (southwest corner) of the square are given numerically. For example, NH0325 means a 1 kilometer square whose southwest corner is 3 kilometers east and 25 kilometers north from the southwest corner of square NH. A location can be indicated to varying resolutions numerically, usually from two digits in each coordinate (for a 1 kilometer square) through to five (for a 1 meter square); in each case the first half of the digits is for the first coordinate and the second half for the other. Grid references may also be quoted as a pair of numbers: eastings then northings in meters, measured from the southwest corner of the SV square.

In the short span of twenty years, due to the rapid innovations in electronic computing and the incorporation of GPS technology into numerous devices, the general public and the military no longer had a need for rectangular coordinates on maps. This situation was enhanced in 2000 when the U.S. Department of Defense ended its policy of Selective Availability, increasing the accuracies available to all users. Following that decision were additional and enhanced systems—GLONASS (Global'naya Navigatsionnaya Sputnikovaya Sistema) has been put into worldwide use, and Galileo and Compass would follow early in the twenty-first century. With these availabilities only geographical coordinates are needed and used.

Not unrelatedly, the number and use of general-purpose paper maps has declined and with it the overprinted rectangular coordinates systems on them. At the same time the number of on-screen maps has increased. No better example exists than the widespread use of GPS navigational devices and free internet map directions software that is replacing the state and metropolitan atlases and highway road maps on paper. The world is left with its geographical coordinate system (over 2,000 years old) and the users of newly developed electronics to enhance their mobility.

JOEL L. MORRISON

SEE ALSO: Conformality; Geodesy: Geodesy and Military Planning; Projections: (1) Projections Defined for the Ellipsoid, (2) Projections Used for Military Grids

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Copyright. See Intellectual Property

Copyright Traps. A copyright trap is an artifact inserted into a creative work by an author to detect and possibly litigate plagiarism in unauthorized derivative works. The effectiveness of a copyright trap is derived from the difficulty in distinguishing fictitious features from actual content. A variety of authors have documented the use of copyright traps on maps, and while the extent of this use is unknown, it is believed to be widespread, particularly among commercial publishers of street and tourist maps (Harvey 2000, 140–41; Bale 2001; Pedley 2005, 106; and Rice 2005).

A cartographic copyright trap has been defined as a "specific form of copyright trap used on maps and cartographic documents to protect intellectual property. It takes the form of an identifiable artifact on the map which is promulgated through the map duplication process, thereby appearing in copies of the original map and derivative works based on the original" (Rice 2005, 21). Several types of cartographic features that function as copyright traps have been described: intentionally false or fictitious map features, map features based on real geographic features that been changed in a significant way to allow unique identification, unique identifiable stylistic elements, and features or artifacts that are the result of uncorrected errors (Rice 2005). In addition, Mark Monmonier (1996, 48–49) discussed the presence in cartographic works of uncorrected errors such as "paper streets" (planned, yet unbuilt streets) known to be erroneous but deliberately left on a map. Several cartographers interviewed asserted that uncorrected errors are a common means of identifying plagiarism (Rice 2005). Although use of errors as traps is not always intentional, they can support claims of copyright infringement when associated with a specific compilation process such as manual digitizing.

The 2001 legal settlement between Britain's Ordnance Survey (OS) and the Automobile Association was a source of popular press coverage of the use of cartographic copyright traps. The £20,000,000 settlement was facilitated by an analysis of copyright traps in OS maps, and was quickly followed by an Ordnance Survey effort to explain the use of the technique, describing the copyright traps as "fingerprints" used to detect plagiarism (Clark 2001; Bale 2001).

Mary Sponberg Pedley (2005, 96–118) suggested that copyright traps have origins in the early European map publishing industries, where identifiable, unique map features were used to identify instances of plagiarism. The economic motivations for the use of copyright traps described by Pedley remained relevant throughout the twentieth century because copyright law afforded broad protection to maps, atlases, and other cartographic works. In the United States, however, several important legal cases have removed the rationale for copyright traps as proof of infringement. The U.S. Supreme Court's ruling in *Feist Publications, Inc., v. Rural Telephone Service Co., Inc.*, 499 U.S. 340 (1991), severely limited the copyright of fact-based works. As legal scholar Dennis S. Karjala (1995, 396) noted, only expressive creative content is protected, and "the expression protected must be the product of intellectual creativity and not merely labor, time, or money invested." Copying the factual content of a map may not be prohibited. In a subsequent case, *Alexandria Drafting Co., Plaintiff, v. Andrew H. Amsterdam d/b/a Franklin Maps*, Civil Action Nos. 95-1987, 95-6036, E.D. Pa. (1997), a court ruled that copyright traps are "false facts" and thus not protected by copyright. Because of these two rulings, neither the factual content of a map nor cartographic traps are clearly protected by copyright. Map producers in the United States gain little benefit from hiding copyright traps within unprotected factual content and therefore rely on copyright protection provided for the creative elements in their work as well as by controlling access to their source data through licensing agreements.

MATTHEW T. RICE

SEE ALSO: Intellectual Property; Marketing of Maps, Mass; Wayfinding and Travel Maps: Indexed Street Maps

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Corona (clandestine government program). See U.S. Intelligence Community, Mapping by the

Corps of Engineers (U.S.). See U.S. Army Corps of Engineers

Cortesão, Armando. Armando de Freitas Zuzarte Cortesão was born near Coimbra, Portugal, on 30 January 1891 and graduated as an agronomist from the Instituto Superior de Agronomia in Lisbon in 1913. He developed his interest in cartography during World War I, when he worked on the geodetic mission of São Tomé Island, a Portuguese colony in the Gulf of Guinea. As a supporter of the Portuguese First Republic (1910–26) as well as the Portuguese colonial empire, Cortesão was appointed head of the Agência Geral das Colónias in 1925.

As had occurred in the nineteenth century when Manuel Francisco de Barros e Sousa, Visconde de Santarém, was a founding father of the history of cartography, reorganization of European overseas territories between the two world wars and the related propaganda campaigns for colonial rights stimulated renewed interest in ancient cartography within Portugal. In 1932 Cortesão broke with the Salazar dictatorship and went into voluntarily exile for over two decades in London and Paris, where he worked at the United Nations Educational, Scientific and Cultural Organization (UNESCO) (1946–52). During that period he wrote some of his most remarkable works on the "golden age" of Portuguese cartography, the fifteenth and sixteenth centuries, and published his essays in academic journals such as the *Geographical Journal, Imago Mundi*, and the *Geographical Review*. He also published two important books on ancient cartographers and their map production: *Cartografia e cartógrafos portugueses dos séculos XV e XVI* (1935) and *The Suma Oriental of Tomé Pires . . . and the Book of Francisco Rodrigues* . . . , for the Hakluyt Society (1944).

In the mid-1950s, Cortesão returned to Portugal and took part in the official quincentenary celebrations (1460–1960) of Henry, prince of Portugal. He then published *Cartografia portuguesa antiga* (1960) and, together with A. Teixeira da Mota, a naval officer, the *Portugaliae monumenta cartographica* (6 vols., 1960–62), an exhaustive inventory and interpretative analysis of hundreds of maps and atlases produced by Portuguese cartographers in the fifteenth through seventeenth centuries and scattered throughout the world in numerous archives, libraries, and collections.

In 1960 the Royal Geographical Society awarded Cortesão the Victoria Medal. At this time he was already a professor at Coimbra University, where in 1961 he had established a research center on ancient cartography. This center was the Coimbra section of the Agrupamento de Estudos de Cartografia Antiga, initially created in Lisbon in 1958 by A. Teixeira da Mota in the framework of the Junta de Investigações Científicas do Ultramar. Important collections of studies and ancient texts were then published.

In addition to Teixeira da Mota, Cortesão had another remarkable collaborator: Luís de Albuquerque, a mathematician and professor at the University of Coimbra. Together they published the *Obras completas de D. João de Castro* (4 vols., 1968–82) and the *History of*

Portuguese Cartography (2 vols., 1969–71), an incomplete work, covering the fifteenth and sixteenth centuries. Near the end of Cortesão's scientific life, the University of Coimbra published an anthology of *Esparsos* (3 vols., 1974–75), which gathered his main articles and papers. Cortesão died in Lisbon on 29 November 1977.

JOÃO CARLOS GARCIA

SEE ALSO: Histories of Cartography

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Mota, A. Teixeira da. 1978. "Armando Cortesão (1891–1977)." *Imago Mundi* 30:92–95.

Counter-Mapping. Coined near the end of the twentieth century, "counter-mapping" describes a broad range of mapping activities that oppose, or counter, dominant delineations or perceptions of space. Counter-mapping can be broadly understood as any cartographic attempt to disrupt prevailing power structures, or more specifically, as any attempt to create and provide mappings that are alternative to those of governments, urban planners, developmental agencies, or other elite groups.

Maps have been created and used in political and social struggles for centuries, but late twentieth-century technological advances—most notably Global Positioning Systems, geographic information systems, remote sensing, and web-based cartography—led to an increased production and use of maps across the globe, which eventually filtered down to people who historically had not held the means of map production. This increased access to mapping tools, coupled with a growing recognition of minority rights and a movement toward the democratization of information, helped marginalized people adopt a broad range of mapping practices for resistance and emancipation. By creating counter-maps focusing on issues that stretched from land use and resource management to unemployment rates and degrading alleyways, less powerful groups began to represent themselves and their demands cartographically and to engage actively in negotiations with dominant powers (Pickles 2004, 184–85).

In 1995, Nancy Lee Peluso used the term "counter-mapping" to indicate alternative mapping efforts used by local activists to delineate and legitimize their territorial claims in the Indonesian forests. With national and international assistance, these marginalized groups used a variety of cartographic techniques to represent their land claims to the government. The maps they created emphasized the human element of the forest and their own land use strategies, which had previously been ignored by the state or erased from state-drawn maps. Though Peluso is generally considered the first person to use the term "counter-map," four years earlier, in 1991, Benjamin S. Orlove described a similar mapping process in Peru. Through a cartographic examination of a territorial conflict between Peruvian state officials and local "peasant" communities over beds of reeds around Lake Titicaca, Orlove showed that the peasant groups' maps emphasized the location and distribution of their communities along the shoreline. By contrast, the peasants and their communities were nearly invisible on the state's official maps.

Peluso and Orlove both researched examples of counter-mapping at the community or local scale. While counter-mapping has become quite common at this scale, it also occurs at other scales. Supranational and sovereignty movements of the twentieth century have used counter-mapping strategies in efforts to reclaim colonized land. As early as the 1940s, for instance, Kurdish leaders had created maps of what they defined as the sovereign nation of Kurdistan extending over the boundaries of the internationally recognized sovereign states of Iraq, Iran, Turkey, and Syria. Some Native American groups have also used maps in their negotiations over sovereignty and land claims. As Matthew Sparke (1998) discussed, two First Nation groups in British Columbia utilized Western style maps in a 1987 Supreme Court case in which they sued the Canadian government over the recognition of their rights to land.

Though counter-mapping often conforms to Western cartographic standards and practices, it also occasionally incorporates non-Western mapping practices and geographic knowledge. For example, Sparke (1998) found that the First Nations' maps incorporated traditional oral knowledge into Western-style maps. By using their own place-names, and indicating the location and ownership of their homes and fishing sites, instead of the more standard lines and boundaries of Canadian colonialism, this merging of styles not only partly disrupted the judiciary's conventional treatment of maps, but may have also prompted a rethinking (or countering) of Canada's official geography. Similarly, Jay T. Johnson, Renee Pualani Louis, and Albertus Hadi Pramono (2005) have encouraged indigenous communities to adopt and adapt Western style cartography (fig. 187). By including their own geographical understandings and symbols in otherwise conventional-looking maps, indigenous communities can promote their land and resource claims while also communicating their own geographic conceptual-

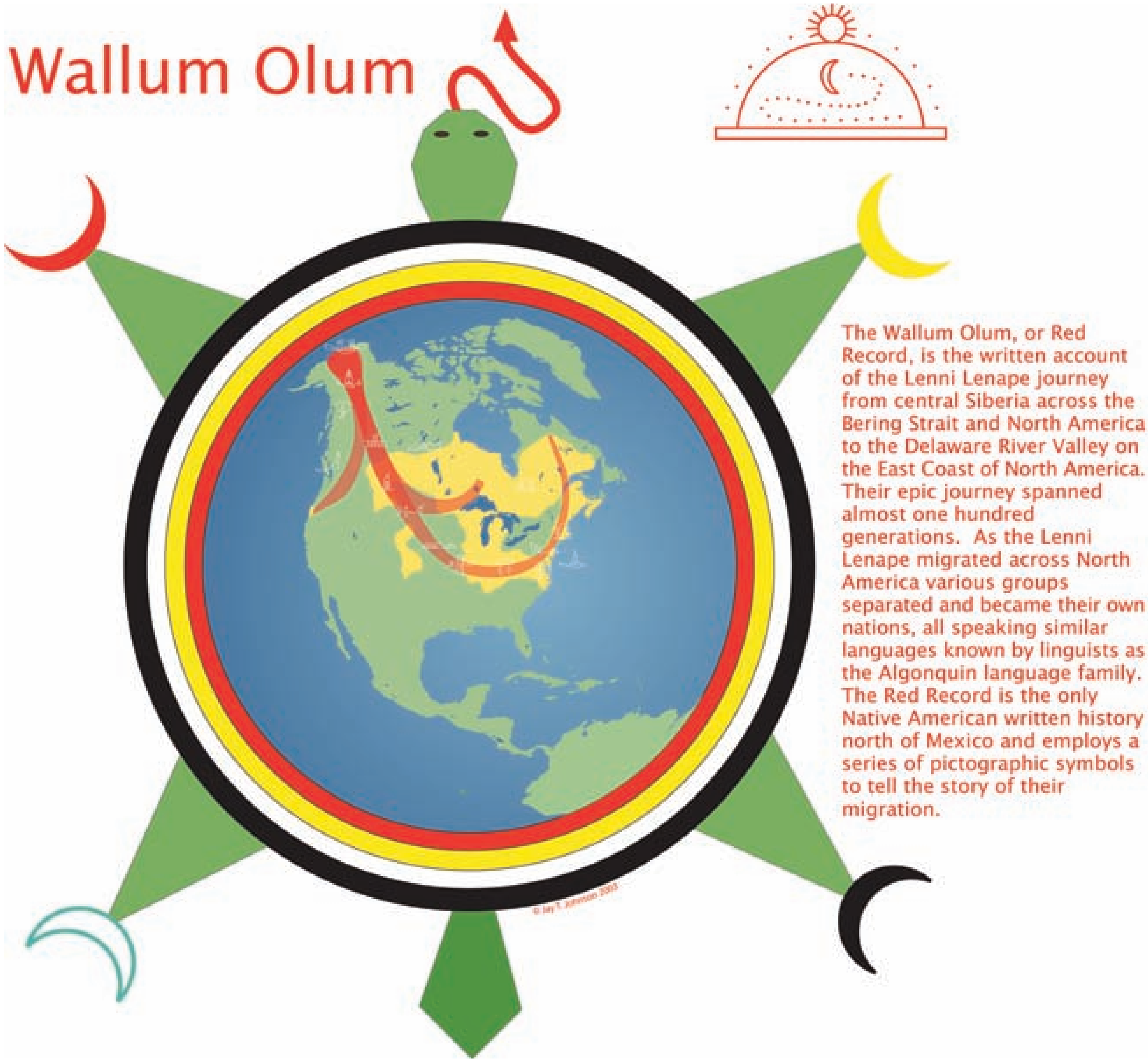

FIG. 187. JAY T. JOHNSON, *WALLUM OLUM*, 2005. This map shows the juxtaposition of Western cartographic standards and Native American geographic concepts.

Image courtesy of Jay T. Johnson.

izations and histories to their own communities and a wider Western audience.

Though its impact is difficult to assess, counter-mapping has, in a broad sense, helped marginalized groups negotiate with more powerful forces both within and outside government. Because of increased access to efficient and affordable cartographic technologies, marginalized groups are likely to continue to draw attention to less commonly mapped social phenomena as well as to social inequalities.

KAREN CULCASI

SEE ALSO: Boundary Disputes; Community Mapping; Geopolitics and Cartography; Indigenous Peoples and Western Cartography

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Crime Map. Crime mapping has undergone several transformations in response to changing technology. As discussed here, these transformations divide the history of crime mapping into three periods: a comparatively rudimentary beginning era, a more systematic era of manual mapping, and the more integrated and powerful era of the geographic information system (GIS) and computer-based analysis.

Some form of crime mapping was probably carried out since at least 1830, when social statistics began to be available in Europe. Early developments in the beginning era were exemplified in London at the end of the nineteenth century by the work of Charles Booth, who mapped small areas according to their socioeconomic standing and, by implication, their potential for criminality. As the nineteenth century progressed, the quality of available data gradually improved, but the lack of systematic data gathering as well as weak or nonexistent data standards and quality control meant that crime maps were often based on indirect measures, such as appearances in court or convictions. Reliable crime maps were scarce because the concept of modern policing was still in its formative stages.

The manual mapping period began when modern policing emerged in the developed world as a more or less universal public service, and law enforcement officials recognized the importance of locations relating to crime even though they lacked an efficient technology for visualizing spatial information. Anecdotal evidence suggests that the New York City Police Department, founded in 1845, used pins stuck in maps to represent crime locations as early as about 1880. Widely adopted and still in use at the end of the twentieth century, these so-called pin maps normally were very large, in order to provide sufficient space for inserting multiple pins—typically with heads color-coded according to crime type—on a citywide street map. Because pin maps were labor intensive and could not be archived, it was essentially impossible to compare crime patterns from one time period to another without photographing the maps and making very large prints.

Pin maps were a standard operating procedure in police departments until the advent of computers in the mid-1980s, and even then the necessary technology for mapping crime data was primitive. The Chicago School of Sociology produced crime maps using conventional cartography (Harries 1999), and other exemplars include the remarkable analysis of crime in the state of Washington by statistical demographers Calvin F. Schmid and Stanton E. Schmid (1972), who appreciated graphics as a powerful tool for both analysis and presentation, and the pioneering work of Hans-Dieter Schwind, Wilfried Ahlborn, and Rüdiger Weiss (1978), who mapped crime in West Germany. In addition, Minnesota political scientist Douglas W. Frisbie and his colleagues at the Governor's Commission on Crime Prevention and Control straddled the technology divide by producing computer line-printer maps dealing with crime in Minneapolis (Frisbie et al. 1977). Because the coarseness of the printout precluded an efficient depiction of point data, line-printer display was practical only for choropleth maps. Although maps produced by software such as SYMAP from the Harvard Laboratory for Computer Graphics and Spatial Analysis were of little practical value for operational crime mapping in police departments, they were occasionally used in technical reports.

With the broad availability of GIS in the 1990s, crime

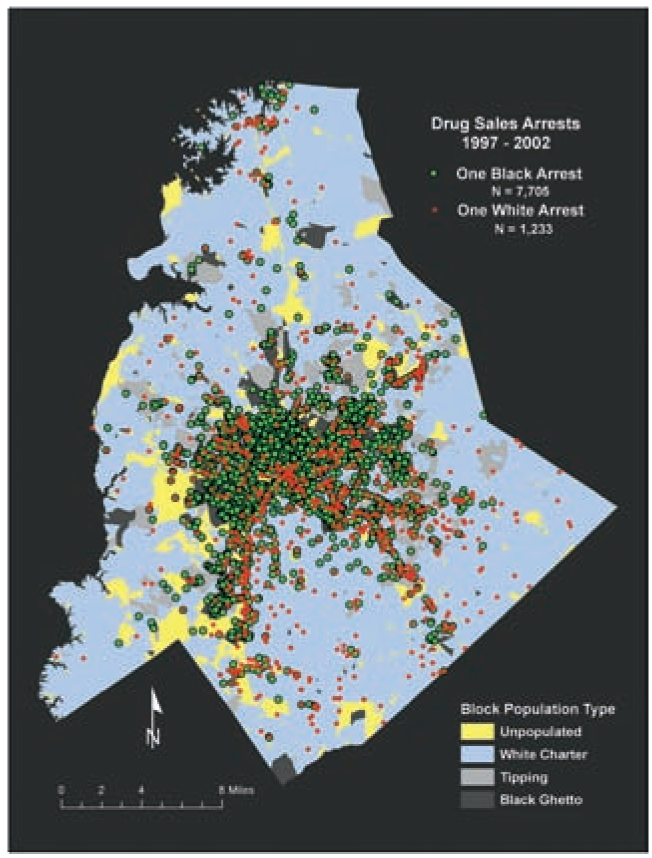

FIG. 188. *DRUG SALES ARRESTS, 1997–2002*, IN CHARLOTTE-MECKLENBURG, NORTH CAROLINA. This map, representative of those using point data in crime analysis, distinguishes between arrests of African Americans and whites, with each dot representing one arrest. Differential shading distinguishes several types of block populations.
Image courtesy of James L. LeBeau, Department of Criminology & Criminal Justice, Southern Illinois University, Carbondale.

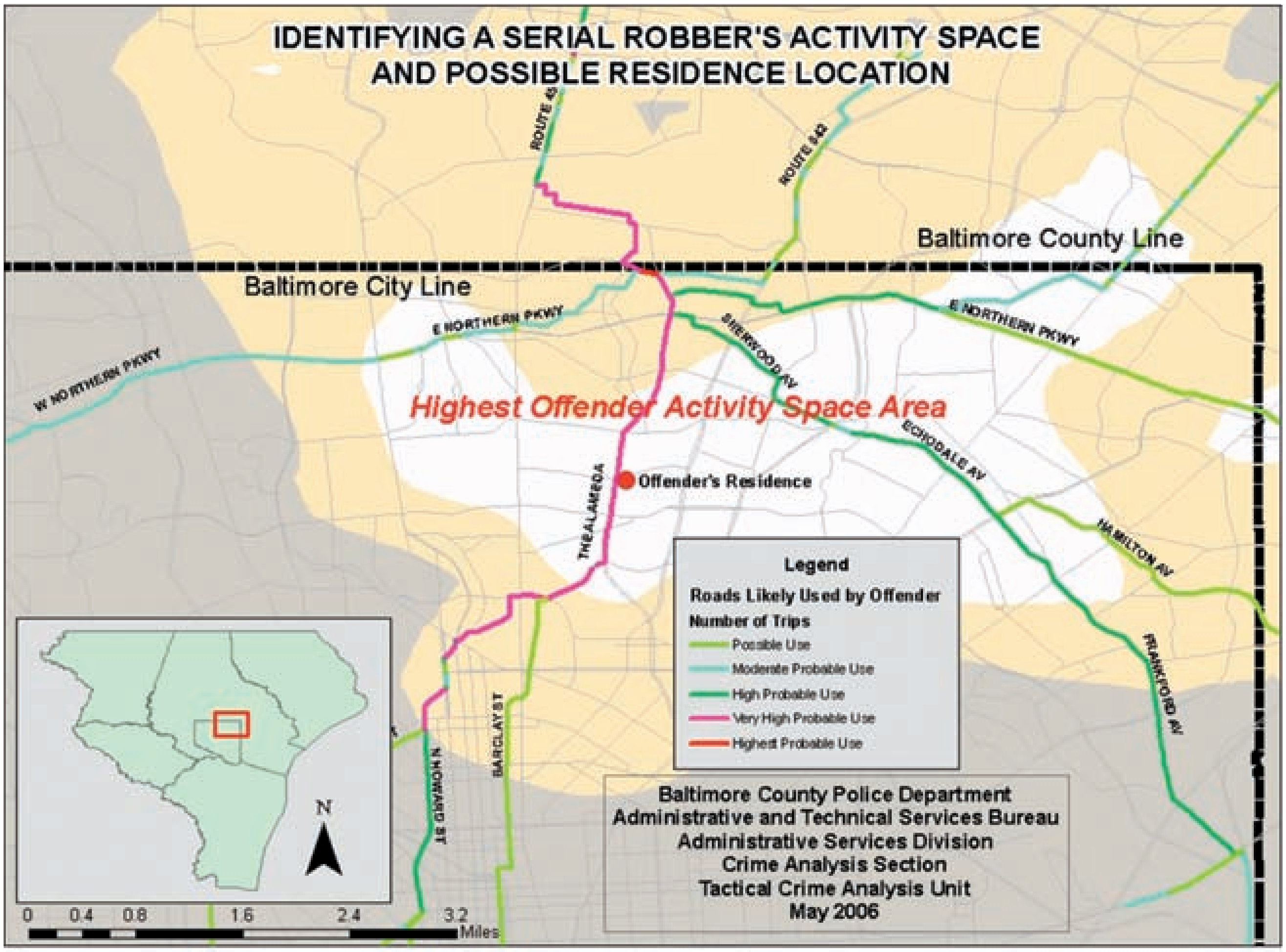

FIG. 189. *IDENTIFYING A SERIAL ROBBER'S ACTIVITY SPACE AND POSSIBLE RESIDENCE LOCATION*, BALTIMORE COUNTY, MARYLAND, 2006. Data relating to suspects matching the race, gender, age range, modus operandi, crime type, and target locations were used to narrow the search and define the area in which the robber appeared to be operating. Algorithms in the CrimeStat III crime analysis program were used to create estimated "journey to crime" data, with the results smoothed to create a continuous surface. Possible routes were also estimated using network analysis software. The map was used by the Baltimore County Police Department for operational purposes.
Image courtesy of Philip R. Canter, Baltimore County Police Department, Towson.

mapping entered a new era in which two distinct types of crime cartography emerged. The first type addressed law enforcement's overarching operational need for the rapid representation of crime locations suitably precise for timely visual analysis. In the context of a GIS, point data (fig. 188) also provided the raw material for choropleth maps at any scale aggregated upward from the city block to cities, counties, or states, as well as the data necessary for producing "hot spot" maps, depicting clusters of crimes in time or space. Informal analysis of crime data by individual detectives and managers was occasionally supplemented by intensive analyses by specialists focused on the spatial analysis of data relating crime locations, the addresses of victims, and the addresses of possible suspects.

A second type of crime cartography is exemplified by the New York City Police Department's CompStat (computerized statistics) process, a 1994 innovation that integrated the display of computerized crime maps with regular sessions at which precinct captains and their superiors discussed the depicted patterns. High-interaction crime mapping thus became a key management tool for sharing insights and promoting accountability. In addition, many police departments set up crime mapping websites to foster crime prevention through public awareness. Online access to locally detailed crime data thus reinforced community-policing and neighborhood watch strategies.

Between the mid-1990s and the mid-2000s, numerous conferences and workshops as well as a vigorous online discussion among law-enforcement professionals and academics skilled in GIS signaled increased interest in crime mapping as an operational tool and stimulated rapid progress in its sophistication and effectiveness. Methodological enhancements documented in several textbooks include numerical analysis and predictive modeling (Boba 2005; Chainey and Ratcliffe 2005; Wang 2005). Integration of spatial statistics with computerized mapping enabled the testing of advanced hypotheses relating to crime patterns (fig. 189), and the U.S. Department of Justice, which had promoted the collection and analysis of crime statistics for decades, was (through its National Institute of Justice unit) an influential catalyst as well as a comprehensive resource for information on these developments.

KEITH D. HARRIES

SEE ALSO: Community Mapping; Hazards and Risk, Mapping of; Interactive Map; Urban Mapping; Web Cartography

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Cruise Missile. Cruise missiles are, essentially, unmanned aircraft. Despite numerous forms and methods of propulsion, these missiles share several characteristics: they are bomb-carrying craft that obtain oxygen for combustion from the atmosphere, they have no pilots, and they generally fly close to the ground to evade detection and for defense (fig. 190). Their impact on cartography has been substantial in three related areas: spatial reference systems developed to link launching and target sites; technologies and methods to characterize terrain over which the craft will fly and coupled to onboard sensor systems that scan the terrain below; and the convergence of these advances in ever more elaborate computer-based guidance and control systems designed to integrate and compare the sensed and positioned environment with digital representations stored onboard. All three arenas have produced technologies and methods with wide application in other areas.

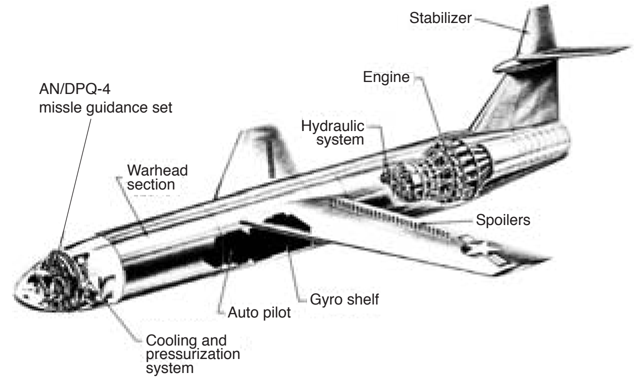

FIG. 190. MACE CRUISE MISSILE WITH ATRAN AN/DPQ-4 GUIDANCE SET.
After Koch and Evans 1980, 7 (fig. 5).

When cruise missiles began is a matter of definition. Arguably, the first significant prototype was the German V-1 or Vergeltungswaffe-1 (Vengeance weapon no. 1), used in the late stages of World War II and called the Buzz Bomb by the British. Its primitive guidance system embodied the basic cartographic necessity of an adequate spatial reference system. The Germans discovered that European national datums did not match up even across distances as short as the English Channel. Although V-1 targeting was so crude that discrepancies made little difference, much postwar geodesy was concerned with harmonizing datums and developing ever larger integrated spatial reference systems.

Post–World War II cruise missile systems were generally classified, and many systems did not work well. Nevertheless, concomitant with the new vehicles came major advances in sensing, characterizing, recording, and comparing terrain—by comparing sensed terrain with a stored representation, the missile's guidance system would determine position and correct its course en route to target. The first American system was ATRAN (automatic terrain recognition and navigation) developed in the late 1940s by Goodyear Aircraft Corporation for the U.S. Air Force. The ATRAN system used an analog computer to compare a series of reference images of terrain based on oblique photography of plaster and plasticine 3-D models with forward-looking radar images. The missile test course ran from White Sands, New Mexico, to the Dugway Proving Grounds in Utah, over basin and range topography. In addition to radar systems, virtually every type of sensing system across the electromagnetic spectrum was tested to provide the missile with "eyes" in a wide variety of conditions and contexts. Consequently, cruise missile sensor systems intersect many other developments in post–World War II photogrammetry and remote sensing, as well as computational systems.

Digital computers and guidance systems originally developed for ICBM (intercontinental ballistic missile) rockets were adapted to cruise missiles, beginning with the 1958 project TERCOM (Terrain Contour Matching). Digital computers required digital terrain models (DTMs; also called digital elevation models [DEMs]), and in a sense most modern iterations of the digital earth were derived from systems developed originally for missile positioning and guidance (figs. 191 and 192). The early DTMs were based on gridded elevation data. One of the more important subsequent developments in digital terrain modeling was triangulated irregular networks (TINs), which characterized the landscape by a continuous surface model of triangular facets, originally derived from point data but projected to better reflect the morphology of actual terrain. As was the common pattern of the Cold War, classified TINs filtered into nonclassified civilian applications with their origins in top-secret missile-guidance programs stripped away.

By the end of the twentieth century, cruise missiles combined an array of positioning and guidance systems, including inertial guidance and externally defined positioning via GPS (Global Positioning System) or GLONASS (Global'naya Navigatsionnaya Sputnikovaya Sistema) coupled to sensor packages that surveyed terrain in many windows of the electromagnetic spectrum and compared it with high-resolution digital models of portions of the earth's terrain derived from many sources. The integrated computer systems and pattern recognition systems that managed sensing and guidance effectively served as the missile's super-human pilots. It is in the development of these earth models and their cartographic mechanization and integration that cruise missiles have had their greatest impact. This impact was largely unrecognized in the cartographic literature because of secrecy surrounding the missile's development as well as scholars' reluctance to acknowledge the significance of a flying bomb.

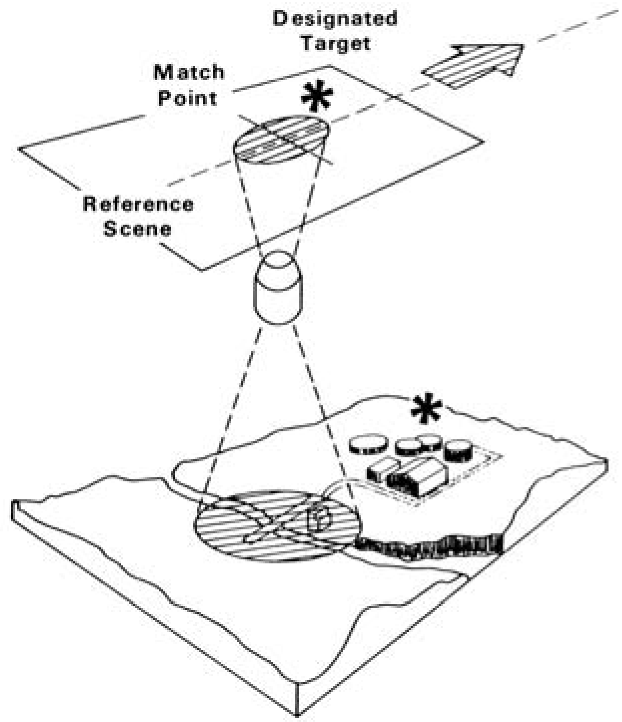

FIG. 192. CRUISE MISSILE DIGITAL SCENE MATCHING AREA CORRELATOR (DSMAC).
From Monmonier 1985, 42. © 1985 by the Board of Regents of the University of Wisconsin System. Reprinted by permission of the University of Wisconsin Press.

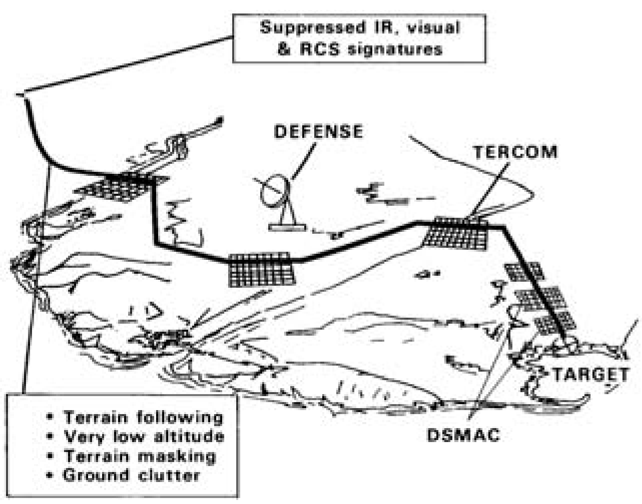

FIG. 191. FLIGHT PROFILE OF A TOMAHAWK CRUISE MISSILE.
From Mark Monmonier, *Technological Transition in Cartography* (Madison: University of Wisconsin Press, 1985), 41. © 1985 by the Board of Regents of the University of Wisconsin System. Reprinted by permission of the University of Wisconsin Press.

JOHN CLOUD

SEE ALSO: Electronic Cartography: Data Structures and the Storage and Retrieval of Spatial Data; Geodesy: Geodesy and Military Planning; Gulf War (1991); Map: Electronic Map; Warfare and Cartography

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Customization of Maps. Maps are used by society, individuals, and cartographers in a variety of situations for many tasks. Because no map is suitable for all tasks (Carter 2005), maps are often annotated, enhanced, or transformed to add information or increase understanding of the patterns and relationships represented. Two distinct processes can be discerned: customization and personalization. Customization, defined as the modification and enhancement of map products by knowledgeable map producers for a specific group of users, is distinct from personalization, which refers to an individual's annotating maps or manipulating symbols or other characteristics to better meet his or her personal needs. Personalization is thus a uniquely individual form of customization.

Personalization of maps increased during the twentieth century largely because mass production had lowered costs, thereby allowing individuals to own greater numbers of paper maps—topographic maps, highway maps, and regional reference maps in particular. Many users personalized their maps by annotating them. During times of military conflict, for instance, people plotted the locations of battles reported in the news as well as places where family members were stationed. Researchers and recreationists annotated topographic maps with field observations, and travelers marked highway maps with places of interest, intended routes, and routes actually followed. In the later part of the century many individuals used personal computers and the Internet to create maps for their personal use.

Customization of maps in the twentieth century is notable for the increased number of situations for which maps were adapted to user needs. Among the diverse examples noted in this entry, maps for Alpine mountaineers provide perhaps the most intriguing, if not the most extreme, form of cartographic customization. Early in the twentieth century mountaineers in the Alps demanded detailed maps that provided a realistic overall impression of relief in areas where they worked or traveled. The result was an artistic and almost instinctive method of depicting rugged terrain aesthetically, without isolines. This type of pictorial depiction was very time-consuming and required considerable artistic skill as well as a profound knowledge of terrain. Because the government mapping agencies used conventional contour lines in creating large-scale topographic maps of Alpine areas, mountaineering groups created their own maps as well as marketing channels different from those for official topographic maps (fig. 193).

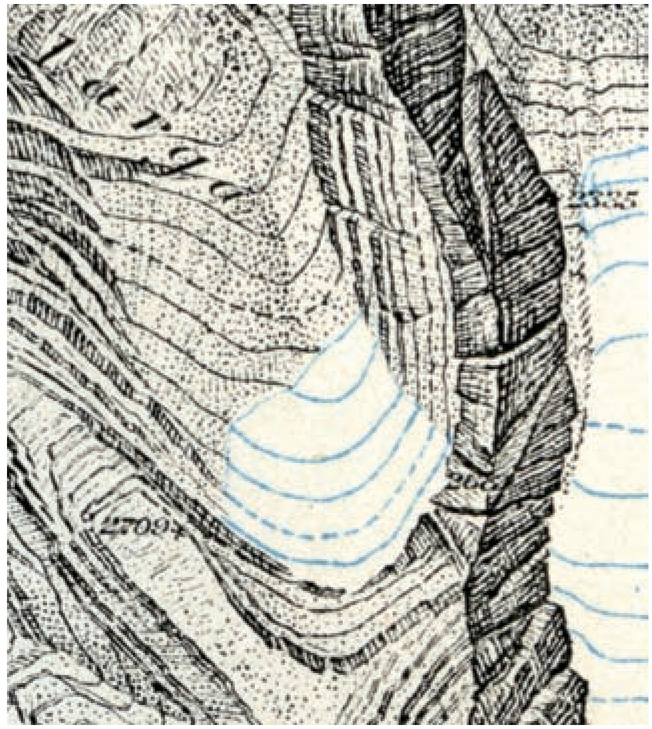

FIG. 193. ROCK DEPICTION EXAMPLE FROM LEO AEGERTER AND HANS ROHN, *KARTE DER BRENTAGRUPPE*, EDITED BY THE DEUTSCHE UND ÖSTERREICHISCHE ALPENVEREIN, NUMBER 51, 1:25,000 (MUNICH, 1908). The map uses the so-called artistic genetic rock depiction method—there are no isolines in the rock areas and therefore low geometric accuracy. However it communicates an outstandingly realistic overall relief impression that gives the map its typical aesthetic as well as artistic quality. This depiction method was very time-consuming and required excellent artistic skills as well as profound topographic knowledge, unfortunately not available and affordable afterward for large-scale topographic maps of the twentieth century.
Size of the entire original: 96 × 54.7 cm; size of detail: 3 × 2.7 cm.

For orienteering, a competitive recreational activity in which participants strive to cover a specific course in the least time, large-scale base maps are created to integrate existing topographic information with special orienteering symbols describing the course, which might be temporary or permanent. For a specific orienteering event, multiple levels of courses are laid out and maps are created on the base for each level of competition. Participants are given a customized map showing the "controls" they must visit as they try to navigate the course as quickly as they can.

From midcentury onward travel agents customized highway maps for drivers. The quintessential example is the TripTiks provided by the American Automobile Association for its members. A traveler specified his or her destination, and travel planners traced out a recommended route on a series of small preprinted map sheets, typically strip maps covering portions of commonly traveled routes or generalized maps of a metropolitan area or prominent tourist destination. The map sheets were stamped with advisories, to alert the driver to speed traps, detours, and road construction delays, and assembled in sequence in a small spiral-bound booklet to provide the traveler with a customized road atlas.

Customized maps also served airline passengers. In the early years of commercial aviation the navigator taped a hand-annotated paper map to the bulkhead so that passengers could follow the route of their aircraft. In later years routes were displayed on monitors throughout the cabin, and later still, on individual seatbacks. These maps traced the current location of the plane and the route covered at various scales of resolution.

Weather maps, which became common in newspapers during the first half of the century, attained greater prominence with the growth of television after World War II. In the early years local weather reporters drew maps on large pieces of paper or stood behind a clear surface and drew their maps backward for the benefit of the viewing audience. Every map was a custom product. Later television weathercasts incorporated satellite imagery and animated graphics prepared at some distant site. Using software systems developed specifically for televised weather reports, television meteorologists would download packages of maps and images and customize their presentations for local audiences (Henson 2010). At appropriate times, the on-air weathercaster would mark on the projected maps to point out specific features or directions of movement. Hand annotation was often used to describe the path of a front or severe storm.

In the last third of the century individuals gained access to computers and databases, which enabled them to create maps for their own use (personalization) or for public display and publication (customization). In the mid-1960s, the SYMAP mapping software package was widely promoted by the Harvard Laboratory for Computer Graphics and Spatial Analysis. This widely distributed computer program allowed users to create their own line-printer maps on a mainframe computer. For the first time large numbers of users could not only generate their own maps but experiment easily with the classification and symbolization of the data. Other computer programs soon followed to produce maps and topographic surfaces on plotters and video monitors. In almost all cases the user was given the power to customize the resulting graphics, and many informed users exercised these options to explore the data or customize maps to communicate a particular message. But users ignorant of cartographic principles often deferred to a program's default values and produced maps that were not particularly effective and in many cases misleading (Carter 2005).

The power of the personal computer in the 1980s led to the production of dynamic maps and atlases, which gave the viewer some control over the sequencing and display of the maps. Scripts were developed to let viewers customize their interaction with the maps (Monmonier 1992).

In the final decade of the century MapQuest and other interactive online mapping tools allowed users to quickly generate personalized maps at various levels of resolution, and many people employed this technology to personalize or customize travel and reference maps. Often a customized map giving directions to a house or event was sent by e-mail. Similarly, census, social services, and environmental agencies provided online mapping programs with which users could explore the thematic data for personal use or to create maps for presentation to wider audiences.

Researchers found that customized maps could enhance cartographic communication in diverse ways, most notably when the map symbols were customized to (1) accommodate map users with limited understanding of the phenomenon portrayed and physical limitations such as color blindness and (2) train the readers to understand and more reliably interpret map symbols (Olson 1976, 151). Research demonstrated that maps could be customized to accommodate the red-green color vision impairment of a few users while not detracting materially from the map reading experience of nonimpaired users (Olson and Brewer 1997).

Text on maps provides numerous opportunities for helpful customization. Some features have a multiplicity of geographic names as a result of the settlement history, military conquest, population displacements, immigrant populations with different languages, and the increased political clout of linguistic minorities. The twentieth century saw greater recognition accorded individual groups, often eager to assert their preferred spelling or names for places and physical features. Maps as well as databases of official toponyms and recognized variants exposed ethnic conflicts that demanded a resolution, sometimes provided by maps with toponyms customized for—or by—each group, for instance, Israeli Jews and Palestinian Arabs, both claiming the naming rights in West Bank and Israel/Palestine. In many cases, the map producer had to decide which names to show and which to omit, and thus which group's claims to acknowledge. A related issue was the question of whether the script would be alphabetic, syllabic, or logographic. Making those choices resulted in a form of customization that reflected on the intended users of the map (Randall 2001).

In the latter half of the twentieth century a new public ethos demanded the removal of geographic names—often relics of an earlier, less culturally sensitive era—that were derogatory or demeaning to ethnic and minority groups. This form of political customization became particularly prominent when controversial feature names on national series of topographic maps were replaced by more acceptable names, whether or not the new name reflected local usage (Monmonier 2006).

Although mapping in the twentieth century was carried out by a host of government agencies, private firms, interest groups, academic and professional institutions, and individuals, user communities often influenced the nature of maps that were produced, and many maps were altered or customized in response to groups that might have instigated the process by making their maps. Low-cost maps and a broadened access to computer-based mapping tools led to an unprecedented profusion of customized and personalized maps, serving the needs, and sometimes the persuasive agendas, of individuals and small groups.

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SEE ALSO: Conventions, Cartographic; Electronic Cartography: Electronic Cartography and the Concept of Digital Map; Interactive Map; Styles, Cartographic; Web Cartography

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Cvijić, Jovan. The Serbian geographer Jovan Cvijić was born in Loznica on 12 October 1865 and educated in Belgrade, where he received his doctorate in 1893. He also spent time in the 1890s in Vienna studying under the great geomorphologist Albrecht Penck (Vasović 1980). Cvijić was notable for his wide travels throughout the Balkans (summarized in his book *La péninsule balkanique, géographie humaine*, 1918), and this fieldwork enabled him to produce many ethnographic maps of the region. He also took part in the famous European Excursion of 1911, where he met many prominent geographers (Martin 1968, 136–38).

Cvijić's main geographical work was identifying and categorizing the karst landscapes of the Balkans (he is reputed to have first applied that term to these landscapes) and the origin of the lake and glacial systems of the peninsula. His most significant cartographic contribution was a series of detailed maps published in English, Serbo-Croat, French, and German showing the distribution of various ethnic groups in the Balkans (fig. 194). During World War I he was exiled to Paris, where he was the protégé of the French geographer Emmanuel de Martonne, son-in-law of Paul Vidal de la Blache (Palsky 2002). At the Paris Peace Conference in Versailles (January–June 1919), Cvijić was an official member of the delegation representing the new Kingdom of Serbs, Croats, and Slovenes (formed in 1918), for which he acted as a territorial specialist. His eagerness to enlarge Yugoslav territory fed a dispute with Italy that caused one of the biggest crises of the conference.

As an ethnic nationalist, Cvijić deployed his geographical knowledge in pursuit of his idea of a unified Yugoslavia based on a greater Serbia, and his ethnographic maps were designed to support this argument. He argued that despite the constant immigration and flux of peoples throughout the Balkans, there were natural "zones of civilization." Each ethnicity had left "a deeper impress than others" in a given region (Cvijić 1918, 470). At Versailles Cvijić pushed for a unified Yugoslavia, suggesting that Serbia, Croatia, Slovenia, and Montenegro were all ethnically south Slavic. He even visited the private rooms of the American delegation, telling them that Slavs were "all one people" and "Slovene differed merely as a dialect differs" (Jefferson 1966, XXXI).

Cvijić's ideas of geographical territory were founded on racial concepts that were becoming outmoded even in his own lifetime, and the breakup of Yugoslavia in the 1990s provided a final repudiation of his theories. Nevertheless, his raw data on ethnic affiliation remains a singular achievement, and his maps are things of beauty.

In 1920 Cvijić was awarded the Patron's Gold Medal of the Royal Geographical Society, and he received many other medals, including the Cullum Medal of the American Geographical Society in 1924. He remains well known in Serbia, where many streets and schools are named after him, and his house is a museum. He died in Belgrade on 10 January 1927.

JEREMY W. CRAMPTON

SEE ALSO: Ethnographic Map; Geologic Map; Military Mapping by Major Powers: Austro-Hungarian Empire; Paris Peace Conference (1919)

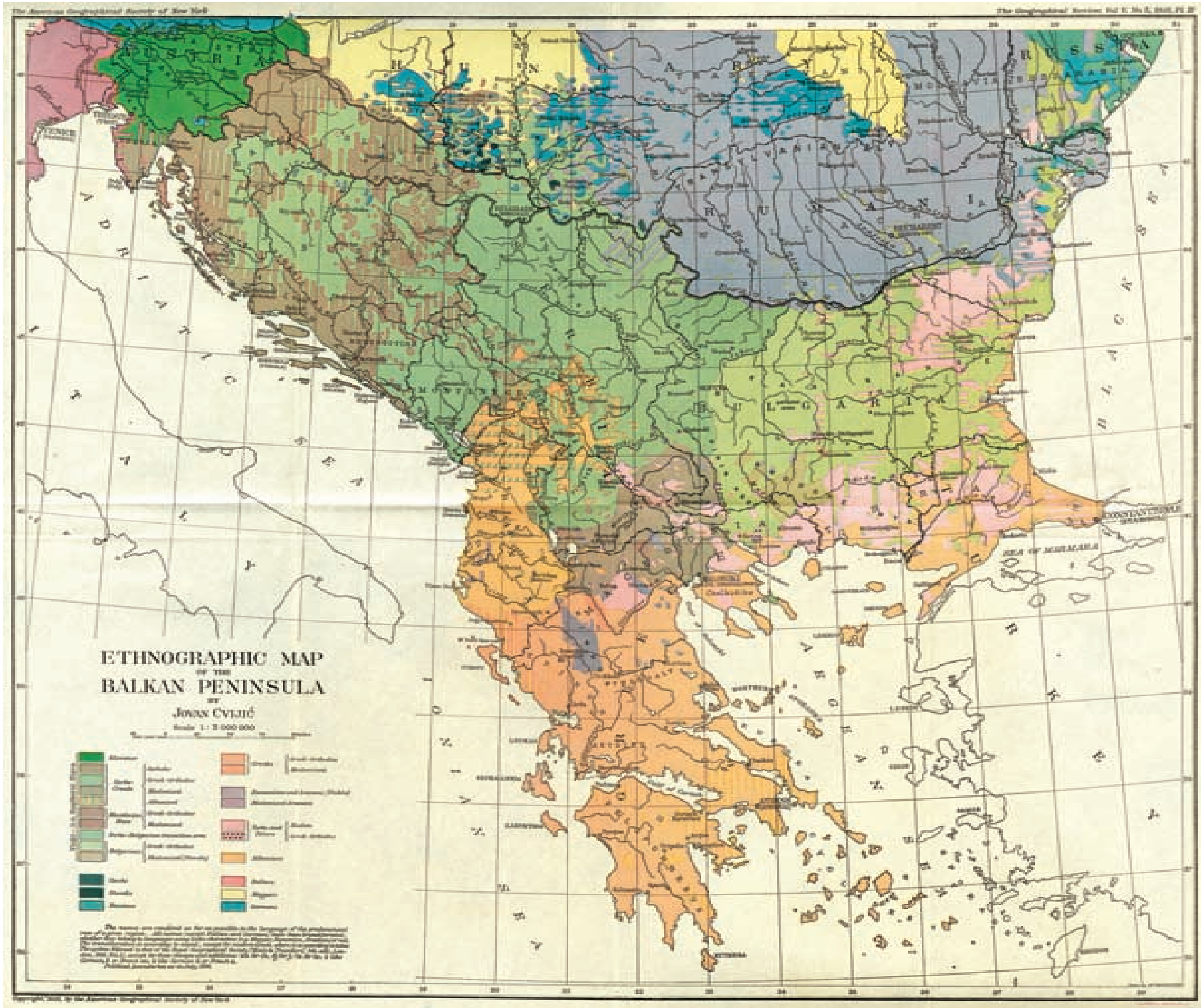

FIG. 194. JOVAN CVIJIĆ'S MAP OF BALKAN ETHNICITY, 1918. For the manuscript, see figure 779.
Size of the original: 42 × 50 cm. From Jovan Cvijić, "The Geographical Distribution of the Balkan Peoples," *Geographical Review* 5 (1918): 345–61, pl. 3.

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Cyclist Map. See Wayfinding and Travel Maps: Cyclist Map