R

Race, Maps and the Social Construction of. The cartographic construction of race refers to the concept that maps and mapping actively create and reproduce race and racial knowledges. Although maps create many different knowledges, those that sustain or create race are particularly important as they undergird projects as diverse as colonialism, redlining, territorialization, and indigeneity.

A racialized territory is a space that a particular race is thought to occupy. The idea that humans can be assigned to a small number of distinct populations was popularized by Carl von Linné (Linnæus), whose mid-eighteenth century *Systema Naturæ* (10th ed.) was highly influential. Linné set out four natural racial categories: blue-eyed white Europeans, kinky-haired black Africans, greedy yellow Asians, and stubborn but free red Native Americans. (These descriptions are those of Linné.)

Twentieth-century race maps extend the nineteenth-century practice of mapping particular kinds of people constituted as populations. By the mid-nineteenth century multiple forms of mapping were in use, including isarithmic, choropleth, and dasymetric maps. Maps were made of race, ethnicity, education, crime, longevity, language, religion, birth and death rates, and age of first marriage. These subjects were of concern as "moral statistics," deemed useful in discerning how best the modern state should be governed.

In the twentieth century there have been at least three ways of thinking about race:

1. Race as essence. In the early twentieth century race was something that was *in* individuals. It was heavily influenced by Mendelian genetics and the "one-drop" rule. Race is in an individual.
2. Race as geographical populations. Individuals are part of a race that occupies or originated in specific territories. An individual is in a race.
3. Modern genetics, with a focus on genetic distinctiveness (however tiny) of groups of people.

Maps that derive from race-based data sources such as the census have had to confront changing official definitions, inclusions, and exclusions. Since the U.S. Census was first collected in 1790 the number and definition of races has changed frequently (table 44).

Racial identity had become more fractured in the United States over time with just four categories in the first census and fifteen by the end of the twentieth century. Conversely some categories have been dropped (Aleut, Eskimo, Hindu, Mulatto) in tune with changing understandings of race and ethnicity. These changes were often politically motivated. The superintendent of the 1870 and 1880 U.S. Census, economist and statistician Francis Amasa Walker, explicitly remodeled its data collection to track what he saw as worrying immigration trends (Hannah 2000). For the first time the Census Bureau published maps of its results and sent the resulting atlas to thousands of schools.

Use of racial categories that can be mapped lay uneasily not only with changing concepts of race, but also with the politics of race. During the early twentieth century geographers and geographical institutions such as the American Geographical Society (AGS) played a significant role in promoting racial and eugenicist views. These were often part of a narrative of the threat of immigration from populations considered unhealthy, degenerate, or otherwise undesirable. For instance, the Harvard geographer and climatologist Robert DeCourcy Ward, president of the Association of American Geographers in 1917, was a eugenicist and cofounder of Boston's Immigration Restriction League. Ward favored immigration laws with exclusions that were "biological" and not socioeconomic (Ward 1922), such as the United States' quota-based 1924 Johnson-Reed Immigration Act. The act limited each country's immigration to 2 percent of their U.S. population in the 1890 census

TABLE 44. Changing categories of race in the American census at selected dates. Adapted from Nobles 2000, tables 1 and 2, and the 2000 U.S. Census form

Date of Census	Racial and ethnic categories used
1790	Free White Males, Free White Females; All Other Free Persons; Slaves
1890	White, Black, Mulatto, Quadroon, Octoroon, Chinese, Japanese, Indian
1900	White, Black, Chinese, Japanese, Indian
1910	White, Black, Mulatto, Chinese, Japanese, Indian, Other (+ write in)
1930	White, Negro, Mexican, Indian, Chinese, Japanese, Filipino, Hindu, Korean, Other races, spell out in full
1960	White, Negro, American-Indian, Japanese, Chinese, Filipino, Hawaiian, Part-Hawaiian, Aleut, Eskimo, etc.
1980	White, Negro or Black, Japanese, Chinese, Filipino, Korean, Vietnamese, Indian (Amer.), Asian, Indian, Hawaiian, Guamanian, Samoan, Eskimo, Aleut, Other (specify)
2000[1]	Spanish/Hispanic/Latino (Mexican, Mexican Am., Chicano; Puerto Rican; Cuban; other); White; Black, African Am., or Negro; American Indian or Alaska Native; Asian Indian; Chinese; Filipino; Japanese; Korean; Vietnamese; Other Asian; Native Hawaiian; Guamanian or Chamorro; Samoan; Other Pacific Islander; Some other race

[1]The 2000 census was the first to allow respondents to select more than one racial category and to combine this with the Spanish/Hispanic/Latino category.

(which restricted Southern and Eastern Europeans and Jews) and banned Asian immigration altogether. It remained in effect until 1965.

Racial mappings blended biological, territorial, and sociodemographic factors in varying degrees. Economist William Zebina Ripley's influential book *The Races of Europe* (1899) was one of the more biological approaches. Ripley, who taught at Columbia, Massachusetts Institute of Technology, and Harvard, proposed a tripartite racial classification for Europe, which was taken up by anthropogeographers such as H. J. Fleure, Thomas Griffith Taylor, and Ellsworth Huntington (Winlow 2006). The three European races—Teutonic, Alpine, and Mediterranean—could be distinguished anthropometrically by head shape, nigrescence and brunetness (measures of pigmentation), and stature (fig. 777). These measures of physical structure fit well with a suite of measures aimed at assessing intellectual development, including the intelligence quotient (IQ) test.

Another highly influential book that utilized anthropometric cartography was Madison Grant's racist *The Passing of the Great Race* (1916), which had gone through four editions by 1921. Grant, a lawyer and amateur anthropologist, was a longtime councilor of the AGS. He had published his theories in the organization's *Geographical Review*, and the AGS drafted the maps in his book. Drawing on Ripley, Grant adopted a similar tripartite division of Europe into Nordic (superior), Alpine, and Mediterranean races (fig. 778). Grant's racial divisions were both biological and territorial, and he drew on a number of geographical sources for his maps, including Ripley, Jean Brunhes, Jovan Cvijić, Eugene Van Cleef, B. C. Wallis, and Leon Dominian. Grant also used his race science to inform his political activities: he was vice president of the Immigration Restriction League, and he provided his maps and statistics to help pass a 1924 Virginia race law as well as the 1924 Immigration Act.

Pre–World War II understandings of race, and the maps that created and sustained racialized territories, varied with the racial theories of their authors. Two of these theories are race science (eugenics) and racial essence (the one-drop rule). Although some authors (Nobles 2000) see these as historically sequential (with race science predominating during the nineteenth and early twentieth centuries and the one-drop rule persisting until the postwar period), to a large degree they were contemporaneous.

Race science, or eugenics, explicitly draws on the mapping of populations understood as identifiable races distributed over discrete territories. For many, these racial divisions were biological, while for others populations could be geographically located by a mix of biology and sociocultural indicators such as religion and language. Geographers, anthropologists, paleontologists, and biologists contributed to race science, which by 1914 had become mainstream science, funded by major institutions, and taught at forty-four major universities (Black 2003, 75).

The center of eugenic research was the Eugenics Record Office (ERO), located in Cold Springs, New York, and headed by Charles Benedict Davenport and Harry Hamilton Laughlin. Together with Grant, Davenport developed a series of questions that were filled out by his fieldworkers in interviews with American families and, during World War I, with new recruits. Wartime data, and specifically the U.S. Army Alpha test of written comprehension, which was used to assess intelligence, provided large-scale data on Americans. Princeton psychologist Carl C. Brigham later modified the

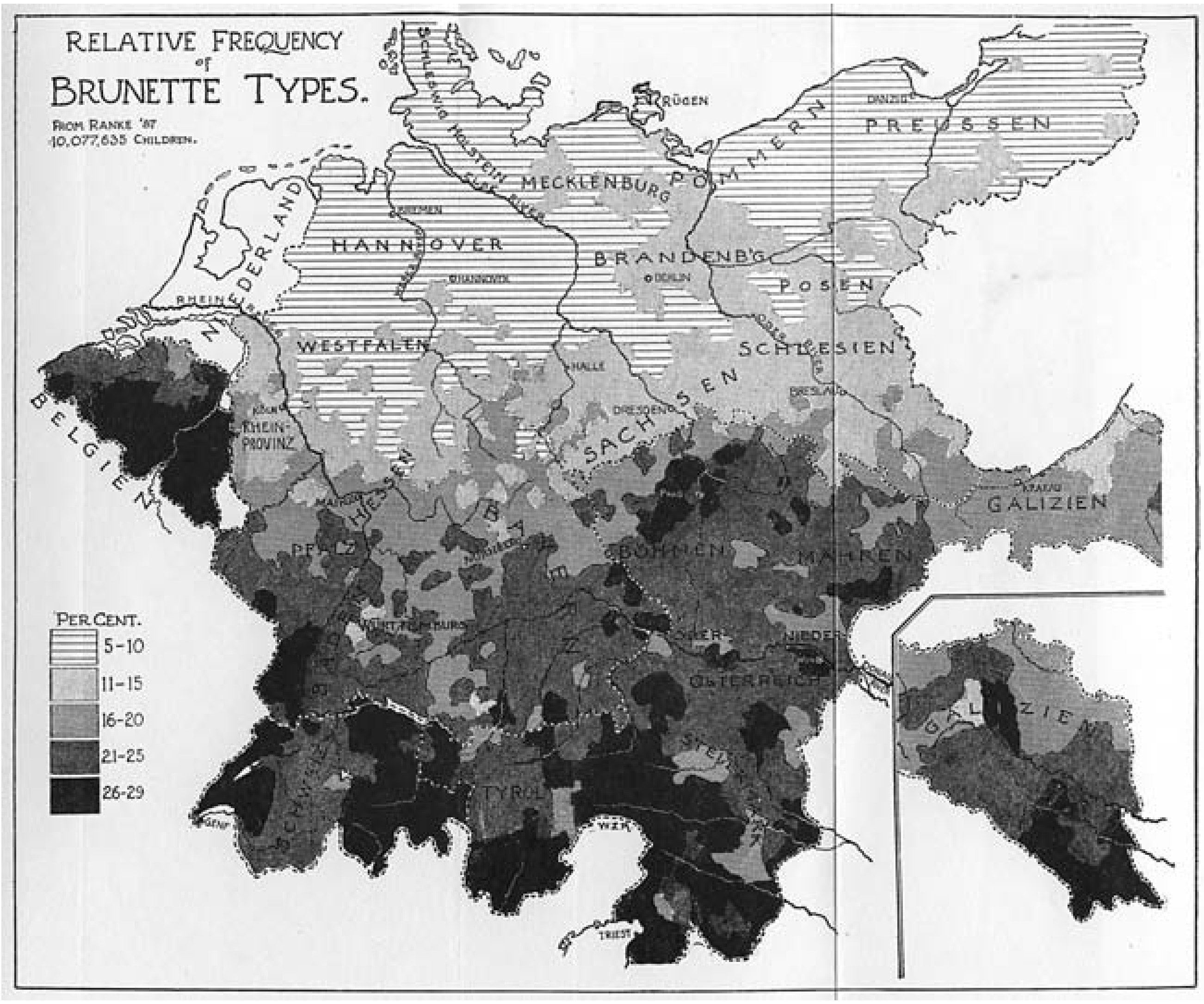

FIG. 777. WILLIAM ZEBINA RIPLEY, *RELATIVE FREQUENCY OF BRUNETTE TYPES* FOR GERMANY, 1899. Size of the original: 16.6 × 20.2 cm. From Ripley 1899, facing 222.

Army Alpha test into a college entrance exam known as the Scholastic Aptitude Test (SAT). There were some who spoke out against this practice. Walter Lippmann, journalist and founder of the *New Republic*, called these measures "quackery" (Black 2003, 84), and anthropologist Franz Boas argued that variation was due to cultural and historical circumstance. Nevertheless, eugenic data collection efforts, including maps, continued to influence policy by, for example, helping to pass forced sterilization laws in dozens of states. Davenport's research also helped inform German race theories even after World War I (Spiro 2009).

Both Lippmann and Davenport were involved in another huge effort to determine human territorial distributions during and after World War I. Known as the Inquiry, it had been founded in 1917 by President Woodrow Wilson and his right-hand man Colonel Edward Mandell House (Gelfand 1963). Headquartered in the AGS offices in New York City at the suggestion of its director, Isaiah Bowman, the Inquiry was a semisecret academic think tank that was effectively charged with determining America's foreign policy after the war. To do this it hired dozens of geographers, historians, geologists, and economists. During 1917–18 it produced a document known as the Black Book, which mapped the most desirable (to U.S. interests) territory of every European country. Lippmann and Bowman helped House draft Wilson's Fourteen Points, which later were cited by the Germans in their armistice agreement (Smith 2003). The Inquiry's mapping efforts run into the hundreds and included physical, cultural, linguistic, religious, and politically contested areas. They also

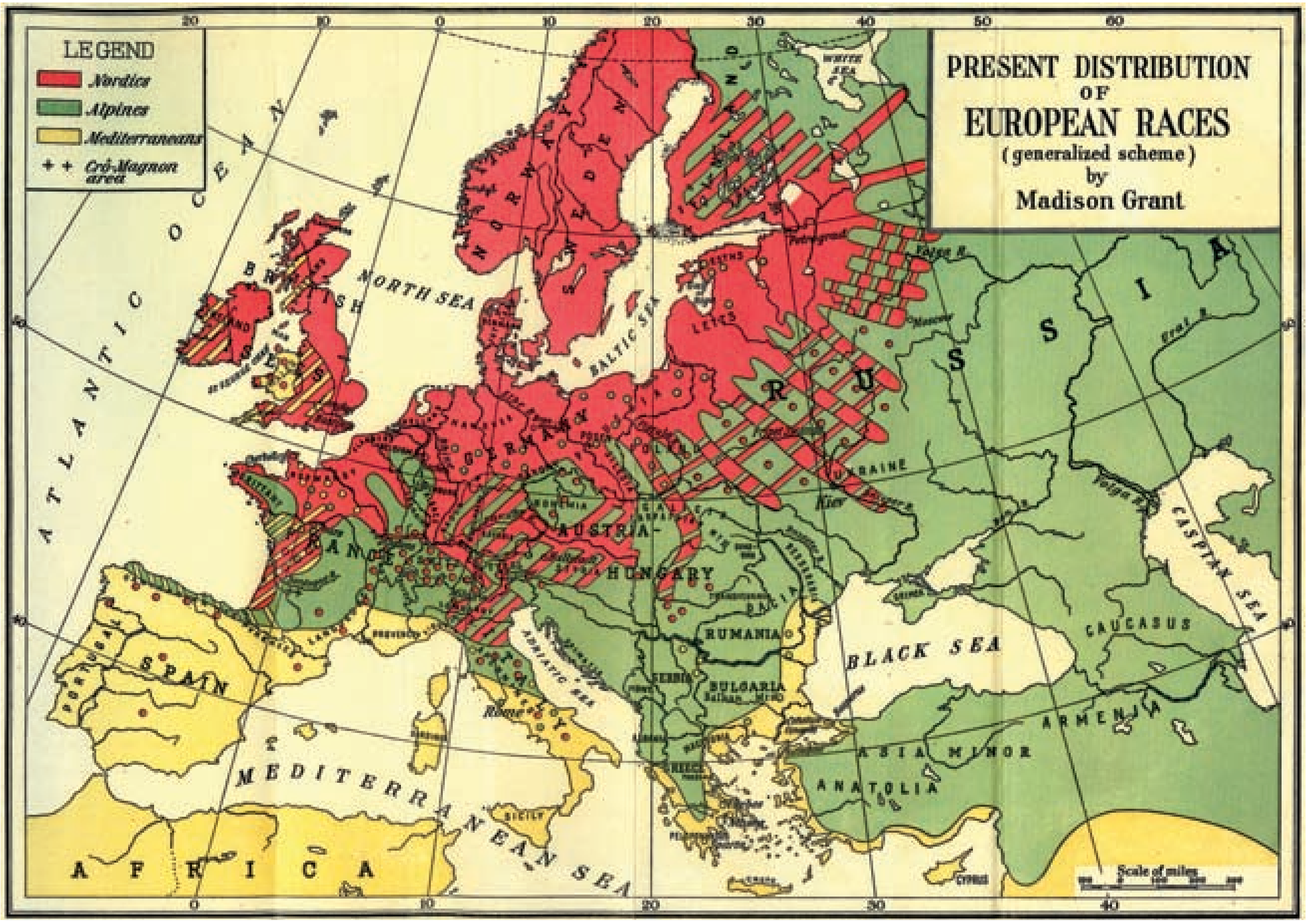

FIG. 778. MADISON GRANT'S *PRESENT DISTRIBUTION OF EUROPEAN RACES*, 1916. Size of the original: 20.3 × 28.9 cm. From Grant 1916.

collected published maps, which were added to the AGS collection; many of these were later taken to Paris for the Peace Conference.

Instead of adopting a biological model of race, the Inquiry chose a more eclectic approach that nevertheless identified clear "zones of civilization," as the Serbian geographer Jovan Cvijić had put it. Cvijić donated his complex manuscript map of these zones to the AGS library (fig. 779). Geographer Leon Dominian, a member of both the AGS and the Inquiry, attempted to show the relation between language and nationality with a view to settling political boundaries in his book *The Frontiers of Language and Nationality in Europe* (1917).

The president took with him to the Peace Conference a core group of Inquiry men, who were salted through the critical territorial commissions that drew up the boundaries of postwar Europe. The chief cartographer was Mark Sylvester William Jefferson, Bowman's old professor. Jefferson's diary provides an exhilarating account of the day-to-day challenges of providing maps to the conference. Many of these reveal the struggle behind the scenes to determine the new political frontiers, which were highly contested by all parties. The Inquiry's position, and that of the United States, frequently prevailed because of its reputation for "scientific boundaries."

Race was clearly a factor in the proliferation of redlining in the 1930s and 1940s. Redlining occurs when a mortgage company refuses mortgages to certain neighborhoods, often by literally drawing red lines on maps around risky areas (it became illegal in 1968). For example, the Home Owners' Loan Corporation mapped 239 U.S. cities between 1935 and 1940, and it has been shown that controlling for building quality, these maps were determined largely by race (Hillier 2005).

Between the wars, the preference for biological (Mendelian) accounts of race was increasingly challenged by cultural, historical, and behavioral explanations of race. Biology did not disappear; the ERO continued its activities until 1939. Bowman's influential political geography text, *The New World* (four editions, 1921–28),

FIG. 779. JOVAN CVIJIĆ'S MANUSCRIPT MAP OF BALKAN ETHNICITY, 1918.

Image courtesy of the American Geographical Society Library, University of Wisconsin–Milwaukee Libraries.

included maps of the postwar world as comprising "kinds of people" who occupied territories with often contested lines of division. These were not races in the sense of continent-wide groupings, but Bowman's maps did group people into territories.

Post–World War II understandings of race differ in three distinct ways. In 1950, in the aftermath of Nazi practices of "racial hygiene," the United Nations Educational, Scientific and Cultural Organization (UNESCO) issued a statement on race that downplayed race's basis in biology. Writers have increasingly eschewed a biological basis for race, while maintaining the reality of race as a lived experience. In 1972 this position received further support from evolutionary biologist Richard C. Lewontin (1972), who showed that genetic differences *between* racial groups was far smaller (6.3 percent of variation) than that observable within a race but *among* local groups (85.4 percent of variation). Thus in anthropology it became more common to talk about "populations" rather than races. Where race has continued as a topic in geography, it has become predominantly used in studies of racial discrimination, especially after the emergence of more politically informed theories and concerns of social justice from the 1970s onward.

Second, writers have generally adopted a geographically continuous notion of human variation, rather than discrete, bordered territories. These geographical continuities are known as clines in anthropology, after a proposal by the biologist Julian Huxley in 1938. Components of human variation became increasingly mapped as gradations across space with changing environmental conditions or genetic drift (changing frequencies of genes within a population). Population geneticists such as L. L. Cavalli-Sforza and Lewontin included many such cline maps in their studies.

Third, race and ethnicity were increasingly understood as part of a cultural-geographic-historical complex, rather than as a single dominating variable. And as the early twentieth century racial purists such as Ward and Grant feared, immigration and global migration have undermined the notion of isolated races.

These three factors meant that maps of races in the prewar sense of geographically bounded territories fell out of favor, to be replaced by clines and emphasis on race as a perceived category. However, many maps still adopt a territorially discrete perspective, often using choropleth maps. Atlases of the 2000 U.S. Census, for example, mapped race in these terms (Brewer and Suchan 2001). The Census Bureau's use of race-based data has been challenged, even where individuals choose their own racial category. In France, for instance, the collection of such data is now banned because it reproduces racial categories.

In the past few decades, maps of race or ethnicity have become a topic of study itself in political geography, sociology, and anthropology. With the advent of critical approaches in cartography (Winlow 2006), mapping by and of indigenous peoples emerged as a significant focus. Such counter-mappings have explicitly considered how indigenous peoples, who have traditionally been the subject of mapping, can map themselves (Wainwright and Bryan 2009). Geographer Bernard Nietschmann, who called this strategy "map or be mapped," explicitly recognized the relations of power to the production of knowledge and vice versa (Bryan 2009, 24 n.2).

The closing years of the century witnessed attempts to bring back biological explanations of race. The sociologist Troy Duster (2005) described this as the biological "reinscription" of race. Much of this biological reinscription comes from the biological and medical communities, including human genetic research. The Genographic Project collected DNA samples from indigenous groups across the world in order to map human diversity and offered genome kits for sale to the public. Launched in 2005 by the National Geographic Society and IBM, the project is an extension of late-twentieth-century gene-mapping projects such as the Human Genome Diversity Project (HGDP). Both the Genographic Project and HGDP have attracted criticism for their reification of racial categories. Many scholars now therefore favor accounts of human variation as the result of the interaction between nature and culture. Nevertheless, race is likely to play a continued role in social policy—and thus in the generation of maps—as long as it remains a significant correlate of inequalities.

JEREMY W. CRAMPTON

SEE ALSO: American Geographical Society; Colonial and Imperial Cartography; Indigenous Peoples and Western Cartography; Paris Peace Conference (1919); Persuasive Cartography; Redlining; U.S. Census Bureau

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Radó, Sándor (Alexander Rado). Sándor Radó was born in 1899 in Újpest (Budapest), Hungary, into a wealthy family. He joined the Hungarian Communist Party at the age of nineteen. Fearing recrimination for his political and military activity during the short-lived Communist revolution in Hungary, he emigrated to Austria in 1919. He studied geography in Vienna, and from 1920 to 1922 Radó was in charge of the Soviet Union's telegraph agency ROSTA in Vienna. He moved to Germany in 1922 and studied at Jena and Leipzig but never graduated. In 1924 he moved to Moscow, where he edited the first civilian map of the Soviet Union, published by Westermann. As a geographical expert, Radó was commissioned to compile a guidebook to the Soviet Union. He traveled the country by air, and his pro-Soviet guidebook was published in 1924. Starting in 1924 he produced pioneering aeronautical charts for the Swedish firm Esselte and later a guide to Lufthansa's European routes.

Radó realized the importance of maps in mass communication and political-ideological propaganda. Following his return to Berlin in 1926 he organized the cartographic agency Pressegeographie, which produced schematic maps for newspapers. In 1930, while serving as the Moscow-based editor of the Soviet world atlas, Radó published the first (and only) volume of his much debated anticapitalist *Atlas für Politik, Wirtschaft, Arbeiterbewegung* (see fig. 332). In 1933 Radó—by then an internationally known geographer and Soviet propaganda agent—moved to Paris, where his cartographic press agency (now known as Inpress) became international. In 1936 the agency was relocated to Geneva, Switzerland, where it was renamed Atlas Permanent. Apart from atlas sheets it also produced the Geopress series of news maps. This activity provided cover for Radó's spying on behalf of Soviet military intelligence. Under the codename "Dora," Radó directed a spy network that became a major source of secret information from Germany. In 1944 he escaped to France and joined the French Resistance.

In 1945 Radó was summoned to Moscow and sent to a Siberian labor camp. Released after Joseph Stalin's death, he returned to Hungary in 1955 and began a second career as a leading civilian cartographer. He headed the cartographic department of the state surveying and mapping office, Állami Földmérési és Térképészeti Hivatal, and in 1956 became supervisor of the state-owned map-publishing monopoly Kartográfiai Vállalat, also known as Cartographia. In addition, between 1958 and 1966 he was chair of geography at the Marx Károly Közgazdaságtudományi Egyetem in Budapest. As an influential figure with important worldwide contacts, Radó helped reorganize and promote Hungarian and socialist cartography. During the Cold War, Cartographia cooperated with Western cartographic companies and publishers such as Larousse and Rand McNally. As president of its editorial committee, Radó initiated publication of a new series of school atlases, the *National Atlas of Hungary, Magyarország nemzeti atlasza* (1967, editions in English and Hungarian), and a series of regional atlases of Hungary. In 1957, he organized the Terra cartographic news agency, which produced news maps and several propaganda maps in the 1970s. In 1964, while in London, he introduced the first sheet of the 1:2,500,000 international world map (*Karta Mira*), a joint project of the Soviet Union and other socialist countries for which he served as chief editor.

In 1965 Radó founded *Cartactual*, a cartographic reference journal that reported geographical changes as a collection of simple maps with legends in English,

FIG. 780. *CARTACTUAL* MAP SHOWING THE NEW UNDERGROUND LINE IN BUDAPEST, 1968. From *Cartactual*, no. 15 (1968), below the table of contents. Image courtesy of Zsolt G. Török.

French, and German (fig. 780). Starting in 1971, this unique cartographic periodical was supplemented by *Cartinform*, which included cartobibliographic information and short reviews of current geographical and cartographic literature and map publications. (Both publications ceased in 1993.) Radó's information-collecting activity was sometimes considered a continuation of his intelligence work.

Radó published his memoirs in 1971—an English translation, titled *Codename Dora*, appeared in 1977—and although his character can be found in books by his contemporaries, parts of his life, especially after World War II, remain unmapped. He died in Budapest in 1981.

ZSOLT G. TÖRÖK

SEE ALSO: Cold War; Military Mapping by Major Powers: Russia and the Soviet Union; World War II

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Railroad Map. The twentieth century witnessed an unparalleled diversification of railroad mapping. From the explosion in popularity of topological schematics like the London Underground diagram (see fig. 483) to increasingly detailed and colorful scenic portrayals of railroad routes that were primarily used for marketing purposes (e.g., by Canadian, British, and French rail operators), maps played a key role in the public perception of services. As railroads were pushed into more inhospitable or uncharted terrain, surveyors and cartographers were challenged to deliver more complex maps to engineers such as those needed for the Gotthard Base Tunnel beneath the Swiss Alps, on which construction began in 1996.

Good surveying practices and the resulting cartography have been key to new railroads—from the first interurban passenger service, the Liverpool & Manchester Railway (surveyed in 1826 and opened in 1830) to the crossing of entire continents, e.g., the Trans-Siberian (completed Moscow–Vladivostok in 1903). Placing railways under major waterways, like the Channel Tunnel between France and England, which opened in 1994 (Kirkland 1995), and the building of high-speed lines in heavily urbanized areas, for example, the Japanese Shinkansen (opened in 1964), all demanded increasingly detailed and accurate surveying and cartography (Nock 1978).

The point of most railroad maps is not to convey topographic detail, but to illustrate the general trajectory of a route: it is more important in this genre of cartography to see which station follows which and where a transfer might be necessary than to see the precise weaving of a line in relation to geographic features—hence the success of schematics in this field. Even the most apparently detailed railroad maps (fig. 781) are best taken as approximations of landscapes produced with some artistic license rather than as indicators of the precise locations and sizes of topography. Schematics often sacrifice the genuine position of a location in favor of tidiness; a common characteristic is the use of a single angle for diagonal lines (often 45 degrees). As long as the key principle—which station follows which—is not compromised, the guiding design rule can be aesthetic. Examples include the 1972 New York Subway map designed by Massimo Vignelli and the 1977 rail network diagram of France (fig. 782). However, while these principles are acceptable on maps produced for the public, engineers' maps need to be topographically accurate. Railway junction diagrams (RJDs) produced by the U.K.'s Railway Clearing House showed the exact distance (in imperial miles and chains) between every junction (many hundreds were drawn between 1871 and 1955).

A hybrid representation of track was used in signal boxes (also called interlocking towers in American vernacular). While the spatial relations were not geographically accurate (partly due to the nature of the display space, which was often in a thin landscape-shaped box above signal control levers and usually with lamps behind to indicate the position of trains), the correct relationship of the points (also called railroad switches) and individual tracks (or roads) was crucial so that signal operators could ascertain the position of trains. (Most were replaced with electronic systems and computer displays during the last decades of the twentieth century, but some are preserved by heritage railways.)

Unlike many other forms of cartography, railroad maps are seen in a wide variety of scales. They can be reduced to very small areas (issued on ephemeral items such as matchbox covers or handkerchiefs) or reproduced at very large scale (often seen inside stations). Examples in Europe include ceramic tiled maps of the London & North Eastern (1920s), the Edwardian Lancashire and Yorkshire Railway mural at Manchester Victoria, and the carved art deco maps (1930s) inside ticket offices at Brittany stations (e.g., Dinan, France). Enameled or even three-dimensional relief maps have also been made.

FIG. 781. YOSHIDA HATSUSABURŌ 吉田初三郎, *NIHON RAIN WO CHŪSHIN TO SERU NAGOYA TETSUDŌ ENSEN MEISHO ZUE* 日本ラインを中心とせる名古屋鐵道沿線名所圖繪 (ILLUSTRATION OF FAMOUS SITES ALONG THE NAGOYA RAILWAY, WITH THE NIHON LINE FEATURED), JAPAN, [1928]. This stylized and apparently detailed bird's-eye view of rail routes near Nagoya depicts individual mountains and even trees, but there is much artistic license in the artist's interpretation. The map is at the Library of Congress, Washington, D.C.
Image courtesy of Mark Ovenden.

Most railroads were built by private companies, but during the course of the twentieth century some smaller operations were taken over by larger conglomerates and many were brought under state control (Indian Railways were taken over by the government in 1907, Britain's railways were nationalized in 1948, and Amtrak was created by the U.S. federal government in 1971). Competition between rival companies led to thousands of posters being produced in the first few decades of the twentieth century (the heyday for the rail travel poster), many of which included maps of their routes that either exaggerated their ease of use or directness (Ovenden 2011). Often competitors' routes would be entirely eliminated in order to enhance the value of one company's lines over another (fig. 783). Some of the fiercest competition was seen in Europe and North America, where several potential routes were available for longer trips.

Railroad maps played an important role in the settlement of Canada, the sale of land adjacent to track for development in Australia, and the expansion of cities like London and New York. In these instances the map was predominantly used alongside idyllic or fanciful images of the area to be populated.

Another defining feature of the twentieth century was the decline of railroads after World War II—countries that were once criss-crossed with a myriad lines found their rail services (and maps thereof) considerably curtailed. The United States went from 408,777 kilometers of track and more than 40,000 stations to just a few key routes by 1971 (the first Amtrak diagram showing only 500 stations). Argentina, whose rail maps once showed it as the king of South American railroads, went from over 47,000 kilometers of track to almost no running railroads by 2001. There were huge cuts to Irish, French, Spanish, and British systems. Jamaica, Libya, Lebanon, and Ecuador (among others) have been wiped off the world's rail map having lost all their train services. But the introduction of high-speed routes, first in Japan and then in France, led to a railroad renaissance that by the close of the twentieth century was accurately predicted by the International Union of Railways as likely to spread to the richer nations of the world (International Union of Railways 2010).

MARK OVENDEN

SEE ALSO: Advertising, Maps as; London Underground Map; Rand McNally & Company; Wax Engraving; Wayfinding and Travel Maps: Public Transportation Map

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Raisz, Erwin (Josephus). Following the death of J. Paul Goode in 1932 and before the rise of a number of post–World War II map scholars, notably Arthur H. Robinson, Erwin Raisz was the most visible academic cartographer in the United States. For twenty-five years he dominated the field. However, unlike Goode and Robinson, Raisz produced no significant cadre of followers.

Erwin Josephus Raisz (he soon dropped his middle name and even the initial) was born in 1893 in Lőcse, Hungary (now Levoča, Slovakia). His father was a civil engineer, a profession the young Raisz also prepared for at the Royal Polytechnicum in Budapest, along with architecture. He received his diploma, with honors, in 1914.

According to family tradition, the Raisz ancestors had emigrated from Russia to Hungary, where they were engaged in the hand printing of cloth. This may explain the young Erwin's interest in art, which he pursued throughout his life as an avocation and which shows up strongly in his map production. Cartography is a profession in which art and science meet, and in it Raisz found his perfect medium of expression. Educated Hungarians, by necessity, are often skilled in languages, but this was not Raisz's academic strength. He was a producer more than a theoretician and never fully mastered the English language.

Upon graduation the young Erwin Raisz enlisted in the Imperial Sappeurs (engineers), a corps of the Austro-Hungarian Army of the Central Powers. As a lieutenant he was employed laying mines during World War I, which required accurate mapping if they were later to be found and detonated. After the war, Raisz worked in an architect's office in Budapest from 1918 to 1923, a satisfactory position.

But life was not easy in Central Europe after the war, and, like many other veterans from both sides, Raisz emigrated to the United States. He found employment in the Ohman Map Company, a private enterprise in New York, but soon enrolled at Columbia University where he studied under Professor Douglas Wilson Johnson, who had drawn maps of, and written about, the Great War in Europe. This was fortunate in a number of ways, as Raisz made many valuable contacts and supported himself by drawing maps. From Columbia he received a master of arts in geology in 1924 and that same year married his fiancé from Budapest, Marika (familiarly Marie) Patai. The couple soon became parents of a son, Lawrence. Meanwhile, Raisz continued his studies toward the doctorate while supporting his

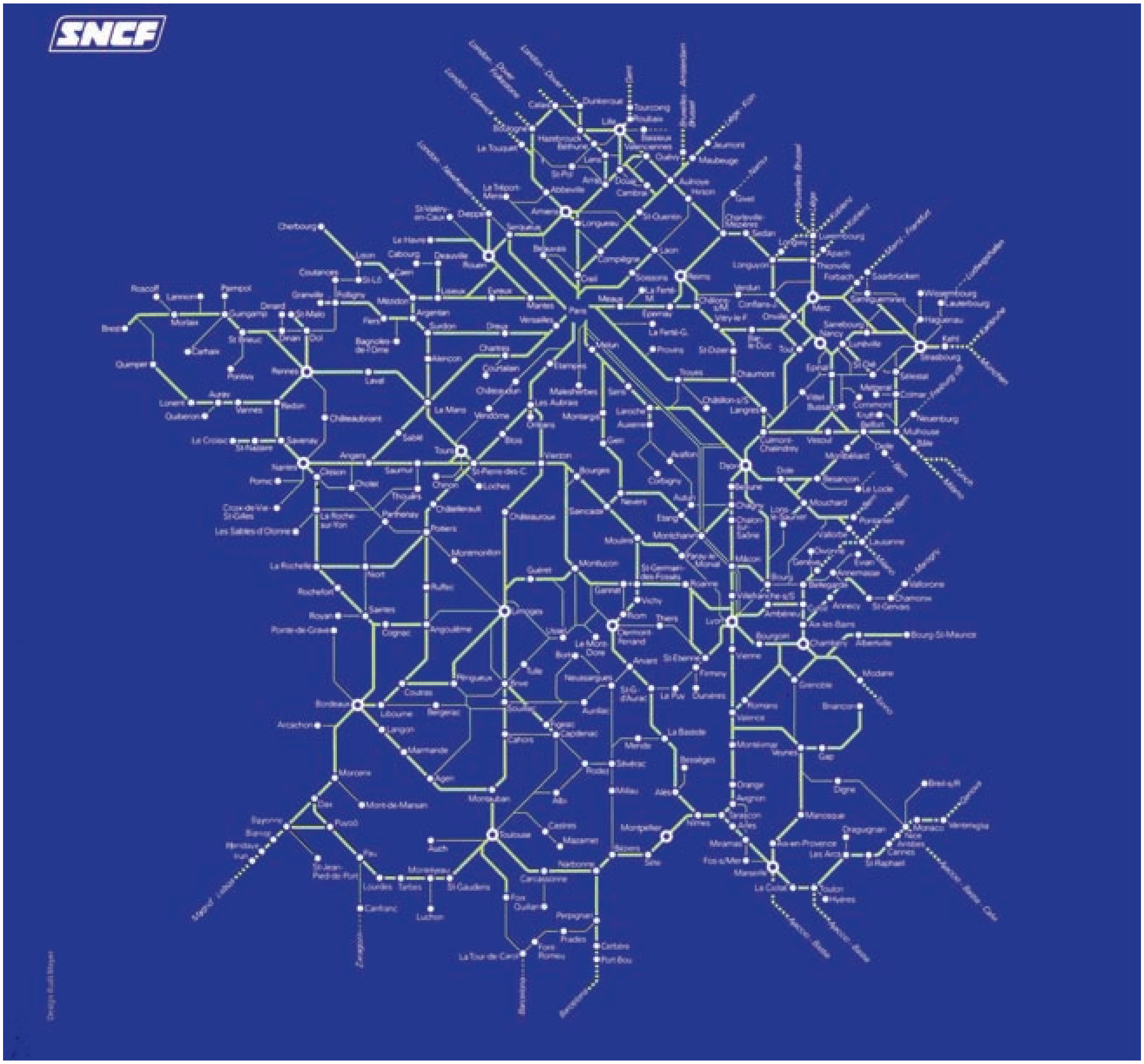

FIG. 782. RUDI MEYER, PLAN OF TRAVEL NETWORK IN FRANCE, PARIS, 1976. This schematic of the French national rail network (*plan du réseau voyageurs*), commissioned by the Société nationale des chemins de fer français (SNCF) and displayed inside their trains, contains no geographic references at all, yet manages to effectively convey the hexagonal shape of France. Meyer, a graphic designer, was at the time working as a cartographer for SNCF.
Size of the original: 32.5 × 29.5 cm. Image courtesy of the Mark Ovenden Collection.

young family. Marika later developed a very successful business importing antiques from Europe to the United States, which enabled Erwin to pursue his career during hard times. In 1927 he gave the first course offered in cartography at Columbia, which awarded him a doctorate in geology in 1930.

Johnson's mentor had been William Morris Davis, one of the founders of modern geomorphology and a professor at Harvard University who contributed significantly to cartography. Through this connection, Raisz was recommended to Dr. Alexander Hamilton Rice, who founded and financed the Institute of Geographical Exploration at Harvard in 1930. Raisz was invited to join the institute as a cartographer. This was not a regular faculty position, but it allowed more flexibility than a tenured appointment. Raisz later said (to

FIG. 783. *LONDON & NORTH WESTERN RAILWAY AND CONNECTIONS*, LONDON, 1911. While showing geographically accurate relief and even illustrating most of Britain and Ireland's major waterways, the L&NWR deliberately omits the rail routes of all its competitors.
Image courtesy of the Ashworth Collection, London.

the author of this essay) that he had made a mistake in not insisting on a tenured position that, if not offered to him at Harvard, would have been available elsewhere. As events transpired he decided to accept the offer from Harvard and stayed there for twenty years.

Raisz's published maps and writings more than compensated for his inadequacies as a speaker. His cartography consisted, mainly, of what he called "landform maps," on which simulated three-dimensional terrain was drawn on a two-dimensional map base. Purists such as Armin K. Lobeck, who was also very accomplished at such delineations where parts of landforms in perspective might be greatly displaced from their true planimetric location, used and preferred the term "physiographic diagram" for such graphic productions. Nevertheless, Raisz produced many landform maps, which were greatly valued by educators and students (see fig. 721). Most were of subcontinental areas at small scale and reflected Raisz's knowledge of both geology and geography, and some were adapted for other publications. For example, excerpts from Raisz's landform map of the United States illustrated Bernard Augustine De Voto's *The Course of Empire* (1952), among other popular works. There are ten subcontinental, six country or regional, and eight mostly local landform maps by Raisz, usually undated but drawn over a period of some four decades and revised periodically. It is a remarkable cartographic corpus by any measure.

Established academicians and university administrators, who thought only in terms of written contributions, were not always impressed by Raisz's work. One university president who was shown a folio of Raisz's landform maps of many parts of the world remarked: "What else has he done?" (quote attributed to James Bryant Conant). The answer to this question is a body of published writings that would secure tenure and further promotion at most universities. Raisz's written work includes a number of in-house and other local contributions, some twenty-five refereed articles in international or national journals, three textbooks, and two atlases.

General Cartography (Raisz 1938) is Raisz's most influential book. At the time of its initial publication it was the only textbook on the subject in the English language and remained so through its second edition (1948) until the late 1950s. Raisz observed that although he didn't receive a great deal of money from this book, it had made his academic reputation. The book contains much practical information but is short on theory, as critics were quick to point out. But a generation of geographers and others were influenced by its wide-ranging coverage. *Principles of Cartography* (Raisz 1962), a somewhat simplified version of *General Cartography*, was an attempt to recapture a market being lost to newcomers, such as Robinson's *Elements of Cartography*. Raisz's other books, especially his atlases of Cuba and Florida, are innovative and colorful but of much less general interest. Similarly, only a few of his articles, although published in scholarly journals, are groundbreaking, and his in-house papers served primarily temporal purposes. Accordingly, Raisz's reputation now rests heavily on his landform maps, which are still in print.

It was easy for Harvard to dismiss the untenured Raisz a few years after the Geography Department there was dissolved in 1947. Raisz then accepted visiting appointments at Clark University, the University of British Columbia, and other institutions. He spent parts of the academic years 1953–55 at the University of Virginia, where he felt greatly honored to be working alongside Count Geza Teleki, a geologist, diplomat, and political refugee from Hungary. Raisz ended his instructional career at the University of Florida, through the invitation of scholar-administrator Shannon McCune, one of his many admirers. Erwin Raisz died of a cerebral hemorrhage in Bangkok, 1 December 1968. He was traveling to New Delhi, in the company of his wife of nearly forty-five years, to attend meetings of the International Geographical Union. A world traveler, Raisz "died with his boots on."

NORMAN J. W. THROWER

SEE ALSO: Centrography; Education and Cartography: Cartographic Textbooks; Lobeck, Armin K(ohl); Physiographic Diagram; Relief Depiction: Relief Map

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***Rand McNally & Company** (U.S.).* Perhaps no name in the United States is more closely associated with maps than Rand McNally. Founded in Chicago just after the Civil War, the company was initially a partnership formed between William Rand and Andrew McNally to print tickets and other materials to serve the expanding railroad industry. Within a few years, the firm began to print maps of the United States, which accounted for 40 percent of the company's revenue by the 1880s (Grant ca. 1956, 8). Andrew McNally's prominence in Chicago's business community aided the company's growth in the late nineteenth century, and by the turn of the century the firm's map division was one of its key endeavors.

Rand McNally's early success had much to do with its decision to adopt a new printing technology known as wax engraving. This technology, which facilitated the inclusion of more type on the map, eventually generated a particular cartographic style (e.g., see figs. 455 and 1095). The company emphasized this desire for cartographic information—even at the expense of cartographic artistry—in its advertising. Rarely were the company's maps and atlases promoted for their artistry or beauty; instead, they were primarily informational and instrumental tools. For instance, many were designed with businessmen in mind, particularly those who needed information on counties, towns, and rail systems rather than terrain or geographic relationships. In other words, part of Rand McNally's success—as well as a mark of its influence—was its recognition that the American map industry was primarily driven not by aesthetic concerns but rather by the expansion of railroads and markets, especially in the West.

Rand McNally hitched its star to the growth of the rails by distributing its books, maps, and atlases on trains and in stations. It also mapped, and thereby promoted, particular lines. David Woodward has even identified instances in which the company manipulated rail routes in order to suggest a wider reach or a more direct route (Woodward 1977, 33–36). Rand McNally also successfully mastered incipient marketing techniques for its products and as a result controlled the largest share of the domestic map market by the turn of the century. Yet this was also a time when the United States was producing cartographers who were decreasingly likely to be trained in drafting, and this in turn entrenched a particular style of map.

Despite the inflexibility of the maps themselves, the company responded quickly to the nation's growing international posture at the turn of the century by increasing the number of maps of areas outside the United States. But the most important area of growth at the company in these years was road maps, a reflection of the exploding automobile culture in the United States. Rand McNally quickly mastered this new genre and, along with a few other firms, shaped not just the map but the experience of the landscape through its products (see fig. 856). As James R. Akerman has ably shown, there existed a striking difference between American and European road maps at the turn of the century: the former were oriented almost exclusively toward driving, while the latter incorporated topography, which would matter to cyclists, as well as roads. To Akerman, this indicates a substantial difference in patterns of thought and behavior around map use and understanding. Rand McNally's maps of the American countryside were sparse in detail, offering scant diversions to take tourists off the main roads. Through this cartographic approach, tourists were invited to travel *through* the country rather than *in* it. In Akerman's words, the company's actions at the turn of the century were in no small part responsible for the nation's "aesthetic sympathy to rapid long-distance automobile travel" (1993, 77–79, quotation on 80).

Highway building proceeded fitfully in the first two decades of the twentieth century and then accelerated due to the concerns of military planners in the Great War. Faced with the prospect of defending a massive country, they pressured the federal government to consider the construction of national roads. And while Rand McNally had been publishing road maps since 1904, it wasn't until this later period that the company undertook a more systematic approach to road mapping through its Auto Trails and Blazed Trails route designation and marking program. Rand McNally found local highway interests willing to collaborate in marking routes for its maps. As Akerman observes, in this practice Rand McNally provided a public interest while earning goodwill and customer loyalty, all the while ensuring that its own maps would be the most useful for motorists (Akerman 1993, 81–85). Ultimately it helped sell the national highway system that became so crucial to the American landscape.

The company's maps were used in unanticipated ways as well, a reminder of the reactive dimension of cartographic production. As Ralph E. Ehrenberg has documented, in the early 1920s Rand McNally's state maps were widely used by army, navy, and airmail pilots. The road and railroad markings proved invaluable details and landmarks from the air, particularly those found in the company's Indexed Pocket Map series. These state maps were compact enough to be carried in a cockpit and contained sufficient information—even some terrain. Perhaps in response to this, the company published its first dedicated aviation map of the United States in April 1923, followed by one of the first published directories of landing fields (Ehrenberg 2006, 229–30, 237).

A less inadvertent contribution to cartography came from Rand McNally's chief cartographer, J. Paul Goode, who played a critical role in the understanding of map projections in the twentieth century. In 1923, Rand McNally published the first edition of his *Goode's School Atlas*, which is revised regularly and still widely used by students in the United States. Until this point, the world had consistently been depicted on the sixteenth-century Mercator projection, which made the publication of *Goode's* seminal for its presentation of the Mercator

FIG. 784. GOODE'S HOMOLOSINE PROJECTION, *WORLD—PHYSICAL*, 1932.
Size of the original: ca. 26.5 × 41.2 cm. From J. Paul Goode, *Goode's School Atlas: Physical, Political and Economic, for American Schools and Colleges*, 4th ed., rev. and enl. (Chicago: Rand McNally, 1932), 4–5. Map © Rand McNally; R.L. 11–S–001.

projection as just one of a wide range of possibilities. Suddenly students were confronted with multiple projections that shaped the world in widely differing ways.

Goode's own contribution to map projection was his homolosine projection (fig. 784). Despite its greater ability to preserve scale and continental shapes, the interruptions at the northern and southern latitudes made this projection particularly disorienting to a public reared on the Mercator projection. Andrew McNally recalled that although *Goode's School Atlas* sold well in schools, its unfamiliarity and jagged appearance would limit its public appeal. Even so, Gilbert Hovey Grosvenor, editor of the *National Geographic Magazine*, was inspired by Goode's projection and directed the National Geographic Society's own cartographers to devise a projection that improved on Mercator as well in the interwar period (Grant ca. 1956, 21; Schulten 2001, 187–96).

Rand McNally struggled to maintain its dominance over the map market in the interwar period and was particularly assertive about protecting its products against less expensive European imports to be used in rival publications. In 1929, the company fought to tax European maps under the Smoot-Hawley tariff. For their part, rivals argued that they imported maps not for their lower cost, but for their superiority to domestically available maps. Despite Senator Smoot's sympathy with Rand McNally, the tariffs were not raised.

At the same time the company embarked on an aggressive advertising campaign to capitalize on both the prosperity of the 1920s and the interest in geography generated by the war and the ensuing peace treaty. Maps and atlases, which had long been marketed primarily as reference tools, were now treated as leisure commodities as well, perhaps due in part to the popularity of the National Geographic Society and its magazine. Rand McNally parlayed this interest into a broadened audience for cartography, aided substantially by the booming demand for domestic road maps in the 1920s. The Great Depression, coupled with the aggressive marketing and pricing of the "big three" road map companies (Rand McNally, General Drafting Company, and H. M. Gousha), drove many other firms out of business, solidifying the company's market share (Akerman 2006, 183).

Rand McNally's atlases changed little over the first half of the century, a result of the limits of contemporary map printing technology as well as the stylistic tradition entrenched by American commercial map companies generally. But the exigencies of World War II created an opportunity for the company to advance its cartographic work. Rand McNally sold an enormous number of maps and atlases in the early stages of the conflict. Woodward (1977, 40–41) has argued that Rand McNally recognized the need to reconstruct its materials to the postwar political realm, but these changes were also brought by the competition within the commercial cartographic industry, particularly those maps emerging from the National Geographic Society and journalistic cartographers.

These changes were exemplified by Rand McNally's postwar *Cosmopolitan World Atlas* (1949), the company's most ambitious undertaking to date. The atlas received wide praise for its attention to scale, projection, terrain, and other features that had heretofore been relatively low priorities in its mass-market world atlases. In fact, the war also prompted greater attention to geopolitics and history, emphasizing regions within continents and relationships between nations. Consider that this atlas not only added two altogether new maps—one of the Atlantic Ocean (fig. 785) and one of the Pacific Ocean—but also updated its polar map to illustrate the proximity of the Eastern and Western Hemispheres. After World War II, oceans could no longer be placed at the margins between nations but in fact constituted the center of the world.

Since the 1980s, the company has also incorporated digital technologies that have transformed the nature and execution of its products. Examples include software ventures such as TripMaker and StreetFinder, and especially the decision to digitize the databases on which the company's cartographic products are created. The products most affected by this digitization were the world atlas, the road and state atlases, and the city street maps. Electronic cartography gave the company more speed and flexibility, and also simplified the process of updating and correcting information across different formats and different products. This technological advance was not without its costs, however. As Michael W. Dobson (1995) has noted, it not only allowed greater freedom of design but also demanded different skills that could—by virtue of the nearly limitless options—complicate decisions about production, thereby raising costs.

Since 1899, when William Rand retired and sold his share to Andrew McNally, the company has been controlled by the McNally family. Andrew McNally led the company until his death in 1904, when his only son, Frederick George McNally, succeeded him. Upon Frederick George's untimely death in 1907, the company fell to his brother-in-law Harry Beach Clow, who was president until 1933, when Andrew McNally II (grandson of Andrew McNally) assumed control. Andrew McNally III took the company's reins in 1948, and presided over a period of tremendous growth that also saw the company move from its headquarters in Chicago to Skokie, Illinois. In 1974, his son Andrew "Sandy" McNally IV assumed control, and helped usher in an era that included the establishment of retail map and travel stores. The company has continued to control a healthy share of the market by acquiring other cartographic companies, including Allmaps Canada Limited in 1993, Thomas Brothers in 1995, and Perly's Maps in 2004. In 1997, the McNally family sold the company to a private investment group.

SUSAN SCHULTEN

SEE ALSO: Goode, J(ohn) Paul; Marketing of Maps, Mass; Robinson Projection; Road Mapping: Canada and the United States; Wall Map; Wax Engraving; Wayfinding and Travel Maps: (1) Indexed Street Map, (2) Road Atlas

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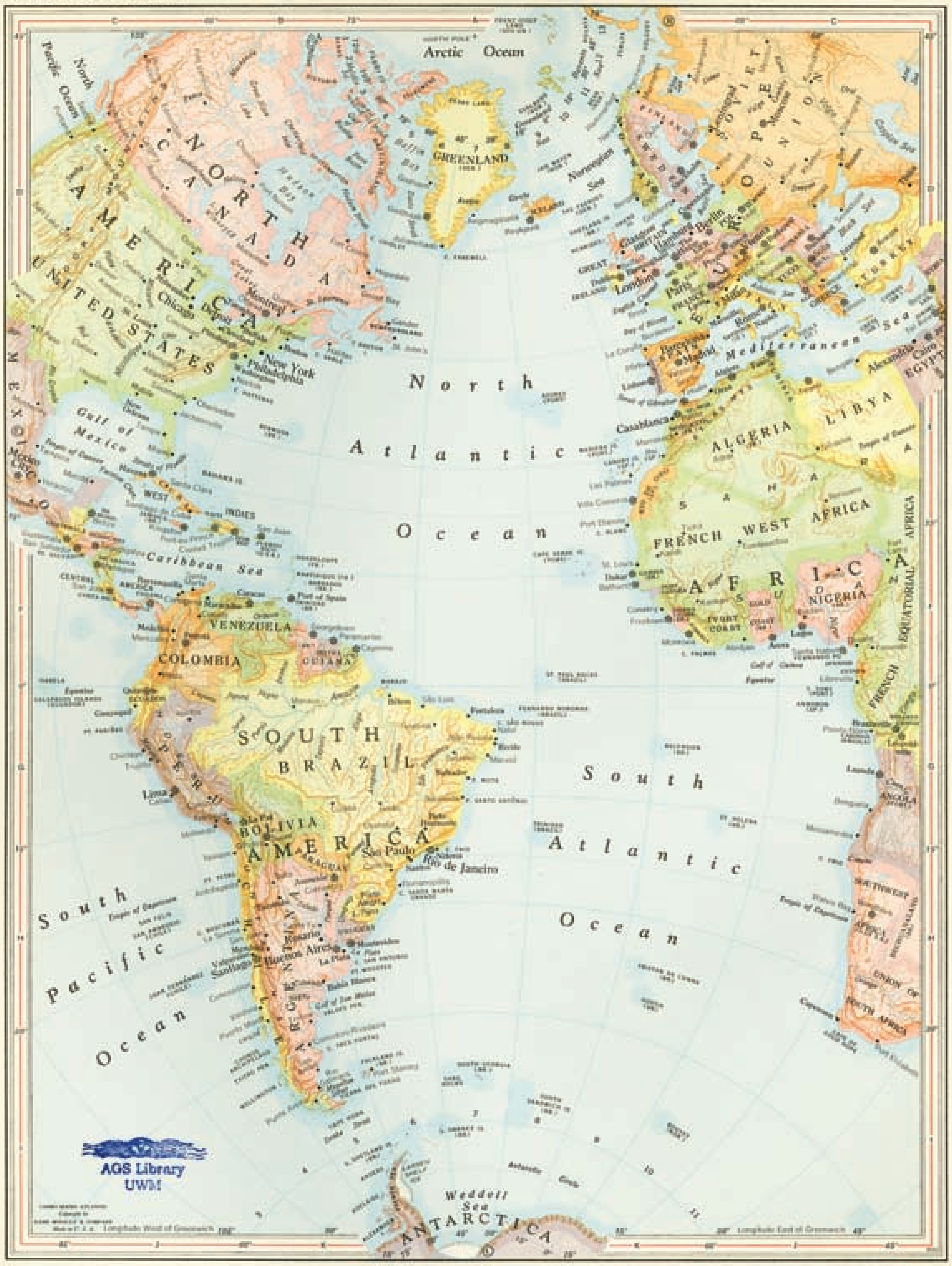
ATLANTIC OCEAN



Ratajski, Lech. Lech Ratajski was born on 16 April 1921 in Rawa Mazowiecka, central Poland. In 1939 he graduated from Kościuszko mathematics and natural science liceum in Łomża. During World War II, he took an active part in the Polish resistance movement against the German occupiers, first as a member of a secret military organization, Brigade of Poland Defenders, and then in the Armia Krajowa (Home Army).

After the war, Ratajski taught geography and drawing in a gymnasium in Węgrów and studied at the fine arts academy Akademia Sztuk Pięknych and at Jagiellonian University in Cracow, where he took his master's degree in geography in 1950 and his doctorate in 1962. From 1950 until his death in 1977, he worked at Warsaw University, first on the Faculty of Anthropological Geography and then the Faculty of Regional Geography of the Instytut Geografii, where he headed African studies (1959–62) and cartography (1967–77). During this period he directed the laboratory of cartography in the Instytut Geografii of the Polska Akademia Nauk. He became an assistant professor in 1966 and an associate professor in 1973. Between 1972 and 1976 he served as deputy director of the Instytut Geografii of Warsaw University. He supervised eighty-six master's and six doctoral candidates in cartography.

Ratajski was elected vice-president of the International Cartographic Association (ICA) twice (in 1972 and 1976), and he chaired the ICA Commission on Cartographic Communication from 1972 to 1977. From 1973 he headed Poland's Commission on Standardization of Geographical Names. He was active in the Polish geographic society, Polskie Towarzystwo Geograficzne (chairman of the Cartographic Commission, 1966–75) and was a member of the Committee of Geographical Sciences of the Polska Akademia Nauk and several other commissions. In 1968 he became the editor-in-chief of the monthly *Poznaj Świat* and also a vice-chairman of the editorial board of the quarterly *Polski Przegląd Kartograficzny*. His awards include the Cross of Courage (1949), the Gold Cross of Merit (1973), and the Cavalier Cross of the Poland Revival Order.

Ratajski's early scientific activity concentrated on the standardization of Polish toponyms and the development of school maps and world atlases. He wrote the first Polish textbook on economic cartography, *Kartografia ekonomiczna* (1960, with Bogodar Winid), as well as a textbook on socioeconomic cartography, *Metodyka kartografii społeczno-gospodarczej* (1973).

Ratajski's theoretical contributions include the concept of cartology (1970) for understanding cartographic data transmission and the concept of map language as a system of graphic signs with explicit grammatical rules (1976). He published more than 400 scientific works (Ostrowski 1978a), about 900 maps, and the *Podręczny atlas świata*, a reference atlas of the world in five parts (1954–61). He also promoted popular geographical knowledge about countries and continents, and, starting in 1948, contributed roughly 250 articles to the journal *Poznaj Świat*. Ratajski died in Warsaw on 22 November 1977.

NIKOLAY KOMEDCHIKOV

SEE ALSO: International Cartographic Association

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Ravenstein Verlag *(Germany).* Friedrich August Ravenstein founded Ravenstein's Geographische Verlagsanstalt in Frankfurt am Main in 1830. Within a few decades, the company became one of Germany's leading map publishers. Its success reflects recognition of the cartographic needs of hikers, mountain climbers, bicyclists, and motorcyclists in the nineteenth century and the needs of motorists in the twentieth century. Hans Ravenstein, grandson of the firm's founder, became a joint partner in 1899 and sole owner in 1915, after the death of his father, Ludwig Ravenstein. In 1898 the company purchased the Liebenow maps of Central Europe at 1:300,000; although not completed until 1914, at the time this was the largest private set of topographic maps of Central Europe. The Liebenow materials formed the basis for the *Kleine Rad- und Autokarte* 1:300,000, published in 164 sheets. During World War I, *Ravensteins Deutsche Kriegskarte*, which featured different war theaters, was a great success.

After the war, cousin and son-in-law Ernst Ravenstein joined the firm. He became commercial director in 1925 and strengthened the company in economically difficult times by temporarily transforming it into

(*Facing page*)
FIG. 785. MAP OF THE ATLANTIC OCEAN FROM RAND McNALLY'S *COSMOPOLITAN WORLD ATLAS*, 1949, 1:60,728,000. Size of the original: 33.2 × 26.1 cm. Image courtesy of the American Geographical Society Library, University of Wisconsin–Milwaukee Libraries. Map © Rand McNally; R.L. 11–S–001.

a corporation. The *Große Rad- und Autokarten von Mitteleuropa*, a series of fifty-two large maps published at a scale of 1:300,000, as well as various hiking maps and illustrated travel guidebooks were endorsed by various motoring associations and tourist boards. In 1930 the company published the first *Großer offizieller Führer des Automobilclubs von Deutschland*, printed on 1,000 pages of thin, durable opaque white paper and featuring overview maps and detailed maps of 200 primary and 150 secondary road routes. Promotional maps for other companies were also published, including a world map for the Hapag steamship line and a relief map of Europe and South America for Zeppelin passengers.

During World War II the company worked for the German army. It was the only printing house in Frankfurt not destroyed by 1945, and it remained under U.S. military government control until 1946. Ernst Ravenstein died during the postwar reconstruction, when the Bundesrepublik Deutschland (West Germany) expanded its road and motorway system. Initially, his son Helmut Ravenstein took charge of the company, but in 1955 his daughter Helga replaced her brother. In 1961 Helmut sold his shares to Dr. Klaus Völger, owner of an aerial surveying company. Völger introduced an annually updated, disposable paperback road atlas, which proved to be tremendously successful. In addition, the company still produced travel maps of Europe and beyond as well as hiking maps, city maps, and maps used in offices. In 1969 sales director Rüdiger Bosse acquired Völger's shares. In 1984, the company moved to the Frankfurt suburb of Bad Soden and became part of the Haupka publishing house, established in 1966 by Bernd Haupka, who had trained under Ravenstein. Finally, the Allgemeiner Deutscher Automobil-Club (ADAC), which began buying parts of the Haupka/Ravenstein enterprise in 2001, changed its name to CartoTravel and acquired the entire firm by 2005. In 2007, after a complex legal battle, ADAC sold the company to MairDumont, which completely liquidated the firm, laying off everyone and shutting down production sites. In 1994 Helga Ravenstein, who had no heirs, established a foundation that perpetuates the name by awarding the annual Ravenstein prize to junior cartographers.

JOACHIM NEUMANN

SEE ALSO: Marketing of Maps, Mass; Road Mapping: Europe; Travel, Tourism, and Place Marketing

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Real Property Assessment. See Tax Map

Recreational Map. Recreational maps emerged in the late nineteenth and early twentieth centuries as byproducts of modernization, which occasioned higher standards of living and material culture, greater mobility, increased leisure time, and enhanced appreciation of play and recreation as important for health and peace of mind. From its beginnings in Western Europe and North America, recreational cartography reached across the world over the twentieth century as part of the process of modern democratic globalization.

Recreational maps are inherently thematic, and the best of them work largely because they are not overloaded with extraneous information. Intended for ready, trouble-free use by an audience generally inexperienced with maps, they can be quite engaging and are often interactive. Largely schematic and diagrammatic in accord with a specific theme or use, recreational maps are often the work of talented design artists rather than professional cartographers. They are often highly pictorial, with symbols emphasizing the "built form," or construction, of major landmarks. Recreational maps typically reflect a recurrent tension between content and function—a tension often resolved during the creative process by innovative uses of symbolization, color, and typography—and they regularly exploit contemporary mass-market mapping technology.

Recreational maps are frequently ephemeral and often intended only for transient use. As diverse as the recreational activities they document, they had become ubiquitous in the Western world by the end of the twentieth century, particularly as the cartographic adjunct to a growing tourist industry. Governments and private businesses, including their representative commercial organizations, pay for the great majority of these numerous widely distributed maps, usually provided free of charge or at low cost to prospective users. Adept in showing tourists how to reach an attraction and in helping them find their way around a site, recreational maps are excellent advertising vehicles. Consequently, many of these maps are revised frequently to reflect the creation and demise of attractions and other recreation-related businesses.

Tourist maps regularly appear on postcards, a cheap, durable, and easy-to-use format. When the maps are subordinate to other themes, the postcards may be regarded as "cartifacts"—more symbolic or decorative than functional. Because of the small space, the ready availability of color, and the need to catch the buyer's eye, there is often considerable tension between content and function in postcard maps.

FIG. 786. POSTCARD MAP OF BARCELONA METRO (CA. 1992). Size of the original: 11.8 × 16.8 cm. Private collection of Dennis Reinhartz.

An exemplar of the late twentieth-century recreational map is the handy, beautiful, and evocative postcard map for the metro in Barcelona, Spain's second largest city (fig. 786). Initially created for the city's myriad visitors during the 1992 summer Olympic Games and the 500th anniversary celebration of the Columbian discovery of the New World, the map was intended to promote Barcelona's underground transportation network. To help users travel between origin and destination, any subway map must at least minimally reflect the above-ground reality. With its irregular streams of bold opaque colors designating the metro routes, which form a vast fan under the city, this map is intentionally suggestive of the area's artistic heritage, particularly the *modernismo* architect Antoni Gaudí and the surrealist painters Salvador Dalí and Joan Miró, whose artistic legacy is pervasive. Functional as well as visually attractive, Barcelona's underground map demonstrates that a single recreational map can support practical and aesthetic objectives.

Perhaps the most widely distributed tourist map on the Caribbean French/Dutch island of Saint Martin/Sint Maarten is based on an enhanced aerial photograph (Reinhartz 2004). It has appeared in bilingual French-English updated glossy editions since 1988 in various formats, including both small and large folded road maps and two-page centerfolds in some of the island's free tourist magazines. Attractive and user friendly, the map offers a clear picture of the island's complex topography, major roads, and various landmarks and attractions (fig. 787). Tourism is by far the island's largest industry, and the folded and magazine versions of the maps are surrounded by numerous advertisements for various tourist-oriented businesses. Other maps offer more detailed, localized views of Philipsburg, the capital and shopping center of the Dutch side of the island; Marigot, its French counterpart; and Grand Case, a city on the French side promoted as the gourmet dining capital of the Caribbean. These three cities have their beaches and harbors as well as their own maps, on separate pages in tourist magazines and on the reverse sides of the folding maps. Not based on aerial photographs, these individual maps are artistic bird's-eye view city

FIG. 787. DETAIL FROM *SAINT MARTIN/SINT MAARTEN*, 2006, TOURIST MAP PUBLISHED BY HART'S AEROPHOTO. The island is about thirty-seven square miles and lies at the juncture of the Caribbean Sea and Atlantic Ocean. This detail shows the eastern half of the island.

Size of the entire original: 30.5 × 41.3 cm; size of detail: 20.9 × 29.3 cm. Private collection of Dennis Reinhartz.

plans, on which pictorial symbols identify specific buildings, piers, and marinas.

Growing concern about both personal health and the natural environment led to the emergence of another large group of recreational maps focused on sports activities such as hiking, camping, skiing, and golf. One of the earliest and largest of these mappable pursuits was bicycling. Cycling maps and the growing need for them date back to the late nineteenth century in North America, France, and Great Britain, and somewhat later in Australia. Better roads and improved bicycle technologies such as pneumatic tires greatly stimulated the growth of bicycling for recreation as well as transport. There was a parallel and even symbiotic development between road and cycling maps in the early twentieth century. Early exemplars include George W. Blum's eighty-page *Cyclers' Guide and Road Book of California*, which cost one dollar in 1896, and *Philips' Clear Print Half-Inch Cycling Map of England & Wales*, consisting of thirty-one sheets, first published in 1903 and revised regularly for many years thereafter by George Philip & Son in London (Nicholson 2001).

Cycling maps experienced a substantial boom in the 1970s in North America and Australia, which are similar in their vast size, diverse landscapes, and large numbers of cycling clubs. The Minnesota Bikeways series, the *Minnesota Bike Atlas*, and the *New Mexico State Highway and Transportation Department Bicycle Guideline Map* (2002) reflected an ever-growing interest of state and local governments as well as cyclists' groups, which even polled riders for suggestions. On these cycling maps the roads are color classified, and the terrain and surrounding countryside is depicted to help cyclists choose safer and more rewarding routes. These maps are waterproofed for all-weather use. Advertising for clubs and related businesses such as cycle shops and outfitters helped to defray the expenses of improvements in design and production. By contrast, the Czech *Velká cykloturistická mapa* with accompanying texts in Czech, German, and English, produced since 1996, is typical of many contemporary European cycling maps; its eighteen individual maps offer a detailed depiction of eighteen different locales.

Closely related to road and cycling maps are maps for hiking, running, riding, and camping, especially those produced by the British Ordnance Survey, the U.S. Department of Interior's National Parks System, and similar government agencies around the world. The growth of national parks created a growing demand for recreation maps. For example, *Hawai'i Volcanoes*, distributed free and revised annually since at least 1979, includes colorful maps of Hawai'i Volcanoes National Park and Kīlauea Caldera with the Chain of Craters (fig. 788). Lava flows since 1900 are color coded; distances along all trails and roads are clearly noted in both miles and kilometers; and campgrounds, water sources, and other features important to campers and hikers are portrayed with easily distinguishable icons. Also pictured and listed are the local fauna and flora, their history, and their rareness or vulnerability to extinction. Other examplars are the Bermuda Department of Tourism's *Bermuda Runners' Map* (1982), designed for runners, walkers, and horseback riders, and the U.S. Army Corps of Engineers 1980 map *Lake Seminole: Jim Woodruff Lock & Dam*, along the Florida-Alabama-Georgia border area, which was a true multipurpose, multiuse recreational map intended, as its extended title declared, for "boating, swimming, fishing, waterskiing, camping, sightseeing, hiking, sailing, bicycling, sunbathing, canoeing, diving, picnicking, hunting, bird watching, photography." These and other recreational maps are valuable source material on contemporary history, geography, politics, economics, and popular culture.

DENNIS REINHARTZ

SEE ALSO: Orienteering Map; Wayfinding and Travel Maps: (1) Cyclist Map, (2) Hiking and Trail Map

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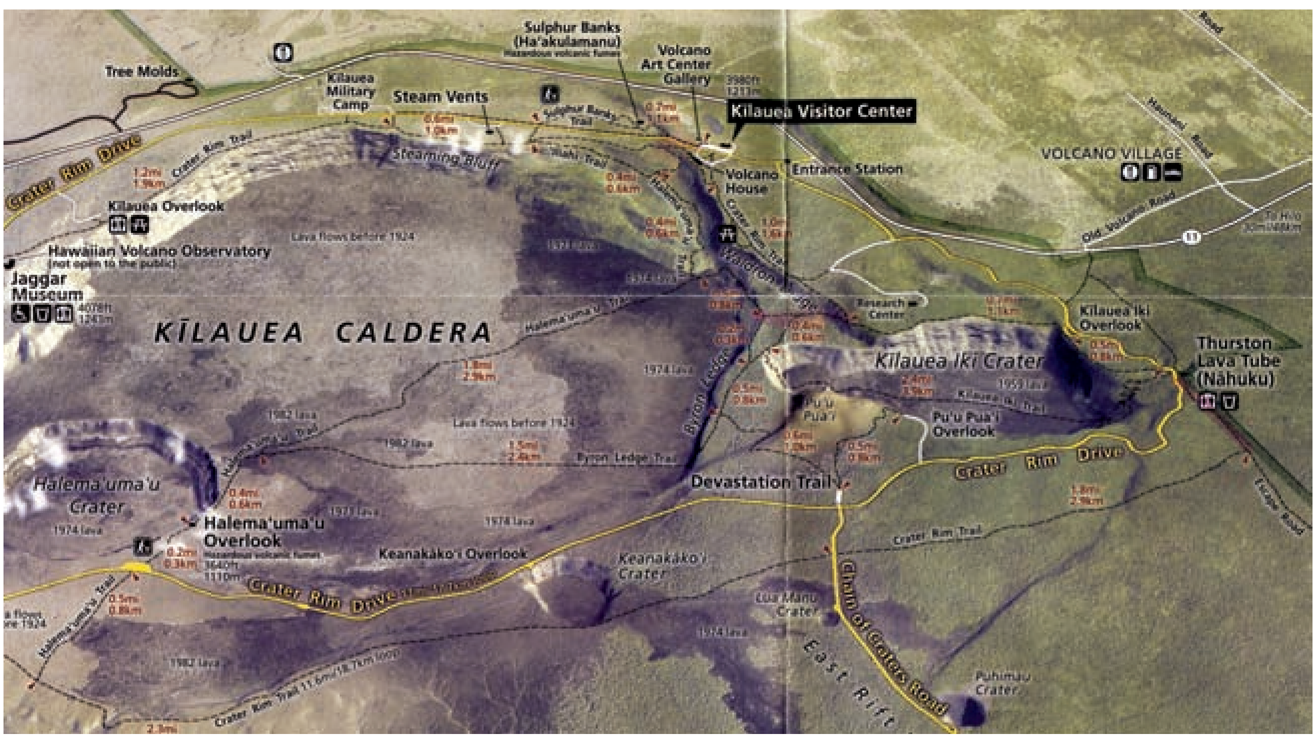

FIG. 788. DETAIL FROM *HAWAI'I VOLCANOES NATIONAL PARK*. Map produced by the U.S. National Park Service, U.S. Department of the Interior. Size of the entire original: 59.5 × 42 cm; size of detail: 13.5 × 24.4 cm. Image courtesy of the U.S. Government Printing Office, Washington, D.C.

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Redlining. Redlining draws its name from the literal or figurative process of drawing red lines on maps around neighborhoods perceived to be too risky to provide mortgages or property insurance. This focus on location rather than the creditworthiness of the prospective borrower distinguishes it from most other types of housing discrimination, which are based on the race, ethnicity, religion, national origin, family status, or disability of the prospective owner rather than the neighborhood. Historically, lenders and insurance providers redlined areas that they considered too risky because of the racial composition of borrowers and owners or the age and condition of the properties. Although redlining is most commonly understood as a refusal to provide loans or insurance, it can also involve charging more for credit or insurance because of the perceived higher risk. The importance of location to decisions about lending made maps a critical part of redlining practices during the twentieth century.

The word *redlining* was not used until the 1960s, but the practice of discriminating against certain urban areas, particularly those home to African Americans, dates back much further. Writing in the wake of Chicago's 1919 race riot, the Chicago Commission on Race Relations noted difficulty in obtaining and selling mortgages as the chief obstacle to African American homeownership (1922, 220–27). The urban riots of the 1960s brought the issue of redlining to the attention of the nation. The U.S. President's National Advisory Panel on Insurance in Riot-Affected Areas quoted an underwriting guide that warned against providing insurance to areas with certain high-risk characteristics. "A good way to keep this information available and up to date is by *the use of a red line* around the questionable areas on territorial maps" (1968, 6). The Douglas Commission found the same thing in 1969. "There was evidence of a tacit agreement among all groups—lending institutions, fire insurance companies, and FHA—to block off certain areas of cities within 'red lines,' and not to loan or insure within them. The net result, of course, was that the slums and the areas surrounding them went downhill farther and faster than before" (U.S. National Commission on Urban Problems 1969, 101).

Arguably, the Civil Rights Acts of 1866 and 1870 made any form of housing discrimination illegal because they outlawed discrimination in contracts, but they had little impact on real estate practices. The Fair Housing Act of 1968 did not mention redlining specifically, although it did extend protection against discrimination at any stage of the lending or home insurance process. Concern about redlining among community activists, fair housing advocates, and researchers in the 1970s finally led to the creation of the Equal Credit Opportunity Act (ECOA) in 1974, the Home Mortgage Disclosure Act (HMDA) in 1975, and the Community Reinvestment Act (CRA) in 1977, which not only outlawed redlining but required certain classes of lenders to report on the location of their loans and extend credit to all parts of their service area.

Only in the years since these laws were passed has redlining been recognized as illegal. For much of the century, redlining was simply considered good business, promoted by the real estate, appraisal, and insurance industries, the federal government, and local governments. The Federal Housing Administration (FHA) and the Home Owners' Loan Corporation (HOLC), federal housing agencies created to reinvigorate the real estate, lending, and construction industries in the wake of the Great Depression, are often described by historians as the leading promoters of redlining (Jackson 1985, 195–218). But their policies and mapping efforts reflected widespread principles and practices within the academic and private sectors as much as they shaped them. Redlining became an important factor in urban disinvestment because every sector involved in real estate adhered to its principles.

Frederick Morrison Babcock and Homer Hoyt were leaders in shaping those principles. Babcock argued that "the future history of a property is conditioned by the trend of development of the district and city within which the property lies" (1932, 49). Hoyt studied with Robert Ezra Park and Ernest W. Burgess in the Chicago School of Sociology in the early 1930s and applied their ecological theory to real estate, positing that cities undergo constant transformation and that neighborhood decline is natural and inevitable. People with the necessary means push outward toward the edges and suburbs of cities, he explained, filtering down the older and less desirable housing to African Americans and other racial and ethnic minorities in the final stage of neighborhood decline.

The FHA was the most important source of information about neighborhood risk ratings during the 1930s and 1940s, in part because both Babcock and Hoyt joined its staff. Created in 1934, the FHA provided insurance on mortgages for qualifying properties in order to protect lenders against the kinds of losses suffered during the Depression. When homeowners failed to pay their mortgages, the FHA would compensate the lenders. Lenders were eager to reduce their risks by obtaining FHA insurance, so they were very responsive to guidelines the FHA established to qualify. The National Housing Act of 1934 called for the FHA's administrator to conduct and publish statistical surveys and economic studies to guide the development of a sound mortgage market. The Division of Economics and Statistics was responsible for most of this work and conducted several studies and collected existing data from a variety of sources. Maps became an important way for the FHA to collect, analyze, and distribute information about neighborhood risk to lenders and developers.

The FHA had an extensive map collection, consisting largely of maps created from the 1934 and 1939 real property surveys conducted across the United States by the Works Progress Administration (WPA). The surveys included data about many of the same housing variables the U.S. Census Bureau later included in the 1940 decennial census, such as housing tenure, housing age and condition, vacancy, and overcrowding. The FHA collected other local maps about urban growth patterns, public transportation, industry, and commerce in order to understand conditions in different metropolitan areas. The agency also conducted its own surveys under the supervision of Hoyt, who served as the principal housing economist. Hoyt outlined guidelines for preparing maps for rating neighborhood risk as part of a study of sixty-two cities that formed the basis for his 1939 book. It included a map (fig. 789) with transparent overlays showing the relationship between housing conditions, age of housing, and racial composition in Richmond, Virginia, anticipating Ian L. McHarg's overlay analyses and GIS (geographic information system) techniques that were still years away. The FHA also conducted a series of Housing Market Analyses to determine where it was "safe" for the FHA to insure mortgages (U.S. FHA 1935a). A map included in a Chicago Housing Association report from 1938 is likely a product of this project (fig. 790). The map used letters and colors to indicate risk levels. Most of the central core of Chicago was graded "D" and colored red, indicating that the FHA would not provide insurance in those areas.

The FHA's *Underwriting Manual* ultimately proved more influential than any of its maps. Unlike some of the studies conducted internally, the *Underwriting Manual* was intended for use outside the agency and was widely distributed. Lenders interested in securing FHA insurance for their loans had an incentive to follow the agency's guidelines. In addition to protecting against losses, FHA insurance virtually guaranteed that a loan could be resold on the secondary mortgage market. Lenders were told to consider the stability of an area, its protection from "adverse influences," access to transportation, general appeal, utilities and services, taxation levels, civic, social, and commercial institutions, and its topography in determining the neighborhood rating (U.S. FHA 1935b). These standards favored new tract developments like Levittown, in New York and Pennsylvania, and devalued new construction and renovation in older urban communities, contributing to white migration out of cities and disinvestment within cities.

While the FHA was created as a permanent agency and continues to insure mortgages, the HOLC was created on an emergency basis in 1933 to provide mortgage assistance to homeowners at risk of foreclosure. The HOLC refinanced more than one million loans between 1933 and 1936, servicing those mortgages until the agency was liquidated in 1951. In late 1935, the HOLC embarked on the ambitious and secretive City Survey Program to investigate real estate conditions in cities across the country. This program resulted in a series of residential security maps for 239 cities that were designed to show how desirable neighborhoods were for investment. The maps assigned residential areas a grade from one to four, coloring fourth-grade areas red and deeming them "hazardous" (fig. 791). The maps have been cited widely in discussions of historical redlining even though there is little evidence that the maps were shared widely with lenders or affected private lending decisions (Hillier 2003). Lenders had a much greater incentive to follow FHA guidelines about neighborhood risk, in the form of the *Underwriting Manual*, than the HOLC's maps since the latter stopped making new loans in 1936. Even so, the HOLC maps are the best representation of the widespread practice of assessing neighborhood risk, and the City Survey Program was the largest of the federal risk mapping efforts of this era. The FHA and the HOLC most likely worked closely together, sharing maps and possibly sharing staff and technical expertise.

Realtors, appraisers, and lenders were busy creating their own surveys and maps before the FHA and the HOLC embarked on their ambitious research efforts and well after. But because most of the records of private companies were not preserved as they were for federal agencies, the evidence of redlining within the private sector is scarcer. One of the best surviving examples of private mapmaking is a large, detailed map created by J. M. Brewer, chief real estate appraiser for the Metropolitan Life Insurance Company in Philadelphia. Brewer conducted his own survey rather than relying on the real property surveys. Using different colors and cross-hatchings, he indicated the location and degree of three racial concentrations, "Jews," "Italians," and "Colored," as well as businesses and industry (figs. 792 and 793). He rated blocks based on class, referring to the lowest-class areas as "Decadent," and estimated the age and value of housing. After completing the map, Brewer was invited to advise the HOLC on the residential security map for Philadelphia.

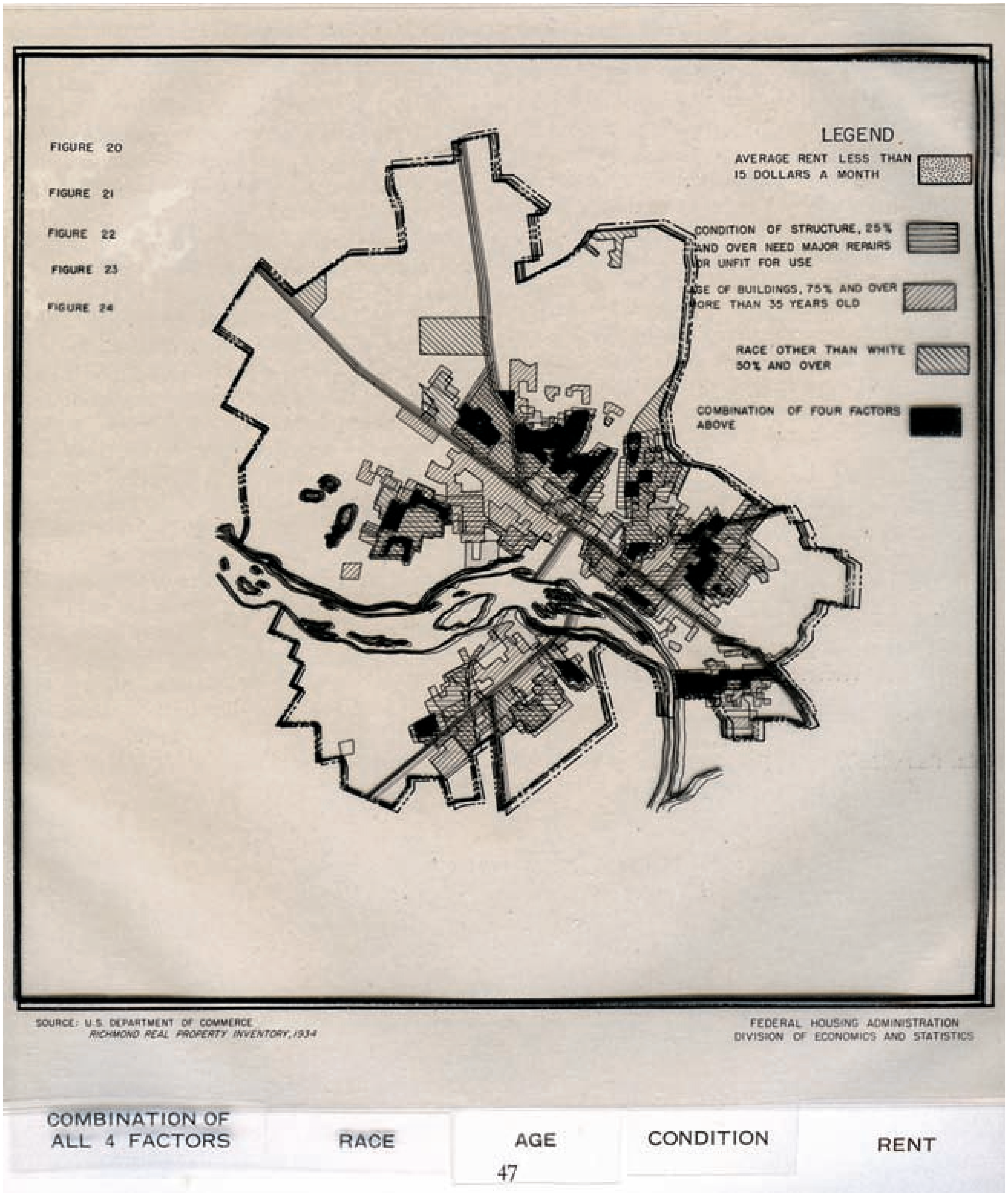

FIG. 789. HOMER HOYT, *THE COINCIDENCE OF FACTORS INDICATIVE OF POOR HOUSING, RICHMOND, VIRGINIA, 1934*. Hoyt used clear overlays to demonstrate how lenders should consider multiple factors, such as housing condition and racial composition, when assessing neighborhood risk. Size of the underlying rent map: 18.3 × 18.6 cm. From Hoyt 1939, 47, figs. 20 (printed rent map), 21 (condition overlay), 22 (age overlay), 23 (race overlay), and 24 (all four factors overlay).

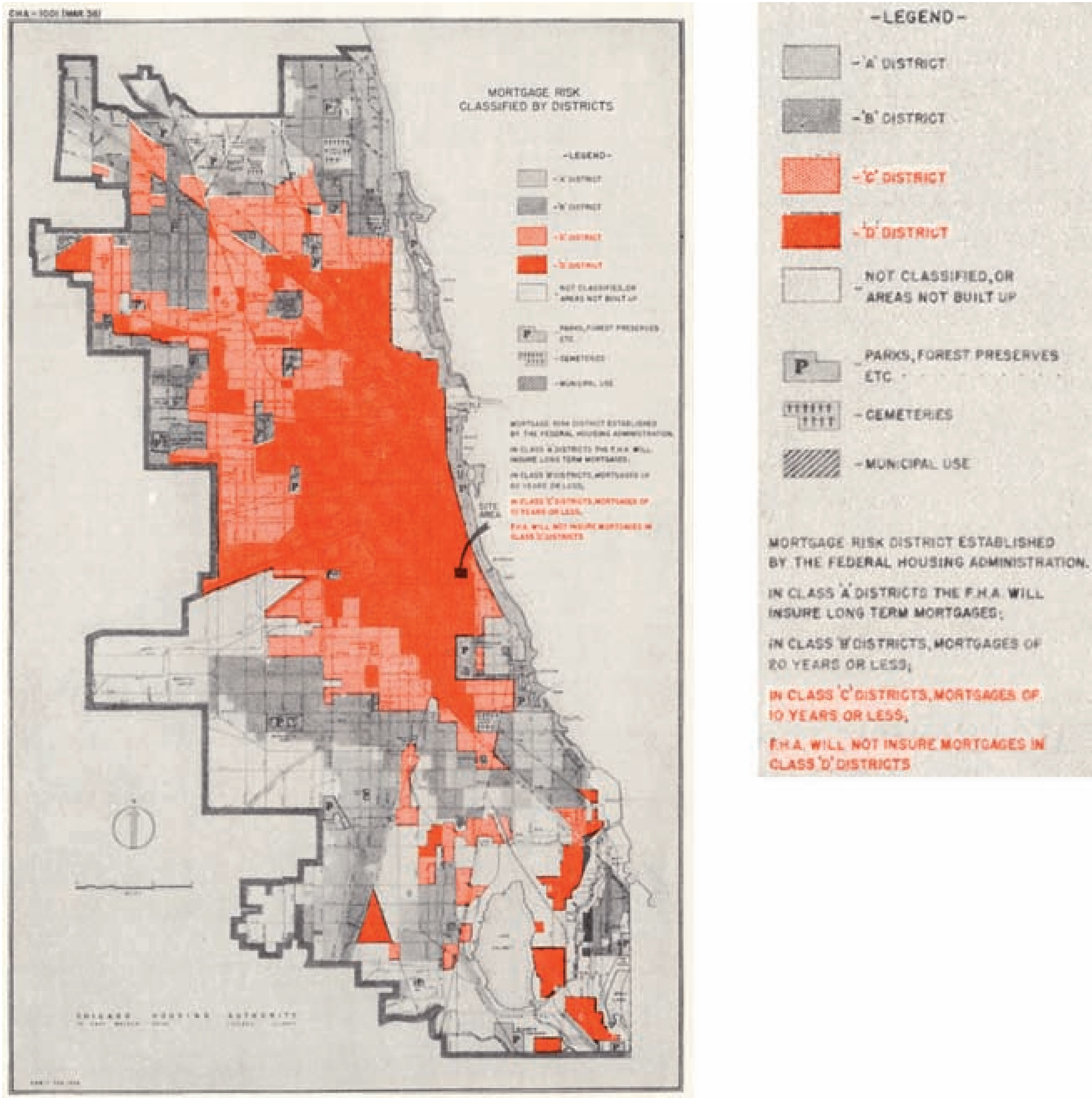

FIG. 790. *MORTGAGE RISK CLASSIFIED BY DISTRICTS*, 1938, AND LEGEND (ENLARGED). The Federal Housing Administration created maps like these as part of the Housing Market Analyses in the 1930s aimed at determining neighborhood risk levels for FHA-insured properties. Size of the original: 18.2 × 11.4 cm. In the Illinois State Housing Board Report, 1938. Image courtesy of the Special Collections Research Center, University of Chicago Library (Ernest W. Burgess Papers, 1886–1966, box 9, folder 1).

Additional evidence of private mapmaking comes from Los Angeles. L. Elden Smith, head of the research department at Security-First National Bank, outlined his bank's research program in a 1938 article in the FHA's journal, *Insured Mortgage Portfolio*. Neighborhoods have a life cycle through which they are born, grow rapidly, become mature, begin to decline, and eventually become blighted, he explained, consistent with the ecological principles espoused by Hoyt and reflected in the HOLC's maps. Smith applied this life cycle concept to Los Angeles, categorizing each neighborhood's life cycle as subdivision, growth, maturity, decline, or

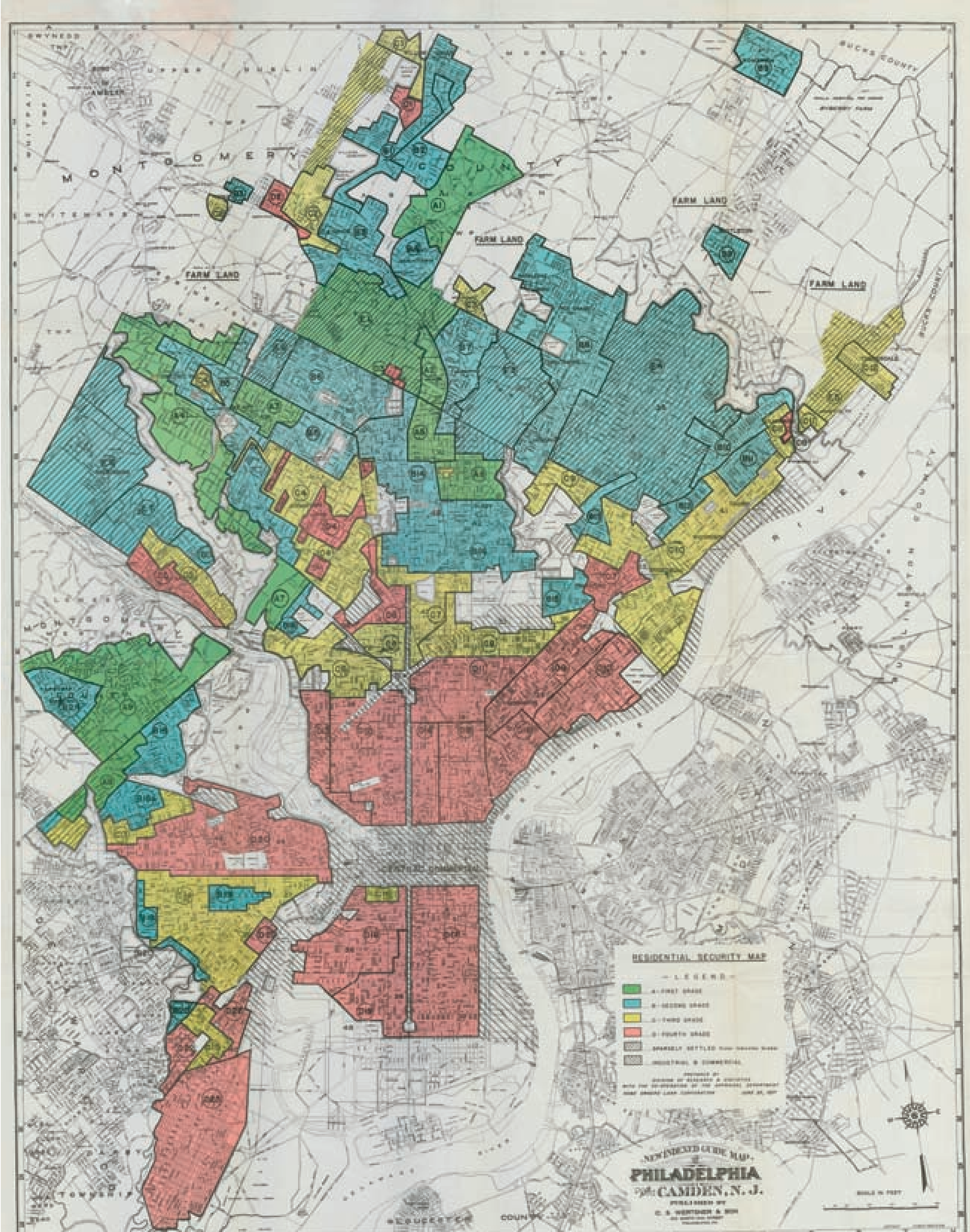

FIG. 791. *RESIDENTIAL SECURITY MAP* FOR PHILADELPHIA, PENNSYLVANIA, 1937. The Home Owners' Loan Corporation created residential security maps for 239 cities across the country, identifying areas "hazardous" to investment with the color red (Federal Home Loan Bank Board, Division of Research and Statistics, "Philadelphia PA: Explanation and Area Description").

Size of the original: ca. 109 × 85 cm. Image courtesy of the U.S. National Archives, Washington, D.C. (RG 195, stack 450, 68:5:2, box 95).

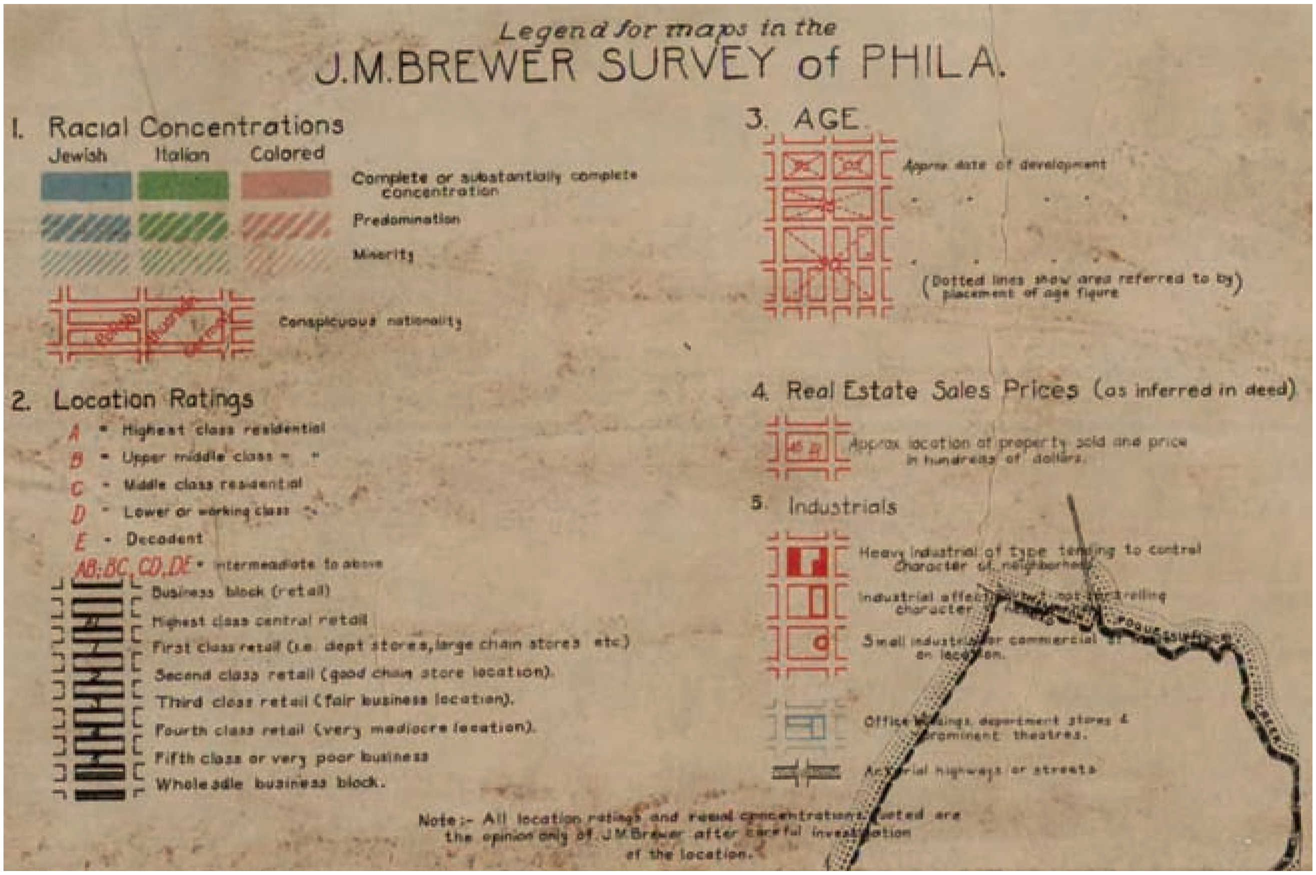

FIG. 792. LEGEND FROM J. M. BREWER'S SURVEY OF PHILADELPHIA, 1934. J. M. Brewer, real estate appraiser in Philadelphia, incorporated block-level information on race, social class, housing values, and industry into this 1934 map. Black line in the lower right corner is part of a boundary and creek on the map. See also figure 793.
Size of the entire original: 57.4 × 115.8 cm; size of detail: 8.4. × 12.7 cm. Map Collection, Free Library of Philadelphia.

decadence. Acknowledging the FHA's pioneering role in rating neighborhoods, Smith noted that other lending institutions like his were also working to develop their own methods for assessing risk.

Since the HMDA began requiring lenders to provide information about where they make loans, maps have played a different role in redlining. The Federal Financial Institutions Examination Council provides aggregate data collected under the HMDA, facilitating research on disparities in lending by race and neighborhood. The CRA also requires lenders to provide maps of their service area and to demonstrate that they are meeting the credit needs of all parts of the area they serve.

AMY HILLIER

SEE ALSO: Administrative Cartography; Crime Map; Electoral Map; Race, Maps and the Social Construction of

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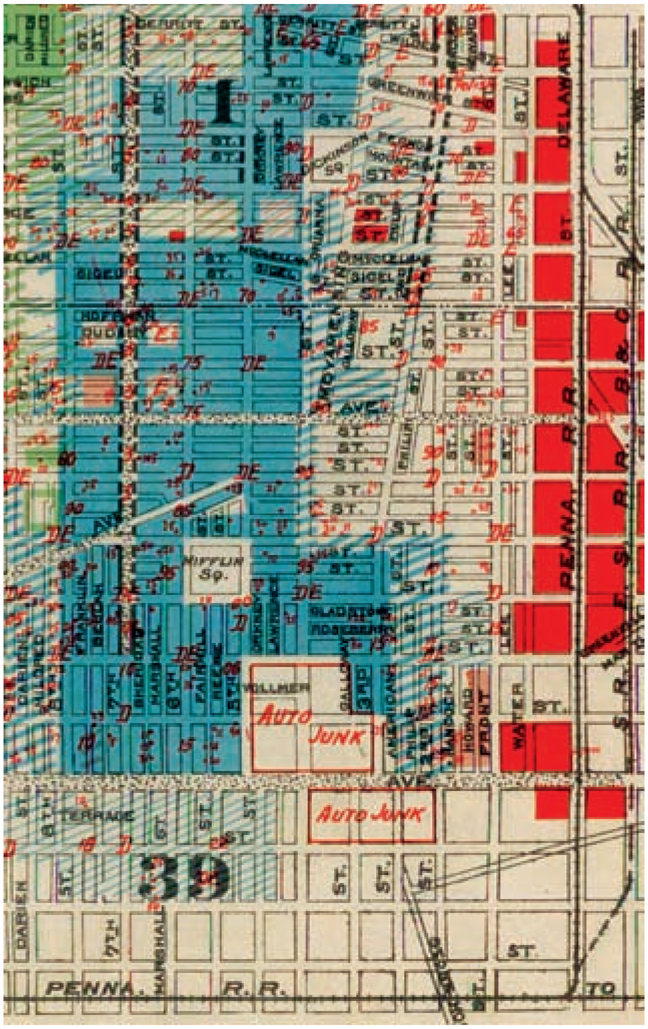

FIG. 793. DETAIL FROM J. M. BREWER'S SURVEY OF PHILADELPHIA, 1934. Small part of South Philadelphia is shown.
Size of the entire original: 57.4 × 115.8 cm; size of detail: 13.4 × 8.4 cm. Map Collection, Free Library of Philadelphia.

Regional Atlas. See Atlas: Regional Atlas

Regional Planning. See Planning, Urban and Regional

Reliability. See Uncertainty and Reliability

Relief Depiction.

RELIEF MAP
RELIEF MODEL
RELIEF SHADING

Relief Map. Definitions vary as to what constitutes a relief map. In its simplest form, the relief map offers the map reader an orthogonal view of the earth's surface with all other complicating topographic features stripped away. However, the term often includes relief models or perspective views more akin to landform maps or physiographic diagrams. It could be argued that many topographic maps fulfilled a similar role. Nevertheless, the relief map filled a niche in education, training, and research that ensured its survival as a distinct map type, and it became a popular focus for cartographic experimentation as the twentieth century progressed.

At the beginning of the century the new science of geomorphology had focused attention on the importance of studying landforms. For the first time geography textbooks ventured to describe the geological and geomorphological evolution of mountains, plateaus, valleys, and plains using terms that are now familiar such as block mountains, ice sheets, glacial drift, coastal plains, and drowned valleys (Dryer 1924). One of the first school texts to respond to this new discipline was Alex Everett Frye's *Primary Geography* (1894). Apart from its being a notable advance in content on its predecessors, its popularity and extensive use for a quarter of a century were in part due to its illustrations, which included photographs of physical models to create relief maps. Such maps were considered an essential way of conveying an accurate impression of topography to an untechnical mind and were promoted as essential tools for geologists, architects, and engineers. Their popularity was particularly strong in education, where children were believed to be struggling with the almost exclusive use of contouring in mapmaking. Cosmos Mindeleff (1900) provided guidelines for the production of relief models using cardboard layers cut to the shape of contours then covered with wax or clay and modeled to replicate the relief. Suggestions were given for the amount of vertical exaggeration to use, a necessity when creating relief models at small scales. Photographic reproductions of models were viewed as an effective way of providing an easily understood depiction of relief (fig. 794), so much so that Major John Wesley Powell, director of the U.S. Geological Survey, put together the largest collection of relief maps in the United States.

In Europe, relief maps were already popular in education but moreover had provided a vehicle through which innovative relief depiction could be presented and discussed. Hermann Kümmerly became famous for his school wall map of Switzerland of 1896 and the school wall map of the canton of Grisons in 1902 and was also highly influential in topographic map design. His influence continued through his company, Kümmerly & Frey, which published highly effective relief maps for wall display for the rest of the century. Fridolin Becker, who was largely responsible for the so-called Swiss style relief map, had already introduced a new design through

FIG. 794. RELIEF MAP OF SOUTH AMERICA BY COSMOS MINDELEFF. The map was reproduced by photoengraving from a model with a vertical exaggeration of twenty-five. Size of the original: 19.4 × 13.8 cm. From Jacques W. Redway, *Butler's Complete Geography* (Philadelphia: E. H. Butler, 1887), 85.

his relief map of the Albis Ridge near Zurich in 1887. The Swiss style combined shading with rock drawing, contour lines, scree mapping, and often some kind of subtle background color effect, making full use of contemporary advances in color lithographic printing.

Hypsometric tinting, the assigning of colors solely by elevation, had become a popular method of relief depiction on small-scale topographic, atlas, and wall maps. Austrian cartographers such as Karl Peucker were among the first to base hypsometric color sequences on perceptual considerations (Kretschmer 2000; see fig. 680) and maps dominated by relief were published to demonstrate these principles. Peucker's recommendation that color saturation should increase with rising elevation and end in red had a long-term influence on European small-scale relief mapping. Austrian approaches to color were countered by alternatives, particularly by the Swiss. Eduard Imhof completed his relief map of Wadensee in 1938, and thus demonstrated the potential of relief maps to allow the artistic skill of the cartographer to flourish. Imhof's classic *Kartographische Geländerdarstellung*, published in 1965 and translated into English in 1982 as *Cartographic Relief Presentation*, provided numerous guidelines and accompanying illustrations for properly representing different terrain features in the Swiss style both on large- and small-scale maps. More naturalistic approaches to the depiction of relief evolved through relief maps or natural color maps published by cartographers such as Fritz Hölzel, Hal Shelton, and Tibor G. Toth. As the century progressed, such developments were made more feasible by photomechanical reprographic methods combined with ever more effective methods of printing.

Relief maps continued to play a valuable role in education throughout the century. Construction of raised relief maps by pupils and students at all levels of education provided a rewarding hands-on learning experience. Materials were readily available, inexpensive, and manageable by the students themselves. As Vern Harnapp and Debbie King highlight (1991), tracing from topographic maps onto cardboard involved the student in important interpretation techniques such as determining elevations from contours and hypsometric tints, recognizing symbols, and understanding map scale. Construction of a raised relief map gave the student an appreciation of the three-dimensional nature of topography.

The 1970s witnessed a rapid rise in the number of experimentally based studies on map legibility and perception. Human perception of alternative methods of relief depiction became a popular subject for study, and along with it came the production of maps specifically designed to isolate the relief component. Psychologists designed tests on specially designed relief maps that employed distinctive methods of depiction and sought to develop scientific design principles based upon the objective testing of cartographic products using techniques already devised by human factor engineers, psychologists, and physiologists (Phillips 1982; Potash, Farrell, and Jeffrey 1978). However, such approaches were criticized on the grounds that the particular maps employed were not representative of relief maps in general.

During the 1980s, the systematic input of heights from published printed maps rejuvenated interest in relief maps. Not only were relief maps relatively easy to produce, but scientists recognized the possibilities of reassessing geological and geomorphological interpretations. For example, Christian Elvhage and Karna Lidmar-Bergström (1987) identified and interpreted the paleotectonic activity and denudation surfaces of Sweden using one of the new generation of relief maps (fig. 795). The map was produced by computer techniques using the Swedish Lantmäteriet's elevation database at 500-meter intervals derived from the topographical map at 1:50,000 scale.

The relief maps generated from such digital data gave geologists and other map users an attractive and comprehensive view of the landforms. Furthermore, as such maps were derived from millions of height values and automatically generated hill shading techniques, scientists felt reassured that the structures and lineaments visible on the map really existed. This had not always been the case when manual techniques for hill shading had been used subjectively by the cartographer.

At the end of the century, private companies such as Solid Terrain Modeling, Inc., in the United States were using digital elevation model data with rapid prototyping devices that create 3-D relief models without the handwork of traditional methods. Relief model production starts with a solid block of high-density foam that is cut according to the digital elevation model using a digitally controlled milling machine. Aerial photographs, satellite images, or topographic maps are then added directly onto the terrain using an inkjet printer. The process takes just a few days, not weeks or months as with manual model construction, and the results are accurate to a higher degree of precision.

ALASTAIR W. PEARSON

SEE ALSO: Anaglyph Map; Lobeck, Armin K(ohl); Physiographic Diagram; Raisz, Erwin (Josephus); Shelton, Hal; Topographic Map

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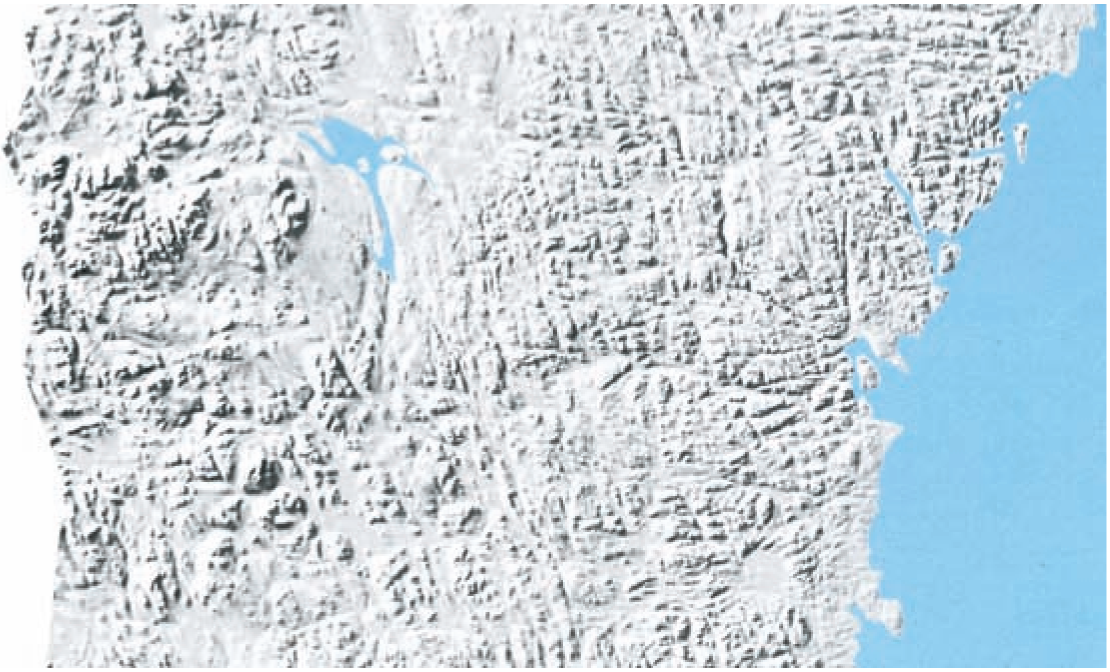

FIG. 795. DETAIL FROM THE *RELIEF MAP OF SWEDEN AT THE SCALE OF 1:2.5 M*. The map was created by the Swedish Lantmäteriet and used by Christian Elvhage and Karna Lidmar-Bergström to interpret the geological and geomorphological history of the country. Due to limitations of the Scitex Cartographic 200 system the map was plotted several times on the same film to attain enough tones in the shading. In the final picture 5 pixels/millimeter and 2 percent step between tones is enough for the human eye to see a continuous tone. Size of the entire original: 63 × 28 cm; size of detail: 8.8 × 14.8 cm. From Elvahage and Lidmar-Bergström 1987 (map in pocket). © Lantmäteriet Ref. no. R50325948_140001.

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Relief Model. The eminent Swiss cartographer Eduard Imhof asserted that early in a career "every cartographer, every topographer, every geographer, and every geologist should construct a terrain model based upon an interesting contour plan" (Imhof 1982, 43). Imhof recognized the importance of models to educate those responsible for depicting relief on maps and thus maintain the excellent standards of relief portrayal of Alpine Europe. This expertise was based on a long history of relief modeling, particularly by the Swiss, who had made numerous attempts to model the Alps. Relief models held certain advantages over maps when it came to the depiction of relief, chief of which was their ability to simply fill gaps between the few known height points and yet still provide a realistic (or at least a human) view of reality. Fueled by the growing interest in Alpine mountaineering and by the growing fascination of geologists and geographers with the Alps, the Swiss modelmakers of the late nineteenth century such as Albert Heim, Xaver Imfeld, and Carl Meili together with Austrian modelers such as Paul Oberlercher sought to create near-perfect replicas of their most notable peaks. This obsession with realism had practical benefits. Imfeld's model of the Jungfrau in Switzerland was used to promote the Jungfrau Railway, and Heim's models were designed to assist in geomorphological interpretation. Although visually effective, they were laborious to construct, and with more than thirty personnel being engaged in the manufacture of the Jungfrau model, they were also very expensive.

These masters of the modelmaking art typically used the layer method of construction. Layers of plywood were cut with a jigsaw to the shape of contours taken from a topographic map, the thickness of each plywood layer relating to the contour interval. The steps between the different layers were filled out using a ductile material, sometimes clay, and a plaster cast was then made to serve as a master model from which other casts could be made (Imhof 1981, esp. 143–50).

The accuracy of these models improved as new topographic surveys were completed. The greater density and accuracy of contouring enabled the cutting of more accurate layers of hardboard or plywood in the construction of relief models. Photography provided the essential detail to enhance the depiction of surface texture, particularly the intricacies of the rock and ice terrain. These advances in technology were used to great effect by Imhof for his models of the Swiss mountains Bietschhorn, Grosse Windgälle (fig. 796), and Mürtschenstock. Imhof had access to a large number of terrestrial photogrammetric images, including detailed aerial photographs that were specifically taken for him, as well as geological maps and profiles. His own drawings and photographs also served as base material.

While the justification for charting the development of modelmaking for didactic purposes during the twentieth century is clear, one could argue that it is in their military application that the major technological advances were made. By the end of the nineteenth century, sophisticated models of towns and cities were in regular use to assist in the architectural planning and assessment of fortifications. However, the twentieth century witnessed a significant increase in the use of relief models to more actively support military operations. Hitherto, an officer's experience with relief models had typically been limited to the so-called sand table, with a raised rim containing a bed of coarse sand used during military training at military schools. The practical benefits of relief models began to improve with the board and plaster models created during World War I by both Allied and Axis forces. The static nature of the war allowed sufficient time for relief models to be constructed—a factor that had hitherto inhibited their widespread use. Though relief models could not be used in the field due to their weight and fragility, they were employed at headquarters for

FIG. 796. MODEL OF GROSSE WINDGÄLLE AT A SCALE OF 1:2,000 BY EDUARD IMHOF, 1938. This supreme example of model making is testimony to the artistic talent of Imhof and to the growing availability of high-quality maps and aerial photographs during the twentieth century. Size of the original: 163 × 307 cm. Photo credit: Dani Schaffner. Image courtesy of the Naturmuseum Winterthur.

preliminary reconnaissance planning, visibility studies, and the interrogation of prisoners. Infantry or artillery operations could also be planned on these models, and they were even used to obtain calculations for artillery and machine gun fire. This information could then be transferred to maps for distribution to field units.

Some of the highest-quality models were produced by the long-established modelmaking section based in Paris under the direction of the Service géographique de l'armée. By 1918 more than forty workmen were employed in the manufacture of relief models, and by the war's close, the section had produced relief models covering some 15,000 square miles of territory along the Western Front (Walker 1918). Somewhat cruder campaign maps at a scale of 1:20,000 were made of the Western Front by a modelmaking subdivision of the Ordnance Survey. Layers of cardboard were cut to the shape of the contour, then pasted together and covered by a map sheet of the area printed on special paper, with the latest positions of the trenches marked (Chasseaud 1999). The German army made considerable use of relief models and demonstrated a similar capacity to produce detailed and highly accurate models to assist in visibility studies and tactical planning.

After the war, the Wenschow Works in Munich created models using a relief pantograph, an important tool for subsequent model production. Contour lines of topographical maps were used to guide a milling cutter by means of the pantograph. As the operator guided a tracing stylus over the map along the contours, the pantograph translated this motion to a milling cutter, which cut out the contours on a block of plaster. Though relief pantograph techniques had been used earlier to create smaller-scale general purpose models, for example, by Charles Eugène Perron, Karl Wenschow refined these techniques so that detailed models could be produced relatively quickly. These models were also used to create relief shading on maps through model photography.

The nature of warfare had changed by the onset of World War II. Military planning of joint air, sea, and land forces for combined operations demanded that personnel be suitably briefed and able to act with a high degree of initiative. As a result, modelmaking sections were established by both Allied and Axis forces to create models for interpretation and briefing (fig. 797). Skilled modelmakers with art training as well as work experience as professional and commercial artists, sculptors, architects, or architectural modelmakers were trained in air photo interpretation.

Though relief models were used in most theaters of World War II, such as the Russian attack on the Mannerheim Line and the attack on Pearl Harbor by the Japanese (Ristow 1964, vii), it was in Europe that the most sophisticated terrain models were made. A joint British and American modelmaking detachment based in England constructed a remarkably fine series of models, which ranged from 1:500,000 scale for strategic planning to scales large enough to accommodate reasonably detailed elevations of buildings and give pilots and navigators a representative three-dimensional picture of the target and surrounding terrain. Depiction of side elevations of buildings was crucial in enabling pilots to recognize a specific navigation mark or target. Models that survived the war included those used to brief crews for the Dambuster Raid of May 1943 (Pearson 2002, 233–34) (fig. 798). Invasion plans for the Sicilian and Normandy coasts dominated the work of the detachment as the war progressed. Photographs of the models taken under special lighting conditions were distributed to personnel to assist in preoperation briefing. Later on, the unit supplied models of the experimental V-weapon sites at Peenemünde and launching sites in northwestern Europe.

FIG. 797. MODEL MAKING AT LA MARSA, TUNISIA. During the later stages of World War II, model making was carried out closer to the front line in conditions that were less than ideal.
Image courtesy of Tim Scott.

There were two main methods of model construction: the photo-skinned method and the eggcrate method (Pearson 2002, 229–32; Reed 1946; Abrams 1991, 39–40). The photo-skinning method used the traditional layer approach but with aerial photographs grafted onto the smoothed model surface. Model detail was then added on top of the photo detail. Eggcrate models were constructed using vertical sets of cardboard that were cut to the shape of vertical profiles running north-south and east-west as taken from the available topographic maps. The combination of both sets of profiles gave the method its distinctive eggcrate type of construction.

The value of terrain models had been clearly demonstrated during World War II, and research into methods

FIG. 798. MODEL OF THE SORPE DAM, GERMANY. This model was used for briefing aircrews prior to their mission to destroy the Ruhr dams in May 1943, the famous Dambuster Raid. Model is at the Imperial War Museum, Duxford, U.K. Image courtesy of Alastair W. Pearson.

for their mass production continued in the United States at the Relief Map Division of the Army Map Service (AMS) and the Naval Photographic Interpretation Center (U.S. Army Map Service 1950). New equipment was developed, old methods revised, and new materials introduced so that by the outbreak of the Korean War hundreds of plastic reproductions produced through a derivative of Wenschow's vacuum-forming techniques were being supplied to the armed forces in Korea. C. S. Spooner (1953, 61) claims that monthly production might have reached 20,000 copies. Judging from the machine pantographs and molding techniques employed, the Americans had acquired considerable technology in war booty from the Wenschow Works in Munich (Reed 1946, 650–51).

The prospect of lowering the time and cost of production was an incentive for automation. The AMS experimented with a Wild A5 Autograph plotting machine to cut terrain models directly from stereomodels. As the stereomodel was profile scanned, topographic profiles were cut into a block of wax material using a pantograph attachment. At the same time, digital or analog records of the scanned profiles could be provided for subsequent use in the construction of the terrain model. By the late 1950s the idea of scanning a profile and recording slope onto magnetic tape had been proposed. A three-dimensional milling machine guided by digital data could cut successive models from solid wax blocks. During the 1960s work continued on the development of digital terrain models, which came to provide analytical capabilities beyond those of the traditional solid terrain model. Nevertheless, an Automatic Model Production System (AMPS) was developed to exploit the terrain data stored in the numerical map file (NMF). Once the AMPS converted the numerical data into a master three-dimensional terrain model automatically, the resulting matrix of terrain elevations could be converted into profiles for a numerically controlled milling machine. Although computer processing was expensive, the system greatly reduced response time, now estimated in days rather than weeks.

The AMS produced large quantities of molded plastic relief quadrangle maps of the United States at a horizontal scale of 1:250,000, eventually expanding geographical coverage to include virtually all of Asia, Europe, and North America. From 1951 to the 1970s more than two million plastic relief reproductions were produced from two thousand master molds (Ehrenberg et al. 1996, 64–67).

During the twentieth century, relief models made from plaster, papier-mâché, sponge rubber, or vinyl plastic had become a common sight in schools, company boardrooms, and private homes. In recent times commercial companies have continued to experiment with new techniques to improve the speed of model production but maintain models' accuracy and aesthetic appeal. Just as the "paperless office" failed to materialize, there was a growing realization that solid models had a role in the digital age. Companies have capitalized on a growing demand for solid models for museum displays, resource planning, litigation proceedings, and emergency planning. Computer-controlled milling machines cut polyurethane foam blocks using readily available digital data as part of a process known as solid terrain modeling. Space-based or aerial imagery can then be draped over the model using specially adapted inkjet printers. The results are impressive, and while they may fall short of the standards set by the Alpine masters, they take a fraction of the time and manual skill to produce.

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SEE ALSO: Imhof, Eduard; Topographic Map; Visualization and Maps; Warfare and Cartography

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Relief Shading. The development of relief (hill) shading—shading applied to relief as if illuminated by light normally from the west or northwest—developed hand in hand with progress in relief measurement and printing techniques. Although hill shading was already an established practice, developments in printing technology during the twentieth century significantly improved its quality. While not universally adopted, hill shading became a common element of relief portrayal on maps, especially after automated techniques became a standard option within terrain modeling software.

Magnificent examples of early hill shading survive. For example, Hans Conrad Gyger's map of 1667 of the Canton of Zurich demonstrates masterful use of the oblique hill-shading technique. Hill shading from an oblique angle had also been common practice in France. In countries such as England and Germany hill shading was typically applied in proportion to the slope of the ground, with the intensities of shadows inversely proportional to the amount of light reflected from the ground when illuminated by a vertical light. This technique of slope shading was significant during the nineteenth century to show slope values for military purposes. The Ordnance Survey of Great Britain, under the influence of the artistically talented Robert Dawson, produced slope shading of an exceptionally high standard for drawings made during the production of its first edition of the one-inch map (1:63,360). As the shadow from vertical light relied on the gradations in color and tonal shade to depict the ground form, it required considerable artistic skill to create the effect that became known as aerial perspective.

Such methods had two major disadvantages. First, they required exceptionally high levels of skill, and second, the printing techniques of the first half of the nineteenth century did not permit facsimile reproduction of continuous-tone hill drawings. It was necessary to convert them to hachured drawings that were engraved on copperplates for printing. Such a process was bound to degrade the impression of relief regardless of whether an oblique or vertical light source was assumed. Nevertheless, skillful employment of engraved shadow hachures could provide impressive results, arguably the finest example being the *Topographische Karte der Schweiz 1:100,000*, also called the Dufour map, which was published between 1842 and 1864. Frederick W. von Egloffstein's engraving of the Rio Colorado of the West in 1858 is another example of expert use of the technique.

Important scientific contributions to the study of light reflected from perfectly diffusing surfaces began to emerge toward the end of the nineteenth century. For example, H. Wiechel (1878) provided future cartographers with a mathematical foundation for hill shading. But because the means for controlled generation of halftones as a function of surface orientation did not then exist, his work was largely ignored until the formative stages of computerized analytical hill shading during the late 1950s.

The Swiss were widely regarded as preeminent in the development of printed maps that demonstrated a more naturalistic approach to relief portrayal and in particular the development of colored relief shading (Cavelti Hammer, Feldmann, and Oehrli 1997). Rudolf Leuzinger exploited the opportunities that chromolithography offered by combining colored relief shading and contour lines in the production of Alpine relief maps in the annual publications of the Schweizer Alpen-Club (SAC) beginning in 1863. Fridolin Becker was a trained topographer and had worked at the Eidgenössisches Topographisches Bureau until 1884, when he moved to what is now the Eidgenössische Technische Hochschule (ETH) in Zurich. As professor at ETH, Becker improved on Leuzinger's ideas by using more natural colors. In 1889 the SAC published his map of the Canton of Glarus, which is considered the first printed Swiss-style map to deliberately simulate the effect of aerial perspective by sharpening color contrast toward higher altitudes.

During the twentieth century, Eduard Imhof, who succeeded Becker as professor at ETH, established the Swiss style of relief representation that would be adopted by the Bundesamt für Landestopographie. Imhof stressed the importance of thorough training for cartographers and placed great emphasis on developing a sound geomorphological knowledge of landforms to accompany the innate visual and graphic aptitude of Swiss cartographers. As a result, Swiss topographic maps demonstrate incomparable attention to detail, employing delicate use of shading techniques for a very satisfying treatment of relief (fig. 799). Imhof (1982) drew attention to the many fine aspects of the Swiss style. Any sudden transition in slope angle was given a crisp switch from light to dark, while softer shading transitions were applied to more gradual changes in slope. Small local deviations from the direction of the light source were employed to avoid the

FIG. 799. DETAIL FROM *KARTE DER GEGEND UM DEN WALENSEE*, BY EDUARD IMHOF. Imhof's passion for naturalistic representations of relief is evident throughout his work. He was particularly proud of his map of Walensee, painted in 1938. Imhof claimed that "the naturalistic and three dimensional impression may be considered nearly perfect" (Eduard Imhof, "Problems of the Cartographic Terrain Representation," in *Second International Cartographic Conference* [Frankfurt: Institut für Angewandte Geodäsie, 1959], pt. V, 9–30, quotation on 14).
Size of the entire original: 200 × 480 cm; size of detail: ca. 189 × 338 cm. Image courtesy of the Alpines Museum der Schweiz, Bern (Inv. 240.151.010).

main direction of light being parallel to the dominant direction of mountain ridges and valleys. Horizontal surfaces were given a medium, homogeneous tone that permitted small colored symbols on the map to be brought out more effectively. The overall effect, according to Imhof, was enhanced by the interplay between the shading and the contours, rock portrayal, and color tones. The whole scheme was based on the natural effects of atmospheric colors in the mountains, with violet tints applied to the shading and yellowish tints applied to the sides facing the imaginary light source. More contrast added to the higher areas further enhanced the impression of relief using the principle of aerial perspective.

One of Imhof's most important contributions was the development of a photomechanical process that derived a series of printing plates from a single monochrome shading for the production of colored shaded relief. Imhof used school maps and atlases as opportunities to experiment. For example, a new color scheme was developed by Imhof for small-scale maps for the thirteenth edition of the *Schweizerischer Mittelschulatlas*, published in 1962. The color scale ranges with increasing elevation from a light gray-blue-green to light olive to brownish reddish yellow tones and finally to white (Jenny and Hurni 2006, 200).

During the second half of the twentieth century, reproduction techniques continued to improve, with large-scale reproduction cameras being used for color separation for offset color printing. Imhof's influence on relief portrayal during the twentieth century was immense and reached beyond the boundaries of Europe. North American cartographers were also influenced by his work and teachings. Hal Shelton began his career with the U.S. Geological Survey and developed his own method of relief portrayal, which echoed much of that achieved by Imhof and other European cartographers. Shelton and Imhof met in 1958 at the Second International Cartographic Conference in Chicago, the so-called Rand McNally conference. Imhof took the opportunity to praise Shelton's natural-color maps. Whereas Imhof preferred to use color exclusively for modeling topography, Shelton felt that whatever existed on the ground mattered as much as its altitude and adjusted the color of the terrain to reflect the nature of the surface (fig. 800).

The Rand McNally conference of 1958 included a special session devoted to relief depiction. The papers demonstrated an increasing trans-Atlantic cross-fertilization of ideas that continued at a special panel meeting conducted during the semiannual convention of the American Congress on Surveying and Mapping and the American Society for Photogrammetry, in St. Louis in 1962. Swiss relief depiction figured prominently during discussion, and maps of the high mountains of North America began to employ the Swiss style. For example, the Canadians introduced the Swiss style of relief depiction to the mapping of the Peyto Glacier (Henoch and Croizet 1976). Rudi Dauwalder of the Swiss federal topographic service was invited to Ottawa to conduct extensive training in rock portrayal for staff at the Surveys and Mapping Branch of the Canada Department of Energy, Mines and Resources and at the Glaciology Division of the Inland Waters Directorate in the Department of the Environment. Training on shaded relief was also provided to staff for a seven-month period in Switzerland. Other fine examples of the employment of Swiss expertise include Bradford Washburn's maps of Mt. McKinley (fig. 801) and Mt. Everest. Inspired by Imhof's map of the Jungfrau and Aletsch Glacier (*Jungfraugruppe und Aletschgletscher*, 1932), Washburn orchestrated the production of maps using the expert relief depiction of the Swiss Landestopographie (Washburn 1961).

Photographing solid models of relief, illuminated by oblique light, was a popular alternative to the slow and expensive skill-dependent techniques described above. From the end of World War I, Karl Wenschow of Munich developed and refined such methods, reducing the problems of central perspective by using telephoto lenses at a distance some 300 times greater than the difference in height within the model. Germany, Italy, France, Great Britain, and the United States all used this technique in the publication of topographic maps. At first glance such mechanical and objective production of shadow modulation would be of great service to cartography. However, some, most notably Imhof, were critical of its dependence on the correct choice of light direction as no single direction of light could ensure that all essential forms were sufficiently visible and that shadows were not excessive. Furthermore, the models themselves were simply not sufficiently accurate for rivers to align with relief, especially as both models and maps were produced independently. Much modification of the shadows was necessary before the shading element of the map was complete. Such criticisms, though valid, did not prevent persistent use of the technique throughout a significant period of the twentieth century because many cartographic agencies simply lacked the resources to implement manual hill shading techniques for the large areas of the world that still lacked adequate topographic maps.

In 1932, Kitirō Tanaka published a paper describing his new method of relief portrayal, which he called the "orthographical relief method" (Tanaka 1932). His method transformed a contoured relief depiction into a type of depiction more akin to hill shading. Whereas contours can be imagined to be intersections with the surface of equidistantly placed horizontal parallel planes, Tanaka's technique used planes inclined at an angle of 45° that cut the surface along east-west lines. This was achieved using a simple but ingenious graphical method that could be employed by cartographers not so well versed in the naturalistic and subjective methods advocated by the Swiss and others. The result is a map that presents neither contours nor profiles, but something in between best described as oblique model illumination by parallel light from the south. Although never a standard practice, the method produced striking results and stimulated much discussion on initial viewing. Aware of the disadvantages of the technique to topographers and advocates of the naturalistic methods, Tanaka recommended his method to physiographers and landscape architects, a recommendation heeded by Arthur H. Robinson and Norman J. W. Thrower, who twenty-five years later revived Tanaka's technique as the basis for their depiction of mountain relief that resembled the landform maps of Erwin Raisz and Armin K. Lobeck (Robinson and Thrower 1957). Further refinement by Thrower as well as coverage of the technique in geomorphology and cartography textbooks stimulated further debate, sometimes forthright criticism, about the merits of Tanaka's inclined contour technique (Oberlander 1968).

Tanaka also promoted the use of illuminated contour lines (Tanaka 1950). Using a gray background, this technique presented contour lines on northwest-facing slopes in white while contours on southeastern slopes were black. The contour lines thin out where the black and white meet. Tanaka acknowledged that this idea was not new—the Ordnance Survey had used a similar technique in 1866. A number of other examples were published in Switzerland, Germany, and Austria (Imhof 1982, 150–54). Though Tanaka's contributions to cartography rarely materialized in practice, he formalized processes that had hitherto relied on manual skill and perhaps unwittingly anticipated the demands for such approaches that the digital age would bring. Indeed, twenty-first-century papers use his pioneering studies as the basis for continued experimental work on relief portrayal (Kennelly 2002).

High standards achieved through the highly skilled subjective employment of manual hill shading presented

a high hurdle for automation to jump. Though formulae for calculating the amount of shade to apply to a specific slope had been known since the previous century (Wiechel 1878), its application awaited the development of computers powerful enough to cope with the number of calculations for automation. Pinhas Yoeli became known throughout the cartographic world for his breakthrough work on the automation of hill shading and contouring (Yoeli 1965). A student of Imhof, Yoeli developed mathematical models that allowed the programming of his mentor's principles. He divided the surface to be shaded into small rectangular segments or facets with the average inclination and orientation of each facet calculated from digitized contours. The brightness of each facet could then be calculated by assuming a direction and inclination of parallel light rays. His experiments with what he termed "analytical shading" pointed the way to further research during the second half of the 1960s and beyond. His pioneering work was continued by other students of Imhof who continued to incorporate scientific research on the characteristics of reflective surfaces and three-dimensional visualization techniques. Kurt E. Brassel, another product of the Swiss school, based his experiments on the same solution developed by Yoeli but varied the light direction according to the topographical characteristics of the terrain and reduced the light and shadow contrast in the low-lying areas thus introducing the effects of aerial perspective (Brassel 1974). Despite these advances, progress in the automation of relief portrayal remained experimental, as the available printing methods and display devices remained primitive by later standards even after special character sets had been developed for line printers. Nevertheless, research explored the automation of alternative shading methods, most notably Tanaka's orthographic relief method (Brassel, Little, and Peucker 1974). Clearly these computer-based methods depended on the availability of detailed digital terrain models. Fortunately, significant parallel progress was being made in the automatic generation of digital terrain models directly from aerial photographs partly as a by-product of work on orthophoto generation. Subsequent research led to the automatic production of digital terrain models using digital photogrammetry. The storage capacity and techniques for handling digital terrain data also began to emerge as did more sophisticated output devices. These factors, together with the development of more compact and appropriate representations for terrain models, promoted the refinement of practical techniques for cartographic production. By the beginning of the 1980s, shading methods that incorporated the Lommel-Seeliger law, Lambertian reflection surfaces, and Peucker's approximation were not only established practice but would become standard options in future terrain modeling software.

The last decade of the twentieth century saw the adaptation of cheaper desktop approaches to shaded relief production. Grayscale raster images showing highlands with light values and lowlands with dark values generated from digital elevation model (DEM) data could be imported into popular graphics programs such as Adobe Photoshop. The cartographer could then use the grayscale images to create the shaded relief using lighting effects options within Photoshop. Unwanted anomalies in the surface such as banding, elevation spikes, and terracing could be disguised, up to a point, with standard painting tools.

In 1999 the General Assembly of the International Cartographic Association (ICA) approved an ICA Commission on Mountain Cartography. Subsequent meetings of the Commission provided a platform to promote the exchange of ideas and scientific collaboration between scientists in high mountain cartography and related fields. Hill shading was significant element of the Commission's proceedings and seemed likely to remain so into the future.

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SEE ALSO: Airbrush; Imhof, Eduard; Tanaka, Kitirō; Topographic Map

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FIG. 800. HAL SHELTON'S 1:5,000,000-SCALE MAP OF EUROPE PAINTED CA. 1968. Shelton's maps of the 1950s and 1960s are rightly regarded as work of the highest standard and anticipated the realism of the first satellite images of the 1970s. Hill shading is skillfully blended with his naturalistic application of color. See also figure 892.

Size of the original: ca. 102 × 127 cm. Image courtesy of the Geography and Map Division, Library of Congress, Washington, D.C., H. M. Gousha Company Collection. Map © Rand McNally; R.L. 11-S-001.

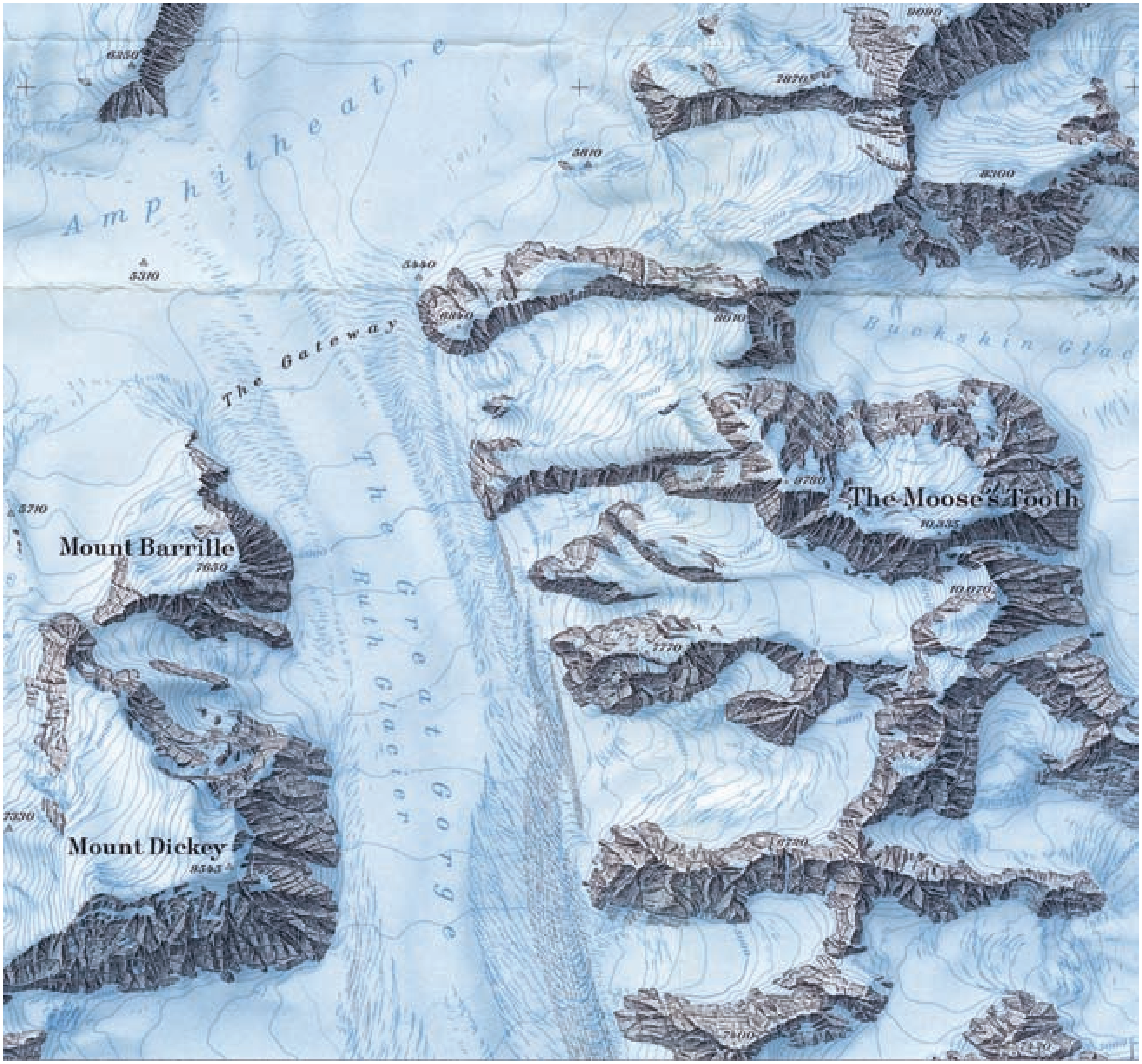

FIG. 801. DETAIL FROM BRADFORD WASHBURN'S MAP OF MOUNT McKINLEY, 1960. Inspired by Imhof's map of the Jungfrau and Aletsch Glacier, Washburn declared that "no other country in the world—in fact, no other team of cartographers even in Switzerland—could equal the job done by Wild and the Landestopographie" (Washburn 1961, 177).

Size of the entire original: 76 × 72.8 cm; size of detail: 16.1 × 17.3 cm. From Washburn 1961 (map at back). Permission courtesy of the American Geographical Society, New York.

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Remote Sensing.

Earth Observation and the Emergence of Remote Sensing. The history of earth observations from remote sensing begins with the history of flight. Cameras carried on balloons, dirigibles, kites, and pigeons acquired images from their vantage point above earth's surface. In the U.S. Civil War, observations from a tethered balloon were used in the Battle of Fair Oaks in 1862 (Jensen 2007, 66–68). Later, once airplanes had been developed, they acquired images for mapping and photogrammetry and for military photo-reconnaissance starting in World War I. Aerial photographs were essential to military strategies in World War II for monitoring locations and movements of troops and vehicles and for targeting facilities for bombing raids (fig. 802).

FIG. 802. GERMAN V-2 ROCKET LAUNCHING FACILITY AT PEENEMÜNDE, USEDOM ISLAND, GERMANY, WORLD WAR II. Enlargement of part of the vertical photographic-reconnaissance aerial taken 23 June 1943.
© Imperial War Museum (C 4782).

With the advent of the Cold War in the 1950s, the need arose for reconnaissance aircraft that could fly high enough to evade missiles and jet fighters. The Lockheed U-2 and its later incarnations were essentially gliders with a single jet engine. Flying at altitudes above twenty kilometers, these U.S. reconnaissance aircraft could acquire images of military installations in denied airspace. Thought to be safe from attack from the surface, a U-2 was shot down over the Soviet Union in May 1960, resulting in President Dwight D. Eisenhower's agreement to suspend flights over Soviet airspace. This incident spurred the United States to develop a satellite-based reconnaissance program.

U-2 flights continued over other areas, however. A photo of missile launch sites in Cuba provided the evidence for President John F. Kennedy to publicly announce the presence of midrange missiles within 150 kilometers of the United States (see fig. 1075). Negotiations with Soviet premier Nikita Khrushchev led to an agreement to withdraw the missiles if the United States would promise not to invade Cuba.

The advent of the space age ushered in an era of earth observations from satellites. Human-made objects began orbiting earth with the Soviet Union's launch of Sputnik in October 1957; much has been written about Sputnik's beneficial prod to U.S. science. The successful launch shocked the U.S. citizenry, creating an impression of a technological and scientific gap between the United States and the Soviet Union. It fostered a climate for increased attention and resources for aerospace efforts, scientific and engineering education, and the birth of the U.S. National Aeronautics and Space Administration (NASA) to manage air and space research and development (Launius 1994). The U.S. satellite Explorer 1, launched in January 1958, made the first scientific discovery from space about earth: powerful radiation belts, later known as the Van Allen belts, surround earth (Van Allen and Frank 1959). Over the five following decades, observations from satellites have fundamentally altered our understanding of the planet and continue to lead to unexpected discoveries about processes that shape earth's environment.

Remote sensing is based on measurements that do not require a medium to transfer the signal (with the exception of undersea acoustic remote sensing). Mostly, the measurements are of electromagnetic radiation, the exceptions being acoustic returns, gravitational and magnetic fields. Two dimensions characterize the electromagnetic signal: reflected versus emitted, and active versus passive. In a reflected signal, the source of the radiation is external to the object being sensed. In much of remote sensing the sun is the source of the radiation, and wavelengths are in the range of about 0.3 to 3.0 micrometers (μm). In an emitted signal, the radiation is generated by the object itself and follows Planck's law describing the intensities of electromagnetic radiation emitted at different wavelengths from a black body at a certain absolute temperature. For earth, wavelengths with appreciable radiation intensities are in the range of about 3.0 μm to 30 millimeters. Most remote sensing systems are passive, in that they measure ambient radiation in the environment, either reflected or emitted. Some systems are active, in that they both generate the signal and measure the reflected component. Examples include lidar, operating in the 0.4 to 0.7 μm wavelengths of the solar spectrum, and radar, which operates at wavelengths from less than 1 millimeter to 60 centimeters. During the two decades after the space age began, six nations designed and launched earth-orbiting satellites: the Soviet Union (1957), the United States (1958), France (1965), Japan (1970), China (1970), and the United Kingdom (1971) (National Research Council 2008, 16). "Just as the invention of the mirror allowed humans to see their own image with clarity for the first time, Earth observations from space have allowed humans to see themselves for the first time living on and altering a dynamic planet" (National Research Council 2008, 1).

Weather from Space

NASA launched the world's first weather satellite, Television Infrared Observation Satellite (TIROS)-1, on 1 April 1960. The remote sensing system on the satellite took television and (on later flights) infrared images of weather patterns from space, helping improve tracking of storms and weather forecasting and providing data for research in atmospheric science. The images revealed storms in areas where few or no observations previously existed and showed unsuspected structures within storms even in areas where extensive observations were available (Wexler and Caskey 1963). In the mid-1960s, the first geostationary weather satellites made global data available more frequently (in principle continuously, in practice about every thirty minutes). Data from geostationary satellites rapidly became a major source of information for weather services worldwide. Since satellite images have become readily available, no tropical cyclone (hurricane or typhoon) has reached land undetected (fig. 803).

Because of their role in weather forecasting, the series of TIROS satellites, the first ten launched between 1960 and 1965, enjoyed strong political and public support. Following them, the National Oceanic and Atmospheric Administration (NOAA) Polar Orbiting Environmental Satellites (POES) began in 1979 with NOAA-6 and continued into the twenty-first century with two satellites in orbit, one crossing the equator in the morning and the other in the afternoon. They have carried the AVHRR (Advanced Very High Resolution Radiometer) sensing system, starting with four and progressing to six spectral bands in visible, near-infrared, and thermal infrared wavelengths, with a spatial resolution of 1.1 kilometers at nadir. In addition to weather observations, the AVHRR's measurements of sea surface temperature provide the longest oceanographic data record from remote sensing. The data have provided information on the ocean's role in regional and global climate variability. Moreover, sea surface temperature images created from the data showed the true structure of the Gulf Stream, which differed markedly from previous estimates based on shipboard measurements. Continuing improvements in the spectral and spatial capabilities of multispectral instruments led to NASA's Moderate Resolution Imaging Spectroradiometer (MODIS), with thirty-six spectral bands at 250 meters to 1 kilometer resolution at nadir. MODIS was launched first on the Terra spacecraft in 1999 and again on Aqua in 2002. Terra flies in a morning orbit, crossing the equator at 10:30 a.m., whereas Aqua is in an afternoon orbit with a 1:30 p.m. crossing.

Stratospheric Ozone

The story of ozone depletion illustrates how laboratory experiments, surface observations, and many satellite data led to the Montreal Protocol, an international agreement in force beginning in 1989, to phase out anthropogenic ozone-destroying, halogen-containing compounds. In 1975 F. S. Rowland and his graduate student Mario J. Molina published a laboratory study demonstrating that chlorofluorocarbons, a class of halocarbons, catalytically reduce stratospheric ozone formation in an environment of ultraviolet light (Rowland and Molina 1975; Rowland 2006, 776–77). The science community urged the elimination of such ozone-destroying compounds because ozone protects earth's inhabitants from damaging ultraviolet radiation. While halocarbons were soon largely eliminated as propellants in aerosol sprays, industry fought their banning as refrigerants and other applications.

In 1984, field and satellite observations revealed the magnitude and extent of ozone depletion. The Antarctic ozone hole was first identified in upward-looking UV radiation measurements by the British Antarctic Survey (Farman, Gardiner, and Shanklin 1985), and examination of data from the TOMS (Total Ozone Mapping Spectrometer) instrument on the Nimbus 7 satellite confirmed the continental scale of the ozone hole, its annual

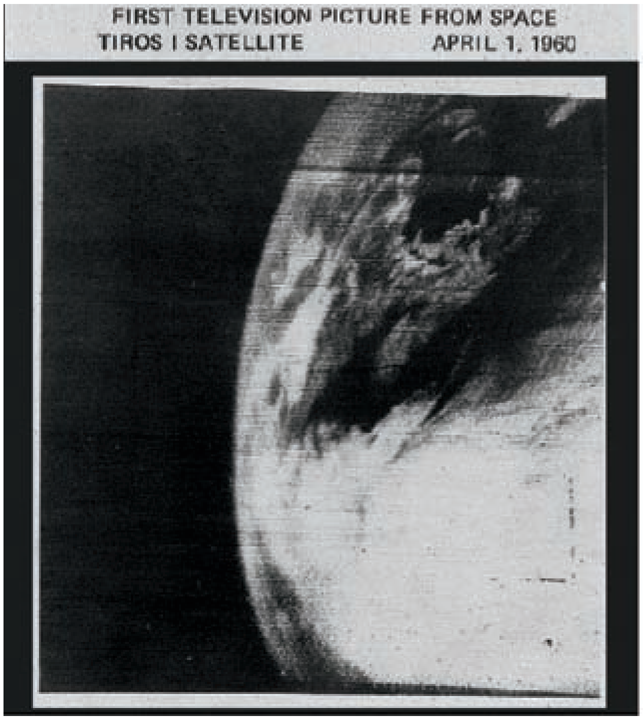

FIG. 803. SATELLITE WEATHER IMAGES, 1960 AND 2005. Left is the first video weather image from space, 1 April 1960, from TIROS-1. Right is Hurricane Katrina over the Gulf of Mexico, 26 August 2005, from MODIS on NASA's Aqua satellite.

Images courtesy of NASA (left) and Jeff Schmaltz, MODIS Rapid Response Team, NASA/GSFC (right).

appearance in the austral spring starting in the early 1980s, and its progressively increasing size. This unexpected increase in the depletion of ozone and the size of the ozone hole suggested that the stratosphere still held surprises. Subsequent measurements from a variety of satellites identified concentrations of trace molecules that lead to or catalyze ozone destruction (Gille 2008). Chlorine from the breakdown of chlorofluorocarbons forms relatively inert hydrochloric acid (HCl), which reacts on the surface of ice crystals in polar stratospheric clouds—which also were discovered from satellite observations—to produce chlorine monoxide (ClO) that catalytically destroys ozone. Satellite observations also confirmed the presence of bromine monoxide (BrO), which is involved in reactions that are even more destructive of stratospheric ozone.

Satellite observations continue to track the size and depth of the Antarctic ozone hole and the more subtle, but dangerous, losses of ozone over heavily populated regions. Recent satellite observations show a decrease in halocarbons and the apparent beginning of an ozone recovery, increasing confidence that the Montreal Protocol is indeed achieving its goal (fig. 804). Rowland and Molina (both from the United States) and Paul J. Crutzen (Germany) shared the 1995 Nobel Prize in Chemistry in recognition of their work on the mechanics of ozone destruction.

Earth's Radiation Budget

Measurement of earth's radiation budget was one of the earliest proposals for a scientific application of satellite remote sensing. Early satellite measurements showed that earth was a warmer and darker planet than earlier estimates had predicted, so more poleward energy transport by the atmosphere and ocean was required (Vonder Haar and Suomi 1969). The components of earth's radiation budget include thermal emission, reflected solar radiation, and the energy coming from the sun. Monitoring of variability and change over seasons and location is important because earth's climate is changing in response to human activities. Accurate observations allow direct measurement of heat transport by the atmosphere and oceans, along with estimates of the degree to which earth's climate is not in steady state.

The Earth Radiation Budget Experiment (ERBE) (Barkstrom 1984) was the first initiative to provide simultaneous observations of earth's radiant energy with identical instruments onboard separate satellites, first with a dedicated satellite launched from the space shuttle in 1984, and then with instruments on NOAA-9 (1985) and NOAA-10 (1986). The design of the ERBE sensing instrument was based on three complementary broadband radiometers that measured the shortwave (< 5 μm), longwave (> 5 μm), and total regions of the spectrum.

By comparing measurements over clear and cloudy periods, the instruments could measure the effects of clouds on earth's radiation balance. The data showed that clouds double earth's albedo from 0.15 to 0.30 and reduce the emitted thermal radiation by about 30 watts per square meter (W/m^2) (Ramanathan et al. 1989). These basic measurements provided a standard against which to test climate models. The amount by which the atmosphere reduces the loss of thermal energy to space is one way to measure the strength of the greenhouse effect. With measurements of the outgoing longwave radiation and observations of the surface temperature and emissivity, the greenhouse effect of the atmosphere at any location can be computed. The average strength of earth's greenhouse effect was found to be about 155 W/m^2, but it varies from about 270 W/m^2 in moist, cloudy regions of the tropics to about 100 W/m^2 at high latitudes.

Three copies of an updated follow-on instrument, the Clouds and the Earth Radiant Energy System (CERES), were launched in 1997 on the Tropical Rainfall Measuring Mission (TRMM), in 1999 on the Terra spacecraft, and in 2002 on Aqua. Each CERES instrument comprised a three-channel radiometer: one to measure reflected sunlight in 0.3–5.0 μm region, one to measure earth-emitted thermal radiation in the 8–12 μm atmospheric window region, and a total channel to measure entire spectrum of outgoing earth's radiation (Wielicki et al. 1996). CERES spatial resolution at nadir view was 10 km for CERES on TRMM, and 20 km for CERES on Terra and Aqua satellites (fig. 805). Based on analyses of CERES data, the most important uncertainties in predictions of future climate were cloud feedback, dominated particularly by low clouds and aerosols as the most uncertain anthropogenic effect.

Ocean Dynamics

Due to the remoteness and size of the oceans, satellites provided the first global ocean-observing system. Observations from ships, moorings, drifters, and other tools could not provide coverage at the temporal and spatial scales required to resolve the dynamic nature of the ocean. Even a well-known current such as the Gulf Stream was not fully characterized until satellite observations were available. Satellite data from scatterometers, altimeters, infrared radiometers, and ocean color sensors enabled understanding of how water moves in the ocean and how energy is exchanged between the ocean and atmosphere.

Monitoring of sea surface temperature from infrared radiometers since 1978—mainly NOAA's AVHRR—

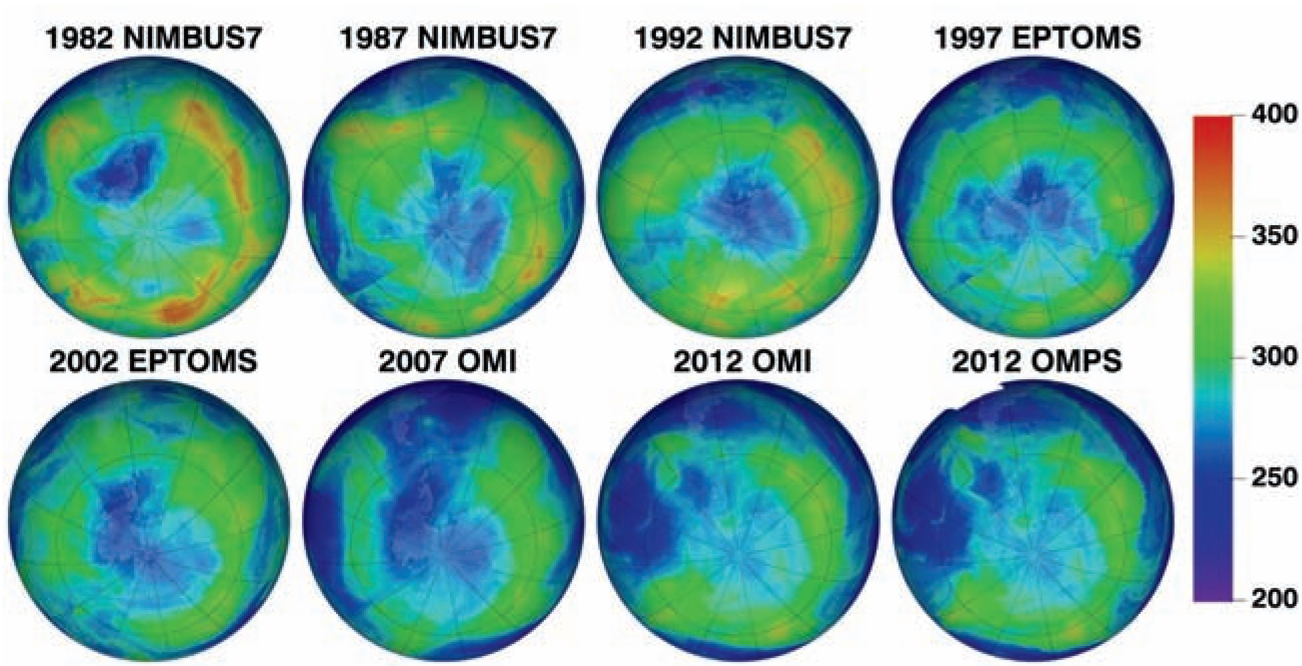

FIG. 804. THICKNESS OF THE OZONE LAYER, 1982–2012, MEASURED IN DOBSON UNITS.

Image courtesy of NASA/NOAA.

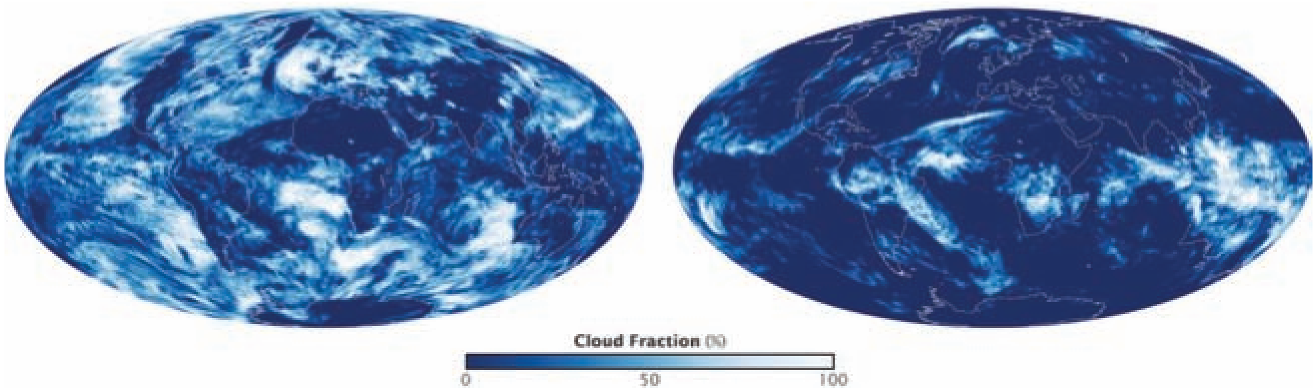

FIG. 805. CERES SATELLITE CLOUD DATA, 27 DECEMBER 2008. Global low-altitude cloud fraction (left) and high-altitude cloud fraction (right).

Images courtesy of Jesse Allen, NASA.

has been the broadest contribution of remote sensing to oceanography. The measurements provide the longest continuous record of any oceanic property from space and are used for a broad range of oceanographic research questions, including studies of regional climate variability, climate change, and ocean currents. More than 80 percent of the total heating of the earth's system is stored in the ocean, and this energy is redistributed around the world by ocean currents and heat and vapor exchange between the atmosphere and ocean (fig. 806).

Observations of ocean color brought about understanding of the coupling between ocean biology and dynamics. The Coastal Zone Color Scanner (CZCS), launched aboard the Nimbus 7 satellite in 1978, provided the first satellite observations used to quantify the chlorophyll concentration in the upper ocean. The first images of surface chlorophyll distributions revealed a high degree of spatial variability, and the availability of global maps of chlorophyll, an estimate for marine plant biomass, has affected the study of biological oceanography in many ways.

Combined with measurements of temperature and approximations for biological activity, the main measurements needed to estimate transport of water, energy, and constituents were ocean topography (from a radar altimeter) and surface winds (from a scatterometer). If topography is known, geostrophic calculations can estimate currents. Most of the advances in understanding global ocean circulation have been made since the launch of altimeters on the European Remote Sensing Satellite (ERS)-1 in 1991 and the joint U.S.-European Topography Experiment (TOPEX)/Poseidon in 1992 (Fu and Chelton 2001). Scatterometers have also made significant contributions to the study of ocean dynamics by providing a synoptic view (approximately 25 km spatial resolution) of vector winds over the ocean. The results showed new insights into the exchange of heat and momentum between the atmosphere and ocean. Scatterometer data are particularly useful for determining the location, strength, and movement of cyclones over the ocean (Chelton et al. 2004).

Ice Sheets

Understanding changes to ice sheets, sea ice, ice caps, and glaciers is important for understanding global climate change and predicting its effects. A significant scientific finding in the first decade of the twenty-first century based on remotely sensed data was the discovery that the great ice sheets of Antarctica and Greenland were losing ice to the ocean at accelerating rates.

In 1997, Radarsat data were used to create the first complete radar-based map of Antarctica. Analyses of radar images enabled detailed measurements of surface velocity, leading to calculations of strain rates and basal shear. New ice streams were identified, and measurements of surface velocity ice streams revealed a complex pattern of flow not apparent from previous measurements (Bindschadler 2006).

In the 1980s as scientists began to consider the effects of global climate change on sea level, the problem was addressed as a balance between snowfall on the ice sheets and their melting and runoff into the ocean. Two sets of measurements that became available in the first decade of the twenty-first century revolutionized this thinking: precise elevations of the ice surface from laser altimetry (ICESat) (Zwally et al. 2002) and indirect estimates of the continental-scale ice mass from gravity from the Gravity Recovery and Climate Experiment (GRACE) (Luthcke et al. 2006; Velicogna and Wahr 2006). These data revealed that in the first decade of the twenty-first century, overall masses were declining and velocities of the ice streams in Antarctica and Greenland had increased, resulting in more ice flow into the ocean (fig. 807).

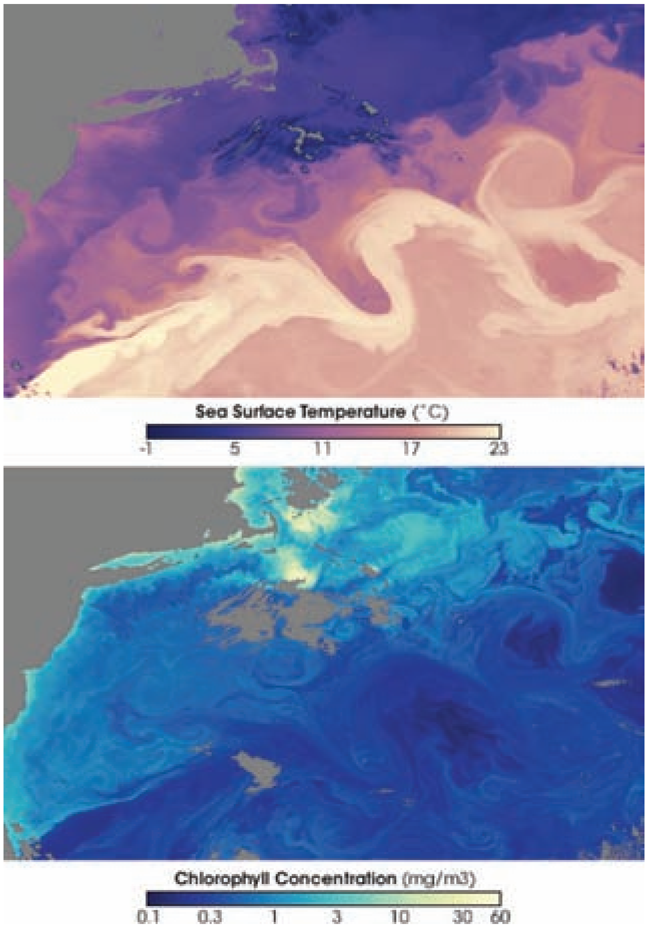

FIG. 806. SEA-SURFACE TEMPERATURE AND CHLOROPHYLL CONCENTRATION IN THE GULF STREAM FROM MODIS, 18 APRIL 2005.
Images courtesy of Norman Kuring, MODIS Ocean Team, NASA.

Vegetation and Agriculture

Early efforts by geographers and ecologists to map global vegetation and land use change required decades of field investigations and compilation of numerous local, national, and regional vegetation maps, atlases, and other literature. Satellite data have enabled characterization of global vegetation and land use at temporal frequencies fine enough to detect change. Satellite sensors offer a synoptic view of earth, as well as the objectivity associated with a consistent measurement and methodology for mapping.

The first civil satellite with a fine enough spatial resolution to resolve patterns of land use was Landsat, first called the Earth Resources Technology Satellite (ERTS). Carrying the Multispectral Scanning System (MSS) with four spectral bands at a spatial resolution of 79 meters, Landsat 1 was launched in 1972. The Landsat 1, 2, and 3 missions used the MSS instrument and demonstrated

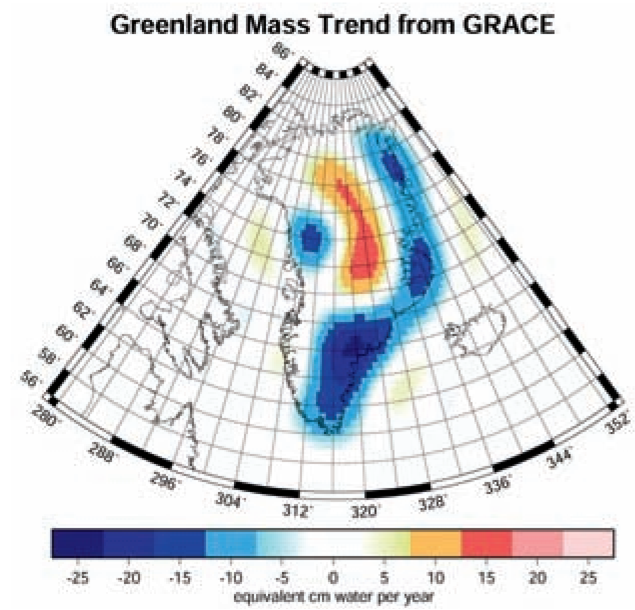

FIG. 807. LOSS OF ICE FROM GREENLAND, 2003–6, AS MEASURED BY GRACE.
Image courtesy of Scott Luthcke, NASA.

the usefulness of the acquired data for cartography, land surveys, agricultural forecasting, water resource management, and forest management. In 1982, Landsat 4 was launched with the Thematic Mapper (TM) instrument, with a 30-meter pixel size and seven spectral bands from visible through thermal-infrared wavelengths (the infrared band had 120-m resolution). Landsat data demonstrated early and continuing success in monitoring earth's croplands, forests, and other natural resources (Landgrebe 1997). The data have provided the longest continuous record of earth's changing land cover. Moreover, the freely available global orthorectified data have made investigations of land use and vegetation change easily feasible.

By the late 1980s commercial enterprises became involved in image acquisition from satellite platforms for land use mapping and other purposes, beginning with the Système Probatoire d'Observation de la Terre (SPOT) satellites launched by the Centre national d'études spatiales (CNES) and operated by the SPOT Image Corporation. Five satellites, SPOT 1 through SPOT 5, were launched between 1986 and 2002, each with a planned four-year lifetime although some SPOT satellites were still operating at the end of the century. SPOT system satellite features of particular interest to mapping were higher spatial resolution imagery than that acquired from the Landsat TM instrument and the ability to acquire imagery up to twenty-seven degrees east or west of vertically downward. This off-nadir image acquisition capability increased the revisit frequency relative to

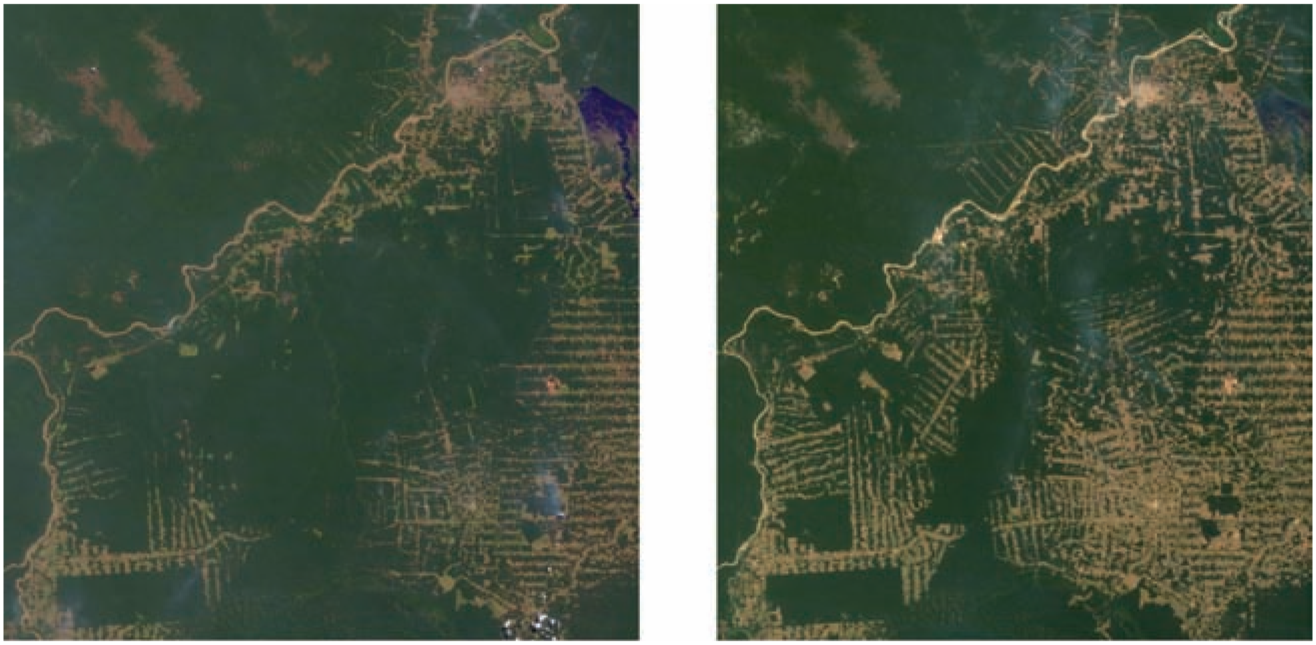

FIG. 808. DEFORESTATION AS OF 2000 (LEFT) AND 2010 (RIGHT) IN RONDÔNIA, BRAZIL, FROM MODIS.

Images courtesy of NASA.

Landsat and provided stereo imagery for digital elevation model creation virtually anywhere on earth.

Because of concern about tropical deforestation and the associated biodiversity loss and environmental consequences, satellite data have been used to measure rates and patterns of forest loss. To trade off between spatial resolution, sampling frequency, and data rates, Landsat data have typically been used to sample areas collected by coarser resolution sensors (AVHRR, MODIS) to estimate tropical deforestation over large areas (DeFries et al. 1998, 2002).

These satellite-based estimates of deforestation rates were lower than those previously reported by ground-based inventories or national surveys. The consequence of these studies was a lower estimate of carbon emissions from deforestation, with important implications for our understanding of the carbon budget. While satellite data have been widely used to map deforestation around the world, good estimates of selective logging were not available until the early twenty-first century, when the Landsat- and model-derived estimates showed that forest damage from selective logging was at least as great as with clear-cutting (Asner et al. 2005) (fig. 808).

Rain and Snow

Precipitation, whether rain or snow, is hard to measure. It is spatially variable, so sampling intensively is usually not possible. Precipitation gauges catch only part of the precipitation, especially if it is frozen. And much of the precipitation occurs over the oceans or in mountains that are not easily accessible. For these reasons, remote sensing of precipitation has been a focus of effort for more than a half-century, beginning in the 1940s with ground-based weather radars and in the satellite era with passive microwave and infrared measurements.

The use of ground-based radar to observe the weather resulted from intensive work on radar technology during World War II (see Whiton et al. 1998a for a comprehensive history). Initially radar was used mostly by the military because of the security classifications assigned to all kinds of radars, but after the war the U.S. National Weather Service began to deploy systems acquired from the military. Although designed for other purposes, radar systems could detect approaching storms. The WSR-57 (Weather Surveillance Radar-1957), developed in 1957, was the first generation of radars designed expressly for a national warning network. They were the main part of the United States weather surveillance system for thirty-five years along with the WSR-74 system; together there were more than 100 weather radars in the United States. These earlier radars measured radar backscatter at specific azimuth and elevation angles, and empirical relations were developed to relate rainfall intensity to radar reflectivity.

Research in the 1970s had shown that Doppler radars could effectively estimate the speed at which storm systems were moving and thereby improve forecasts of arrival times for severe storms. The first NEXRADs (Next Generation Radars, technically the WSR-88D), deployed from 1990 through 1997, provided Doppler velocity, thereby improving tornado prediction ability. They also improved resolution and sensitivity, along with volumetric scans of the atmosphere, thereby seeing fronts, the vertical structure of storms, and detailed wind profiles (Whiton et al. 1998b).

Ground-based radars only collect data within ca. 1000 kilometers of the installation, so they cannot gather data globally, over the ocean, or in remote or underdeveloped areas. Satellite-based methods historically relied on either thermal infrared data to infer cloud top temperatures and thereby correlate with rainfall amounts (Arkin, Joyce, and Janowiak 1994), or passive microwave data to infer raindrop size distribution and thereby rain rate (Wilheit et al. 1994). The infrared data usually used have been from geostationary satellites, because they sample throughout the day. Passive microwave estimates of rainfall began in 1988 with the SSM/I (Special Sensor Microwave/Imager) that flew on the DMSP (Defense Meteorological Satellite Program) series of satellites (Kummerow et al. 2001). The SSM/I progressed to the Advanced Microwave Scanning Radiometer (AMSR and AMSR-E) instrument on the Japanese Advanced Earth Observing Satellite (ADEOS)-II and the U.S. Aqua satellites (Wilheit, Kummerow, and Ferraro 2003). Passive microwave rainfall estimation algorithms have been physically based but have been less accurate over land than over the ocean because of the greater variability of the background signal.

The 1997 combination of a passive microwave imager with a precipitation radar on TRMM transformed the ability to measure rainfall in the tropics, where two-thirds of global precipitation occurs. Such data improve our understanding of air-sea interaction, the role of runoff to the seas in ocean circulation, and the vertical circulation of the oceans (fig. 809). In a non-sun-synchronous orbit, TRMM sampled diurnal variability of rainfall over all longitudes.

Of the seasonal changes that occur on earth's land surface, perhaps the most profound is accumulation and melt of seasonal snow cover. Near many mountain ranges, seasonal snow is the dominant source of runoff, filling rivers and recharging aquifers that more than a billion people depend on for their water resources (Barnett, Adam, and Lettenmaier 2005). For four decades, satellite remote sensing instruments have measured snow properties. At optical wavelengths, sensors such as AVHRR and the Landsat TM have been used to produce maps of snow cover at both continental and drainage-basin scales. As part of the Earth Observing System (EOS), snow cover products are available from MODIS, the Multiangle Imaging Spectroradiometer (MISR), and the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). Snow-water equivalent (the depth of liquid water that the snowpack would produce if it melted) is regularly estimated at coarse spatial resolution from passive microwave data, including SSM/I and the EOS/ADEOS-II instruments AMSR-E/AMSR in a time series that goes back to 1978. However, measuring snow-water equivalent is a difficult problem at the finer spatial resolution necessary for the mountains, with currently no satisfactory solution.

Scientists have reviewed developments in remote sensing of snow and ice (König, Winther, and Isaksson 2001; Dozier and Painter 2004), and among the developments is the use of snow-covered area from MODIS in hydrologic analysis and modeling. Through updates of a runoff model with measurements of snow cover, seasonal streamflow forecasts have been improved (McGuire et al. 2006). Unlike surface measurements, satellite observations are able to show the distribution of snow over the topography, revealing that considerable snow at higher elevations remains after all snow has disappeared from the surface measurement stations.

A recent development in mapping snow cover is subpixel analysis. Snow-covered area in mountainous terrain usually varies at a spatial scale finer than that of the ground instantaneous field of view of the remote sensing instrument. This spatial heterogeneity poses a mixed-pixel problem because the sensor measures radiance reflected from snow, rock, soil, and vegetation. To use the snow characteristics in hydrologic models, snow must be mapped at subpixel resolution in order to accurately represent its spatial distribution; otherwise, systematic errors may result. Mapping of surface constituents at subpixel scale uses a technique called "spectral mixture analysis," based on the assumption that the radiance measured at the sensor is a linear combination of radiances reflected from individual surfaces (Painter et al. 2009).

JEFF DOZIER

SEE ALSO: Biogeography and Cartography; Landsat; Map: Images as Maps; National Aeronautics and Space Administration (U.S.); Photogrammetric Mapping: Military Photogrammetry as a Precursor of Remote Sensing; U.S. Intelligence Community, Mapping by the

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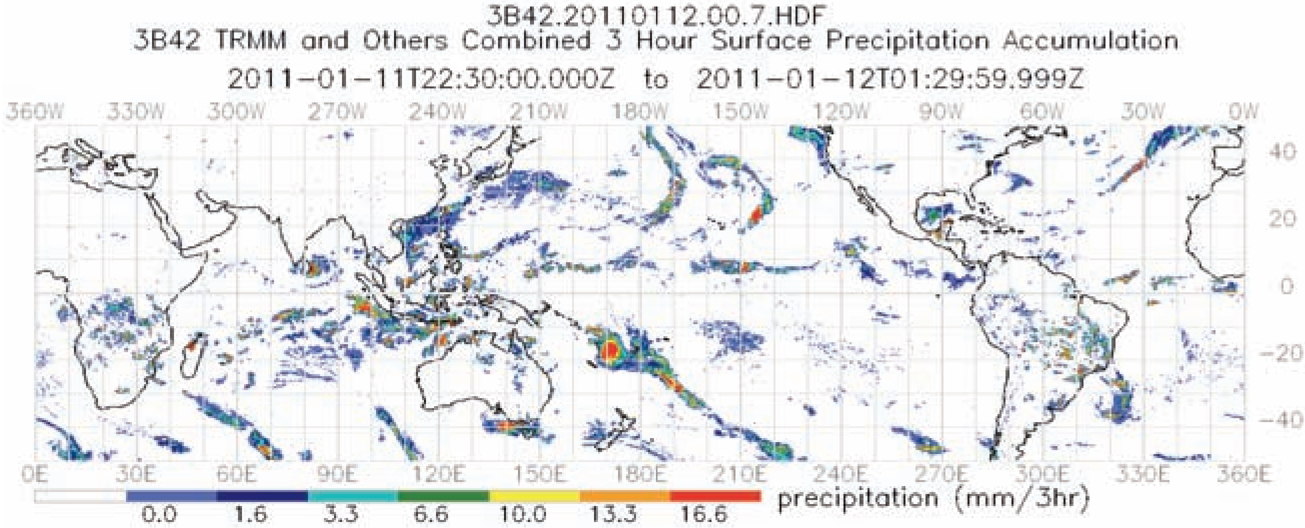

FIG. 809. GLOBAL PRECIPITATION ACCUMULATION, 11 JANUARY 2011, TRMM SATELLITE DATA. Image courtesy of the NASA TRMM Public Data Archive.

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Satellite Systems for Cartographic Applications. Like at the advent of most earlier airborne vehicles, the development of satellite technology has, from its beginning, been used for earth observation. Other than telecommunication and navigation (cf. Navsat), since their early days satellites have mainly been built to acquire information about the earth’s surface.

The term *remote sensing cartography* (German *Fernerkundungskartographie*), however, is highly contested in both the Anglo-American and the German literature, since remote sensing only represents “a” means of information acquisition like aerial photography. By the end of the century, remote sensing had become the norm as an information source for many cartographic applications; therefore, the term that had some justification for the last thirty years of the century had, by its end, become redundant. It is possible to distinguish three possible uses of satellite imagery for cartographic purposes:

1. Topographic information, which is depicted in topographic/reference maps in the form of graphic symbols, can be derived from satellite images. In many instances this is done by means of stereophotogrammetry, a standard method of topographic surveying since approximately 1930.
2. Satellite images are also a source of thematic information, which is represented in many different ways in thematic maps. In this context remotely sensed data may also be of importance for the generation of an appropriate topographic base map.
3. The pictorial representation of the terrain in satellite images led to the development of a new map category, satellite image maps, significantly extending the range of cartographic image products, which initially consisted only of classical orthophotomaps based on aerial photography (Colvocoresses 1984, 1986). The combination of geocoded raster imagery with vector information gave rise to the new type of combined image-line maps (CIL maps; a term coined by Robert Kostka and Manfred F. Buchroithner, introduced to the scientific literature by Buchroithner 2002).

The major factors influencing the application of remote sensing are, in a somewhat arbitrary way, visualized in figure 810. Figure 811 lists approaches for the solution of environment-induced problems immanent to

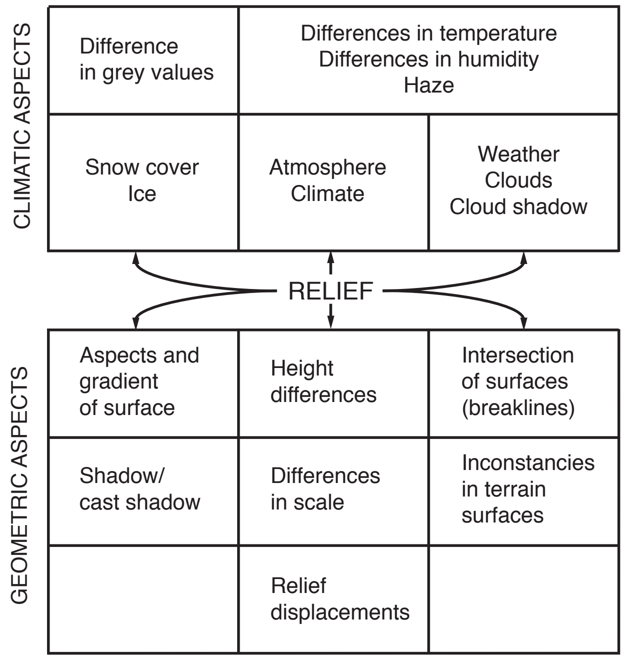

FIG. 810. MAJOR FACTORS INFLUENCING THE APPLICATION OF SATELLITE REMOTE SENSING.

PROBLEM	SOLUTION	REMARKS
RELIEF	High Acquisition Altitude	Displacement Reduction
	Small Field of View	Displacement Reduction
	Stereo Data	Also Multisensoral
	Digital Elevation Models	Also from Remote Sensing Stereo Data
	Shape from Shading	Synthetic Aperature Radar Application. Shadow Problem Remains
	Interferometry	Most Accurate Relief Information
	GPS	
SCALE EFFECTS	Stereo Data	Intrinsic Scale Changes
	Digital Elevation Models	Permit Mono-plotting, Geocoding
	GPS	
SHADOW	Multiseasonal Data	Also Multisensoral
	Multidirectional Radar	Illumination Differences
	Digital Elevation Models	Base for Illumination Models
	Digital Illumination Models	CPU-intensive Integration
	Grey Value Ratioing	Simple, not for Completely Dark Slopes
	Solar Noon Satellites	Shadow Minimization
WEATHER HAZE CLOUDS	Multiseasonal Data (High Temporal Resolution)	Also Multisensoral
	Haze Correction	Simple Approach
	Atmospheric Correction	Problem of Data Availability
	Radar	Cloud Penetration
SNOW COVER	Multiseasonal Data (High Temporal Resolution)	Also Multisensoral
	Passive Microwaves	Snow Type Mapping
	Radar	Penetration to Ground, Snow Type Mapping

FIG. 811. SATELLITE REMOTE SENSING AND RELATED PROBLEMS. Approaches for the solution of environment-induced problems immanent to satellite remote sensing, regarding both data acquisition and interpretation.

satellite remote sensing regarding both data acquisition and interpretation.

A two-volume monograph about the use of space-borne imagery for cartographic purposes entitled *Fernerkundungskartographie mit Satellitenaufnahmen* was published in 1989 by Hans Günter Gierloff-Emden and Manfred F. Buchroithner covering all aspects of topographic, thematic, and CIL mapping by means of satellite earth observation. This was the first comprehensive book dealing not only with space-borne remote sensing as such but explicitly with cartographic applications of satellite imagery.

Remote sensing from space received its first impetus through imaging from rockets. As early as 1891, the Germans developed rocket-propelled camera systems, and in 1897 Swedish landscapes were photographed by a camera mounted on a rocket by Alfred Bernhard Nobel. By 1907 gyro-stabilization was added to improve picture quality. Efficient space-borne remote sensing, however, began between 1946 and 1950 when many cameras were carried on rockets and ballistic missiles. In 1946, V-2 rockets acquired from Germany after World War II were launched to high altitudes from White Sands, New Mexico. These sounding rockets, while never reaching orbit, contained automated still or movie cameras that took pictures during the ascent of the vehicles. Some thirty years later this location was still scientifically important as a spectrometric-radiometric calibration site for satellite sensors. In the civilian field the development of meteorological satellites provided the impetus for what might be called "modern remote sensing."

The Television Infrared Observation Satellite, TIROS-1, was launched by the U.S. National Oceanic and Atmospheric Administration (NOAA) in 1960 and delivered the first coarse views of cloud patterns. With further refinements in sensor technology (e.g., Advanced Very High Resolution Radiometer [AVHRR-1], launched on TIROS-N in 1978), meteorologists also began to collect information about terrestrial features. With the launch of radar satellites the concept of looking through the atmosphere evolved. It was also around 1960 that the term "remote sensing" started to penetrate the scientific and, later, the popular literature.

During the late 1950s and early 1960s, at the height of the Cold War, the CIA and the U.S. Air Force developed the film-based Corona reconnaissance satellite program, while the Soviet Union successfully launched Zenit-2, a derivative of the manned Vostok spacecraft, in April 1962. The manned space flights of the 1960s and 1970s yielded spectacular photography of the earth's surface when the orbiting (Western) astronauts and (Soviet Bloc) cosmonauts acted much like tourists taking photographs out of the windows of their spacecraft (Samant and Kumar 2005). Imagery acquired during the 1961–65 U.S. National Aeronautics and Space Administration (NASA) Ranger Missions resulted in the first accurate maps of the moon. The U.S. Geological Survey (USGS) image map of Phoenix, Arizona, based on photography acquired during the NASA Apollo 9 Mission produced in 1969 was a landmark in satellite cartography. The driving force behind these activities was Frederick J. Doyle, the team leader for Apollo photography. Seventy-millimeter Hasselblad photographs, partly in stereo, taken by the astronauts during the NASA Skylab Program from 1973 to 1979 were used in the whole Western world to produce up-to-date maps of remote areas. The interest in this space-borne imagery led to the first use of earth-observing multispectral and microwave instruments in space.

Following the success of these missions, the first Earth Resources Technology Satellites were planned in 1967, and ERTS 1, later renamed Landsat 1, was launched by NASA in July 1972, a satellite that was to become the first in a forty-year operational earth observation program. It delivered the first readily available digitally sensed satellite imagery to be commercially exploited, and the program continued with the launch of Landsat 7 in 1999.

In 1974 Alden P. Colvocoresses, subsequently a leading photogrammetric scientist at NASA, described the newly formulated Space Oblique Mercator projection. The production of Landsat imagery of high geometric fidelity through NASA and USGS was based on the fact that the positional errors of points on a properly controlled image were less than the eighty-meter instantaneous field of view of the scanner. Such accuracy was attributed to the stability of the scanner and spacecraft and to the corrections made by NASA before each image was printed. The images were formed on a cylindrical surface in space and defined as this specific map projection and resulted in imaging the world between the eighty-two-degree parallels every eighteen days. Moreover, the projection is mathematically definable and thus had the potential of developing into an automated mapping system in which the picture element (pixel) can be discretely related to its position on the figure of the earth (Colvocoresses 1974).

This development became the foundation for the effective use of Landsat data for the retrieval of cartographic information, both topographic and thematic. At the time of the Cold War, when almost no official information in written form was published from Eastern Bloc sources, Colvocoresses gave a detailed report on the status of mapping by means of Landsat at an international symposium (Colvocoresses 1976).

The Landsat-derived image maps of Antarctica published by the United States and the Directorate of Overseas Surveys (DOS) in the early to mid-1970s could be

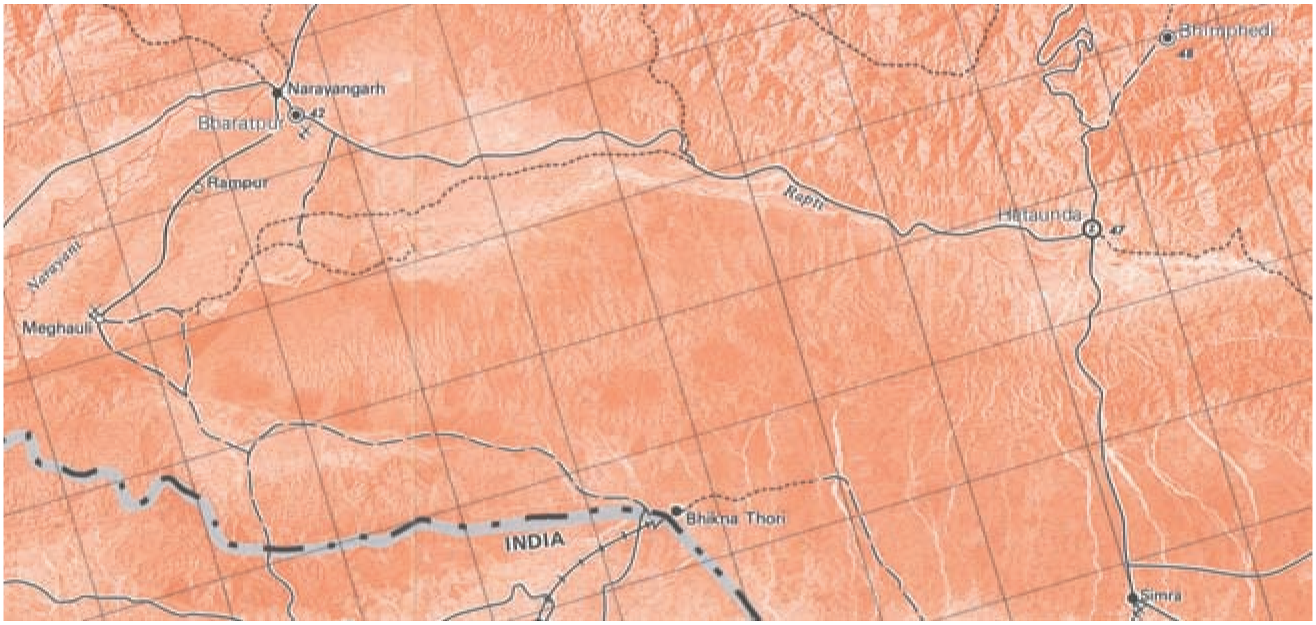

FIG. 812. DETAIL FROM *NEPAL: LANDCOVER INDICATIONS DERIVED FROM LANDSAT IMAGERY . . . 1980*. Produced in two sheets, western and eastern, at 1:500,000 with Universal Transverse Mercator grid, by the Ministry for Economic Cooperation, Federal Republic of Germany and the World Bank, and published in 1981. This detail is in the southwest corner of the eastern sheet and shows south central Nepal.
Size of the eastern sheet: 73.1 × 91 cm; size of detail: ca. 9.9 × 20.9 cm. Image courtesy of the Arthur H. Robinson Map Library, University of Wisconsin–Madison. © World Bank, Washington, D.C.

considered milestones in remote sensing cartography. While the aforementioned USGS image map of Phoenix was experimental, the Antarctic sheets were regular production maps.

In the mid-1970s the availability of Landsat 1 data led to a boom in the development of digital image processing techniques. The first space-borne multispectral scanners on board Landsat 1, 2, and 3 were opto-mechanical systems. Landsat 4 (1982) and Landsat 5 (1984) were the first to be equipped with solid-state CCD (charge-coupled device) array scanners in the seven-band Thematic Mapper (TM) sensor. This gave an improved geometric accuracy, helping to generate map products of appropriate quality, and an improved resolution, which allowed for larger-scale mapping. Landsat 7 (15 April 1999) had the so-called Enhanced Thematic Mapper Plus (ETM+) on board, characterized by a fifteen-meter panchromatic band and a sixty-meter thermal band in addition to the other bands in the visible, near infrared (NIR), and mid-IR wavelengths. On the whole, Landsat is considered the most important and most successful satellite earth observation program during the century.

Landsat imagery of March 1977 was used for the generation of what might be seen as a milestone in the application of satellite imagery for cartography and the actual use of its outcome: a color map consisting of two large-format sheets covering Nepal and its surroundings at a scale of 1:500,000 and the Kathmandu Valley at 1:125,000 (fig. 812). An interesting addition to the map is a Landsat stereo-pair of the Kathmandu Valley, which allows a three-dimensional view of the city and its surroundings.

Space stations are also earth satellites, and on 29 September 1977 the long-serving orbital station (space station) Salyut-6 was put into orbit. Its payload contained the topographic camera KATE-140 with a 140-millimeter focal length lens, covering the visible part of the electromagnetic spectrum, and the multispectral camera MKF-6 with 125-millimeter focal length lenses and six spectral bands in the visible and the NIR (Stiller and Sagdeev 1980). The Interkosmos cosmonauts were urged to take pictures with two additional types of cameras used during the five years of Salyut-6's operation in space: a Pentacon-6 m (60 × 60 mm format camera with 50 mm and 180 mm lenses) and a Praktica-EE 2 (24 × 36 mm format camera with 28, 135, and 200 mm lenses).

Details about these sensors, and in particular about the Soviet approach to information theory regarding the "decoding" of space data (as it was called in Eastern space jargon) are discussed in an atlas (Sagdeev et al. 1982) as well as in a picture book (Koval' and Dessinov

1987). Real examples resulting in thematic maps are rather rare in this volume. However, in 1983 a bilingual book about photographic space-borne remote sensing of the earth was published in German and Russian containing numerous examples of mainly thematic small-size maps derived from these photographs (Akademie der Wissenschaften der DDR et al. 1983).

For climatological and geological mapping the Heat Capacity Mapping Mission (HCMM) of NASA with its Heat Capacity Mapping Radiometer, launched in April 1978 and lasting seventeen months, was of great importance. The 500-meter resolution was sufficient to map climate-related phenomena at small scales (Short and Stuart 1982).

In June 1980 the Soviet Union launched another satellite in their Meteor series, Meteor 1–30 (or Meteor-Priroda-5 spacecraft) with a set of experimental instruments on board designed to investigate natural resources. One of them was the optical Multispectral Scanning System (MSS) Fragment, with a resolution of 85 meters representing a near equivalence to Landsat MSS. It operated in the visible (three bands), NIR (two bands), and short-wavelength IR (three bands) ranges. Although initially designed to map the snow depth over the entire Soviet Union for planning the upcoming work during the spring and summer season, its imagery gave rise to many more cartographic applications, several exemplified in the *Atlas of the Interpretation of Multispectral Scanner Images* (Sagdeev et al. 1989) published simultaneously in Russian, German, and English.

In 1982 the increasing demand for image products with overlaid vector information, georeferenced with a high accuracy onto the geometry of the corresponding topographic maps, led Colvocoresses to the development of an automated satellite mapping system (Mapsat). A system for automatically mapping the surface of a celestial body is based on a satellite in a near polar sun-synchronous orbit about the body with two or three linear sensing photodetector arrays mounted transversely to the satellite heading. The necessary geometric input data are acquired by sensing the same elemental areas of strips first from the forward-looking array and again from a second position by a backward-looking array, and so on for other strips transverse to the ground track of the satellite (Colvocoresses 1982). On 2 February 1982 a patent was issued for this invention, which significantly advanced the space-based mapping business. During the first decade after the launch of the first Landsat satellite, Colvocoresses was, at least in the Western world, *the* driving force behind satellite image mapping, both developing it methodologically and fostering its significance (Colvocoresses 1984, 1986).

Although not satellite programs per se, two important space missions with a significant impact on remote sensing cartography were the stereophotogrammetric experiments on board the NASA space shuttles: the Photogrammetric Camera Experiment (28 November–7 December 1983), jointly conducted by NASA and the European Space Agency (ESA), and the NASA Large Format Camera Experiment (5–13 October 1984) (Konecny 1984; Doyle 1985).

Besides Landsat, the French commercial SPOT (Système Probatoire d'Observation de la Terre) program is the second best-known and probably also second most used satellite earth observation program to date. The system has been operational since February 1986, when SPOT 1 was launched, followed by SPOT 2 (January 1990), SPOT 3 (September 1993), and SPOT 4 (March 1998). The satellites' HRV (high-resolution visible) or HRVIR sensors contain three or four bands in the visible and NIR range with a ground resolution of twenty meters and one panchromatic ten-meter band. The constellation of the three SPOT satellites in orbit since 1998 offers unsurpassed acquisition and revisit capacity to deliver imagery from anywhere in the world, every day (Baetz 2000). Already in 1987 a topographic map at a scale of 1:25,000 was produced for a French test site near Marseille, based on a stereo pair acquired in March and May 1986 by SPOT 1 (Konecny et al. 1987). From 1988 on this early example was followed by a 1:100,000 topographic quadrangle map set covering first the northeast and then the whole of Yemen, the southern part of Morocco, and subsequently other countries (Murray and Newby 1990; Al-Rousan et al. 1997).

Despite the fact that since its arrival satellite remote sensing has been used for the acquisition of map information, the international scientific community reacted hesitantly to the increasing use of satellite imagery explicitly applied to map production. It was not until 1987 that an international symposium, dedicated to the late "father" of the Landsat program, the Austrian-born William Nordberg, the "Willi Nordberg Symposium," took place in Nordberg's hometown Graz. The topic "Remote Sensing: Towards Operational Cartographic Application" gathered leading experts from almost all industrialized countries but also from other parts of the world to demonstrate the state of the art in (quasi) operational remote sensing cartography and to point out the needs and demands for the future. The event was a landmark in the development of what in the era of Google Earth and Google Maps had penetrated everyday life, and the symposium proceedings (Buchroithner and Kostka 1988) are a milestone in the history of remote sensing cartography.

In 1988 a high-quality satellite atlas was published with some fifty color image maps of Austria at a scale of 1:200,000. However, these are only image maps not CIL maps, published together with the corresponding topographic maps (Beckel and Zwittkovits 1988), thus being a precursor for many more of these products to come onto the international market. The Österreichische Akademie der Wissenschaften, under leadership of cartographer Erik Arnberger, spearheaded this work beginning in 1980, when the first tentative examples of 1:200,000 and even 1:100,000 CIL map sheets were published (Buchroithner 1987).

During the entire century and up to today, the demand for geocoded very high-resolution multispectral data has continuously increased, the supply barely meeting both the requirements and the demand of this large market. With the launch of Indian Remote Sensing Satellite (IRS) 1C by the Indian Space Research Organisation (ISRO) in 1995, industrializing countries entered this ever-growing market of space-borne geoinformation. Moreover, for the first time they made available five-meter panchromatic data. Previously, only a resolution of ten meters was available in the panchromatic band of the SPOT sensors.

In the latter third of the century satellite remote sensing in the civilian sector reached a level of spatial resolution finer than one meter. What in 1972 began with a coarse resolution of 57 × 79 meters (Landsat MSS) and permitting the production of maps at a scale of 1:200,000, by the end of the century had reached the resolution of 1 × 1 meter, thus allowing mapping at 1:10,000.

The development of satellite remote sensing systems was almost exclusively carried out by governmental organizations of various countries in the early years, but in 1995 the private U.S. company Orbimage launched the first commercial earth observation satellite, followed by DigiGlobe and Space Imaging in September 1999 (IKONOS imagery, one-meter panchromatic, four-meter multispectral).

Several other satellite programs must be mentioned: the Japanese ADEOS (Advanced Earth Observing Satellite) series, JERS (Japanese Earth Resources Satellite)-1 and MOS (Marine Observation Satellite); the Russian Resurs and Okean series and MOMS (Modular Optoelectronic Multispectral [Stereo] Scanner); the Canadian Radarsat; the ESA's ERS (European Remote Sensing Satellite)-1 and ERS-2; the U.S. Terra system (with the well-known ASTER [Advanced Spaceborne Thermal Emission and Reflection Radiometer] sensor). They all had or have a high potential for cartography (fig. 813).

The demand for ultra-high-resolution satellite imagery that allows large-scale mapping is resilient, but there is also a need for supraregional and global-scale mapping. The meteorological NOAA sensor AVHRR first used on TIROS-N, and later on NOAA Polar Orbiting Environmental Satellites (POES), with its ground resolution of 1.1 kilometer at nadir offered this possibility. With its high repetition rate, the data are ideal for environmental monitoring, thus perfectly meeting the goals of modern digital dynamic or animated cartography. Moreover, a global mosaic of AVHRR scenes generated in the 1980s was published in various styles and formats by different publishers, among them the National Geographic Society.

A major advantage of satellite imagery was its capacity to provide data for regions of the earth that are difficult to access on the ground. This applies particularly to large river basins covered by impenetrable forests such as the Amazon or the Congo, high mountain terrain such as the Andes or the Hindu Kush-Karakorum-Himalaya region, and areas where remote mountain land is covered by dense, impassable forests like in Indonesia, Borneo, or New Guinea. The latter regions are also subject to frequent cloud cover, which requires the capacities of active microwave sensors. This is why thirteen years after the loss of the world's first radar satellite Seasat on 10 October 1978, the launching of the first ERS satellite through the ESA on 17 July 1991 was welcomed by cartographers active in these zones. Using a six-centimeter C-band synthetic aperature radar (SAR), ERS-1 and ERS-2 have since provided data for thematic mapping and environmental monitoring. The ERS satellites have also been of great interest for marine applications.

The Soviets also developed a SAR system mounted on the earth observation satellite Almaz, which was designed for ecological studies of the earth. What in the West was known as the Almaz satellite was actually a whole series of radar and other sensors (not to be confused with the Salyut-Almaz spacecraft). Following its precursor Cosmos-1870, which operated from July 1987 to July 1989, the Almaz-1 SAR sensor was in orbit from March 1991 to October 1992. Almaz-2 was to be active from 1998 (but was never launched). It was at the end of the 1980s that the first Almaz SAR imagery arrived in the Western remote sensing community.

The mapping of coastal zones and of material in the sea to a depth of approximately 50 meters received an impetus from the data delivered by NASA's Coastal Zone Color Scanner (CZCS) with 825-meter spatial resolution, which was in service on NOAA's Nimbus 7 from 24 October 1978 until 22 June 1982 (ESA 1984).

The number of satellite image maps, either image maps or CIL maps, is probably countless. Starting with the first products published in the United States in the mid-1970s, many public and even private institutions generated and published such products during the century. However, one product, the *National Geographic*

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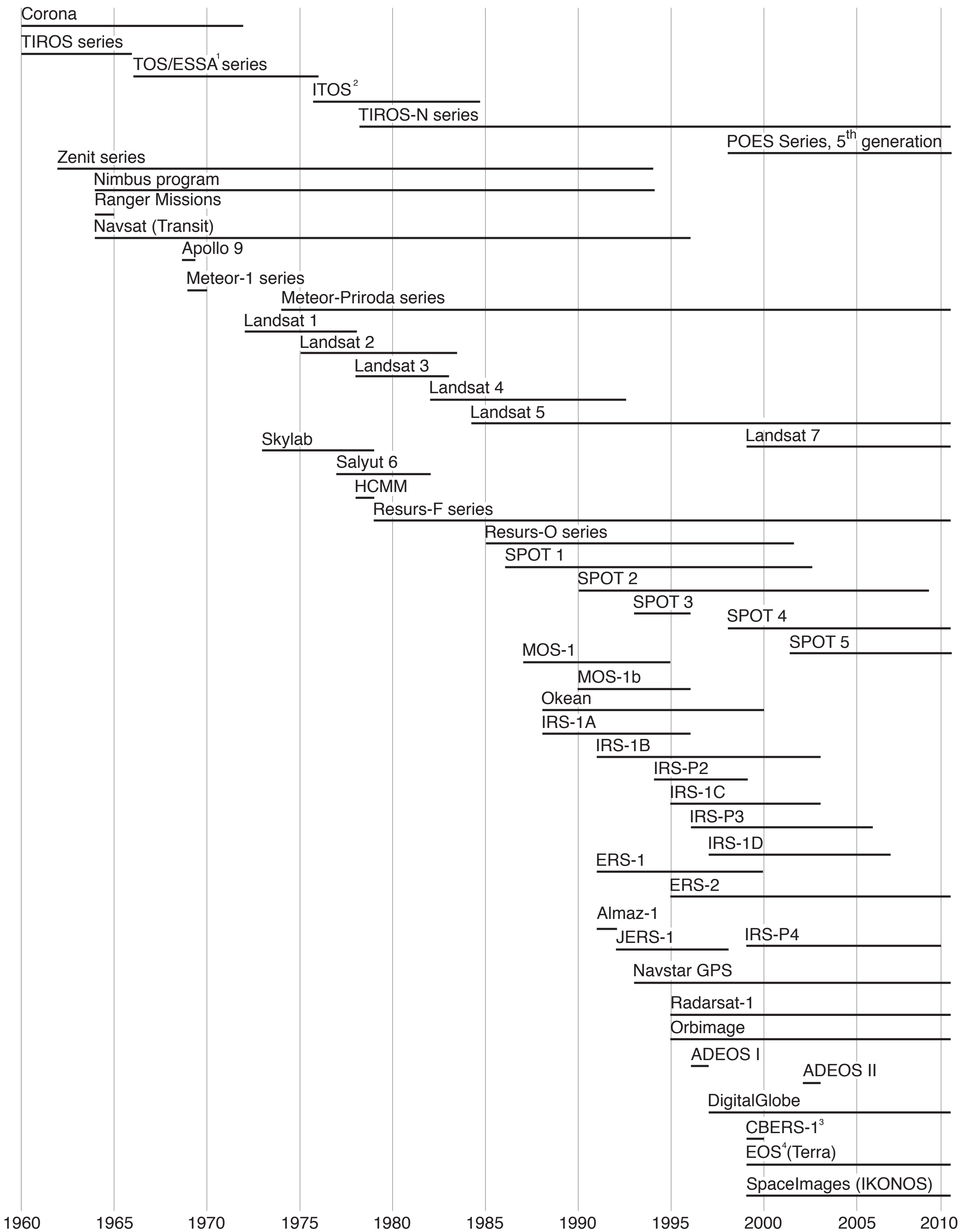
FIG. 813. SELECTED SATELLITE EARTH-OBSERVATION MISSIONS IN THE TWENTIETH CENTURY.



[1] TIROS Operational Satellite/Environmental Science Services Satellite [2] Improved TOS [3] China-Brazil Earth Resources Satellite [4] Earth Observing System

Satellite Atlas of the World (1998), is worth particular mention.

At the very end of the century, in the year 2000, a team of Russian experts from the Moskovskiy institut inzhenerov geodezii, aerofotos"yëmki i kartografii (MIIGAiK) published a comprehensive color textbook on geography from space. In the Russian tradition, numerous examples demonstrate the translation of satellite image data into topographic or thematic maps (Savinykh et al. 2000).

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SEE ALSO: Land Use Map; National Aeronautics and Space Administration (U.S.); Photogrammetric Mapping: Military Photogrammetry as a Precursor of Remote Sensing; Topographic Map; U.S. Intelligence Community, Mapping by the

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Data Handling and Information Extraction from Remotely Sensed Imagery. Remote sensing's development as an efficient, fully functional cartographic technology reflects the integration of several corequisite technologies, principally the spacecraft that provided an orbiting platform; the sensor that imaged the dynamic scene below, often with revealing measurements outside the visible spectrum; the telecommunications system that forwarded raw data through a network of ground stations to a central processing facility; and the data processing system that organized, corrected, archived, and distributed the data as well as supported analysis and display by a diverse community of users. This entry focuses on the development and diversity of data handling and analysis systems for digital rather than photographic images. Although digital images were often generated from pictures captured on film and photographic processing played an important role in making satellite data legible—in the early 1960s the first successful intelligence satellites relied on film drops, which required elaborate preparation—digital processing eclipsed photographic analysis when color monitors connected to microcomputers or time-sharing computers became commonplace in the 1980s. Advances in digital imaging also led to an increased use of aircraft, which had served since the late 1960s as observation platforms for experimental sensors flown in anticipation of the launch in 1972 of Landsat 1 (originally named Earth Resources Technology Satellite 1, or ERTS 1).

Landsat's prominence as the only continuous program for measuring natural earth phenomena over a forty-year period yielded two noteworthy cartographic contributions. One of these is automated land use/land cover modeling, which has been conducted on both domestic and international scales and is epitomized by the Anderson land classification system, derivatives of which have been used for thematic mapping at small scales (Anderson et al. 1976). The other is the periodic epics of the Global Land Survey, published by the U.S. Geological Survey (USGS). Most satellite-based techniques for automated pattern recognition can be traced to Landsat technology.

Data Processing

Several developments in computing and electronic storage facilitated the processing of remotely sensed data. Chief among them was the vast improvement in computer architecture that more or less kept pace since the early 1970s with the expanding computational demands of both active and passive sensors. The volume of data generated by multispectral active sensors swelled as the ground size of pixels for nondefense applications became ever smaller and hyperspectral and multitemporal imagery added further complexity. By the 1980s parallel processing—essentially an array of small processors working simultaneously on the same task—was not only coping with massive data sets but meeting the unprecedented requirements of active sensors like microwave radar, which could operate at night as well as penetrate cloud cover, and lidar, which could produce highly reliable elevation maps with the aid of sophisticated filters. Similarly influential were portable digital storage media, which evolved from the magnetic tape of the early 1960s through the compact optical discs and DVDs of the 1980s and 1990s, respectively, to the comparatively high-capacity solid-state mass storage devices in wide use by century's end. Fiber optic telecommunications also became important in the 1990s, when high-capacity Internet connections allowed the downloading of massive data sets and provided access to specialized processing facilities in distant locations. Because of the size of the data sets, compression/decompression algorithms were useful as well. In addition, the emergence of low-cost, high-performance computer workstations in the 1990s led to an increased use of specialized image-processing software in college classrooms and research laboratories.

Remotely sensed imagery has typically involved two distinct stages of data handing: the first to convert raw measurements to a standardized data format with a known geographic framework and the second to help the end user address a particular research or management task. For Landsat and similar land cover imagery, the first stage includes an atmospheric correction to adjust where possible for the effects of haze and differences in the thickness of the intervening atmosphere or otherwise to mark the pixel as cloud cover and thus unsuitable for subsequent analysis.

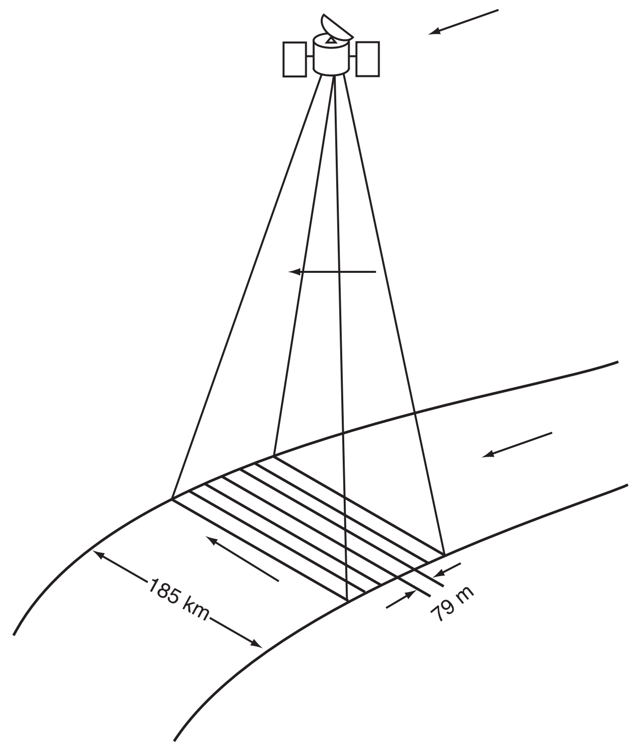

FIG. 814. MULTISPECTRAL SCANNER ON LANDSAT 1 SWEPT SIX SCAN LINES SIMULTANEOUSLY IN A SCAN PATH 185 KILOMETERS LONG. Ground spots with a diameter of 79 meters were sampled at centers 56 meters apart within scan lines 79 meters wide.
After Mark Monmonier, *Technological Transition in Cartography* (Madison: University of Wisconsin Press, 1985), 93.

Landsat's multispectral scanner measured reflected energy for a row of overlapping ground spots roughly seventy-nine meters in diameter, with centers approximately fifty-six meters apart along scan lines canvassed by the sensor's rotating mirror. As shown in figure 814, the scan lines were perpendicular to the satellite's ground track and approximately seventy-nine meters apart. For viewing on a monitor as well as data analysis, these data were typically resampled to a rectangular matrix of square cells fifty-six meters on the side (fig. 815) and framed on a Universal Transverse Mercator (UTM) grid. While the Space Oblique Mercator projection devised by John Parr Snyder provided a framework for relating

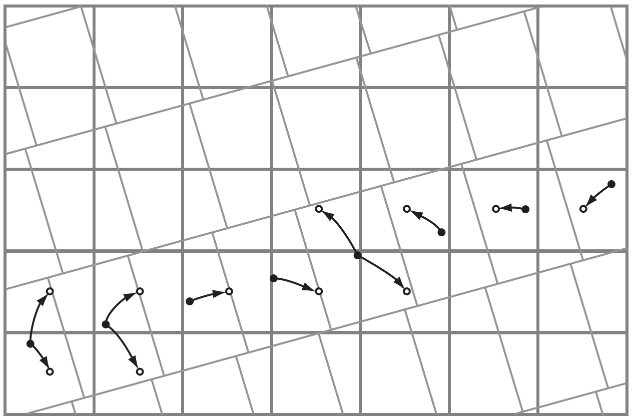

FIG. 815. RESAMPLING OF ORIGINAL, OFFSET GRID OF RECTANGULAR PIXELS TO A CORRECTED GRID OF SQUARE PIXELS.
After Monmonier 1985, 103.

individual pixels to the earth's spherical coordinates, analysts preferred images cast on the UTM projection, which allowed straightforward rectification because the offset between satellite and ground coordinates was constant (Harris 1986). In addition to providing interpolated estimates of reflectance for the resampled pixels, processing included a geometric correction for earth curvature, earth rotation, elevation, skew in the scanner's orientation to the ground track, aberrations in the satellite's velocity and orbit, and other factors (Bernstein et al. 1983).

The basic classification and analysis techniques used with multispectral satellite imagery were well established by the mid-1970s (e.g., Lillesand and Kiefer 1979, 528–99). These included image enhancement techniques like contrast stretching, which applied a larger range of gray tones to a relatively narrow range of reflectance values, which was particularly useful for visual analysis when there was very little variation at one end of the band. Another strategy created a new image by computing a ratio based on two spectral bands, chosen to highlight features known to have a high reflectance in one band and a low reflectance in the other. Other combinations of bands were used to create derived bands showing vegetation indexes where healthier vegetation shows as bright pixels and less healthy as darker pixels. Similarly, nonvegetated surfaces are very dark. These derived combinations of bands are often better behaved than the original data because they mute the effects of shadowing. Multispectral images captured by the early Landsats provided four spectral bands—one each in the green and red portions of the visible spectrum and two others in the so-called reflected-infrared zone, with wavelengths slightly longer than in the visible red band. Analysts could also apply local operators that compared a pixel's reflectance with those of its neighbors—a strategy useful for removing noise or increasing contrast. A researcher who wanted to deemphasize anomalies considered irrelevant to the analysis could apply a smoothing operator, which weakened reflectance values that were much higher than in adjacent pixels. By contrast, an analyst looking for sharp contact zones between adjoining types of land cover, for example, between farmland and residential housing, might use an edge enhancement filter that further increased potentially meaningful differences between adjacent pixels. These adjustments were most efficiently carried out with a highly interactive image analysis system with which the researcher who applied a transformation could quickly view the resulting map and make adjustments that might prove even more revealing.

The most common analysis tool was classification, which partitioned the image into two or more categories. A classification method is either supervised or unsupervised. Supervised classification relies on the researcher's knowledge of the area and underscores the inherent complementarity of fieldwork and image analysis by using a set of pixels for which the land cover is known to classify other parts of the image. A variety of algorithms are provided for assessing a pixel's relative similarity to each of the a priori land cover types and for assessing the overall accuracy of the resulting classification. With a high-interaction image analysis system the researcher could experiment with different algorithms and also use a tolerance to assign pixels with a weak match to an "other" category. By contrast, an unsupervised classifier uses one of a variety of clustering methods to look for natural groupings of cells. As with supervised classification, the user would experiment with algorithms and settings.

If the image was not reliably rectified to the geographic coordinate system used for the ground truth data, supervised classification required an additional preliminary step. A common approach used rubber sheeting, so-called because it was akin to printing an existing map on a flexible medium, attaching specific identifiable features on said medium to the corresponding pixels in the image, and relying on the resulting stretched image for all other assignments. Local transformations for various parts of the scene were represented by algebraic functions such as an affine transformation of the form

$$x' = a_1 + b_1x + c_1y$$

and

$$y' = a_2 + b_2x + c_2y,$$

where x, y and x', y' are coordinate pairs for the original map and the image, respectively, and a_1, a_2, b_1, b_2, c_1, and c_2 are y-intercepts and slope coefficients estimated using least-squares approximation (Jensen 1996, 127–29). An overall root-mean-square error measure that ranged from 0 to 1 represented the reliability of this approximation. An inverse of this transformation could then be used to overlay onto an existing base map any classified image, derived using a supervised or an unsupervised classifier. As the end of the twentieth century approached and computing performance increased, it was more common to use higher-fidelity rectifications including fully rigorous sensor models and terrain to orthorectify the imagery. The net result was imagery that had the geometric integrity of a map.

In much the same way that a usable classification depended upon the reliable registration of ground and image coordinates, multitemporal analysis based on imagery captured at two different times, perhaps with two different sensors, depended on coordinate transformations. Multitemporal analysis was especially useful in mapping deforestation, urban sprawl, and other environmentally significant changes in land cover (Coppin et al. 2004). The intelligence community relied heavily on temporal analysis of high-resolution imagery to detect new military installations, including site preparation and access roads, as well as the possible emergence of strategic targets that merited close surveillance (Corson and Palka 2004; Ruffner 1995).

By century's end spatial modeling and other applications requiring estimates of radiometric or derived values at specific points on the earth had begun to rely on advanced statistical techniques for estimating optimal local values from sample data (Curran and Atkinson 1998). Introduced to remote sensing in the late 1980s, these techniques, collectively known as geostatistics, are based on the mathematical theory of spatial autocorrelation and the semivariogram, a graphic device for describing the evenness or texture of a spatial distribution. Geostatistics was particularly useful for exploring differences in spatial variation between image data and ground data, selecting an appropriate level of resolution for data capture or analysis, and designing optimal classification methods.

Feature and Terrain Extraction

Progress in feature extraction over the fifty-year period 1950 to 2000 was tied to four major advances in overhead imaging and geospatial technology: (1) the emergence of new sensor technology; (2) the rapid development of electronics and digital computing; (3) the development of space technology, including launch vehicles and methods for adjusting and maintaining a satellite's orbit; and (4) new capabilities for geopositioning and modeling the figure of the earth. Figure 816 describes the chronological interrelationship of these trends and overarching historical developments. New sensors reflected recognition by earth scientists and military technologists that exploitation of new parts of the electromagnetic spectrum would provide views of phenomena not observable with visible light sensors alone. Radar was providing all-weather capability, thermal imaging was allowing nighttime observation as well as providing insights into the operations of vehicles and facilities, and increases in the number of spectral bands and improved spectral resolution in the near and midwave infrared portion of the spectrum were affording discrimination of surface materials with far greater certainty than previously thought possible. Space-borne capabilities developed for the military in the 1960s became available to civilian users in the 1970s, and imaging technology advanced from film-based sensors to electronic sensing with film recording, and finally to all-digital sensors by the end of the century. The development of direct digital sensors made possible multispectral, hyperspectral, high-quality thermal infrared, high-quality radar (radio detection and ranging), and lidar (light detecting and ranging). In addition, improved sensors led to new image processing techniques and triggered research on automated feature extraction. Along the way, increased resolving power expanded the ability of all-electronic sensors to "see" features in new ways.

Contemporaneous advances in electronic computing were crucial. By the late 1980s mini- and microcomputers had made computing technology more widely available and much more affordable. By the late 1990s conversion to all-digital production was well under way, fueling efforts to automate the identification of information in digital images.

Although imagery collected from space-borne platforms during the Cold War was shrouded in secrecy, civilian scientists recognized that the perspective of space could yield a new understanding of earth systems. The success of TIROS-1 (Television Infrared Observation Satellite), launched in April 1960, demonstrated that weather satellites could save many lives by fostering the analysis and prediction of severe storms. Improved land cover sensing followed the successes of the early Landsats, which evolved to offer images with ever-higher resolution. Noteworthy breakthroughs included the thirty-meter imagery from the Thematic Mapper on board Landsat 4, launched in 1982. The first SPOT (Système Probatoire d'Observation de la Terre) satellite, launched in 1986 by the French Centre national d'études spatiales (CNES), offered panchromatic and multispectral imagery with resolutions of ten and twenty meters, respectively. By 2000 the first high-resolution commercial spacecraft were returning digital imagery with pixel sizes on the ground of less than one meter.

These electronic, computing, and space initiatives promoted the development of systems for more precise

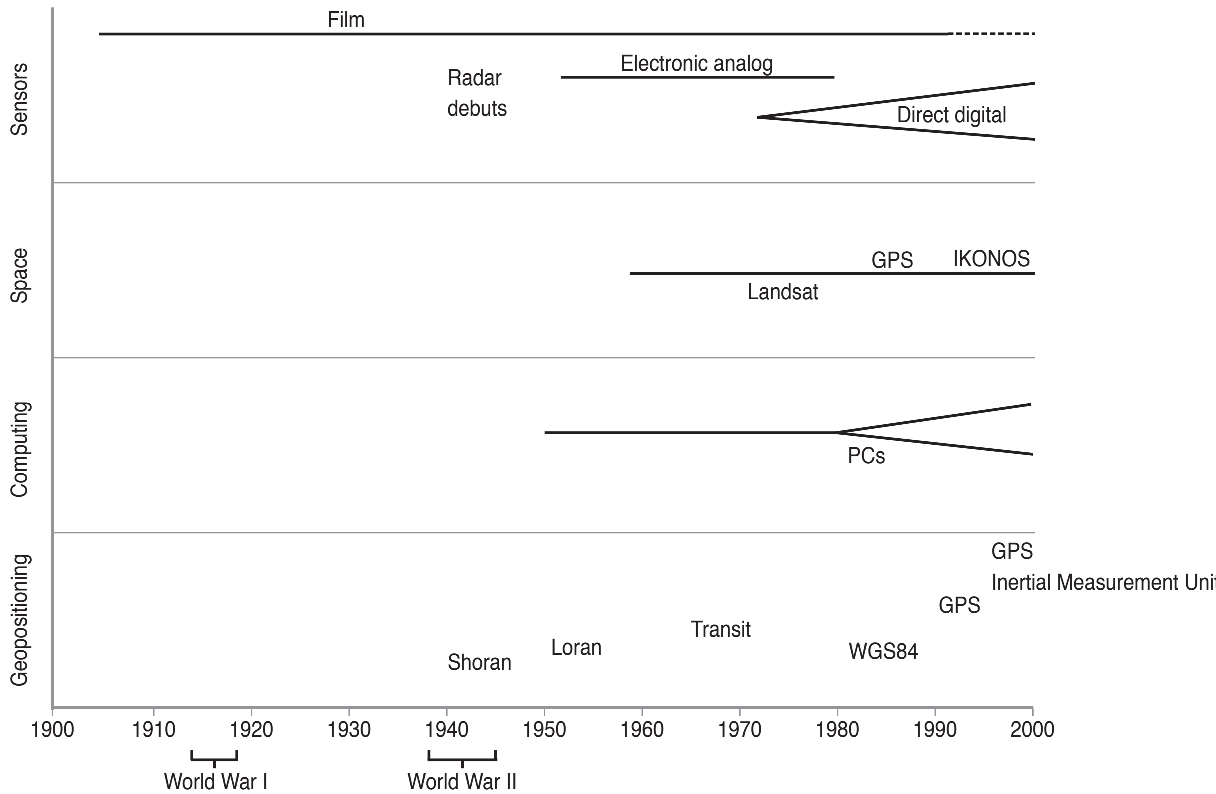

FIG. 816. APPROXIMATE TIMELINE OF SIGNIFICANT EVENTS AFFECTING THE EVOLUTION OF REMOTE SENSING AND FEATURE EXTRACTION IN THE LATE TWENTIETH CENTURY.

geopositioning, starting with radio navigation in the 1940s. By the 1950s Loran (long-range navigation) was widely used for ship navigation as well for estimating the instantaneous coordinates of an aircraft collecting imagery. Although inadequate precision and accuracy prevented the use of Loran alone for geopositioning, similar electronic principles informed the development of satellite-based survey techniques pioneered in the 1960s by the TRANSIT system, which in 1991 gave way to the fully operational NAVSTAR Global Positioning System (GPS). Satellite surveying led in turn to more precise whole-earth datums, most notably the World Geodetic System 1984 (WGS84), which provided a worldwide framework for combining GPS with inertial navigation—integration of these systems allowed precise positioning of sensors with decimeter-level accuracy (Senus 1995). This led to space-borne sensors achieving a pointing accuracy (that is, the ability to image specific ground locations) better than one arc minute (measured from the center of the earth along any great circle). This technological advance also allowed airborne remote sensors to directly georeference the imagery they collected to submeter accuracy (Mostafa and Hutton 2001). These achievements made it possible to register imagery from mission to mission and thereby employ information from previous imagery or other sources in the feature extraction process.

Although photogrammetrists had begun to ponder automated feature extraction in the 1950s, serious research was impossible as long as film was the only recording medium and most computers were analog, not digital. Even so, the quest attained some minor success as automation assumed a role in the extraction of contour lines from stereo imagery, though with human assistance. Digital computing was clearly gaining momentum in the 1970s, when the AS-11-B Stereoplotter and the Gestalt Photomapper came into full production. The AS-11 series of machines produced a grid of data points that was the forerunner of the digital elevation data set, and the Gestalt Photomapper produced contours. Both products were critical components of military guidance systems like Terrain Contour Matching (TERCOM), which kept a missile on course by comparing altimetry of the terrain below with a stored digital representation of the terrain the missile was intended to traverse (Tsipis 1975). This type of feature extraction benefitted from further developments of digital technology, and by century's end the extraction of three-dimensional models from stereo imagery was fully automated (Papapanagiotu and Hatzopoulos 2000).

Terrain extraction technology was widely employed in the United States to develop national-level elevation models, which accentuated the need for similar worldwide data sets. In 2000 the space shuttle *Endeavor* flew the Shuttle Radar Topography Mission (SRTM), which for eleven days collected interferometric SAR (synthetic aperture radar) data between 56°S and 60°N latitude. Subsequent processing produced an elevation model of the world's landmasses with ninety-meter posting—an accomplishment that eclipsed previous photogrammetric work done with photogrammetric mapping and correlation. In the 1990s the successful integration of GPS, inertial navigation technology, and computers able to construct a terrain surface from tens of thousands of pulsed laser beams produced another new technology for terrain mapping: lidar, which relied on airborne (rather than space-borne) platforms to achieve very high-resolution (submeter) digital elevation models. This and other advances in terrain extraction provided ancillary information that expedited the automated and semiautomated extraction of other map features from remotely sensed data.

Automated Feature Recognition

Multispectral pattern recognition assumes that all features have a unique spectral signature. The best example of this approach is the land use/land cover classifications that were published by USGS on a national scale. Later variants developed on a global scale to characterize the earth's surface were derived from Landsat, using a classification system based on Anderson's, which provided a workable compromise between what researchers wanted and what was practicable with the multispectral approach (Anderson et al. 1976).

Though the calibration required for unqualified spectral pattern recognition is problematic, the real issue is that man-made surfaces are seldom consistent with the assumption of a correspondence between spectral signatures and the traditional labeling of cartographic features. For example, although roofs ideally would have a spectral signature that is consistent and predicable, confusion arises because a roof can be made of many materials with a wide variety of colors. Moreover, these materials will change over time with exposure to the elements. Similar problems exist for features like road surfaces. As a result, multispectral pattern recognition works reasonably well for natural surfaces, mineral outcrops, and even vegetation but is inadequate for mapping anthropomorphic features. Intervention by a human operator was often essential (Quackenbush 2004).

Automated pattern recognition can be particularly troublesome where overlapping land covers compel a search for other solutions. A case in point is automated road extraction, which proved so problematic because of interaction with tree cover that it was largely abandoned once key users realized the ease with which the data could be collected at a scale of 1:1 with a vehicle-mounted GPS. Following the launch of the full GPS constellation in the early 1990s, firms requiring a detailed street and highway database discovered that it was more straightforward to put a GPS antenna on the roof and drive all roads systematically than to rely on overhead imagery, photogrammetry, and automated (or semiautomated) pattern recognition. GPS-based data collection figured prominently in the data acquisition practices of firms like Navteq and Tele Atlas, which licensed digital cartographic databases to web mapping firms like MapQuest and to vendors of in-vehicle GPS navigation systems like Garmin. In the early twenty-first century Google began using specially equipped trucks to collect ground-level cityscape and landscape imagery for its web-based Street View service. While this extraction of the road data was more or less automated, it was more GPS-centric than imagery-centric.

As the remote sensing community recognized the shortfalls of multispectral pattern recognition, researchers devised two separate strategies: image segmentation and hyperspectral sensors. The hyperspectral approach worked diligently to increase the spectral fidelity and resolution of the systems in an attempt to attack the limitations of multispectral remote sensing. By the 1980s it was apparent that Moore's law and computing trends in general would eventually overcome the limitations of communications and computing imposed on sensors in the 1970s. Because of the large volume of information collected with a hyperspectral sensor, the challenge for the designer has been how to store or transmit the data. As a result, the user often faced a trade-off between spectral resolution (number of bands) and spatial resolution (distance between ground samples). Though resolution remained a constraint, hyperspectral sensors were used extensively for the analysis of minerals on the surface of the earth as well as for vegetation mapping. Researchers also sought to discover the unique signatures of industrial mishaps.

In the 1970s researchers began to develop object-based techniques for the recognition of features, which led to edge-preserving smoothing algorithms that accurately delineated the edge boundaries of features while providing the machine information about the average spectral characteristics of the objects enclosed. This research not only advanced the extraction of map features but also assumed importance in robotic machine vision (Sowmya and Trinder 2000). Eventually these techniques would evolve into full object-based classification systems and find their way into feature extraction applications like those produced by ITT Visual Information Solutions and the health imaging developer Definiens (Aplin and Smith 2008). Other object-based techniques focused on feature primitives such as line features since these are the basis for recognizing roads and other higher-level semantic features such as vehicles. Researchers also explored the use of fractal geometry to distinguish man-made from natural features. Despite varying degrees of success with limited types of imagery, these approaches did not attain widespread commercial application by 2000.

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SEE ALSO: Computer, Digital; Land Use Map; Landsat; Lidar; Photogrammetric Mapping: Feature Extraction and Photointerpretation; Software: Image Processing Software

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Satellite Imagery and Map Revision. The first use of overhead imagery in map revision occurred during World War I, for trench mapping, and by World War II airborne photographic technology was in use for topographic mapping in most of the world's national mapping efforts. These endeavors involved not only new mapping but also the revision of out-of-date but otherwise geometrically acceptable existing maps. Even so, the complete revision of a quadrangle map was slow and expensive (Moore 2000), especially in the United States, where 7.5-minute topographic coverage of the forty-eight states required more than 55,000 quadrangle maps. Because it was advantageous to know which quadrangles required only minimal revision, rather than a more costly major overhaul, civilian mapping agencies were given access to remote sensing imagery acquired through a top-secret satellite intelligence program with the code name Corona. This clandestine cooperation was revealed in 1995, when Corona imagery was declassified (Ruffner 1995; Peebles 1997).

Corona was initiated by the U.S. Central Intelligence Agency (CIA) during the Cold War, when denial of access to most of the Communist Bloc posed five critical cartographic problems for the defense and intelligence communities: the lack of a global earth-centered datum for mapping, the need for broad-area photogrammetry for targeting, the need for focused photogrammetry for intelligence, the absence of infrastructure for the bulk processing of imagery acquired for mapping, and the challenge of using overhead imagery to make rapid map revisions for change analysis. Each of these problems was solved between 1950 and 1972 as part of the Corona effort. Moreover, between 1960 and 1972, Corona captured 2,109,221 linear feet of film showing the earth at spatial resolutions as great as 0.61 meters, in stereo, and eventually with some multispectral capability.

As Corona's primary intelligence tasks became routine and U.S. congressional budget scrutiny increased, pressure was placed on the CIA to allow use of the imagery for civilian applications. That roughly 6 percent of the Corona imagery provided systematic coverage of the United States presented an opportunity to enhance civilian mapping, disaster planning and relief, pollution monitoring, and general planning. The U.S. Geological Survey (USGS), the Environmental Protection Agency, the National Oceanic and Atmospheric Administration, and the U.S. Forest Service were active participants (Baclawski 1997). The civilian mapping agencies built top-secret Special Mapping Centers and equipped them with specialized hardware and computer software that implemented new automated methods for making and revising standard topographic products, including the 1:250,000 and 1:24,000 topographic map series, the GIRAS (Geographic Information Retrieval and Analysis System) land use/land cover data, and orthophotoquadrangles. The CIA's National Photographic Interpretation Center used identical technology to make 1:250,000 maps as well as composite coverages (based largely on Corona imagery) of Russia, China, Antarctica, and Africa.

The value of Corona was particularly apparent in the film's spatial resolution. The KH (Keyhole) series cameras achieved exceptionally high spatial resolution with impressive contrast on monochrome film. The narrow Corona filmstrips could be enlarged to the limits of their spatial resolution. The hazy KH-1 images with 6.1-meter resolution gave way in only three years to images with 61-centimeters resolution, although the KH-4B provided the best resolution for map revision, at 1.8 meters. This improvement is in stark contrast to the civilian ERTS (Earth Resources Technology Satellite) program, later renamed Landsat, which achieved 79-meter resolution (with three multispectral bands) in 1972, 30 meters with the Thematic Mapper in 1982, and 15 meters with Landsat 7's Enhanced Thematic Mapper Plus in 1999.

By 1966, the still partially classified DISIC (Dual Improved Stellar Index Camera) was completed to complement the higher-resolution KH-4 family of stereo panoramic cameras for the rest of the Corona program. As DISIC allowed automatic position correction, the Universal Photogrammetric Data Reduction and Mapping System (UPDRAMS) could automatically correct the data's geometry. Other hardware included the Universal Automatic Map Compilation Equipment (UNAMACE)

FIG. 817. DETAIL FROM THE 1950 GOLETA, CALIFORNIA, 7.5-MINUTE QUADRANGLE. Section showing the University of California at Santa Barbara [UCSB] and Isla Vista. Size of the entire original: 66.5 × 53 cm; size of detail: 13.6 × 19.3 cm. Image courtesy of the U.S. Geological Survey, Denver.

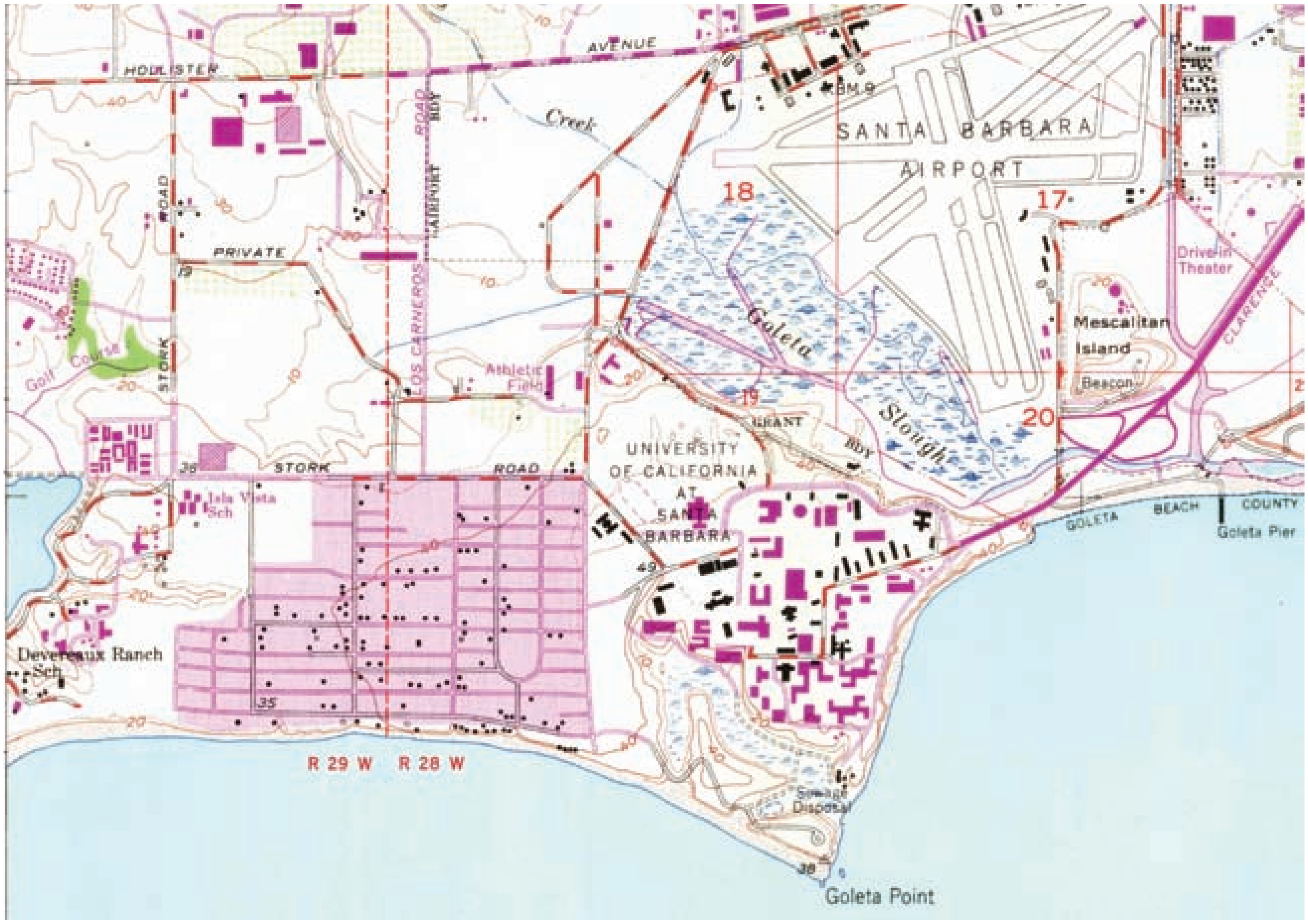

FIG. 818. DETAIL FROM THE REVISED GOLETA, CALIFORNIA, 7.5-MINUTE QUADRANGLE PUBLISHED IN 1967. Revisions are in purple. The map collar acknowledges "based on aerial photographs . . . and other source data." Size of the entire original: 66.5 × 53 cm; size of detail: 13.6 × 19.3 cm. Image courtesy of the U.S. Geological Survey, Denver.

and the Automatic Stereo-mapper model 11 (AS-11). The couplings among Corona film, the DISIC system, UPDRAMS, and the UNAMACE and AS-11 created a mapping and geodata system far more suited to mapping than the original reconnaissance system was for spying (Clarke and Cloud 2000, 199)—it was particularly suited to change detection, including the identification of places in need of map revision. Corona eventually became almost the sole source of data for the military mapping program of the U.S. Defense Mapping Agency (DMA) and was central to the creation of the DMA in January 1972, just months before Landsat initiated the civilian era of satellite-based map revision.

The U.S. Geological Survey (USGS), which became the largest civilian user of the Corona imagery (Baclawski 1997, 237), pioneered the Special Mapping Centers, the first of which was opened in late 1968 in Reston, Virginia, as Building E-1, next to a DMA facility. Inside E-1, the USGS used Corona to revise the 1:250,000 national map series twice, and Corona became the core of the system devised to organize revisions to the 1:24:000 series topographic maps (figs. 817 to 820). The revised maps bear the notice, however subtle, "Photorevisions based on aerial photography and *other* source data" [italics mine]. While this effort was under way, the USGS initiated a new national land use/land cover series, based on its 1:250,000 and 1:100,000 map series but clearly with a more detailed map base. These maps were among the first digital mapping/GIS ventures undertaken by the USGS. The Special Mapping Centers used specialized hardware, methods, and computer software in the same way that Corona imagery was processed for military and intelligence uses, and military personnel often moved there on retirement from the services. As a classified facility with equipment identical to the military's, the Special Mapping Centers were used extensively for emergency intelligence or military purposes, for example, during the first Gulf War (1991).

FIG. 819. DETAIL FROM 70 MM CORONA KH-4B FILM SHOWING GOLETA, CALIFORNIA, TAKEN 15 NOVEMBER 1966.

Image courtesy of the USGS Earth Resources Observation and Science Center (EROS).

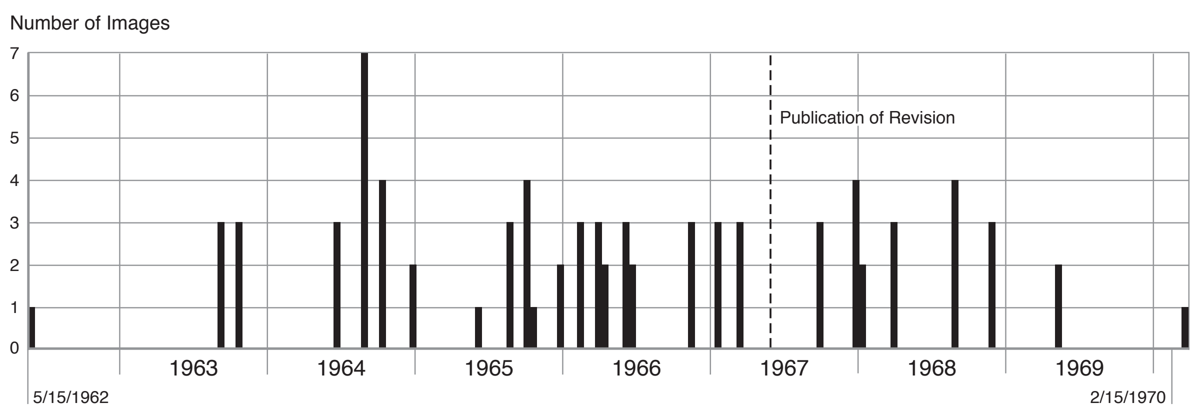

FIG. 820. THE FREQUENCY OF CORONA IMAGES OF GOLETA, CALIFORNIA. The number of images collected between May 1962 and just after February 1970, the time around the revision of the Goleta 7.5-minute quadrangle revision.

The Landsat program, which also benefited from classified remote sensing activities, became a source of data for map revision within and beyond the U.S. government as the resolution of its imagery improved from 79 meters in the early 1970s to 15 meters by century's end (Mack 1990). In addition, commercial data with even higher resolution, notably from the French SPOT (Système Probatoire d'Observation de la Terre) satellite, were often used in research to improve everything from land use maps to census enumeration districts. With the declassification of Corona in 1995, and some of its successor programs in 2002, controls on high-resolution imagery were lifted and a new generation of commercial satellites built for the coming century. By 2000 satellite and aerial imagery had become the sources for virtually all revisions to general topographic maps worldwide as well as the primary source for many special-purpose series such as land use/land cover and vegetation maps.

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SEE ALSO: Marine Chart; Photogrammetric Mapping: Military Photogrammetry as a Precursor of Remote Sensing; Topographic Mapping: United States; U.S. Intelligence Community, Mapping by the

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Remote Sensing as a Cartographic Enterprise. Much of the history of cartography has been characterized by the quest to construct accurate planimetric frameworks and to systematically acquire thematic content to populate those frameworks. Cartographic practice was transformed during the twentieth century by the introduction of aerial imagery—a source that provides systematic geographic coverage, rich with varied thematic content. Dependent on data collected though direct but isolated field observations, statistical summaries, and generalizations of phenomena that could not be directly observed, early twentieth-century cartography had many limitations: incomplete coverage, inadequate spatial control, an inability to represent distributions faithfully, and an inability to provide sequential representations of seasonal and temporal changes. By the end of the century, the field of remote sensing changed the practice of cartography by providing images of the earth's surface for multifaceted data to depict a wealth of thematic subjects.

Concisely defined, remote sensing is the practice of collecting and analyzing imagery of the earth using specialized instruments, such as aerial cameras and scanners, carried by aircraft and satellites. The cartographic status of remotely sensed imagery is nebulous in that its thematic content has not been simplified and generalized to create genuine cartographic entities, and it carries a scale and positional framework derived from an instrument rather than a systematic cartographic projection. An aerial photograph, for example, ostensibly qualifies as a cartographic object but lacks the coherent projection and the symbolization of its thematic content that are often considered prerequisites for cartographic status. Yet relatively simple processing can present images in accurate spatial frameworks and can select and enhance thematic information to present effective cartographic products. Nonetheless, much work still remains to design tools specifically tailored for the cartographic display of data extracted from remotely sensed imagery.

The origins and maturing of aerial imagery in cartography have closely followed the arc of events that have defined the twentieth century. Although the early history of photography includes much evidence of an innate human interest in photographing landscapes from elevated perspectives (such as high buildings and topographic features and then, later, kites and balloons), early aerial images served mainly as novelties, usually without scientific or practical value. World War I served as the catalyst to integrate the camera and the airplane as a coherent system (Campbell 2008). The British and French military services were leaders in aerial photography, although the bitter, brutal conflict provided incentives for all belligerents to make rapid innovations, mainly for the collection of tactical intelligence. Military pilots immediately recognized the value of aerial photography, but practical and institutional barriers initially inhibited the pace of this integration. The end of World War I interrupted rapid development of systems that would systematically acquire photographs representing large geographic regions. Although military applications continued to promote development of aerial imaging technologies throughout the century, applications migrated to encompass broader societal needs.

During the interwar period (1919–39) military interest in aerial reconnaissance focused mainly on specialized topics and demonstration projects. Thus, some of the most important developments occurred in private industry during this period. For example, Sherman M. Fairchild founded numerous companies, including Fairchild Surveys and Fairchild Camera and Instruments, which became leaders in aviation and in aerial camera design. Talbert Abrams produced many innovations in aerial survey, aviation, camera design, training, and international operations. Willis T. Lee (1922) provided an overview of the capabilities of aerial photography during the early postwar era, including a vision of the scope of applications that might be possible in, for example, coastal geomorphology, urban planning, geological investigations, forestry, and agriculture.

Aerial mapping was recognized as an important tool to provide cost-effective data to guide remedies for both economic and environmental problems during the worldwide economic depression of the 1930s. For example, soil erosion, dust storms, and floods were among the many forms of land degradation related to economic decline in the United States. Aerial surveys of agricultural lands supported programs to stabilize agricultural commodity prices and to support soil survey and conservation efforts (Monmonier 2002). The Tennessee Valley Authority (TVA) began systematic use of aerial photography in the 1930s to support cadastral mapping and document land transfers of areas flooded behind the dams constructed to provide electrical power. The TVA utilized aerial photography for land use mapping, for malaria suppression, and for monitoring construction projects. Probably the TVA's most important cartographic contribution was development and application of photogrammetric principles for accurate survey of large regions. Although private enterprise of this era invested in civil aerial mapping, their contributions were often focused on acquisition and extraction of planimetric detail rather than extraction of thematic detail.

During World War II the role of aerial reconnaissance expanded from a purely tactical focus into the realm of strategy, assuming a much broader scope both geographically (deeper into hostile territory) as well as thematically (seeking a more profound understanding of the nature of the enemy's economic and transportation infrastructure). The most visible advances during this war featured specialized equipment and systematic training programs. However, institutionalization of aerial reconnaissance and photo intelligence were the most important changes. The military value of photo intelligence was proven by routine applications in all theaters, but at the strategic level its value was validated by high-visibility successes such as the photographic analysis that permitted detection and monitoring of the deployment of the German V-1 and V-2 weapons (Babington Smith 1957). Furthermore, surplus equipment and experienced personnel at the end of the war encouraged development of aerial survey firms. During the postwar decades, institutionalization of the practice of photogrammetry and the routine use of color infrared film formed the basis for a wide range of practical applications of aerial imagery across a wide spectrum of uses.

Meanwhile, the Cold War fueled innovation in military and strategic reconnaissance that resulted in improved films and optics and new sensor systems effective in the nonvisible spectrum. While mapping remained under state control in the Soviet Union and its allies, Western countries released many outmoded military capabilities by the mid-1960s as more advanced systems became operational. As a result, there was a wide range of uses in civil mapping applications (fig. 821). By

FIG. 821. MANUAL RELIEF DEPICTION FROM AERIAL PHOTOGRAPH. A cartographic technician uses an airbrush to depict relief, as interpreted from aerial photographs, 1961. Within a few decades, computer cartography could routinely create this effect by applying hillshading algorithms to digital elevation models to simulate the northwest light source that creates the 3-D effect.
Image courtesy of the Photographic Library, U.S. Geological Survey, Denver. Photograph by E. F. Patterson (no. 1024).

1970, a report prepared by the U.S. National Research Council outlined how these technologies might address problems in the civil sector, which included forestry, agriculture, and hydrology. Aerial survey and remote sensing technologies also supported investigations of water and air pollution and related environmental issues. The U.S. Environmental Protection Agency, formed in 1970, made effective use of aerial survey and remote sensing in enforcement of environmental laws and regulations (Erb et al. 1981; Lyon 1987).

By the late 1960s, the U.S. government mapping activities included a multiplicity of organizations and agencies conducting mapping and aerial survey operations. In the early 1970s, the Executive Office of the President and the Office of Management and Budget conducted a study of the multiple mapping and geodetic activities within the federal government; its objective was to reduce duplication, improve compatibility, and assure full use of available technology. The findings, published as *Report of the Federal Mapping Task Force on Mapping, Charting, Geodesy and Surveying*, 1973, led to consolidation and coordination of governmental programs and the formation of federal standards for accuracy and compatibility.

At the height of Cold War tensions, strategic reconnaissance capabilities were evident in the U-2 program, the decisive U.S. use of aerial reconnaissance in the Cuban Missile Crisis (1962) (Brugioni 1991), and the development of then-classified satellite capabilities. In

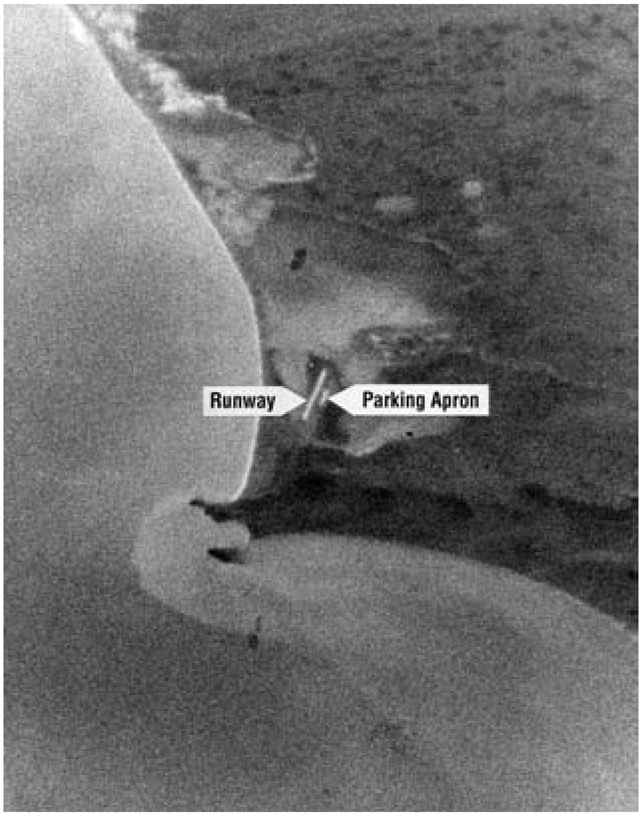


FIG. 822. IMAGE FROM EARLIEST SUCCESSFUL CORONA MISSION. Mys Shmidta Air Field, Soviet Union, 18 August 1960 as viewed by the U.S. Corona strategic reconnaissance satellite imaging system. This is the first detailed image of the earth's surface collected from space. It depicts a remote airfield situated on the Arctic coast of Siberia. Later imagery provided much finer spatial detail that built an understanding of the Soviet military infrastructure and a geodetic framework for large regions of the earth. The Corona system formed a precursor for later satellite imaging systems.
Image courtesy of the U.S. National Archives, Washington, D.C. (Record group 263, folder #51).

1959 the Corona satellite system proved the capability and efficacy of capturing earth imagery from outer space (fig. 822), and in April 1962 the Soviet Union launched Zenit-2, a derivative of the manned Vostok spacecraft. Launched as a highly classified program by the Central Intelligence Agency (CIA), the Corona system acquired detailed photographs of the earth. Unlike current satellite systems that transmit data electronically, Corona film was returned to earth in specialized canisters that were retrieved during their descent by aircraft equipped to snag the parachutes as they entered the lower atmosphere. Although such developments had no immediate impact on cartographic practice, they validated aerial and satellite imagery as a source of reliable data within the mapping profession and established the infrastructure for the remote sensing industry and standards that are in place today (Perry 2012).

The Landsat earth observation system, launched in 1972, provided systematic coverage of the earth's land area by imaging systems on a repetitive basis. In the context of remote sensing, the innovative design of Landsat imagery recognized the value in systematic collection of broad-scale, moderate-resolution multispectral data. Formerly such broad-scale patterns could be represented only by interpolation from rather sparse detail or by composites formed by assembling pieces often collected at different times, with different techniques, or with different levels of detail. Once Landsat offered a steady stream of data in a standardized form, the community of users improvised experiments and innovations beyond the initial formalized strategies. Landsat data are freely available to laymen as well as scientists—the decadal scope of this archive of intercalibrated imagery, with spectral and spatial continuity, has provided a unique cartographic resource for examining temporal changes in earth resource, agricultural, and urban systems (Woodcock et al. 2008).

One example of the capabilities of land observation satellite systems is the Large Area Crop Inventory Experiment (LACIE), initiated in 1974 as a program to apply systematic, repetitive, multispectral satellite imagery to broad-scale crop inventory. LACIE was a collaboration of three U.S. government agencies: the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration, and the Department of Agriculture. The experiment used Landsat imagery, together with computer-based climate models and satellite-based meteorological data to develop and validate a procedure for estimating crop production within the world's principal wheat-producing regions. The objectives were to forecast wheat production, to anticipate fluctuations in crop yields, and to stabilize markets by providing timely and accurate information. Although the accuracies of specific forecasts were mixed, LACIE successfully estimated U.S. crops and accurately forecast the 1977 Soviet spring wheat crop.

One of the Landsat system's most far-reaching impacts has been to stimulate design of similar earth observation systems by Japan, India, Brazil, Indonesia, China, and the European Space Agency, among others (see fig. 813). One of the first of these, SPOT (Système Probatoire d'Observation de la Terre) satellites, are operated by SPOT Image Corporation, a public company created in 1982 by the Centre national d'études spatiales (CNES), the Institut géographique national (IGN), and a consortium of European manufacturers. First launched in 1986, SPOT is notable because it modified the Landsat model for systematic multispectral imaging of the earth's land resources based on a later generation of imaging technology and by pioneering commercial satellite imaging. SPOT's commercial enterprise formed a worldwide system for delivering products and services. The system's advanced technical capabilities employed stereoscopic sensors to generate digital elevation models and its off-nadir viewing capability to improve monitoring of time-critical events such as floods, fires, and other natural disasters.

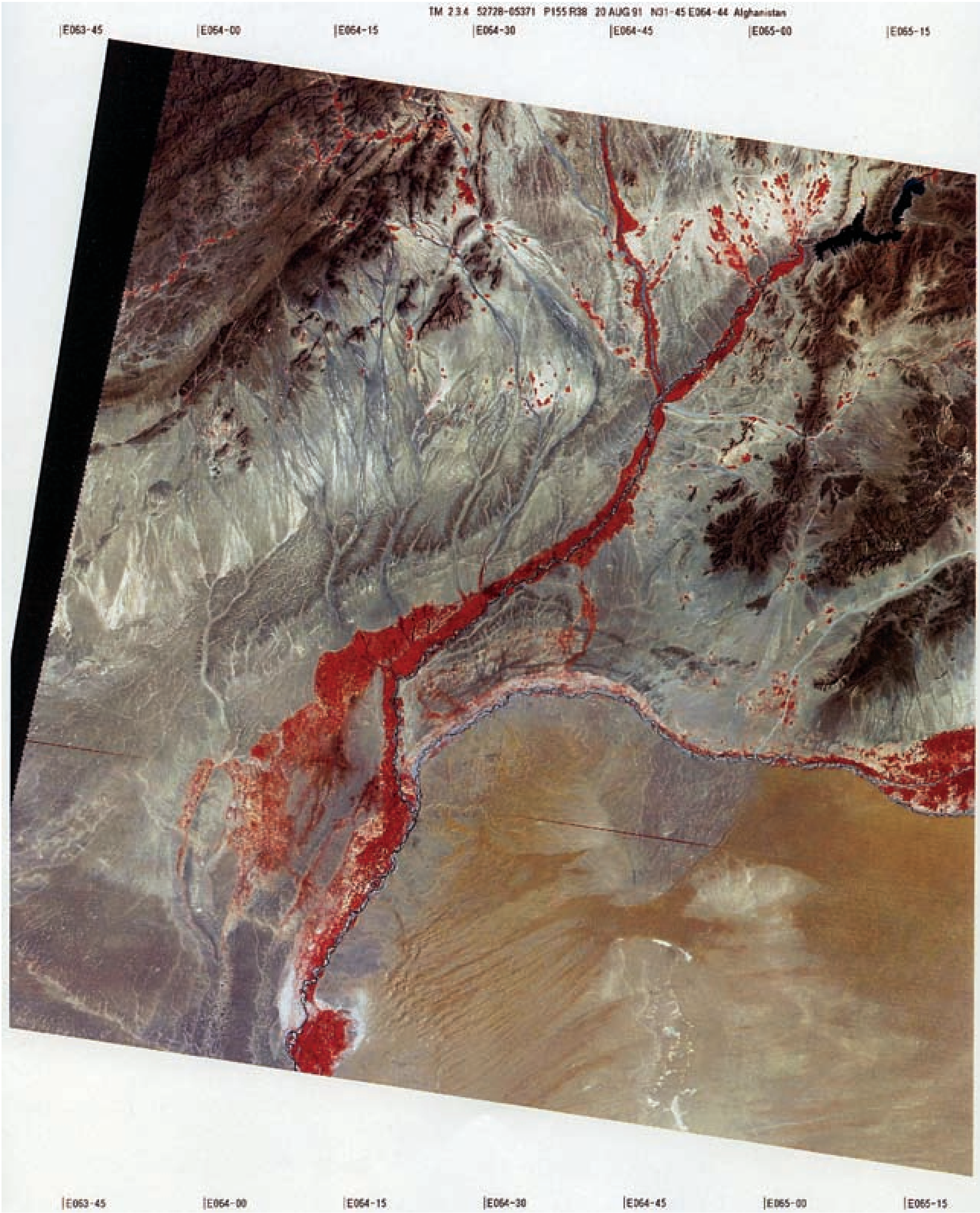
Parallel developments in the Soviet Union between 1961 and 1989 (and thereafter in Russia) applied satellite imaging systems to collect imagery supporting cartographic practice. Several systems were designed initially for security missions but later were tailored for more broadly defined cartographic and resource missions. Most of these imaging systems were based on returned-film technology, where the exposed film was returned to earth for processing. Initially, these cameras relied upon prevailing film formats and lens systems, and then, later, on electronic imaging instruments. The various system designs included stereo capabilities, usually including panchromatic, natural color, and color infrared coverage (and spectrazonal film—a Soviet variation on the more common color infrared films). Depending upon sensor and date, imagery provided detail as coarse as 137 meters to as fine as 2 meters. The systems of greatest significance for cartography are probably the Meteor and Resurs-O satellites, designed for combined meteorological and resource missions. These systems initially used videocons, and later (1974), optical-mechanical cameras. Later, synthetic-aperture radar (SAR) systems carried on-board Almaz satellites acquired imagery at 15- to 30-meter detail. Russian returned-film imagery was commercially available from the Russian firm NPO Planeta in digital form, derived from scanned film—a product that was attractive to some customers because the orbital tracks provide coverage of polar regions, unlike many other satellite imaging systems.

In 1969, the establishment of Earth Satellite Corporation (EarthSat) (as of 2005, MDA Federal Inc. [MacDonald Dettwiler and Associates]) formed the beginnings of a new industry that focused not only on acquisition of imagery but also on applications of image processing and geographic information technologies for the exploration and management of natural resources (fig. 823). Such organizations focused on bringing varied forms of aerial imagery together to address customers' needs. These developments created an environment promoting extraction of thematic data from digital multispectral data, tasks that formerly could be carried out only by assembling information from diverse sources, formats, and scales to create composite representations of broad-scale patterns (forests, agriculture, water bodies). Through decades of incremental progress, ultimately such capabilities created new audiences and new markets for new classes of data and information despite uncertain reliability, unfamiliar scales, and unclear matches to scientific and conceptual requirements. By the early 1980s, a second generation of instruments for collecting satellite imagery provided finer spatial detail at thirty-meter, twenty-meter, ten-meter, and, by the late 1990s, meter and submeter resolutions. By the late 1990s, development of commercial systems (e.g., GeoEye and IKONOS) for acquiring fine-resolution satellite imagery (initially at spatial resolutions of several meters, but eventually submeter detail) opened new applications formerly available only through the use of aerial photography. Such progress in the field of remote sensing advanced in tandem with advances in geographic information systems (GIS), which brought remotely sensed data and other geospatial data into a common analytical framework, thereby enhancing the range of products and opening new markets, such as mapping of urban infrastructure and supporting precision agriculture and floodplain mapping.

Decentralization of computing capabilities put processing in the hands of a broad population of entrepreneurs. Products tailored to specific markets grew out of the needs of commerce and industry, agriculture and forestry, hydrology and water management, exploration geology, and urban planning (but, it should be noted, usually very specific niches within each of these areas). Fine-resolution data opened markets for news media (fig. 824), and, behind the scenes, continued markets within the military and national security communities. Although these developments began by the 1990s, they did not mature until the first decade of the next century.

The context for the development of many of these new cartographic applications of remotely sensed data includes: (1) a public policy that has maintained relaxed constraints on the acquisition of fine-resolution satellite data and (2) personal privacy policies that favor the collection of imagery (Campbell, Hardy, and Barnard 2010). There has been a class of cartographic products derived from remotely sensed data, including, for example, those created by MapQuest and related navigation software, which rely on road networks that are systematically updated by analysis of remotely sensed imagery. In the dynamic cartographic environments of these applications, resolution, scale, symbolization, and selection of information have become plastic qualities.

Thus, by the end of the twentieth century cartographic practice experienced profound changes through the blurring of distinctions between images and maps. In the world of map use, digital replacement of analog format seems almost complete, tailored for dynamic delivery of cartographic detail to a public that has developed a huge appetite for cartographic information and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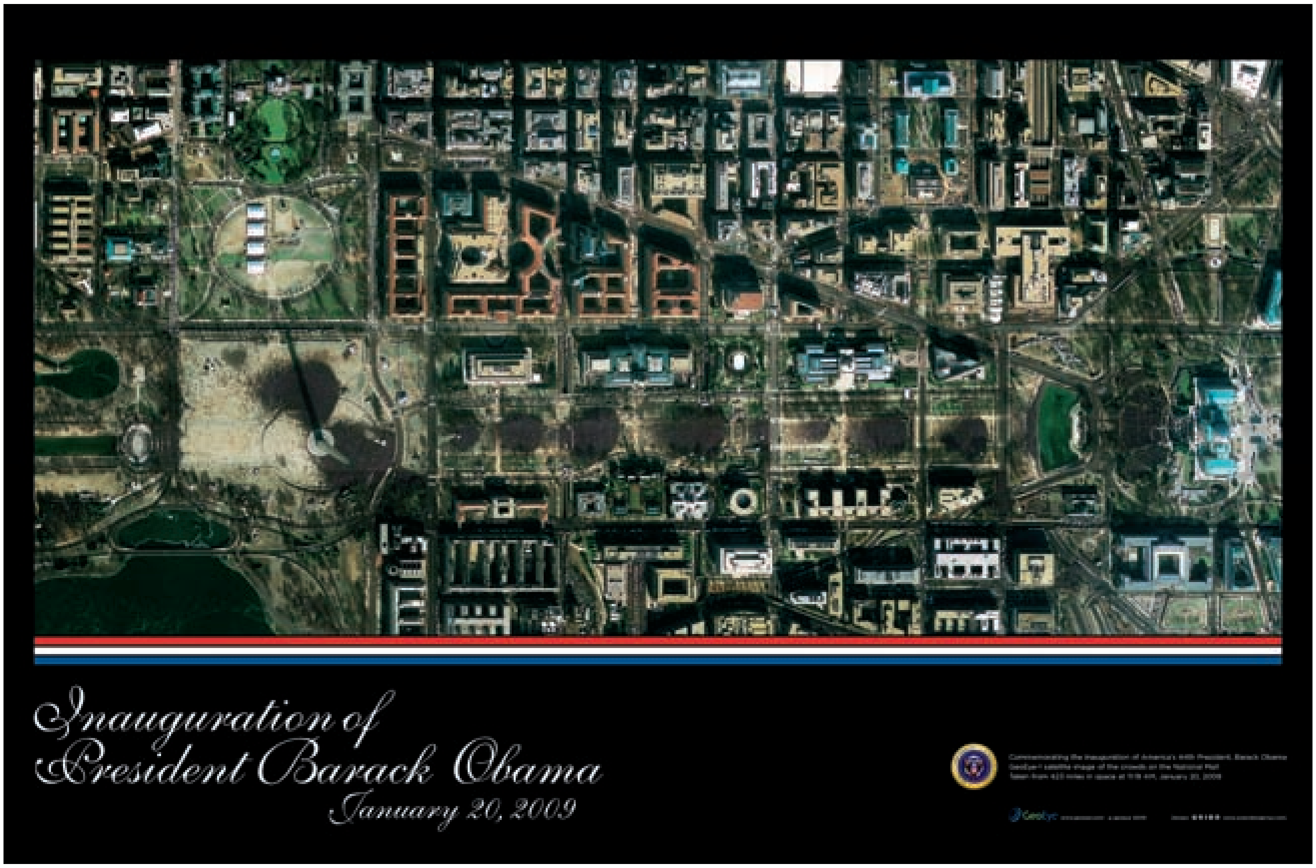

FIG. 824. SATELLITE IMAGERY USED TO MAP MEDIA EVENT. Poster of the first presidential inauguration of Barack Obama as viewed by GeoEye-1. By the end of the twentieth century, commercial satellite imagery could provide fine-resolution imagery for a wide range of applications, including many far beyond the technical and scientific applications of typical of earlier eras. The news media were interested in uses of satellite imagery to report not only public events, such as the 2009 inauguration, but also those relating to natural disasters, national security, and environmental issues.
Satellite image courtesy of GeoEye. Poster image courtesy of Joel Campbell.

a willingness to accept wide departures from traditional cartographic conventions in display and presentation. Changes in cartographic style and practice were not innovations of cartographers, defined in the usual sense, but rather adoptions tailored to fit the use of nontraditional delivery formats. By the end of the century, the Internet, mobile phone displays, and screens of Global Positioning System (GPS) receivers formed the vellum of the age. These changes of course have been implemented through pragmatic design decisions made by programmers and graphics artists without regard for conventional cartographic practice. The success of such designs has been mixed: some of the new technologies were innovative, but others lacked legibility, clarity, and functionality.

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SEE ALSO: Landsat; Map: Images as Maps; Marketing Cartographic and Spatial Data; Scale; Software: Image Processing Software

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FIG. 823. PHOTOMAP BASED ON LANDSAT THEMATIC MAPPER (TM) IMAGERY. TM digital imagery, collected in the green, red, and near infrared regions of the spectrum, has been processed to enhance its visual qualities and project it into an accurate map base. During the 1980s, such products formed map substitutes for remote regions that were not then represented by conventional maps—often prepared for use by international development agencies, by military services, and for mineral exploration. This photomap depicts Helmand province, Afghanistan—the reds represent irrigated crops, the light browns indicate sand sheets, the grays correspond to broad alluvial outwash sheets, and the dark browns represent rocky outcrops. This product is typical of those produced in the 1980s by private corporations specializing in custom processing of digital imagery.
Size of the original: 26 × 20.7 cm. Image courtesy of James B. Campbell. Permission courtesy of MDA Information Systems, Gaithersburg.

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Report of the Committee of Enquiry into the Handling of Geographic Information (1987). Named the Chorley Report after its chairman, Lord Roger Chorley, the Report of the Committee of Enquiry into the Handling of Geographic Information assessed the potential in the United Kingdom for the emerging geographic information systems (GIS) technology. It was preceded by two reports, one from the Ordnance Survey Review Committee (1979), chaired by Sir David Serpell, a former senior civil servant, and the other from the House of Lords Select Committee on Science and Technology (1983). Several threads connect these three reports, notably persons. Lord Chorley was a member of all three committees. Walter Smith, the first civilian head of the Ordnance Survey (OS), acted as advisor to Serpell and was a member of the Chorley Committee, as was David Rhind, who was technical adviser to the House of Lords Committee and subsequently became head of the OS.

The Serpell Committee was established in 1978 "to consider and make recommendations about the longer term policies and activities of the Ordnance Survey" within "the context of national surveying and mapping needs" (Great Britain, Ordnance Survey Review Committee 1979, ix) and in anticipation of the completion by 1980 of the 1938 resurvey program. Aware of the financial advantages of digital cartography, the committee set long-term objectives for the OS to develop digital methods of map production.

Four years later, the House of Lords saw digital techniques as opening up "new horizons for handling spatial data; and that as a result the demands of map users will gradually change" (Great Britain, Parliament, House of Lords Select Committee on Science and Technology 1983, 1:42). Endorsing Serpell, the House of Lords Committee recommended a major increase in research and development as well as a ten-year digital program that included small-scale mapping and GIS. Their call for further study of the handling of geographic information led to formation of the Committee of Enquiry into the Handling of Geographic Information (1987).

The Chorley Committee compared the significance of GIS in spatial analysis to the importance of the microscope and telescope in science. Focusing on barriers to the effective use of GIS, the committee identified several pressing matters, specifically the need to (1) accelerate the OS digital program and for government to settle the issues of copyright and pricing policy; (2) identify and make available the huge range of government-collected spatially related data, mostly of a socioeconomic nature, and to deal with inhibiting factors such as confidentiality, administrative attitudes, and full-cost pricing; (3) promote increased compatibility through data transfer standards, consistent spatial units (especially the postal code system), and uniform locational referencing (such as the OS National Grid); and (4) generate wider awareness of these powerful new tools among analysts and decision makers. Recommendations included a Centre for Geographic Information to provide a forum for discussion and exchange of experience among widely different interest groups.

The report was submitted to the government in May 1987. The Ordnance Survey responded positively to the relevant recommendations, and the Association for Geographic Information was set up by a private-sector initiative and with the encouragement of the Royal Geographical Society and the Royal Institute of Chartered Surveyors.

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SEE ALSO: Geographic Information System (GIS): GIS as an Institutional Revolution; Ordnance Survey (U.K.)

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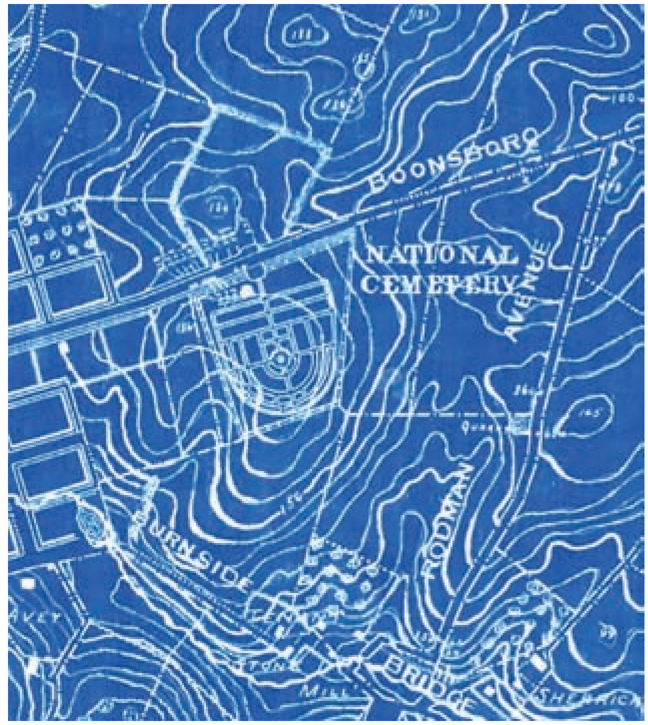

FIG. 825. DETAIL FROM *MAP OF THE BATTLEFIELD OF ANTIETAM* ([N.p.]: ANTIETAM BATTLEFIELD BOARD, 1898). Surveyed and drawn by Colonel E. B. Cope, engineer, and H. W. Mattern, assistant engineer, Gettysburg National Park, ca. 1:10,560. This blueprint illustrates the capacity of the process to make exact copies of detailed line drawings by contact printing.
Size of the entire original: 79 × 65 cm; size of detail: 9.5 × 8.4 cm. Image courtesy of the Geography and Map Division, Library of Congress, Washington, D.C.

Reproduction of Maps.

REPRODUCTION OF MAPS BY ONE-OFF PROCESSES
REPRODUCTION OF MAPS BY PRINTING
ENGRAVING
PHOTOMECHANICAL PROCESSES
COLOR REPRODUCTION
PREPRESS TECHNIQUES
REPRODUCTION, DESIGN, AND AESTHETICS
FOLDING STRATEGIES

Reproduction of Maps by One-Off Processes. Photography, based on the ability to create images automatically through the action of light on a sensitized emulsion, was invented in Europe during the 1830s. By the 1860s photography was in use for creating intermediate cartographic images used in printing multiple copies of maps as well as the final, duplicated map when only one or a few paper copies were needed. For the first time it became possible to duplicate map drawings on demand (Rhodes and Streeter 1999, 155). One-off duplication processes are so called because exposing, developing, and fixing the image yields a single duplicate and must be repeated for each copy.

Surviving maps duplicated in the 1860s by one-off processes reveal limitations. One example is a U.S. Civil War map made in 1864 by sunlight passing through a positive drawing (black lines on thin white paper) to expose the chemically treated paper placed underneath, resulting in a negative contact print (McElfresh 1999, 173). Larger-format maps could be photographed and printed in sections. For example, the British Library holds four copies of a Turco-Persian boundary map produced in St. Petersburg in 1869, each made by assembling photographic prints on backing sheets (Chirikow et al. 1869).

The blueprint process, invented by Sir John Frederick William Herschel in England in 1842, became more widely used for contact copying after commercially produced blueprint paper was introduced in France in 1876. It employed complex ferro-prussiate (iron) salts, which stained the exposed paper dark blue after wet developing. Exposure by electric light became possible in 1895, and machines capable of exposing, developing, and drying blueprints came into use in the 1920s (Kissel and Vigneau 1999, 31). Negative blueprints with white lines on a blue ground resulted from exposure through positive line drawings (fig. 825), while exposure through negatives produced positive blueprints. Also called cyanotypes and ferro-prussiate prints (Kissel and Vigneau 1999, 31), such blueprints were common in North America until World War II. Related but less common processes were the Pellet process (registered by Henri Pellet in 1877 and patented in the United States in 1881), the ferrogallic process (invented by Alphonse Poitevin in France in 1860 and used mainly in Europe), and Vandyke prints (patented in Paris in 1889 and later introduced to England) (Kissel and Vigneau 1999, 45–46, 57–59, 73–74). Blueprint was so much more popular that the name "blueprint" was not only sometimes applied to successor processes (such as diazotype) but also acquired, by association with the maps and plans that it duplicated, the meaning of design or plan, as in the expression "blueprint for the future," which outlived the originating technology.

The diazotype process, invented in England in 1890, took its name from the diazonium salts that gave its prints a wide range of colors, mainly purple, blue, black, and brown, but also red and green. Other English names for diazotype include "primiline" (the original name of the process), "Ozalid" (a brand name often used as a generic term), "dyeline," "white print," "direct print," "blueline," "blackline," and even "blueprint" (Kissel and Vigneau 1999, 37), while names in other languages most often incorporated the word diazo. Advantages over blueprint lay in positive-to-positive images and dry developing (by exposure to ammonia fumes or to heat, which did not alter the dimensions of the paper or, consequently, the scale of the drawing) (Kissel and Vigneau 1999, 37–39). The German firm Kalle & Co. followed the 1917 introduction of its Ozalid process by employing high-quality presensitized paper with a 1920 British patent for the first dry process. More versatile than blueprint, diazotype was printed onto drafting cloth and, from the 1930s onward, many types of plastics and papers served as both intermediate and end products of cartographic reproduction (Kissel and Vigneau 1999, 37–38). Diazotypes could be made from an original drawing in ink or pencil on thin paper, from intermediate diazotypes on translucent paper, or from photographic film negatives or positives. By the 1930s sepia diazo prints were serving as intermediates from which further diazo copies could be made, often after making deletions (with eradicator fluids or, after 1970, by erasure) or additions (by drawing on the plain verso of the reverse-reading print) (Kissel and Vigneau 1999, 64). Government agencies often maintained master copies of maps needing frequent updating (such as utilities maps) or in low demand (such as U.S. Geological Survey Open-File Reports) that could be copied on demand for customers as diazotype prints. Diazotype film copies of maps found various uses, ranging from transparencies for overhead projectors (Tarbet 1965, 266), which were common in American schoolrooms from the 1950s onward but had declined in use by 2000, to color composites of Landsat imagery, deemed more cost-effective for data extraction in the early 1980s than digital processing (Langeraar 1993, 415–16).

FIG. 826. *APPROACHES TO CHARLESTON, S.C.* Redrawn from the *Official Records of the Union and Confederate Navies in the War of the Rebellion*. Photostat reproduction. [N.p.]: [U.S. Navy, 19—?]. This negative photostat is a reproduction of a redrawn chart showing the positions of U.S. Navy ships and shipwrecks during the Charleston Campaign, 1863–65 of the American Civil War.
Image courtesy of the Naval Historical Foundation, Washington Navy Yard, D.C.

The photostatic process filled a different market niche and successfully coexisted first with blueprint and later with diazotype until after midcentury. Introduced in 1909, the Photostat machine became available in 1911 from the Commercial Camera Co., Rochester, New York (Kissel and Vigneau 1999, 51). The Photostat, a photographic copying machine combining a camera with developing and fixing apparatus, produced black-and-white photographic prints without an intervening negative (fig. 826). Unlike most other duplicating processes, the drawing did not have to be on a translucent medium. Until positive-to-positive copies became possible in 1953, photostatic prints were negatives, although positives could be made by the second step of photostating negative photostats. The silver emulsion used for photostatic prints reproduced colors and tones as shades of gray, while the graduated scales on the machine made accurate enlargement and reduction easy (Kissel and Vigneau 1999, 50–51). The photostatic process was commonly used for facsimile copying of maps (such as by library copy services) during the first half of the twentieth century.

Electrostatic photocopying, invented in the late 1930s by Chester Floyd Carlson, who patented it in 1940, became practical after the process was reduced to a single step in 1960 and replaced photostat as a cheaper means of black-and-white copying with the facility of enlarging or reducing to exact percentages. Variants of the terms *photocopy* and *Xerox copy*—the Haloid Photographic Company of Rochester, New York, was renamed Xerox Corporation in 1961—occur in languages around the world. In this process, exposing the original image to a sheet of electrostatically charged paper discharges the nonimage areas, creating a pattern of static charges that attract a powdered toner that is then fused by heat to the paper or film, forming a permanent duplicated copy (Rhodes and Streeter 1999, 159–61). In contrast to earlier one-off duplicating methods, the widespread availability of photocopiers in offices, libraries, post offices, and commercial copying centers as well as the relatively low unit cost of photocopies democratized photocopying. In that respect, it went even further than spirit duplicating and mimeograph machines, which were limited-quantity copying processes (as opposed to one-off processes) commonly used during the mid-twentieth century in business, government, and educational establishments. Photocopiers were used widely for copying almost every type of textual or graphic image, including maps. Initially limited to copying and printing page-size copies in black and white, photocopiers developed by the mid-1970s to include numerous large-format and color printing options (Saffady 1975). In a late twentieth-century example, cartographic empowerment met modern art in the work of Helen Chadwick, who assembled color photocopies of found objects from Littleheath Woods into a map for the Parish Maps Project of the Common Ground group (fig. 827) (Crouch and Matless 1996). Simultaneously, at the scientific end of the cartographic spectrum, color photocopies could constitute the end product of an ArcInfo GIS project to map shoreline attributes (Dewing 1997). With the integration of laser and digital technologies into photocopier design, the twenty-first century opened with the promise of further developments in this category of map reproduction.

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FIG. 827. HELEN CHADWICK WORKING ON HER PARISH MAP OF LITTLEHEATH WOODS, NEAR CROYDON. [N.p.]: Common Ground, 1986. Using color photocopies of leaves, limbs, a child's head, animals, wires, pylons, and houses, British artist Helen Chadwick is assembling a nostalgic map of her childhood turf.

Image courtesy of Common Ground. Helen Chadwick was commissioned by Common Ground for their exhibition "Knowing Your Place—Artists' Parish Maps," London and touring England, 1986.

SEE ALSO: Electronic Cartography: Display Hardware; Geographic Information System (GIS): GIS as a Tool for Map Production; Photography in Map Design and Production; Software: Mapping Software

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Reproduction of Maps by Printing. The first map printed in Europe appeared in a book in 1472; its woodcut block, with its relief (raised) printing image created by cutting away the nonprinting areas, could be set up, inked, and printed simultaneously with the book's text, handset in movable metal type. Reproduction of maps by woodcut soon yielded to copper engraving, its fine incised (intaglio) lines better for rendering cartographic details, although copper-engraved map illustrations had to be printed separately from the typographic text pages. Until the 1800s map reproduction remained a manual multistep process that began with engraving the map image and included inking the copperplate, operating a printing press to print the map on paper, and coloring the printed map by hand (Verner 1975, 67–68).

The nineteenth century's Industrial Revolution mechanized every aspect of printing, including machine-made paper in rolls (1820s), steam-powered cast-iron presses with rotary cylinders (1840s), paper-folding and bookbinding machines (1860s), hot-metal typesetting machines (1880s), the rotary four-color printing press (1890s), and the offset printing press (1904) (Bosse 1954–55, 1:13–25). While the printing of text remained typographic, by the early 1900s map reproduction by faster and cheaper printing processes, both relief and planographic (flat printing surface with chemically differentiated image), had largely replaced copper engraving (Harris 1975; Koeman 1975). Equally important for reproducing maps and other graphic images were new preprinting techniques enabling the mechanical and, later, photomechanical creation and manipulation of printable images, the transfer of images from one surface to another, the creation of patterns and tones, the duplication of images, the reducing and enlarging of images, and the separation of colored images for multicolor printing. Throughout the twentieth century, successive technological innovations affecting printing kept shifting the balance in favor of this or that process for reproducing maps in different formats (Bosse 1954–55; Koeman 1975, 154–55).

Wood engraving, a refined version of the woodcut technique worked on the endgrain of hardwood, had originated in England just before 1800. A relief printing process, it found common use for uncolored pictorial and map illustrations in textbooks, periodicals, and newspapers until supplanted by new photomechanical processes around 1900 (Hackleman 1921, 369–75; Woodward 1975, 41).

Wax engraving, in commercial use by the mid-1800s and most popular in America, combined engraving (or impressing) an image in a wax layer on a metal plate with electrolytic casting to create relief printing plates. Much used for map illustrations and atlases, its production combined the ease of stamping type labels and engraving line patterns in wax with color printing (Hackleman 1921, 376–81). Although also affected by photomechanical competition after 1900, wax engraving lingered until 1960 among commercial map and atlas publishers heavily invested in its equipment and plates (Harris 1975, 131–32).

Lithography, invented just before 1800 in Bavaria, was soon employed there to print official cadastral maps, while in England it was used to quickly turn reports of Napoleonic battles into maps (Ristow 1975, 79–80, 90). In addition to printing maps, lithography was in use around the world by midcentury to reproduce pictures, music, and business documents. Lithography is based on the chemical differentiation of the greasy printing image and moistened nonimage areas of the lithographic printing surface; when printing ink is rolled over the surface, the greasy ink adheres only to the greasy image areas. Initially, the lithographic printing surface was fine-grained limestone, but by the late 1800s zinc plates and then aluminum plates took over, and after 1900 paper and plastic plates also came into use.

Although slower than relief processes and lacking the crisp line quality of copper engraving, lithography offered other advantages. It was flexible in allowing image creation with either pen or brush along with ink, crayon, engraving needle (to remove a grease-resistant coating), and mechanical transfer from another surface. Some publishers of official map series extended the life of their expensive store of copper-engraved plates into the twentieth century by maintaining them as high-quality master images, updating portions as required, and transferring them as needed for lithographic printing of a new edition (Cahierre 1945, 100–101). At the same time, lithography, favored for color printing of pictures and maps since the mid-1800s, worked well for maps drawn and reproduced in a single edition, such as colored maps of explorers' routes folded and inserted into geographical journals.

By the 1890s maps formerly drawn directly on the lithographic stone or on coated paper for mechanical transfer onto the lithographic stone were instead being drafted in black ink on paper for photography, with the resulting photographic negative then exposed directly on the sensitized zinc or aluminum plate (Walker 1890, 716). Drawing at larger scale for photographic reduction to final size (10 to 50 percent of original size) minimized the imperfections of the pen-drawn ink image and remained the standard approach until the photographic

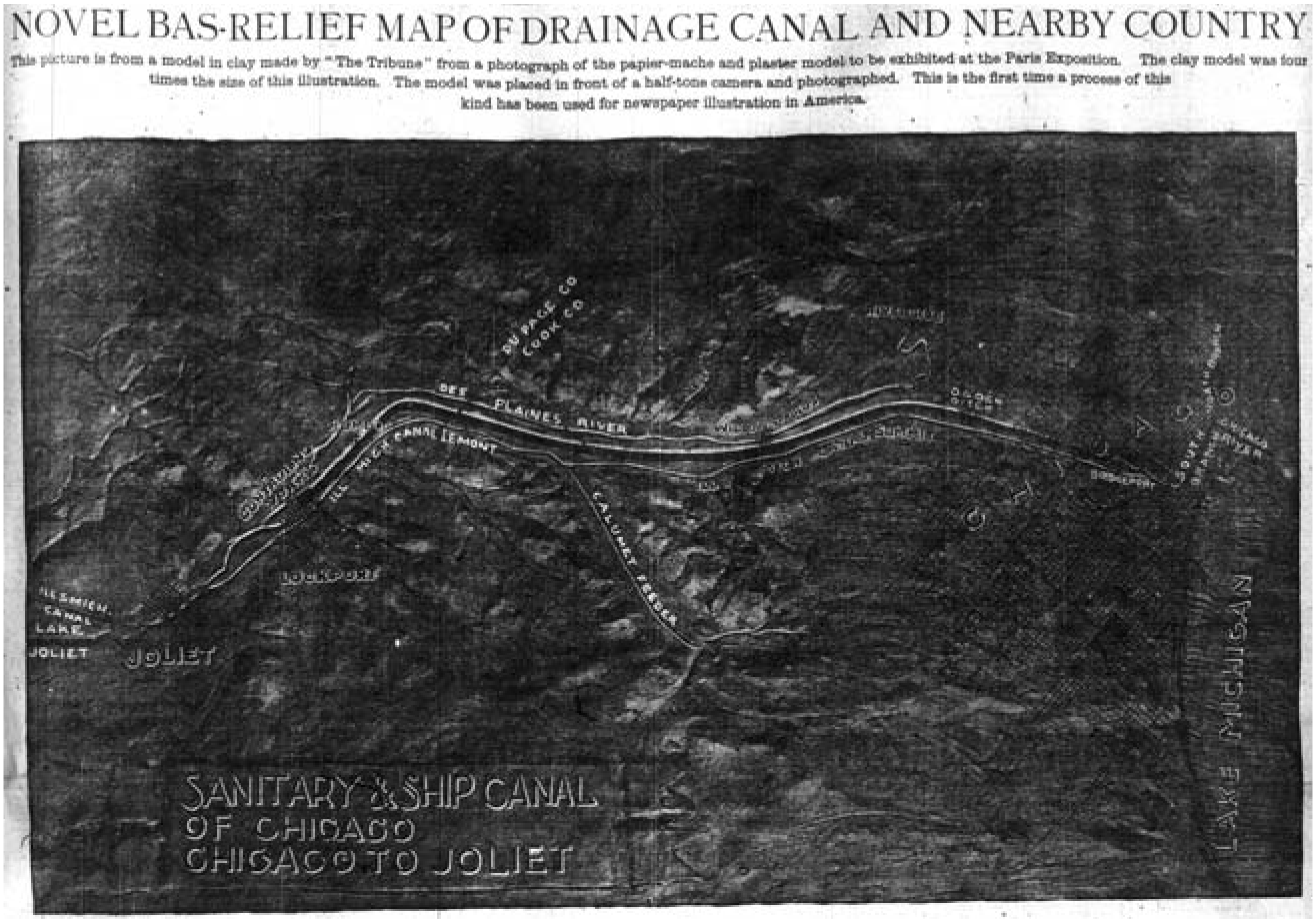

FIG. 828. *SANITARY & SHIP CANAL OF CHICAGO, CHICAGO TO JOLIET*, 1900. This halftone photograph of a relief model by Edwin E. Howell (a copy of the one to be displayed at the Exposition Universelle, Paris) was the first time this process had been used for newspaper illustration in America.

From "Novel Bas-Relief Map of Drainage Canal and Nearby Country," *Chicago Daily Tribune*, 13 Jan. 1900, 9. Image courtesy of the Historical Genealogy Department, Allen County Public Library, Fort Wayne.

era ended in the late 1900s. By 1925 the Ordnance Survey in England, eager to match the quality of copper-engraved topographic sheets, was drawing maps at twice final size for heliozincography. The extreme 50 percent reduction was enabled by their £3000 camera lens, expensive equipment that smaller government or commercial operations lacked (Craster 1925, 302, 309–10).

Line photolithographic processes, which had been developed independently for map reproduction in Australia and England about 1860, soon spread to Europe and America. After 1900 photolithography became the accepted method for reproducing sheets of existing map series and new map series.

By 1900, though, photography was also being used for reproducing flat and graded tonal images, as well as linear elements and lettering, on maps. The halftone photographic screen, perfected in America (1890s), could transform tonal images into printable patterns of black dots or lines for relief, lithographic, or intaglio printing (Hackleman 1921, 242–75; Bosse 1954–55, 2:73–100). By the early 1900s halftone photographs of three-dimensional terrain models were illustrating geography books, atlases, and newspapers (fig. 828).

Early 1900s book illustrations were mainly photoengravings, produced using photography and etching to create zinc metal plates in relief for printing with typographic text. Photographing the map drawing was only one step in photoengraving; numerous steps were required in the printshop to turn the photographic image into print-ready relief metal plates (Hackleman 1921, 217–30). For example, the flat areas of pattern (finer patterns giving the appearance of gray tones) common on maps were generally added at the printshop by the application of Ben Day tints, an 1878 invention involving flexible gelatin plates with raised patterns that were inked and rubbed down on the plate before etching it

(Hackleman 1921, 67). After World War II the trend shifted toward photolithography for printing books, periodicals, and newspapers. Map production was facilitated by new tools (such as reservoir pens in standard sizes) and materials (such as preprinted adhesive-backed lettering, point symbols, patterns, and tints). Simple black-and-white line maps drafted as a single finished piece of artwork required only a single high-contrast photograph and typified much small-format map illustration.

In the early 1900s the preparation of colored pictorial images for printing shifted from manual separation by the lithographic draftsman to photomechanical color separation by the printer. Photomechanical separation into the four process colors (cyan, yellow, magenta, and black) employed different colored filters in turn to block out all but one color (Hackleman 1921, 276–300; Cahierre 1945, 185–212). By about 1930 photoengraving processes, which required costly plate work by the printer, began yielding to cheaper photolithography for both text and graphic reproduction. Use of photogravure (a photomechanical intaglio process) for high-quality monotone and color printing of periodicals had begun in the early 1900s, but this process, which broke up the entire image into dots, was unsuited for reproducing lettering and lines on maps (Lefebvre 1952, 3). The use of full-color images requiring photomechanical color separation was more limited in map reproduction than in pictorial work; the relatively few examples include panoramic maps, such as those created by Hal Shelton in the 1950s and 1960s.

Making color separations for most maps remained largely a task for the cartographic draftsman until the photomechanical era ended in the late 1900s. This held true even on experimental maps produced by the U.S. Geological Survey (USGS) in the 1960s, which added color to orthophotographs (rectified composite aerial photographs) to show vegetation types (fig. 829) and relied on conventional map symbols and labels to indicate cultural features (Pumpelly 1967). On most maps, delimited areas were filled with solid color or colored patterns, an approach sometimes called "black-and-tint" or "flat halftone combination work" in the printing trade. In the mid-twentieth century small-format maps were often drafted in ink as separate, registered overlays that were photographed individually to form open-window negatives and combined with photographic tint or pattern screens to form a composite negative. However, in the 1960s it became more common to scribe large-format maps (using sharp tools to remove actinically opaque coating from transparent plastic backing), thus creating the line negatives directly and from them making peelable open-window negatives for tint screening (Koeman 1975, 152–55). Scribing, which offered a quality of line comparable to copper engraving, became the acme of map production, but only for a decade or two.

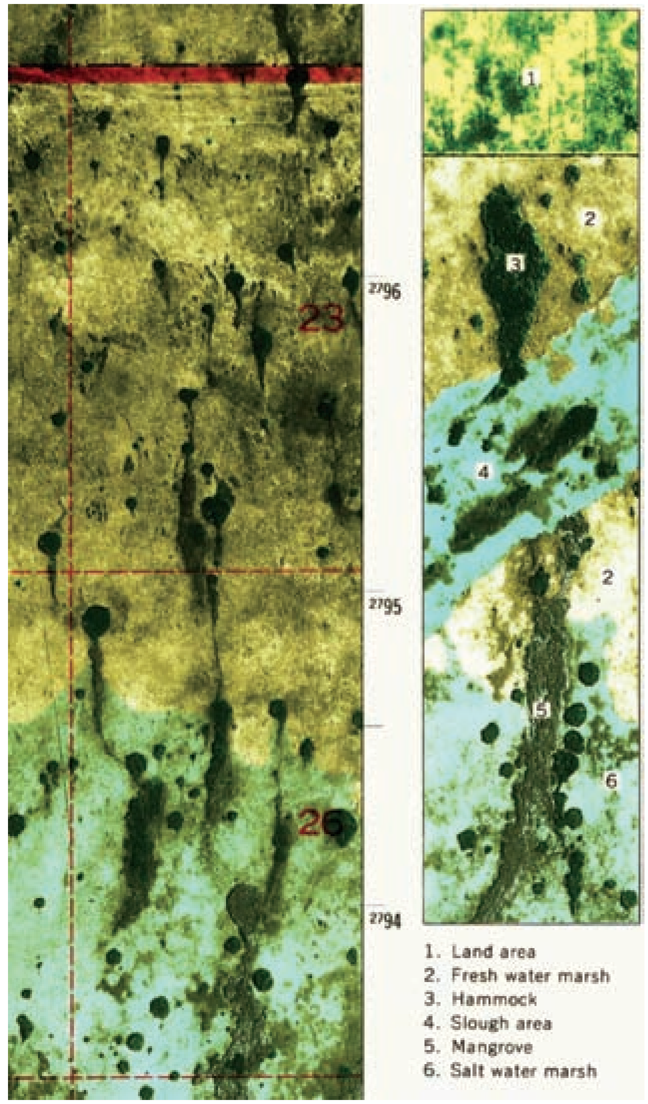

FIG. 829. MAP DETAIL AND LEGEND FROM THE *ROYAL PALM RANGER STATION SE, FLA*. (WASHINGTON: U.S. GEOLOGICAL SURVEY, 1967). Experimental edition, 1:24,000. The legend at the right of this topographic sheet detail identifies the different types of wetland vegetation distinguished by experimental colorization of an orthophoto.
Size of the entire original: 66.7 × 57.8 cm; size of detail and legend: 14.1 × 8.4 cm. Image courtesy of the U.S. Geological Survey, Denver.

Compositing and overprinting multiple overlays required precise registration. Registration hole punches were developed, and considerable attention was given to the dimensional stability of materials used as image supports. Machine-made paper tends to be dimensionally stable in one direction but not the other. In the 1920s the Ordnance Survey avoided the problem by using only handmade paper, which lacks directional grain, for map drafting (Craster 1925, 303–4). By the 1950s an approach in use in America was to laminate two sheets of machine-made paper together at right angles and stabilize them even more by mounting on a sheet of aluminum. In the second half of the century new plastic materials that were dimensionally stable, flexible, and durable were developed and adopted for both drafting and scribing. Attention was also given to the development of sturdier map papers able to withstand the rigors of outdoor military or recreational use. For example, the addition of melamine resin to map printing paper enhanced whiteness, opacity, strength, and stability (Wickland 1952, 16–18).

Typographic printing of newspapers had remained competitive through midcentury by continuing technological innovation. For example, stereotyping (pressing a form of set type and illustration blocks into a mat of soft paper to form a mold that was then used as a hot-metal cast) was employed to duplicate printing plates for offset printing (Hackleman 1921, 366–68) (fig. 830). Another was the development of bigger, faster printing presses capable of precision color printing of the advertisements and pictorial sections introduced to attract readers. Some high-quality magazine sections were printed by photogravure. Lithographic printing, however, already established as the preferred method for printing sheet maps, increasingly replaced relief processes for printing books, periodicals, and newspapers and their illustrations in the decades following World War II. Improved lithographic presses came into use, reducing the hands-on craft aspect of printing and turning it into a more automated process.

The economy of scale achieved by large press runs could leave publishers holding stocks of aging unsold maps. Strategies such as overprinting interim updates in magenta on existing USGS topographic maps reduced but did not solve the problem. Other government agencies began to store and update full-size master maps, duplicating them on demand by one-to-one processes such as Ozalid (invented 1917), while microphotography allowed storage of miniaturized map images. Spirit duplicating processes and, later, electrostatic copying were employed to copy small maps for temporary uses. Meanwhile the thirty-five-millimeter slide projector, movies, television, and radarscopes displayed maps more ephemerally. Other reproduction methods and map formats were infringing on the domain of the printed map.

All of these developments nibbled away at the market for the conventionally printed map, but it was the computer revolution that engulfed cartography (as well as photography) during the late twentieth century. Needs for on-the-spot mapmaking in the field that had been met during the two world wars by mobile lithographic printing units (fig. 831) were partly met during the Persian Gulf War in the early 1990s by color photocopier and computer equipment (Clarke 1992, 85). As predicted decades earlier, geographic information systems (GIS) had shifted the focus from the fixed cartographic end product, the printed map, to the spatial database that software could transform into different visualizations and formats. A prediction in 1981 that 90 percent of all maps would be computer generated by 2000 (Hodgkiss 1981, 69) was probably exceeded. Maps printed lithographically from computer-generated printing plates remained cost-effective and convenient for some purposes, such as printing an energy utility's facilities maps from GIS-created electronic files sent directly to the printer (Shields 2004), but had become only one among many options.

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SEE ALSO: Color and Cartography; Map: Printed Map; Paper; Wax Engraving

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THE WEATHER

NEW YORK Herald Tribune EXTRA LATE CITY EDITION

VOL. CIV No. 35,632 TUESDAY, JUNE 6, 1944

Invasion On, Allies Land in France As Planes and Ships Blast Coast; Montgomery Leads the Advance

Allies Across Tiber on Heels Of Routed Foe

Planes Hammer at Nazis Jamming Highways to North; Tanks Follow Up

Enemy May Delay Stand for 150 Miles

500 U. S. Bombers Blast Rail Lines to Cut Off Flow of Reinforcements

Hitler Loses Standing As a Vegetarian, Too

Insurance Held Subject to U. S. Anti-Trust Law

Supreme Court Rules It Is Interstate Trade, Upsets 75-Year-Old Precedent

'Tough' Fight Ahead Is Seen By Roosevelt

President Says Capture of Rome Finds Allies Poised for New Blows

Hails Victory With: 'One Up, Two to Go'

Says Italy Will Get Help, but Cannot Hope for a Militaristic Empire

By Bert Andrews

Battle Raging Over 75-Mile Coastal Area

Attack on Europe Follows Air Campaign to Pave Way for Land Forces

Invasion Centers In Seine Estuary

Air-Borne Troops Drop After 'Terrific' Rain of Shells and Bombs

FIG. 830. STEREOTYPE MAT OF THE FRONT PAGE OF THE *NEW YORK HERALD TRIBUNE*, 1944. The top half of this newspaper front page—which includes a historic map, *Where the Allies Have Struck in France*, of the D-Day landing in Normandy—is part of a stereotype mat made for casting a hot-metal duplicate of the printing plate.

From the *New York Herald Tribune*, 6 June 1944, 1A. Courtesy of Special Collections, Spencer Research Library, University of Kansas, Lawrence.

A Dictionary of Arts, Sciences, and General Literature, 9th ed., 25 vols., 22:695–722. New York: Henry G. Allen.

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Engraving. "Engraving" refers to marks incised in a surface for whatever purpose. In Europe engraved metal plates were first printed in the fifteenth century by selectively inking and imprinting onto paper either the physically higher surface left in relief or the engraved grooves. The latter method, intaglio printing, dominated


WAR MAPS WHILE YOU WAIT

↑ Officers of the army War Plans Division study a world map as Brig. Gen. Leonard T. Gerow, division chief, points to a scene of operations. Map-making for the Army, Navy and Air Forces is a big industry in which American business machines and printing equipment have proved of outstanding value. Data for map-making are obtained by plane, patrol and reconnaissance, brought in by radio, telephone or courier and experts quickly compile and print the maps with duplicating machines, lithograph presses, mimeograph and multigraph. Some machines turn out multi-color maps. In the battle of Egypt quick changes in maps were made by using green carbon for allied positions, red for the enemy

↑ A sergeant of the U. S. Army engineers making a military map in the field prints a lithographic plate in an offset press. Fast duplication is necessary to supply all ground and air units with up-to-the-minute maps in quick time

← On the wall of field headquarters a master map of the battle zone is mounted, the lines changing as phone, radio or plane reports tell of advances or withdrawals. Strategic movements are plotted on the transparent overlay

FIG. 831. "WAR MAPS WHILE YOU WAIT," 1943. During World War II mobile map printing units facilitated data collection, map compilation, drafting, printing, and use at the front. Size of the original: 20.7 × 13.2 cm. From *Popular Mechanics Magazine* 80, no. 5 (November 1943): 46–47 (46 is shown here).

map and other graphic reproduction for several centuries. The precisely controlled lines created by the graver or burin and the ability to store, update, and reuse the expensive metal plates made copper engraving nearly ideal for map reproduction. After 1800, though, various new techniques appropriated the names "engraving" and "gravure" and stretched their usage.

New and cheaper printing processes (lithography and wax engraving) offering color printing encroached upon copper engraving during the 1800s. Another factor was the ability to print wax and wood engraving with type. They involved an initial engraving step, but wood and wax engraving were relief processes, whereas lithographic engraving was planographic.

While engraving new maps on copper became less common, the practice of transferring a copper-engraved map onto a stone or a zinc or aluminum plate for lithographic printing persisted into the early 1900s. Although new photomechanical processes were increasingly adopted for map reproduction, publishers held expensive stocks of engraved plates. Such master images could be revised and transferred more economically than creating a new map. Although the Director of the Ordnance Survey stated in 1925 that engraving new topographic maps had been abandoned (Craster 1925, 308), nine years later sections of existing Ordnance Survey plates were described as planished (hammered flat) for revision, lettered with steel punches, and transferred to zinc plates for lithographic offset printing (Curwen 1934, 26, 59–60, 69).

Toward the end of the nineteenth century, lithographic, wood, and wax engraving joined copper engraving as processes under threat, this time by new photomechanical processes that took over map reproduction after 1900. Wax engraving lingered longest, until the 1950s in America, where some map publishers continued revising and republishing existing plates.

It was the incorporation of photography and the halftone screen, especially when combined with color separation using filters and four-color process printing shortly after 1900, that enabled photomechanical processes to take over graphic reproduction (Flader and Mertle 1948, xxxix). The terms "engraving" and "gravure" survived in photoengraving, a relief process, and in the similar intaglio processes, heliogravure, photogravure, and rotogravure. All of these involved image creation by chemical etching (see, e.g., Soubiran 1941, 24–25), not hand engraving, although early process-engraved blocks often required manual touch-up to improve tonal contrast.

The photomechanical intaglio processes cost more to print than photoengraving and photolithography but yielded prints closer to copper engraving in quality and character. The cost factor restricted the photomechanical intaglio processes to sporadic special use rather than general use from the late 1800s to the mid-1900s. In 1925 Colonel H. S. L. Winterbotham suggested that photogravure should be used for some Ordnance Survey maps (Craster 1925, 309). Although photolithography saw general use for sheet-map reproduction by the 1930s, continuing preference for the crisp intaglio image led the military survey in Berlin to print the 1:25,000 topographic map in three-color heliogravure (Koeman 1975, 150). The success of a photogravure map of Jan Mayen Island (fig. 832) encouraged the Royal Geographical Society to select photogravure in 1940 for the three-sheet British Council Map (Hinks 1942, 123).

However, photoengraving was a strong competitor in book and atlas illustration until the mid-1900s. The term "photoengraving" encompasses various relief printing processes involving photographic exposure of a zinc plate, followed by etching to create a relief printing image. Limited at first to line images, photoengraving was soon combined with the photographic screen perfected in the 1890s. Also called process engravings, monochrome halftoned-screened photoengravings of maps, globes, and bird's-eye views, among other subjects, became common in books and newspapers after 1900.

Just as common in map reproduction by photoengraving were area tints and patterns applied using a Ben Day tint frame. In photoengraving these were applied to line blocks before etching. By the 1920s process engravings were also being color separated manually or photographically (using filters) and printed in the four colors now standard (cyan, yellow, magenta, and black). However, the same technical developments were taking place in photolithography. The balance shifted in favor of photolithography after World War II, when phototypesetting became commercially viable. This made it possible to print text lithographically more cheaply than by letterpress. With the demise of commercial photogravure and photoengraving after the mid-twentieth century, both intaglio and relief printing as well as the terms "gravure" and "engraving" disappeared from everyday map reproduction.

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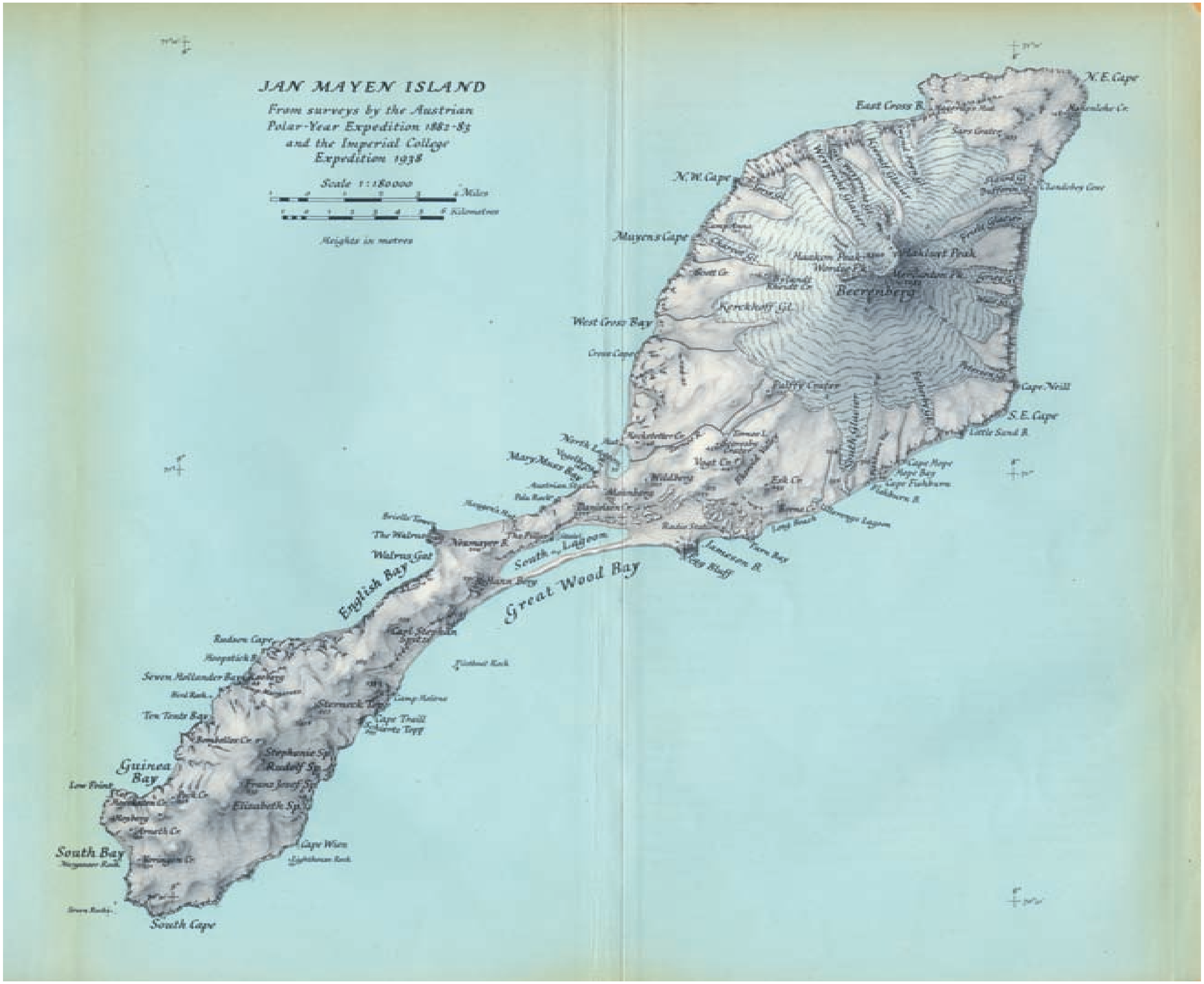
(*Facing page*)

FIG. 832. *JAN MAYEN ISLAND*, 1939. Printed in two colors by photogravure, this map combines subtle shading with the sharp detail typical of intaglio printing.

Size of the original: 23.7 × 28.9 cm. From Alexander King, "The Imperial College Expedition to Jan Mayen Island," *Geographical Journal* 94 (1939): 115–31, map facing 126. Permission courtesy of John Wiley & Sons, Inc.


JAN MAYEN ISLAND
From surveys by the Austrian
Polar-Year Expedition 1882-83
and the Imperial College
Expedition 1938
Scale 1:180000
Miles
Kilometres
Heights in metres
N.E. Cape
East Cross B.
N.W. Cape
Mayens Cape
Beerenberg
West Cross Bay
Cross Cape
Cape Neill
S.E. Cape
Little Sand B.
Cape Hope
Hope Bay
Cape Fishburn
Fishburn B.
Long Beach
North Lagoon
Mary Muss Bay
South Lagoon
Great Wood Bay
Jameson B.
Egg Bluff
The Walrus
Walrus Gat
English Bay
Radarn Cape
Seven Hollander Bay
Ten Tents Bay
Camp Helena
Cape Traill
Stephanie Sp.
Rudolf Sp.
Franz Josef Sp.
Elizabeth Sp.
Guinea Bay
Low Point
Cape Wien
South Bay
South Cape
Kerckhoff Gl.
Eik Cr.
Vogt Cr.
Wildberg
Sars Crater
Haakon Peak
Dufferin
Karl Stephan Spitze

SEE ALSO: Wax Engraving

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Photomechanical Processes. Photomechanical processes employ photographic images directly in the preparation of printing plates to be inked and printed by impression on paper or another material. They combine the ability of photography to create images automatically (by the selective exposure of a light-sensitive emulsion) with the ability of relief, intaglio, and planographic printing processes to produce multiple exact copies by repeated inking and impression of a printing image (Nadeau 1989–90, 2:377).

Photomechanical applications of photography were the subject of early experiments by Nicéphore Niépce in France in 1826 and by William Henry Fox Talbot in England in 1852 (Nadeau 1989–90, 2:367, 370). After several decades of experimental development, photomechanical processes found use in map reproduction from the 1860s onward. Advances in photomechanical processes were also facilitated by the improvement and commercial production of photographic equipment and materials, including copy cameras, photographic film, emulsions, and artificial light sources. Technical innovations continued to expand the graphic capabilities of photomechanical processes until their use in map reproduction peaked in the 1970s. By that time, advances in computer technology were offering new alternatives, and the focus of innovation shifted in that direction. Electronic technology had almost entirely supplanted photomechanical processes in map reproduction by the 1990s. This brief overview of the rise and fall of photomechanical processes provides a historical backdrop for the succession of innovations and their impact on mapmaking and map use discussed next in greater detail.

The invention just before 1800 of lithography (a planographic or flat-image printing process in which the greasy printing image was differentiated chemically from the dampened nonprinting area of the limestone printing surface) had upset the long-standing equilibrium between relief and intaglio printing processes in map reproduction. Woodcut (a relief process in which the nonprinting areas of the woodblock were cut away to leave raised lines and other marks as the printing image) had found early use for map printing in Europe from 1472 onward. Despite the coarse texture dictated by its medium, woodcut was favored for book illustrations printed with text, because woodblocks could be printed with metal type. Meanwhile, copper engraving (an intaglio or sunken-image process created by incising lines and other marks in a copperplate) gained appreciation for its ability to portray fine details. It dominated large-format map reproduction, including foldout maps inserted as plates in books, into the nineteenth century. From the early 1800s onward, though, lithography's relative cheapness, speed, and versatility often outweighed its inferior image quality (less controlled and precise linework than copper engraving), an advantage strengthened by the development of lithographic color printing in the mid-1800s. Although image production for printing remained primarily manual, the mass production of varying tones and flat tints was made possible by a range of innovations—aquatint (mid-1600s), mezzotint (mid-1600s), ruling machine (late 1700s), transfer paper (early 1800s), and the Ben Day tint machine (1878). During the nineteenth century, wood engraving (a refined version of woodcut printable on smoother machine-made paper, also introduced around 1800) and wax engraving (a relief process developed in the mid-1800s and employing metal printing plates electrotyped from images incised in wax) were employed for printing maps, chiefly illustrations in books, magazines, and newspapers.

During the early nineteenth century, the first attempts had been made to produce intaglio, relief, and lithographic printing images photomechanically. In France as early as 1827, Niépce created a metal intaglio printing plate by coating it with bitumen (a light-sensitive natural tar) and contact exposing it to sunlight through an intaglio paper print (Gascoigne 2004, 37). The unexposed bitumen beneath the opaque lines of the print could be dissolved to expose the copper plate for etching. However, further experiments with the process, later known as photogravure, did not occur until the 1850s, and widespread use came even later, in the 1870s (Gascoigne 2004, 37).

In contrast, photolithography found earlier practical application in map printing. Since the early 1800s, transfer paper with a water-soluble coating had been used for mechanical transfer of hand-drawn or printed images from one printing surface to another. While earlier photolithographic trials involved direct exposure of a lithographic stone coated with a photosensitive emulsion, experimenters soon realized that a sheet of flexible, photosensitized transfer paper afforded better contact with the glass negative and thus a higher-quality image.

In 1859 photolithographic transfer based on a method invented by Eduard Isaac Asser in Amsterdam in 1857 was improved and applied in printing maps, first in Australia by John Walter Osborne of the Government Survey Office in Melbourne (Nadeau 1989–90, 2:374) and later that year in Britain by the Ordnance Survey, headed by Colonel Sir Henry James (Mumford 1999, 168–78). The transfer paper was coated with a colloid (such as gelatin, fish glue, or gum arabic) mixed with a light-sensitive compound (ammonium dichromate, potassium dichromate, or sodium dichromate) (Nadeau 1989–90, 1:86–87). Even though capable at first of producing only high-contrast line images, photolithographic transfer met the great need in the compilation, production, and reproduction of maps for exact copies, often at a different scale, of images consisting largely, as most maps did, of line and point symbols and lettering. However, the dampened transfer paper tended to stretch under pressure, causing ink spread and scale change (Gascoigne 2004, 41c), significant drawbacks in map printing. Although photolithographic transfer remained in use until at least the 1930s (Nadeau 1989–90, 2:374), the balance had already shifted in favor of direct exposure of lithographic printing plates composed of thin, flexible zinc or aluminum sheets suitable for rotary offset printing, by offsetting the image onto a rubber roller interposed between the printing plate and the paper, which reduced wear on the printing plate and improved control of the ink (Gascoigne 2004, 41c).

Among the various line photoengraving processes for producing relief-etched printing blocks, the most successful was a modification of Gillotage, a nonphotographic process patented in France in 1850 by Firmin Gillot and involving transferral of a greasy image to a zinc plate and fixing it with asphalt or resin dust to create a resist before etching around it with acid. In the 1870s his son Charles began using a photo resist instead and set up the first photorelief print shop in Paris (Nadeau 1989–90, 1:117). Photoengraving was much used for illustrations in commercial printing until after letterpress printing of text gave way to photolithography in the mid-1900s (Gascoigne 2004, 34). Although it developed into an involved process requiring mastery of many exacting steps, photoengraving remained a craft process based in the printshop (Flader 1927; Soubiran 1946).

Photogravure (a line intaglio process stemming from the photoglyphic engraving process developed by Talbot in 1852) was costly but found intermittent use in mapmaking. In 1925, for example, Colonel H. S. L. Winterbotham suggested that photogravure might be used in Britain for selected Ordnance Survey maps (Craster 1925, 309). During the 1930s, governmental cartographic organizations in Germany, still preferring the quality of the intaglio image over offset lithography, chose somewhat anachronistically to use photogravure for map reproduction (Koeman 1975, 150).

However, the ability to print high-contrast images was soon followed by photomechanical processes capable of printing tonal images. The earliest such process is now known generally as collotype. Invented in France in about 1855, it first became popular in Europe and America in the 1870s, having been improved in 1868 in Munich by Joseph Albert (Nadeau 1989–90, 1:73; Gascoigne 2004, 40). In collotype, the action of light passing through a tonal photographic negative selectively hardens a coating of dichromated gelatin, especially along the cracks in the reticulated gelatin surface, which gain the ability to attract greasy printing ink, while less exposed areas still take up water and repel the ink (Gascoigne 2004, 40). The resulting fine network of black lines of varying width is printable and simulates the gray tones of the original image. Although related to lithography, collotype was less viable commercially because the delicate printing image was limited to short print runs (Nadeau 1989–90, 1:73). Its greatest cartographic use, persisting into the mid-twentieth century, was facsimile reproduction of early maps.

A different method of breaking the tonal surface into a pattern of variable-size printable marks was the halftone screen. First conceived by Talbot in the 1850s as a photographic veil of gauze mesh, it had developed by 1885 into a grid of opaque lines on glass (Nadeau 1989–90, 1: 121–22). The lighter the area of the tonal photographic negative, the more light would pass through the openings in the halftone screen and the larger would be the black dots created on the photosensitive surface beneath. The halftone screen was employed successfully in relief printing of photographs to illustrate newspapers from the 1880s onward. Soon, photoengraved halftone images of relief models began to illustrate geography textbooks, atlases, and other publications and remained common until the mid-twentieth century (fig. 833). The halftone screen was quickly adopted for intaglio and planographic printing as well.

Rotogravure, a later improvement on photogravure, was adopted in Europe around 1907 and introduced in the United States in 1913 (Nadeau 1989–90, 2:418–19). In rotogravure the metal plate exposed through the cross-line screen was etched to form ink-holding cells of differing depth (rather than width); the deeper cells held more ink and produced larger, darker dots separated by distinctive white grid lines (Gascoigne 2004, 74d). Although commonly used for photographs and pictorial subjects in illustrated magazines and newspapers, it could also reproduce maps sketched using tonal techniques (fig. 834).

The halftone screen was slower to find a place in photolithography, whose main cartographic role continued

FIG. 833. *RELIEF MAP OF WESTERN NORTH CAROLINA*, 1929. On this photoengraved map reproduction, the halftone screened photograph of topographic relief has been combined at the printshop with the separately photographed, unscreened neatline, title block, and legend. Size of the original: 10.8 × 19.1 cm. From Henry J. Cox, "Weather Conditions and Thermal Belts in the North Carolina Mountain Region and Their Relation to Fruit Growing," *Annals of the Association of American Geographers* 10 (1920): 57–68, map on 62.

to be printing of large-format maps. However, the balance had shifted in its favor by the 1960s. One reason was that halftone lithographs could be printed on the same paper as text and line illustrations, while photoengraved halftones had to be printed on shiny coated paper (Gascoigne 2004, 41c).

At first such illustrations were mostly black-and-white, but increasingly they were colored. The ability to separate images into colors for multicolor lithographic printing, already developed during the mid-1800s as a manual process, had been combined with photography before 1900 (Gascoigne 2004, 65–67). For example, in 1898 the Swiss firm Orell Füssli, of Zurich, patented the photochrom process, thought to have involved exposing bitumen-coated stone under a continuous-tone negative and processing it to form an image with a reticulated grain, followed by manual color separations (Nadeau 1989–90, 2:365). The process facilitated the World War I–era fad for colorized photographic postcards, among them map-like aerial views, but the cartographic connection lies more in Orell Füssli's role later in the century as a publisher of larger-format maps printed in color by photolithography.

During the early twentieth century, though, color printing by photolithography still faced stiff competition from other processes, chiefly photoengraving, photogravure, and wax engraving. Rand McNally and other commercial map publishers in America were still creating wax-engraved maps (nonphotomechanically, although using photography to transform pen drawings into guide images for the wax engraver) with mechanical line patterns printed in color to illustrate books and atlases (Hackleman 1924, 377; Woodward 1977, 27–28).

Although it was photomechanical, photogravure was also essentially a line process. As used about 1930 in Berlin by the military survey (Reichsamt für Landesaufnahme) to print 1:25,000-scale topographic maps, the photogravure process produced a set of three intaglio plates used to print the black lines and lettering, brown contours, and blue water (Bosse 1954–55, 1:115–18; Koeman 1975, 150).

A more fruitful avenue for photomechanical color printing of maps opened around 1900 with the adoption of photographic halftone screens (for continuous-tone images) and photographic tint screens (for flat tones) to prepare color-separated printing plates for multicolor, especially four-color (cyan, yellow, magenta, and black), process printing. Sometimes a full color image of a map

FIG. 834. *GERMAN OCCUPIED TERRITORY*, 1919. This monocolor bird's-eye view printed in brown illustrates the tonal reproduction capabilities of rotogravure, an intaglio process introduced to America only four years earlier and already popular for magazine and newspaper illustration. Size of the original: 18.8 × 12.7 cm. From *The New York Times Current History: The European War*, vol. 18 (January–March 1919) (New York: The New York Times Company, 1919), between xv and 1.

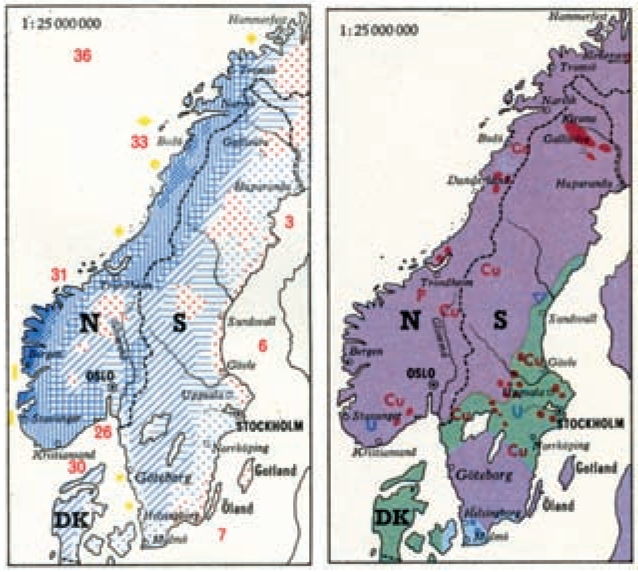

FIG. 835. WESTERN EUROPE CLIMATE AND GEOLOGICAL MAPS (INSETS), 1963. Transitional between the line and screen tint styles of photolithography, the split personality of this atlas is evident in the climate map (left detail, showing precipitation by means of a sequence of coarse dot and line patterns) facing the geological and mineral deposits map (right detail, showing rock formations by process-color screen tints).
Size of the original pages: 28.7 × 20.1 cm; size of each detail: ca. 7.3 × 4 cm. From Jean Dollfus, *Atlas of Western Europe* (Paris: Société Européenne d'Études et d'Informations, 1963), 10 and 11.

might be halftoned and color separated using colored filters for reproduction in color. Printed map color, however, continuing the tradition of hand coloring, was more likely to present the map as a black image composed of lines, point symbols, and lettering colorized by the addition of flat color tints. Because mapmakers were already used to printing and overprinting mechanical patterns to create different color combinations, the advent of photographic tint and pattern screens was little more than an extension of an existing approach, the main change being from coarse-textured patterns to fine-textured nearly invisible patterns (tints) (fig. 835).

The use of photographic screens for map color work became more common after World War II. Artwork for such maps was created in black and white on registered overlays (typically one overlay per color or tint percentage) subsequently photographed separately and first assembled at the following stage of photographic compositing by a sequence of exposures (Keates 1973, 74). Although halftoned plastic shading was often used for topographic relief, lithographic maps printed in color typically had flat area colors and patterns, printed either separately or superimposed.

By the mid-twentieth century, the general shift of printing from letterpress to photolithography was giving the cartographer greater control over map design and production. A contemporary review of *The National Atlas of the United States of America* (1970) placed it at the cutting edge, acknowledging that the design risks taken by its cartographers had been facilitated by new technology (fig. 836). Its sixty-five basic inks blended by photographic tint screens were observed to have "produced some truly psychedelic pages" (Dean, Matthews, and Hare 1972, 283), although another reviewer thought the bright colors interfered with legibility (Jenks 1971, 792). By the 1960s and 1970s a wide range of photomechanical techniques and associated equipment and materials were being described as standard operating procedure in cartographic textbooks (Keates 1973, 74–110; Robinson and Sale 1969, 312–35). The new technique of scribing (using gravers to create precise lines by removing an actinically opaque coating on a dimensionally stable

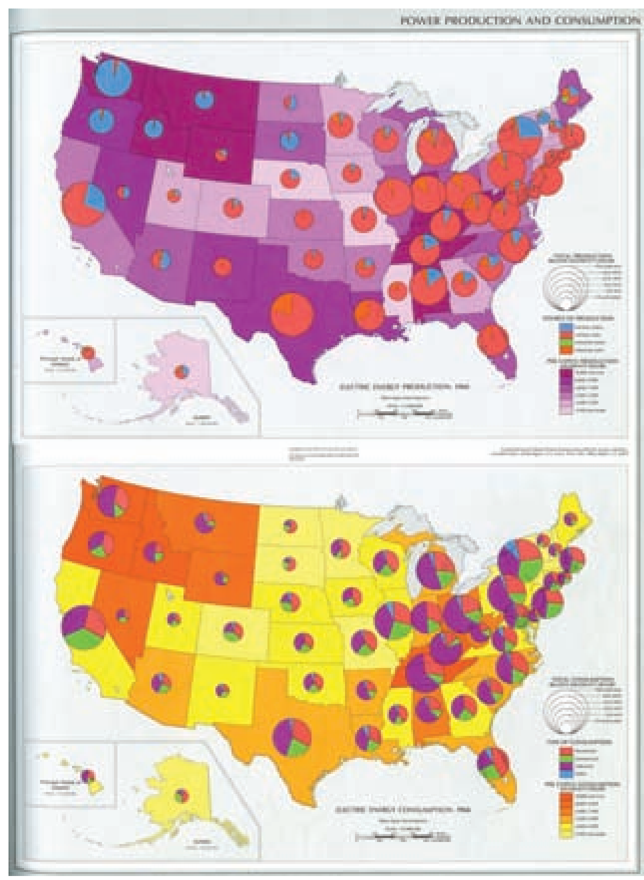

FIG. 836. U.S. ELECTRIC ENERGY PRODUCTION AND CONSUMPTION, 1966. Although in general agreement about the high technical quality of the photomechanical processes used to create this atlas, one reviewer found the color selection on this page unaesthetic, while others more charitably called it psychedelic.
Size of the original: 43.2 × 31.7 cm. From U. S. Geological Survey, *The National Atlas of the United States of America*, ed. Arch C. Gerlach (Washington, D.C.: [Department of the Interior], 1970), 189.

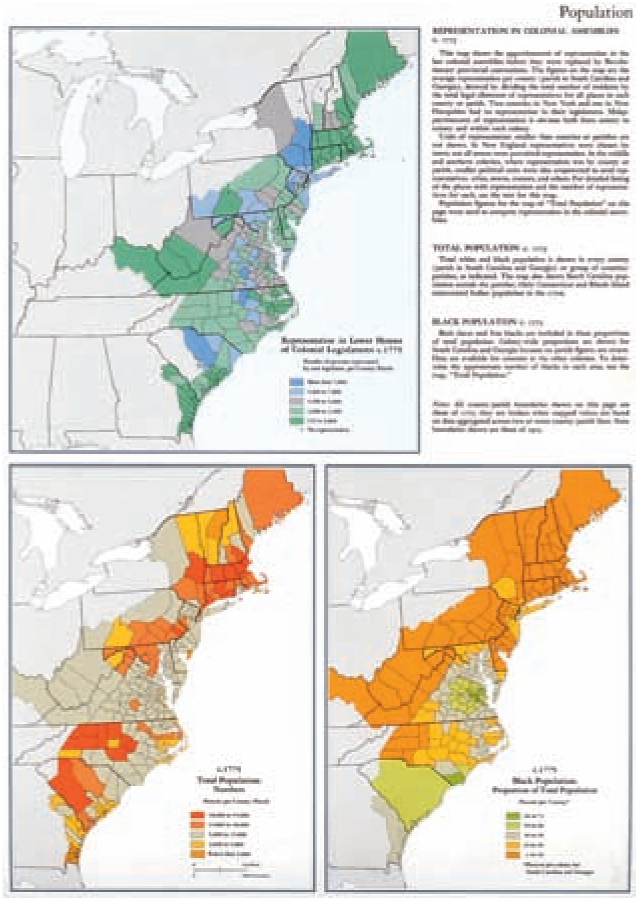

FIG. 837. U.S. POPULATION, CA. 1775. Using specially selected inks reminiscent of revolutionary-era color schemes, cartographic editor Barbara Bartz Petchenik created a page on which colors contrast just enough to convey the meaning of the choroplethically mapped populations but little enough to establish a subtle harmony overall.
Size of the original: 41.6 × 29.1 cm. From Lester J. Cappon, ed., *Atlas of Early American History: The Revolutionary Era, 1760–1790* (Princeton: Published for the Newberry Library and the Institute of Early American History and Culture by Princeton University Press, 1976), 25. © 1976 Princeton University Press, 2004 renewed PUP. Reprinted by permission of Princeton University Press.

plastic sheet) introduced the direct production of final-size negatives and positives in combination with open-window negatives. At first photographic work was often outsourced to commercial vendors, such as printers or typesetting firms. By the 1960s and 1970s, even small mapmaking operations, such as university cartographic laboratories, were employing their own copy cameras, phototypesetting equipment, contact printers, and PMT (photomechanical transfer) equipment. Photomechanical techniques for manipulating the graphic characteristics of images, black-and-white or color, flat or graded, and solid or patterned, grew in sophistication, as did map design (Robinson 1975, 20–22) (fig. 837).

A further technological shift occurred in the final third of the twentieth century, when the computer began to oust photomechanical processes from mapmaking. By the 1990s computer graphics software, developed for graphic arts in general but adopted for map production, was able to duplicate and surpass the graphic effects of the photomechanical processes.

The successive technical innovations in photomechanical processes during the twentieth century resulted in a constantly shifting cost-effective balance among the various relief, intaglio, and planographic printing processes. While they helped cartography meet growing societal needs for rapidly produced maps, the photomechanical processes also expanded the graphic capabilities of map reproduction. The map design skills developed during the photomechanical era lived on in the early twenty-first century in the work of the diminished number of professional cartographers producing high-quality maps for publication. Meanwhile, the democratization of computer mapping software enabled a broader, if less knowledgeable, use of the default design options it offers.

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SEE ALSO: Labeling of Maps: Labeling Techniques; Photography in Map Design and Production

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Color Reproduction. The twentieth century was a period of rapid technological change in cartography, particularly in how maps were constructed and reproduced in color. Technological advances over the century transformed the reproduction of multicolor maps from a manual activity to a photochemical process and then to a computer-controlled digital process (fig. 838). These revolutions in color map reproduction were responses to shortcomings in the manual methods—copperplate engraving, lithography, and cerography (wax engraving)—that dominated the early decades of the century.

The first two decades saw the end of copperplate engraving as an important method of map reproduction (Robinson 1975, 5–6). The two techniques used at this time to create colored engravings help explain its demise. Most maps printed in black and white from linework and lettering engraved in reverse on flat copperplates had additional colors applied by hand. Manual water coloring of areas, cartouches, and line boundaries was a cottage industry in neighborhoods surrounding printing houses. The reproduction of color maps in this manner was time-consuming and costly.

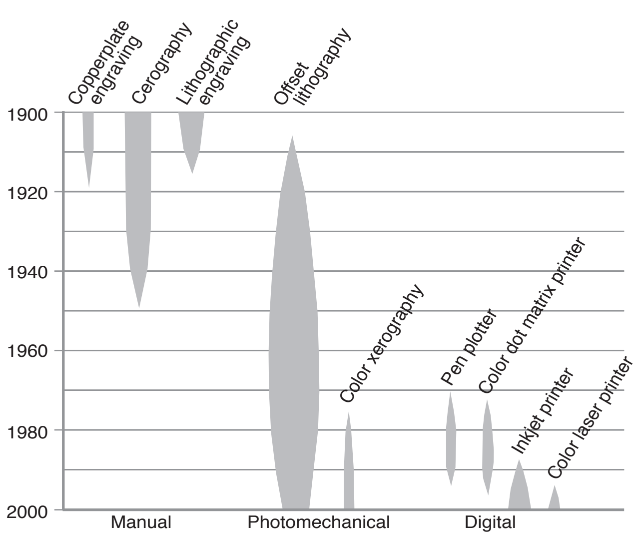

FIG. 838. TIMELINE OF TWENTIETH-CENTURY COLOR MAP REPRODUCTION TECHNOLOGY, FOCUSING ON THE UNITED STATES. The widths of the bars give a rough indication of the relative importance over the century of each manual, photomechanical, or digital color method of map reproduction.
Source A. Jon Kimerling.

The second technique was to engrave a different plate for each ink color. Early twentieth-century U.S. Geological Survey (USGS) topographic maps, for example, were reproduced by making separate impressions for solid black, blue, and brown map symbols. Exact registry of the paper sheet with each plate placed in succession on the bed of the rolling press was very difficult to achieve. In addition, continuous color shading was possible only through laborious mechanical ruling of thin finely spaced lines. These limitations led cartographers to reproduce color maps lithographically and by cerography.

At the beginning of the twentieth century roughly half of all printed maps were reproduced by lithography, and by 1975 virtually all maps copied in large numbers were printed lithographically (Robinson 1975, 6). In 1900, zinc sheets or flat pieces of a special type of limestone were the standard printing surfaces. An oil-based image of the map was drawn on or photographically transferred to the zinc or limestone surface and then slightly etched into the surface by acid. A water-soluble solution was then applied to the surface, sticking only to the non-oily surface. The oily ink used for printing adhered only to the oily parts of the map image.

Chromolithography was used to produce multicolor printed maps. In this process, a separate stone or plate was created for each ink color, and the map print was pressed into each ink in a fixed sequence of colors. The major technical difficulty was keeping the paper registered correctly to each stone or plate. The high cost of preparing the surface for each ink color caused some publishers to print maps in black ink and have colors applied manually by the same water coloring techniques used to color maps printed by copperplate engraving.

In 1900 nearly as many maps were copied by cerography (wax engraving) as by lithography (Woodward 1977). Until the 1950s, Rand McNally and other large U.S. map publishing firms used cerography to produced atlas, road, and other popular maps. Engravers first covered a smooth copperplate with a thin layer of wax, then engraved linework and other map symbols through the wax to the surface of the plate. Lettering was hand engraved or made by pressing individual metal type into the wax. A subsequent electroplating procedure created a relief-printing plate that could be printed on letterpresses along with type set for pages in books and atlases.

Production of multicolor maps by wax engraving relied on creating separate relief plates for each ink used. Flat tints of an ink color were composed of thin parallel lines tediously engraved manually using a precise ruling machine. Additional colors could be created by overprinting flat tints ruled at different angles.

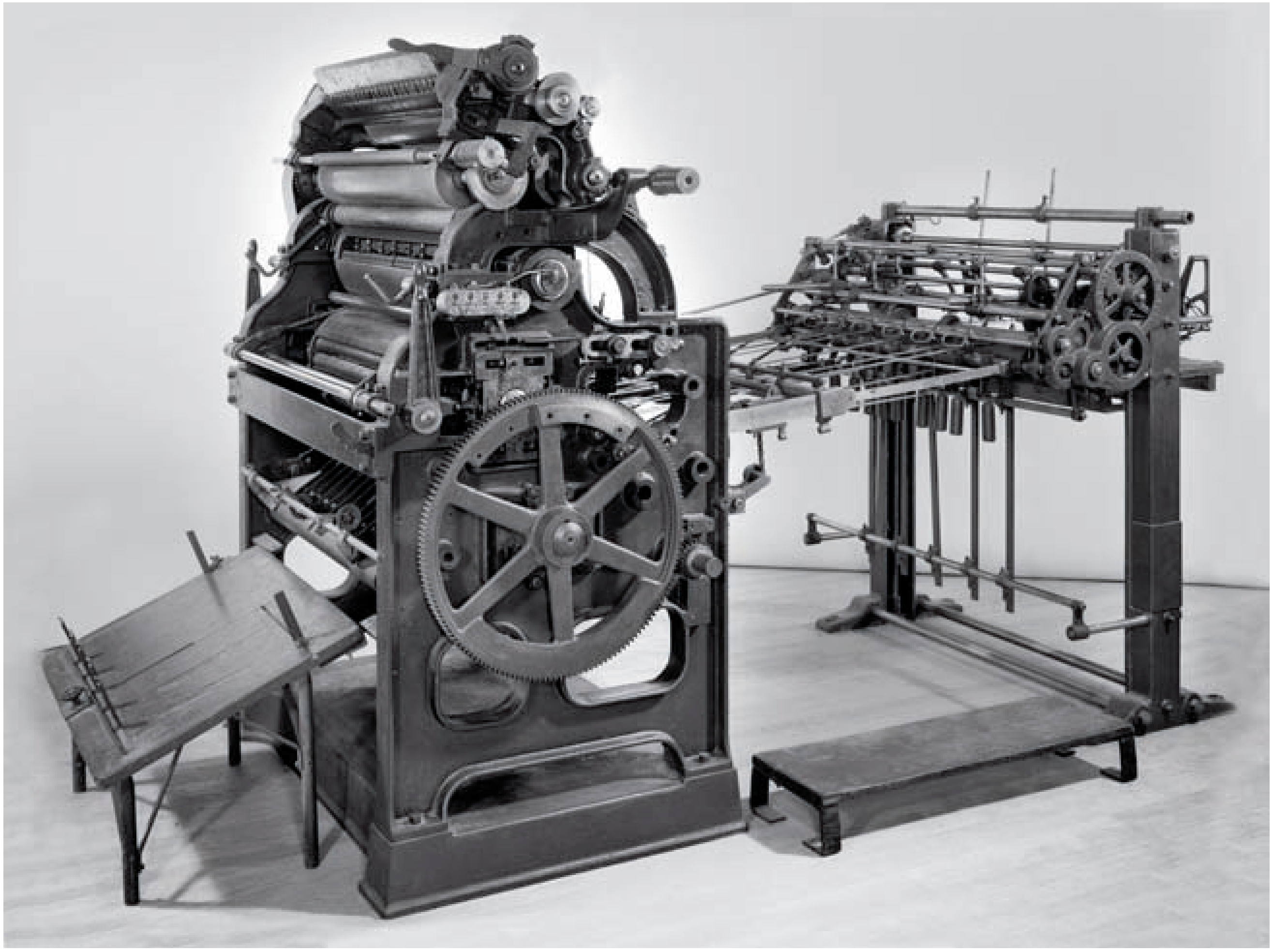

FIG. 839. FIRST OFFSET LITHOGRAPHIC PRESS. Sold by Ira W. Rubel to the H. S. Crocker Company in San Francisco, California.

Image courtesy of the Graphic Arts Collection, National Museum of American History, Smithsonian Institution, Washington, D.C.

Offset lithography and associated photomechanical color reproduction methods slowly replaced wax engraving as the preferred printing method. Cerography faded out of existence, and the photomechanical approach to color reproduction dominated map printing from around 1950 to the last decade of the century. A number of technical advances came together to allow multiple colors to be created photomechanically and printed easily in high-volume print runs, but the central innovation was the accidental discovery in 1904 of the offset lithography principle by American Ira W. Rubel (fig. 839). Rubel observed that when a sheet of paper failed to pass between the flat printing plate and rubber-coated pressure cylinder on a flatbed press, the next sheet was printed more crisply in reverse from the inked image that was accidentally transferred to the pressure cylinder.

The first offset lithography printing presses used the offset principle by transferring a right-reading inked image on the flat lithographic printing plate to a reversed image on a rubber-coated offset cylinder. The map sheet then traveled between the offset cylinder and an impression cylinder that applied the pressure required to transfer the right-reading map image to the paper (Keates 1973, 126). In 1875, the English printer Robert Barclay invented the rotary offset press (Meggs 1998, 146–50) on which the printing plate was a thin flexible sheet of zinc (later aluminum) that was wrapped around and secured to a plate cylinder. Soon afterward, two sets of cylinders were placed in tandem to create a two-color offset press. By 1950, refinements in plate alignment and paper feeding between cylinders allowed expansion to the large-format four-color presses in common use today. Specialized six-color presses were also created for printing the six inks used on USGS topographic maps. By 1975, most multicolor maps copied in large quantities were printed on four-color offset presses.

Specifying and mixing ink colors, called spot colors, for maps was a technical issue of concern until color matching systems were devised in the second half of the twentieth century. Map printers quickly adopted the Pantone Matching System (PMS), introduced in 1962, for their color specification and ink mixing. Cartographers selected spot colors from a swatch book of printed samples, and the printer could easily mix the ink from the color formula found below the sample (Eckstein 1991).

Printing flat tints of an ink color required breaking the tinted area into an array of tiny dots that when printed created the impression of a flat tinted area. Screen tints, such as those produced after World War II by ByChrome Ltd., of Springfield, Ohio, were used to expose printing plates. Plastic screen tint sheets were available up to several square feet in area and in dot rulings from 65 to 300 lines per inch. They accommodated the coarse rulings required for poor-quality newspaper printing as well as the fine rulings used for the highest-quality color maps printed on coated paper stock. Tints normally were sold in 10 percent increments of area covered by dots, but in negative form, so that a low-percentage screen appeared dark to the eye. Reflection densitometers were introduced at midcentury as a numerical way to measure dot gain, a phenomenon wherein dots printed larger than intended because of the viscosity of ink and its ability to soak into different types of paper.

As in cerography, additional colors could be created by overprinting screen tints of two or more ink colors, adjusting the angle between the rows of dots on each screen to avoid creating unwanted moiré interference patterns. From the beginning of offset lithography, printers created greater tonal and texture definition by using overprints of the process color inks cyan, magenta, and yellow, plus black (CMYK), yielding a wide gamut of map colors. The four-color offset press and process inks became integral components of both flat and continuous-color map printing (Yule 2000).

Printing continuous color on maps (e.g., relief shading combined with layer tinting), presented special challenges because the color artwork had to be color separated as negative images into red, green, blue, and gray components, which were then printed in positive using the cyan, magenta, yellow, and black process inks. Halftone screens were put into use around 1890 as a photomechanical way of reproducing the details of any continuous-tone color drawing or photograph, the term "halftone" coming from the reproduction of grays and half tones of other colors. The original halftone screens were made of two sheets of glass engraved with closely spaced blackened parallel lines at rulings from 60 to 150 lines per inch. The glass sheets were glued together with the engraved lines perpendicular so that light from the copy camera used to reproduce the map was divided into identical tiny squares as it passed through the screen to a high-contrast film negative in the camera. Diffusion of light through the squares caused lighter areas on the map to be imaged as large dots on the negative and vice versa. Color separation was accomplished by placing blue, green, and red filters over the camera lens and exposing separate negatives through the contact screen and by adjusting the screen angle between exposures to eliminate moiré patterns when the map was printed. By 1950, halftone screens on flexible plastic sheets at the different screen angles required for color separation reduced the cost and increased the durability of the screens.

Xerography, invented in 1938 by the American Chester Floyd Carlson, came into commercial use in 1959 (Owen 2004). Xerographic copiers use a light-sensitive selenium-coated plate initially given a positive electrostatic charge. The positive charge dissipates when exposed to light reflected from the image through a lens, leaving a latent image to which toner powder adheres. The latent image is then transferred to a positively charged paper sheet and heat fused to the sheet. In 1973, Xerox unveiled its first color copier, an expansion of the monochrome copier whereby the image was color separated and directed to different plates coated with cyan, magenta, and yellow toner. Color xerography remains an attractive way to reproduce page-size color maps in small quantities. The cost per copy is constant, and the color quality of the copy is satisfactory for many map users.

The last three decades of the century saw digital technology profoundly change the way multicolor maps were compiled, constructed, and reproduced. In our digital age, maps are constructed from databases using computer mapping software that displays an electronic image of the map on a color monitor. The challenge was (and still is) to make hard copy prints that faithfully match the color image on the monitor. Vector plotters and raster printers first appeared in the early 1960s as devices for making small numbers of prints economically (Johnson 2005).

By the late 1960s, cartographers were learning how to make hard copies of rudimentary multicolor digital line maps using Calcomp, Hewlett-Packard, and other vector plotters that mimicked hand drafting (Robinson et al. 1995, 602–3). With these machines, a paper sheet was affixed to a flatbed or rotating drum located close to a drawing head containing ink pens of different colors and line widths. A plotter language such as Hewlett-Packard Graphics Language (HPGL) converted the vector color map image created by the mapping software into instructions guiding the selection of pens and the drawing of linework as a series of small horizontal and vertical increments. A key advantage of vector plotters was the ability of expensive large-format drum plotters to make copies of multicolor maps a meter or more in width and length. Large mapping agencies and companies also began using very expensive large-format flatbed plotters, produced by companies such as Gerber Scientific, to expose pieces of lithographic negative film directly, by drawing with a narrow beam of light from a point source placed on the drawing head. However, the widespread cartographic use of vector plotters was hindered by their lack of color versatility, and by the mid-1990s they were obsolete, replaced by raster printers.

Raster printers create hard copies by printing closely spaced dots using a print head device that scans across the print surface row by row downward on the page. Color printers repeat the raster scan for each of the process ink colors (CMYK). Building color copies in this manner allows linework, lettering, area tints, and continuous-tone map artwork to be combined and printed simultaneously. The complexity of the map symbolism has no effect on the time required to generate a copy.

To print a hard copy of a color map displayed on a color monitor, colors defined numerically in the red-green-blue (RGB), hue-lightness-saturation (HLS), or other specification system must be first converted to their CMYK equivalents. The vector and raster data underlying the map, including all CMYK specifications, can then be converted to printing instructions in a page description language such as PostScript, the industry standard first released by Adobe in 1984. Raster image processing (RIP) hardware and software built into the printer then converts the PostScript instructions, pixel by pixel, into a bitmap image of the printed page that drives the color printer.

The first dot matrix printers were introduced in 1970, and until the early 1990s they were the most common printer used with personal computers. These printers ran a print head across the page and then stepped the page vertically in small increments. In the print head was a small matrix of tiny metal rods that were pushed up electronically to strike an ink-soaked ribbon, creating different patterns of tiny dots seen as letters, line segments, or tinted areas. Color printing required the print head to pass across a ribbon striped with the process ink colors four times. Slow printing speed and poor color quality led to their widespread replacement by inkjet printers in the mid-1990s.

The thermal inkjet printer was invented independently in 1976 by Hewlett-Packard engineers in Corvallis, Oregon, and Canon researchers in Tokyo, Japan, but it was not until the late 1980s that the two companies introduced their first color printers (fig. 840). The heart of the printer is an inkjet print head made up of tiny nozzles that produce ink droplets that are transferred to the paper as minuscule colored dots. Cartridges containing liquid ink reservoirs for each process color supply the nozzles, and ink dots are sprayed either in the circular rosette pattern used in offset lithography or in a more random pattern using a technique called stochastic screening. Dots vary in size, creating continuous color prints in a process called digital halftoning.

FIG. 840. HEWLETT-PACKARD PAINTJET PRINTER, 1987. The first Hewlett-Packard Paintjet color inkjet printer was introduced commercially in 1987. Full-color page-size maps could be printed quickly at 180 dot per inch resolution. In 1993 Paintjet printers were replaced by the less expensive Deskjet series.
Size of the printer: 9.8 × 44.2 × 30.2 cm. Image courtesy of the HP Computer Museum, Melbourne.

In 1991, Tektronix, of Beaverton, Oregon, introduced its first Phaser solid-ink printer. Solid sticks of waxy CMYK inks were melted and fed into the print head, producing intense, glossy colors on the copy. Large format inkjet printers economically copied maps more than a meter wide and in small numbers. The quality of the printed map came close to large-format offset lithography.

The first laser printer was created in 1971 at the Xerox Palo Alto Research Center. Printers such as the Hewlett-Packard Laserjet, introduced in 1984, work on the xerographic principle but use thin laser beams that create a latent image on the photosensitive drum by reversing the electrostatic charge pixel by pixel. Color laser printers use separate colored toners, usually the cyan, magenta, and yellow process colors, in three additional passes across the drum. Color laser printers, introduced in 1993, were far more expensive than desktop inkjet printers but produced high-quality color prints of page-size maps at higher printing speeds.

At the end of the twentieth century, offset lithography still offered the most economical and highest-quality color reproductions for large print runs of digitally created maps. Imagesetters were introduced in the 1980s to expose lithographic film negatives. A laser or electron beam print head exposes the film at extremely high spatial resolutions from 1,200 to 4,800 dots per inch. Composite negatives containing the linework, lettering, area tints, and continuous-tone artwork for each ink color are created for platemaking. Imagesetting directly on printing plates, called platesetting, closed the century. Platesetting has eliminated the photomechanical filmwork that had been such an important part of color map reproduction in previous decades.

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SEE ALSO: Color and Cartography; Photography in Map Design and Production

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Prepress Techniques. From 1900 the mass output of large-format, multicolored maps, at low unit cost, was the result of concentrating the production flow line on lithographic printing as the primary means of final image presentation. The development of image handling methods associated with such lithographic printing led to the application of a set of techniques considered the prepress stages of the flow line. Such techniques had not been required prior to the 1880s, as the predominant printing plate creation method—engraving onto copperplates—had allowed for subsequent direct impression of multiple copies onto paper. It was new image manipulation requirements and possibilities governing the flow line from initial image creation (in a drawing office) to the final map impression (at the printing shop) that flourished from the 1880s to the 1970s (Cook 2002). During the twentieth century the range of these procedures and variability in their adoption were evident among mapping agencies worldwide and even within different product lines of the same organization (Cruickshank 2005). Using these techniques, map detail, already color-separated, was further image-separated so that a single image might present only the intended blue linework, or the black linework, or the blue text, and so forth.

These more complex and time-consuming steps in image handling necessitated the establishment of a separate prepress section within the map production unit to deal specifically with activities undertaken between the drawing office and the printing section. The section relied on photomechanical methods, whereby images on one base material could be copied, transformed, combined, modified, and separated as new images on another material. Such image handling relied on light-sensitive emulsions evenly spread onto a base carrier; on certain characteristics of the base material itself; on the utilization of equipment designed to introduce light, stabilize exposure, and change image scale; and on processing operations that fixed the new image onto the base.

With the exception of artistic drawing directly onto the base lithographic stone, lithographic platemaking has always required the copying of images held on one substrate material to another. In 1900 the flow line started with the prepress section taking high-contrast drawing office originals, usually in drafting ink on an opaque material such as paper or etching-type ink on white ceramic-covered metal sheets, imaging them through lens systems, and creating printing plates by projection onto photosensitive emulsions spread on lithographic stones or on newly available flexible metal (zinc or aluminum) plates. The nature of the resultant coplanar image on a lithographic plate, distinguished by an oleophilic (ink- or grease-attracting) detail image and a hydrophilic (water-attracting and grease-repelling) background non-image area, imitated the distinction between engraved and untouched areas on a copperplate and was advantageous to crisp image quality. Lens-based camera systems handling these potentially large-format original images were engineered to allow for exact scale changes, or to ensure maintenance of original scale (as required), when the image was projected onto the light-sensitive surface of the plate (Craster 1925).

Image separates of each map element could be maintained in positive (map detail rendered black, or opaque; background in white, or transparent) or in negative (the reverse) form. Images created as continuous tone (e.g., hillshading overlays or orthophotograph base layers of a midcentury photomap) had to be converted into

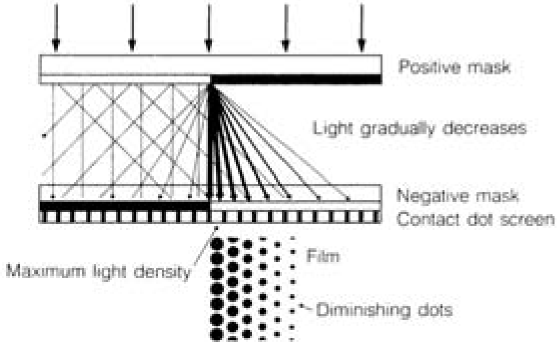

FIG. 841. VIGNETTING. Exposing a positive and associated negative mask separated by clear plastic spacers to cause light dispersion.
Size of the original: 4.4 × 7.2 cm. From Curran 1988, 74 (fig. 7.38). Copyright Elsevier (1988).

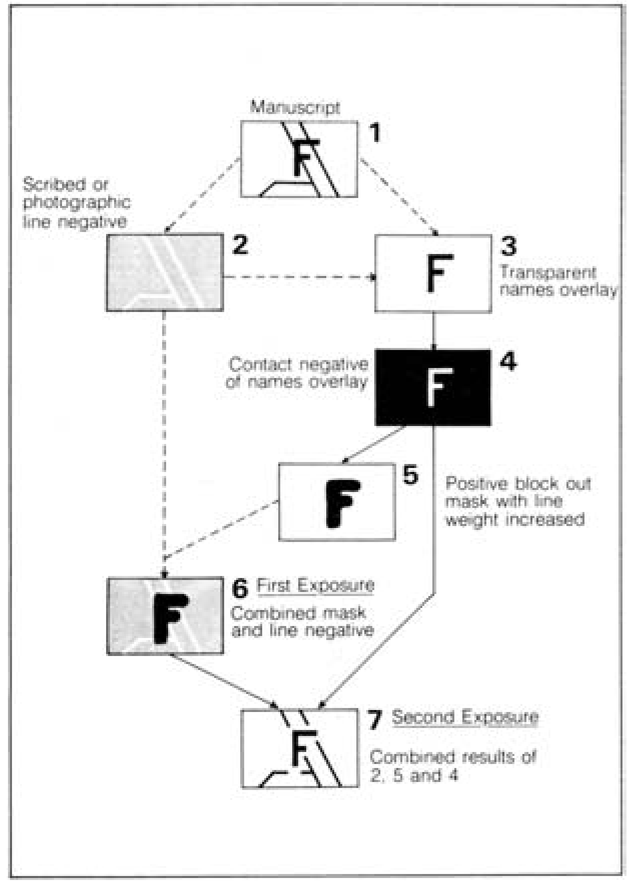

FIG. 842. FAT MASKING. Overexposing a text negative to create a block-out mask, used to interrupt linework.
Size of the original: 11.5 × 8 cm. From Curran 1988, 79 (fig. 7.52). Copyright Elsevier (1988).

printable form (halftone) by screening, rendering the continuously varying image into an array of different-sized dots at fine resolution. Such conversion was typical of the possible forms of image handling undertaken in the prepress section, many of which influenced contemporaneous design possibilities. Vignetting (creating bands varying in density away from a boundary line by exposing masks separated by clear spacer sheets [fig. 841]), parallel line casing (creating lines on either side of one existing centerline, e.g., road symbols), and fat masking (creating a buffer zone around text, subsequently used to mask out all detail in that area [fig. 842]) were all examples of image creation using photographic methods in the prepress section. Image manipulation might involve changing specifications (e.g., thickening lines), converting area symbols from solid to tint-screened form, and changing scale, or base material—again, all standard operations introduced from the beginnings of the prepress section. By the 1970s, when the section was at its technical and volume peak, the major role was to combine image separates (e.g., all the linework, multiple tint-screened areas, point symbols, and text for a given color) onto one final large-format photographic film from which a printing plate could be made directly.

Screening, in particular, was a delicate operation. The term covered continuous-tone to halftone image modification as well as tinting, introduced photographically into the flow line as line screens in the nineteenth century and as dot screens in the twentieth century (Ehrensvärd 1987). Screens were used to make colors more transparent, establish tint gradations, and allow for color combinations by overprinting. Tints and patterned screens could be laid down directly onto plates, as with the Ben Day method (described in Raisz 1948, 157–58), but stick-on screens quickly became more prevalent earlier in the flow line, that is, in the drawing office. Highest quality was, however, obtained by photographing tint screens in conjunction with masks created using opaque paint or, later, peelcoat materials (Curran 1988). Angling the tint screens to avoid interference patterns—the moiré effect—in the final print was also the responsibility of the prepress section.

The transfer of images from one material to another almost always involved an image transformation—perhaps from negative to positive or from right-reading to mirror-reversed—due to the nature of the photomechanical process. For example, offset printing, first used for map production in 1910 (Cruickshank 2005, 43), required plates to be produced as right-reading images. To preserve quality and scale by contact copying, a flow line that often encompassed many image transfers and manipulations had to lead to a mirror-reversed combined final film.

All the image handling operations in prepress relied on transferring images from one base material to another using light-sensitive emulsions dried onto the substrate and exposed using specialist equipment. The initial reliance on an opaque image carrier produced by the drawing office meant that lens-based equipment, with its potential for distortion and difficulties in registering the images of different elements and colors, was the norm. Contact copying, by contrast, involved the positioning of an original image face down on a sensitive emulsion and the transmission of light through the former to the latter: the original had to be on a transparent base material. Thus ink drawings on opaque material were often photographed onto silver halide emulsion coatings on glass plates as an intermediate step. Such reproductions could subsequently be used to create printing plates by contact as well as efficiently archiving drawing office work. By the 1950s glass plates, covered by a coating opaque to certain wavelengths of light, on which engraving tools could be used for image creation by scribing, became popular in drawing offices. This led to the decline of lens-based systems in the prepress section.

The improved image quality possible with scribing was further applied to translucent and transparent base materials made from plastics, available from 1955. Polyvinyl chloride and polyester sheets, like glass, were more dimensionally stable than paper. The image produced on them—whether a drawn or scribed original, or a photographic image—was easier to correct and edit, and the clear base material ensured high-quality image transfer using contact methods, rather than cameras, thus rigorously maintaining scale.

The photographic emulsions used in prepress were silver halide–based and thus sensitive to standard white light, although their sensitivity was set to ensure that no midtones were created, thereby maintaining the distinction between pure opaque and clear transparent elements. Many other emulsions were invented and patented in the first half of the twentieth century: emulsions sensitive to varying windows in the spectrum (e.g., ultraviolet, blue light), photoreactive in different ways when exposed to the appropriate wavelength (e.g., hardening, softening, chemically reacting, bleaching), and variably processed (using water, proprietary chemicals, adhesive toner, in automatic machines or by hand, or not at all). Ferric salts, dichromated colloids, diazo, photopolymer, thermographic systems, and electrostatic processes are types of light-sensitive coatings described by J. S. Keates (1973, 111–22) as nonphotographic systems: during the twentieth century each has been used for image transfer processes, for creating guide images (such as guides for scribing), for color proofing, for printing plates, and for final image printing.

Although the materials onto which such emulsions were laid also varied, a major development was the transparent polyester that Keates (1977, 38) called "possibly the most important single development . . . the achievement of a single base material" for drawing, photographic purposes, and proofing. And although an array of different printing plate materials, emulsions, and functions was apparent by the 1920s—letterpress, intaglio, lithographic stone, and metal lithographic plates, the last of these coated with photosensitive dichromated colloids or diazo, and resulting in surface, deep etch, and bimetallic detail/background images thereon—convergence on standardized aluminum base materials was evident by the 1950s. From 1900 onward metal plates that could be used in rotary presses were cheaper and less fragile than stones and could be stored efficiently. From the 1930s mass-produced printing plates became increasingly able to hold fine details, such as the tiny dots of a tint screen, and specialist manufacturers obviated the need for the prepress section to prepare the plate surface (graining a surface to receive the lithographic image using a sandbox and glass balls) or spread the emulsion using a whirler—techniques that were required in-house during the first half of the century.

Additional necessary equipment was associated with exposure and processing: light sources, vacuum-frame contact boxes, and cameras required darkrooms as well as processing sinks (from the 1950s, automated processors) and their associated chemicals. Because large-format map materials were handled in safe-light conditions, maintaining the fit and register of the image- and color-separated materials required particular care. Opaque materials required the creation of register marks, often corner crosses, but these were much less effective than the punch-register systems possible when contact copying was used (Keates 1973, 155).

In addition to printing plate creation and assisting the drawing office, the other major task of the prepress section was to prepare color proofs. This could be done by photomechanical means, attempting to simulate the printing process by successively exposing each final film to colored light-sensitive layers sequentially coated onto one opaque white substrate or to a series of transparent colored overlays. Colored dichromated colloids and diazo dyes were popular techniques for producing *proofs in color*. *Proofs of color* could be produced only on the printing press, using the final printing ink and paper, thus requiring expensive platemaking. The object of color proofing was to check content, fit, design, color balance, quality, and completeness and show the drawing office where corrections were needed earlier in the flow line (U.K. Ministry of Defence 1976).

The complex nature of the image handling operations undertaken in prepress led to a need to standardize reference to techniques and characteristics by visualizing the flow line, as illustrated by figures 843 and 844. Flow diagrams were significant in project planning, costing, scheduling, and quality control during

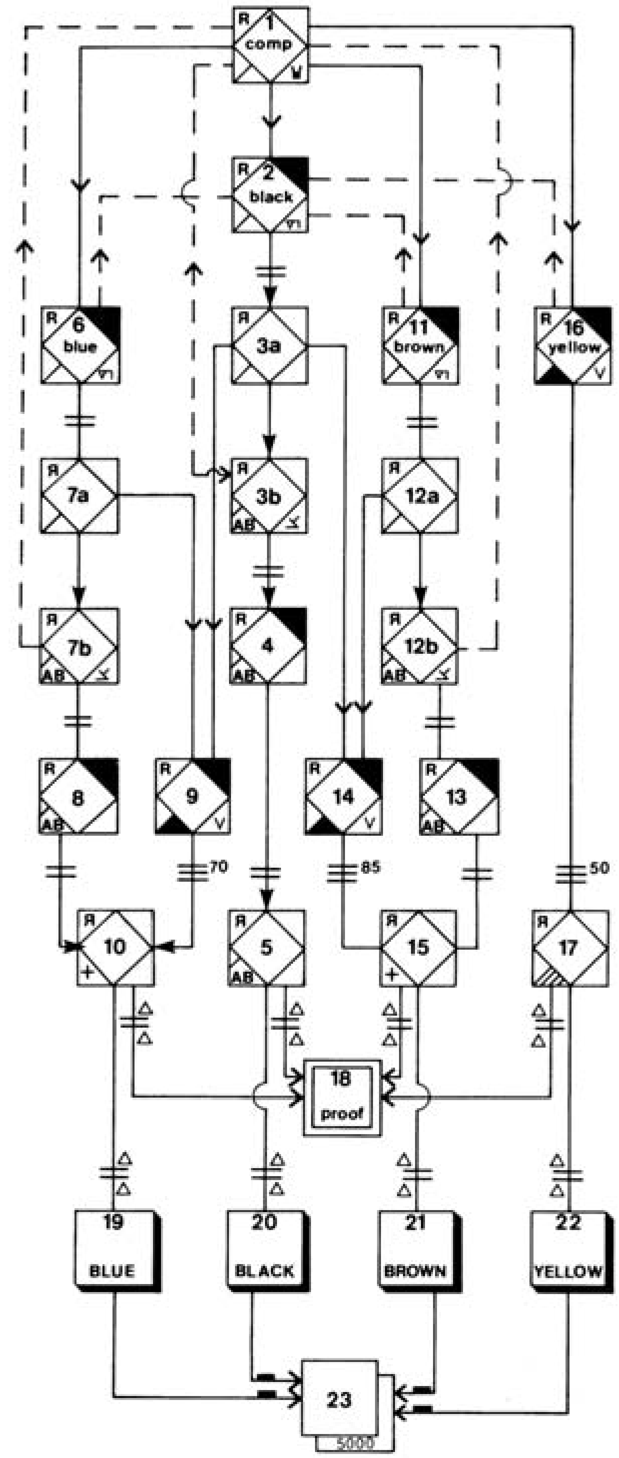

FIG. 843. TYPICAL PRODUCTION FLOW DIAGRAM SCHEMA FOR A FOUR-COLOR MAP. See figure 844.
Size of the original: 19.1 × 7.9 cm. From Shearer 1982, 15 (fig. 22). Copyright © British Cartographic Society. Permission courtesy of Maney Publishing, Leeds.

map production for much of the twentieth century (Shearer 1982).

Toward the end of the century, the concept of creating the final image directly on a single sheet of photographic film (from which a printing plate could be made) replaced the sequence of photomechanical steps. The digital photowriter, also called an imagewriter, was able to create a finely detailed high-resolution image using light under the control of an electronic file. Within ten years even the film step was no longer necessary, as it became possible to undertake platewriting directly from a digital database or Portable Document Format (PDF) file, yielding color separated files of images, one for each plate, using computer-to-plate methods (Kipphan 2001).

In 2000 there was still a need for lithographic printing for finished map artifacts, but the original drawing office techniques of image creation had been replaced by automated drawing output from geospatial databases, and image manipulation techniques (including screening and color separation to produce appropriate images for printing plate sourcing) were undertaken using software. As quickly as the prepress set of techniques appeared, the rise of digital technologies in platemaking led to their demise (Cook 2002): the map production flow line again moved data directly from a database (digital, rather than an analog original) directly to a plate for printing.

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SEE ALSO: Photography in Map Design and Production

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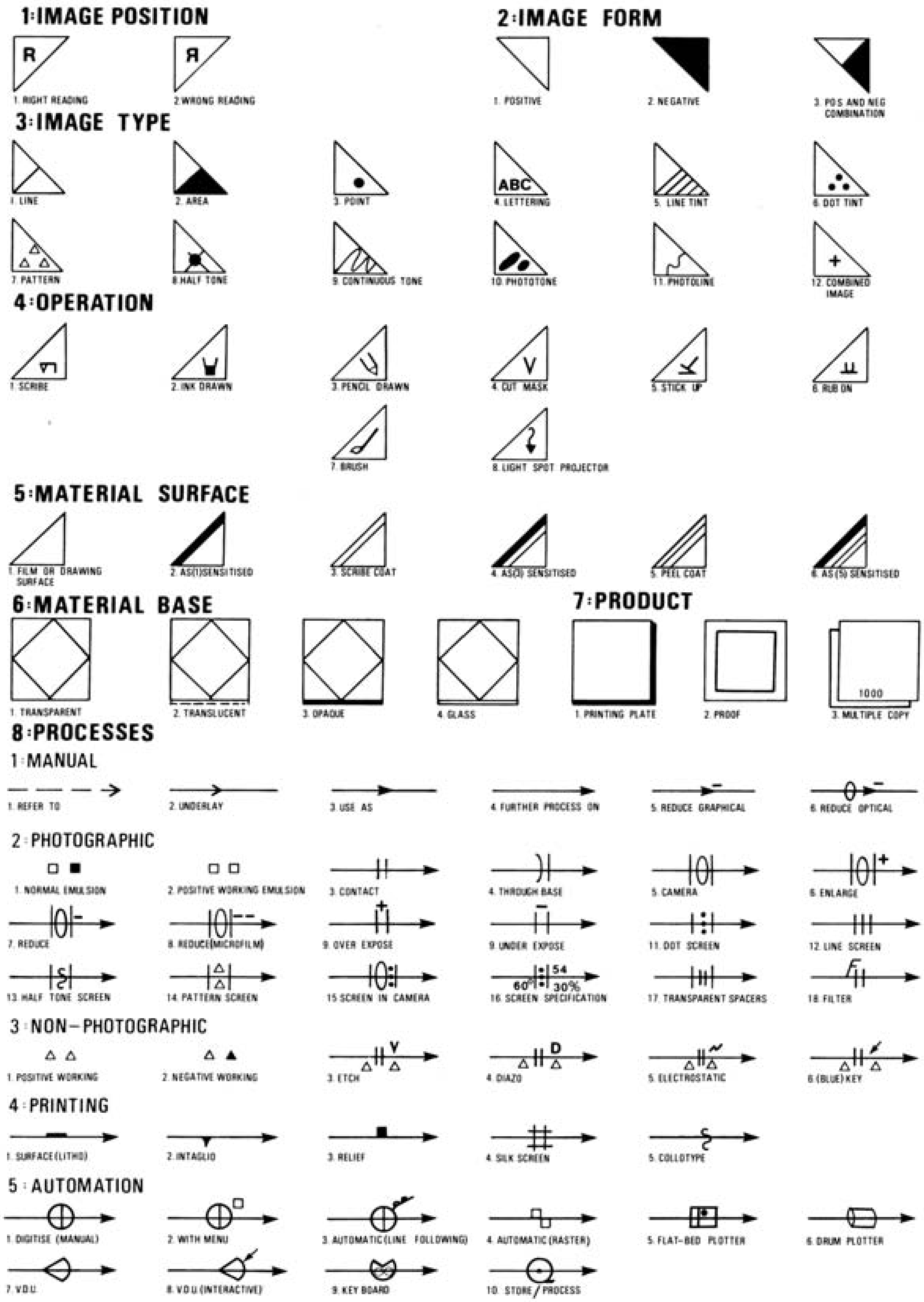

FIG. 844. ASSOCIATED SYMBOLIZATION TO PRODUCTION FLOW DIAGRAM. See figure 843.

Size of the original: 24 × 17 cm. From Shearer 1982, 8 (fig. 4).

Reproduction, Design, and Aesthetics. Mapmaking involves a succession of interdependent stages from the initial concept through to the finished product. Where multiple copies of a map are to be made, their final appearance depends upon the techniques, tools, and materials used in creating the artwork and upon the nature of the reproduction process employed. Affecting both design and content, these shape the distinctive look of maps and construct a particular cartographic aesthetic that becomes familiar to map users. The twentieth century saw a rapid and extensive development of map reproduction techniques, which had an unprecedented impact on the design and aesthetics of cartography.

As the lithographic press developed in the early nineteenth century, the enhanced possibilities of color printing afforded the cartographer greater scope in design, especially with more control over the amount of information to convey with graphical clarity. In 1859, the Ordnance Survey coupled the recent invention of photography with the introduction of grained metal printing plates (usually zinc and later aluminum), which were less expensive and more convenient than stone. Photolithography transformed the lithographic press by allowing an image to be transferred to the plate without manual engraving (Hinks 1944, 59); a map drawn on paper could be photographed and the resulting negative used to expose the light-sensitive coating on the printing plate. Wax engraving (cerography), invented in the United States in 1839, involved spreading a thin layer of wax over a polished plate, usually copper, then transferring an image to the wax by drafting or photography (Hodgkiss 1981, 68). The rotogravure process provided another development in the 1890s with the application of carbon tissue covered with light-sensitive gelatin to metal plates on rotating cylinders (one for each color), improving the speed of multicolor reproduction.

By the close of the nineteenth century, the introduction of photolithography, wax engraving, and rotogravure—printing processes that lent themselves to color printing—had brought increased flexibility, variety, and speed to cartographic production, each shaping the appearance of the final map. With the advent of photolithography, the quality of the map drawing was adapted to the camera (Koeman 1975, 140), leading to the loss of fine linework and the adoption of sans serif fonts (Craster 1925, 304). The minute type possible through wax engraving made the inclusion of lettering easier and by 1900 lent itself to a certain style in popular maps in the United States (Purinton 2003), which some considered "mechanical" and "over-lettered" (Hodgkiss 1981, 68). While rotogravure brought greater speed, the reproduction of images using patterns of dots visible to the naked eye gave a less clean result than other methods.

The invention of the offset printing press by Ira W. Rubel in 1904 brought the twentieth century's first major development in the reproduction of maps. Rubel was inspired when he noticed that when a sheet of paper failed to pass between the plate and the cylinder, the following sheet received a mirror impression from the cylinder on its reverse (Koeman 1975, 152). Adapting the recently established rotary printing method, the key development was to offset the inked image onto a resilient rubber blanket on another cylinder before making contact with the paper, resulting in cleaner and sharper prints than direct lithographic printing. Another major advantage was speed; offset lithographic presses were able to run off 1,500 prints per hour, a figure that exceeded 7,500 by the 1980s (Hodgkiss 1981, 69).

Offset presses could be single-color machines or print several colors in sequence, and their development led to new possibilities in the simultaneous presentation of geographical information. From the sixteenth through the mid-nineteenth century, most maps were engraved on copper, the resulting cartographic style being a fine-line image embellished by some hand-applied area color (Keates 1989, 91). Since all detail on the engraved sheets was black, contour lines were not always conspicuous (Crone 1978, 118). Lithographic color printing gradually enabled more accentuated figure-ground relationships, in which darker linework and lettering contrasted effectively with lighter area coloring, increasing legibility. The "fully coloured" third edition of the one-inch (1:63,360) topographic maps of the Ordnance Survey (completed in 1912) achieved this by printing in six colors: brown hachures, red contours, blue water, green woods, burnt sienna roads, and black place-names and other detail (Crone 1978, 118).

The initial use of offset printing was slow in Europe, mainly due to the huge stock of original lithographic stones (Koeman 1975, 152). The International Map of the World, proposed by Albrecht Penck in 1891 with first sheets appearing in 1911, employed a degree of symbol standardization that relied on the consistency of color and detail made possible by the offset press. World War I saw the need to produce large numbers of maps in the field that were detailed, clear, and accurate. The resulting trench maps were printed by portable offset presses with topographic information reproduced in gray overprinted by red and blue linework denoting positions of the opposing armies. By World War II, most medium-scale topographic map series exhibited what Keates (1996, 256) described as the "classical style": black planimetry, blue water, brown contours, and green vegetation (fig. 845).

While flat and varying tones, area patterns, and colored symbols became increasingly common on maps after the mid-nineteenth century (Cook 2002, 143), the

FIG. 845. DETAIL FROM *OBERDRAUBURG UND MAUTHEN*, 2d ED., *SPEZIALKARTE 1:75,000* (VIENNA: MILITÄRGEOGRAPHISCHES INSTITUT, 1925). An example of the classical style that dominated topographic mapping in the first half of the twentieth century, which employs gray hachures in addition to brown contours for depicting relief.
Size of the entire original: 38.5 × 52.8 cm; size of detail: 11.1 × 17.3 cm.

halftone screen, in general use around 1895, played a key role in the twentieth (Kainen 1952, 409). The technique used a photographic device to break up a solid image into evenly spaced dots of varying sizes, creating the impression of a continuous tone (Palm and Van der Steen 1993, 181) and expanding possibilities for the reproduction of area images. Around the turn of the century, monochrome halftone photographs of relief models became popular in school atlases, geography books, and wall maps, continuing to be used in the United States *Newsmap* series through World War II and meeting the consumer taste for natural-looking topography (Cook 2002, 146–48).

In the 1920s, the quality of map reproduction declined with the introduction of translucent plastics in map drawing. This had advantages of transparency and handling but led to coarse line elements, spoiling the traditional graphic beauty of the copper engraving or lithographic drawing (Koeman 1975, 153). However, designers of tourist and motoring maps began to draw greater inspiration from wider graphic arts, such as posters and advertising. The public image of the Ordnance Survey was transformed through the artwork of Ellis Martin (fig. 846), and T. R. Nicholson (2004, 194) went so far as to identify art nouveau, art deco, and "the wilder shores of Italian Futurism" in the style of early twentieth-century European motoring map covers. Attitudes toward lettering, however, remained conservative. There was a preference for hand-drawn lettering and calligraphy in posters, advertising, and map titles because the method offered greater flexibility of style and size with improved speed and cost (Holland 1980, 213).

After World War II, technical developments in cartographic reproduction proceeded apace. The most important of these were the introduction of dimensionally stable plastic sheet materials (first polyvinyl and subsequently polyester); the development of light-sensitive coatings; the widespread adoption of scribing as a means of line construction; the use of photolettering output on film in place of type impressions on paper; the production of better and larger tint screens for producing area colors; and the development of peelable colored surface films

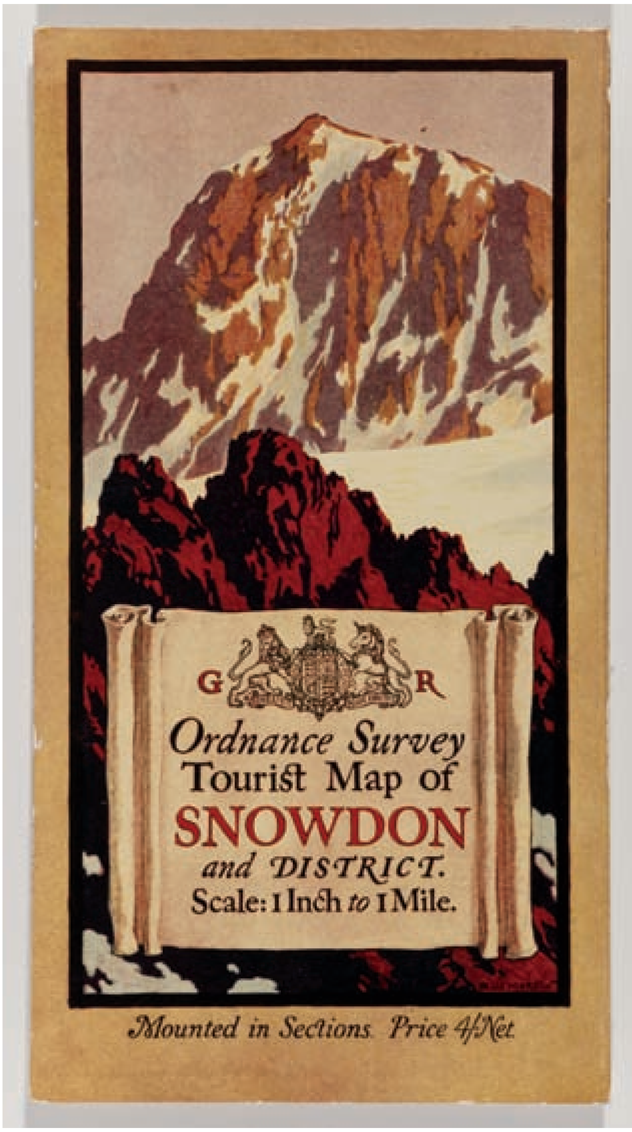

FIG. 846. ELLIS MARTIN, COVER OF *ORDNANCE SURVEY TOURIST MAP OF SNOWDON AND DISTRICT*, 1920. Ellis Martin's highly graphical illustration for the cover of the first Ordnance Survey tourist map was a new departure for the organization, transforming its public image after World War I.
Size of the original: 35 × 19.8 cm. Image courtesy of the Charles Close Society Archives, Map Department of the Cambridge University Library (OS_400_26).

on polyester supports for use as open-window negatives (Keates 1989, 245–46). Direct scribing of negatives, first on glass and later on plastic sheets, became widespread in the late 1940s and 1950s. By cutting lines and symbols in plastic sheets to create cleaner, more consistent linework, the cartographer or draftsman became the new engraver (Hodgkiss 1981, 69).

The uniformity and regularity of lettering and point symbols were improved in the 1960s with the introduction of phototypesetting. Each typeface character was stored as a photographic negative, and the series forming a name were printed off on a sensitized film (with the appropriate size and spacing). The developed film was then cut up and pasted on to the fair drawing of the map (Crone 1978, 142). The introduction of preprinted dry transfer (rub-down) by the 1960s allowed the application of positive lettering and symbols while enabling the combination of linework with dot screens and other patterns without the need for complex photomechanical operations (Kanazawa 1993, 99–100). Whereas typeset words applied by stick-up exhibited uniformity of appearance but had "a certain stiffness" (Kilminster 1962, 83), dry transfer letters could be positioned more flexibly, but, even when applied with great care one-by-one to form words, displayed slight irregularities of alignment and spacing.

Over the course of the twentieth century, developments in map reproduction gradually gave cartographers more control over quality and design, bringing greater consistency, uniformity, and a sense of graphic perfection to the finished map, with improved speed, convenience, and cost. With photolithography, reproduction from original artwork allowed the cartographer to bypass the interpretative craftsman entirely (Robinson 1975, 21). When artwork consisted of numerous pieces, often both positive and negative, the combined effect remained guesswork until the final map was printed (Cook 2002, 142). The ideal arrangement was to print a separate color for every desired color difference to allow maximum control, but the creation of a new plate for each of these made this an uneconomical goal. This was especially true for complex maps, such as general reference atlases of the 1970s, which incorporated color photography of plastic relief models (fig. 847) as backgrounds to detailed topographic information. At the same time, the U.S. Geological Survey began producing orthophotographs for backgrounds on topographic, soils, and geological maps (Cook 2002, 146–47).

With the introduction of personal computers in the early 1980s and more sophisticated graphics software packages in the 1990s, desktop mapping became more widespread as costs decreased. The production of lettering and very fine patterns, such as identical point symbols, was faster than scribing or phototypesetting, and it also became easier to make geometric transformations (e.g., changing map projections). In using analog methods, the cartographer tended to think in terms of the predetermined printing colors rather than the appearance of the map (Keates 1996, 236). Taking the different color gamuts of computer monitor and print into consideration, the WYSIWYG (what you see is what you get) graphical user interface allowed experimentation with color and

FIG. 847. *EUROPE*, 1975. The successful adoption of raised-relief models in depicting topography after World War II continued to influence the cartographic style of general reference atlases for decades. Size of the original: 39.2 × 26.4 cm. From *The Reader's Digest Great World Atlas*, 2d ed., ed. Frank Debenham (London: Reader's Digest Association, 1975), 12.

layout to obtain a clearer idea of the final output. In addition to enabling the cartographer's aesthetic response and judgment to play a more prominent role in map design (Kent 2005), graphics software also allowed the generation of files from which the separate printing plates could be made. In the transition from analog to digital mapmaking techniques, therefore, a major step toward the democratization of cartography had been accomplished.

In the early 1990s, the coupling of desktop mapping with inkjet printing (which directed fine particles of colored ink onto the paper) allowed individual mapmakers to print economically, if not to reproduce maps at the same quality as an offset lithographic press. The development of inkjet printers for larger formats enabled single topographic sheets to be printed on demand, a solution that became especially attractive to national mapping organizations where the printing of less popular sheets became uneconomical and the demand for electronic maps exceeded that for static media. With the launch of IKONOS, the world's first commercial one-meter resolution satellite in 1999, atlas publishers aimed to capture the photographic aesthetic of natural topography by fully incorporating remotely sensed imagery (fig. 848) before the advent of virtual globes, such as Google Earth, in 2005.

ALEXANDER J. KENT

SEE ALSO: Photography in Map Design and Production

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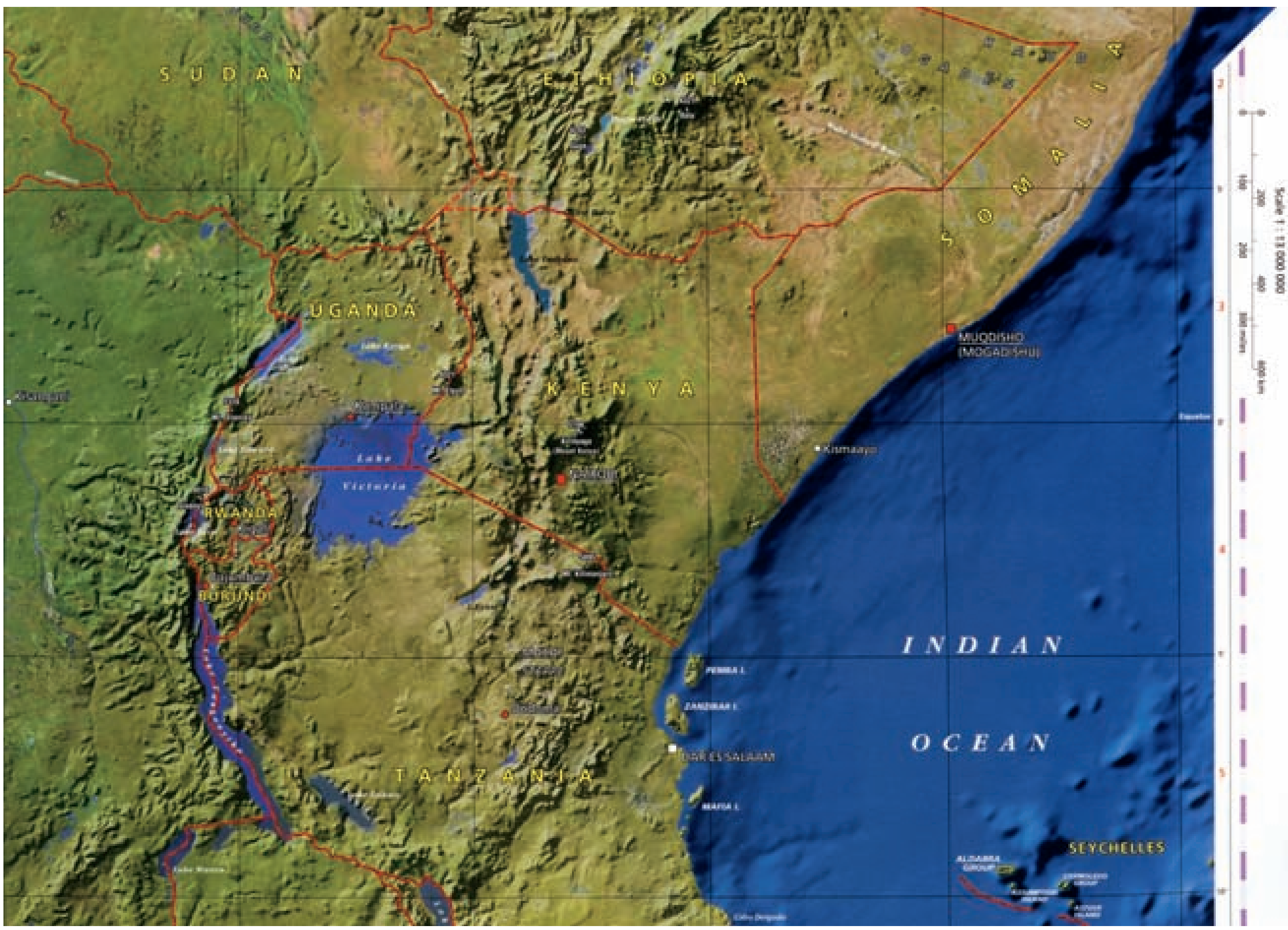

FIG. 848. DETAIL FROM *CENTRAL AFRICA*, 2001. As the availability of aerial and satellite imagery increased toward the end of the twentieth century, general reference atlases incorporated image maps to reflect the changing public taste for natural-looking topography.

Size of the entire original: 23.9 × 34.2 cm; size of detail: 16.6 × 23.1 cm. From *Satellite World Atlas: Two Stunning Views of Our World* ([New York]: MetroBooks, 2001), 96.

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Folding Strategies. The commercial production of folded maps began in nineteenth-century Europe as improvements in road, canal, and railway networks facilitated long-distance travel and generated a need for compact, portable route maps. By 1830 British road maps, dissected and mounted on cloth for durability and easier folding into a slipcase, typically bore a publisher's label and advertising but sold to a limited market. By 1850 spreading railways had created a larger mass market for route maps printed cheaply by lithography and embellished with all sorts of advertising (Nicholson 2008, 43).

Next came the cycling craze, escalating in the 1890s after the introduction of the safety bicycle and the inflatable tire. In Britain press runs of Bartholomew's cycling maps jumped from 2,000 in the early 1890s and to 60,000 in 1908 (Nicholson 2008, 43–44). Mechanical folding machines, introduced in the mid-nineteenth century, typically created a combination of tumble (accordion) folds running in one direction and gate folds in the opposite direction, reducing the dimensions of the folded map to about 4 by 6.5 inches (Board 1993, 120). Folded cycling maps, often adapted from existing road or railway maps by overprinting information about cycling hazards and services, usually had protective card covers bearing title information and advertising (Wallis and Robinson 1987, 61–62).

After 1900 the automobile radically changed patterns of living, work, and commerce and increased the demand for folded road maps. After midcentury the growth of tourism and other leisure activities in landscapes ranging from national parks to urban areas cre-

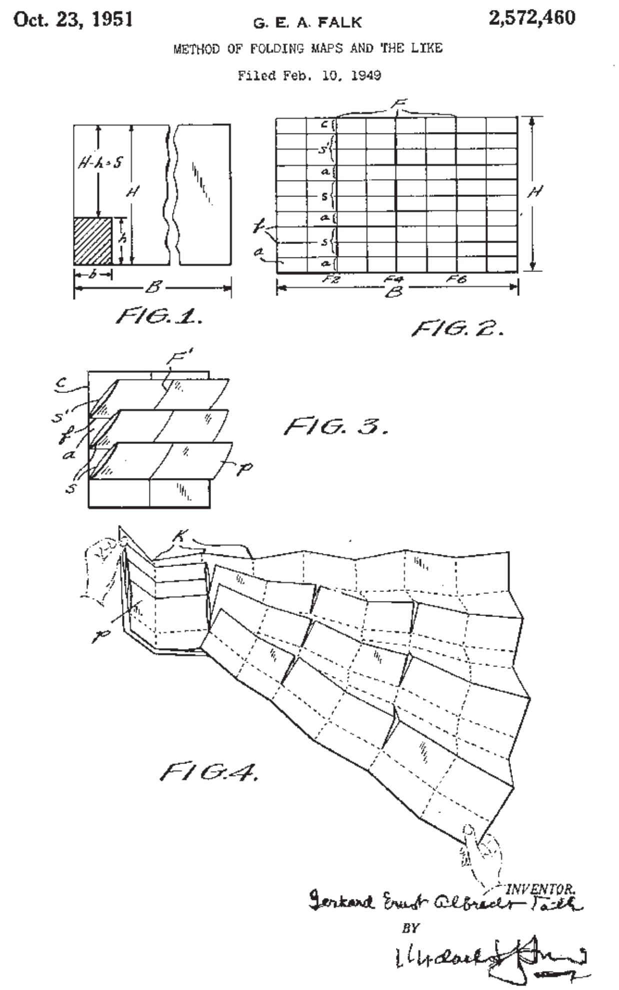

FIG. 849. G. E. A. FALK, METHOD OF FOLDING MAPS AND THE LIKE, 23 OCTOBER 1951. The first American patent for the folding system of German map publisher, Gerhard Falk, shows how the folds can be turned to navigate horizontally and vertically within the mapped area without having to open the entire map. Washington, D.C., United States Patent Office, Patent no. 2,572,460.

FIG. 850. *THE GEORGIAN CITY OF BATH*, POPOUT MAP, 1995. Intended to be compact and convenient yet useful for the wayfinding tourist, PopOut city maps are offered as individual maps, pairs of attached maps, or with an accompanying MiniGuide. Size of the original, opened: 21.2 × 24.6 cm; closed: 9.5 × 12.9 cm. © Compass Maps Ltd.

ated niche markets for specialty maps. Accompanying the popularization of personal wayfinding maps during the twentieth century were improvements making map folding machinery more efficient, map materials more durable, map images more colorful, advertising more enticing, and map folding systems easier to open and close—all intended to give map publishers a competitive advantage.

Some folding concepts migrated between government and private sectors. The longer-format folding system introduced on Michelin Tyre Company road maps in 1914 was adopted by the British Ordnance Survey (OS) in 1934 because the single horizontal fold made it possible to turn over the map and read the other half without opening it (see fig. 529). A 1937 modification by A. R. E. Bender of the OS, known as the Bender fold, became widely used throughout Europe by midcentury. The Ansell system, developed by Major G. K. Ansell and patented by Stanford's mapsellers of London in 1906, involved map panels mounted back-to-back on linen; because only part of the map was visible at one time, it was better for route following than for planning. Bridges Patent Mounting system, also popular with Stanford's, allowed the map to be mounted above the steering wheel of a car with the outer covers fixed in place, so the driver could follow a route horizontally or vertically across the sheet (Board 1993, 120–21).

Another folding system allowing the user to view sections of interest without unfolding the entire map was developed by Gerhard Falk, who founded Falk-Verlag in 1945 and patented his method in Germany (1949) and the United States (1951) (fig. 849). Disliked by some for its inability to reveal the entire map at once and for the tendency of the slits along its folds to tear, the system nevertheless became very popular. By the 1990s Falk was the most successful city map publisher worldwide

(Loebbecke and Huyskens 2007, 37). Although it was purchased by Mairs Geographischer Verlag in 1998, and they became MairDumont in 2005, Falk folded maps remained available under the Falk logo.

The Miura-ori system, originally developed by an aeronautical engineer for use in space science, was demonstrated at the 1980 International Cartographic Conference in Tokyo. It was illustrated by a map of Venice folded along thirty-five congruent parallelograms, making opening by pulling on diagonally opposite corners and closing equally easy. Disadvantages were the irregular folded outline and the need to open the map entirely to read it (Board 1993, 121). Others have used successively smaller accordion folds to expose marginal strips bearing information about adjacent map sections, color coding, or other useful information (G.A.H. 1984, 138). The PopOut mini-sized city maps produced since 1992 by Compass Maps have easy-opening star-shaped folds and were inspired, according to the company's website, by miniature air charts used by the British founder, a former airline pilot (fig. 850). A "zoomable map" of London advertised on the Internet in 2010 consists of a city map, each quadrant of which opens into a larger-scale map of that quadrant. As the term suggests, by the early twenty-first century folded paper wayfinding maps were competing with computer-based maps zoomable and printable on demand from Internet sites and in-car navigation systems.

LUCINDA BOYLE

SEE ALSO: Marketing of Maps, Mass; Travel, Tourism, and Place Marketing; Wayfinding and Travel Maps: (1) Cyclist Map, (2) Indexed Street Map, (3) Public Transportation Map

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Risk Map. See Hazards and Risk, Mapping of

Ristow, Walter W(illiam). Walter William Ristow, born on 20 April 1908 in La Crosse, Wisconsin, is noted for his contributions to the history of cartography, map librarianship, and map collecting. Founder of the Geography and Map Section of the Special Libraries Association (U.S.), cofounder of the Geography and Map Libraries Section of the International Federation of Library Associations, and cofounder and first president of the Washington Map Society, Ristow had a distinguished professional career that spanned seven decades. He inspired countless individuals by his original research, writings, committee work, professional society activity, and leadership in map librarianship. He was a pioneer in professional map librarianship in the United States, and his "Library Map Collection" (1942) was one of the earliest articles on the subject to appear in an American library publication. During his direction of the Geography and Map Division of the U.S. Library of Congress, he oversaw the development of machine-readable cataloging for cartographic objects (MARC maps) and developed a program of summer internships that contributed maps to countless academic map collections in the United States. His cartographic research interests spanned time and genre from early modern European cartography to twentieth-century mapping expressions, most notably in aviation cartography, journalistic mapping, marketing maps, and oil company road maps.

Ristow received his formal training in geography from the University of Wisconsin–Madison (BA 1931), Oberlin College (MA 1933), and Clark University (PhD 1937). Upon completion of his graduate studies, he began his career in map librarianship as head and later chief of the Map Division of the New York Public Library (1937–46). In New York City he served also with the Military Intelligence Service as a wartime map analyst from 1941 to 1944. He moved to Washington in 1946 to begin his thirty-two-year career in the Geography and Map Division, U.S. Library of Congress (1946–78, assistant chief 1946–68, chief 1968–78, and, after retirement, as honorary consultant in the History of American Cartography 1978–87). He devoted substantial energies to the scholarly organizations in his field, serving as the secretary-treasurer of the Cartography Division of the American Congress on Surveying and Mapping (1942–44) and its publications committee (1954–61), secretary of the Association of American Geographers (1949–50), and as editor, consulting editor, and advisory editor for scholarly journals, including *Canadian Cartographer*, *Imago Mundi*, *Acta Cartographica*, and *Map Collector*. He served as member, vice chairman (1954–57), and chairman (1957–59) of the U.S. Board on Geographic Names.

Ristow wrote, edited, and compiled prolifically between 1933 and the late 1980s. Among his most noteworthy publications were *The Emergence of Maps in Libraries* (1980), *American Maps and Mapmakers: Commercial Cartography in the Nineteenth Century* (1985), *Nautical Charts on Vellum in the Library of Congress*

(1977, compiled with R. A. Skelton), *A la Carte: Selected Papers on Maps and Atlases* (compiled, 1972), *Marketing Maps of the United States: An Annotated Bibliography* (1951, 1952, and 1958), and *Aviation Cartography: A Historico-Bibliographic Study of Aeronautical Charts* (1956, 1957, and 1960). Ristow firmly believed that maps should be in the hands of the people, whether in public libraries–which were rare when he began his career–or in general circulation. Ristow died from coronary artery disease on 3 April 2006 in Mitchellville, Maryland.

JOHN R. HÉBERT

SEE ALSO: Journalistic Cartography; Libraries, Map; Libraries and Map Collections, National

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Road Atlas. See Wayfinding and Travel Maps: Road Atlas

Road Mapping.

CANADA AND THE UNITED STATES
LATIN AMERICA
AFRICA
EUROPE
AUSTRALIA AND OCEANIA

Road Mapping in Canada and the United States. Though road maps have been published with some regularity since the eighteenth century, the automobile age raised them to a status in the commercial map trade that few cartographic genres ever achieved. Nowhere was this truer than in Canada and the United States, where the car emerged not only as the primary means of local and interregional transportation but also as a cultural icon (Flink 1988). The iconic, colorful, and free road maps oil companies distributed to their customers from the 1920s to the 1980s alone accounted for annual production of about 200 million maps by the mid-1960s (Ristow 1964, 623). Nearly every private interest in North America, state or provincial authority, roadside attraction, or local authority that might benefit from automobiles passing their way distributed road maps in the twentieth century.

From the mid-1920s, the maps issued by the three largest sources—oil companies, state or provincial highway authorities, and automobile clubs—differed little in content and design. Most depicted provinces, states, or regions at varying scales, from about 1:100,000 to 1:3,000,000. (Sectional road map series with uniform scales, common in Europe, were never popular in North America.) Though often richly colored and illustrated, the North American road map design was spare and simple (fig. 851). Roads and highways were carefully identified, delineated, and classified by their surface quality, width, method of access, and significance. Cities, towns, points of interest, parks, and forests, major political divisions, lakes, and rivers were also shown, but relief was only minimally indicated by spot elevations or highly generalized shading. Though simple, this design nevertheless supported the navigational needs of most motorists. It was easily revised on an annual basis in response to the evolving road network, while remaining inexpensive to print and easily customized to suit the promotional needs of businesses and government agencies dependent on the growth of automobile travel (Akerman 2002, 182–83).

The idiomatic design and promotional character of North American automobile road maps owes a particular debt to railroad mapping from the last half of the nineteenth century. Railroad companies fueled, and also depended upon, the economic growth of the regions they served, especially in the Midwest and West, where competition between railroads was intense. Maps added to timetables and promotional publications or published on their own as handbills or broadsides helped railroad operators and agents persuade investors, shippers, and travelers their railroad was well located in relation to growing markets and productive lands or provided access to places people wanted to visit or inhabit (Musich 2006). Most of these maps were cheaply produced by printing firms already specializing in inexpensive mass printing for newspapers, advertisers, and industrial operations. Some of these publishers, most notably Rand McNally & Co., came to specialize in cartography and were well positioned to adapt their business model to serve the emerging complex of automobile-related industries (Peters 1984; Akerman 1993).

The Good Roads movement of the 1880s–1920s provided a more immediate context for the development of a new type of road map suited to the needs of North American motorists. Though the arguments that Good Roads advocates made for greater state, provincial, and federal investment in rural roads were essentially economic, much of the movement's energy and leadership derived from enthusiasm for the new pastimes of cycling and motoring, the enjoyment of which was hindered by bad roads (Hugill 1982). During the 1880s and 1890s sporting and social events, conventions, and publications of the Canadian Wheelmen's Association (CWA), the League of American Wheelmen (LAW), and local affiliate clubs mixed advocacy of good roads with sponsorship of races and tours. The publication of road books and maps was a natural extension of these

FIG. 851. DETAIL OF NORTHWESTERN NORTH DAKOTA AND MAP LEGEND.
Size of the entire original: 46 × 77 cm; size of detail: 18.3 × 28.8 cm. From *North Dakota, South Dakota, Sunoco, DX, Sun Oil Company* (San Jose: H. M. Gousha for Sun Oil Company, 1973). Image courtesy of James R. Akerman. Map © Rand McNally; R.L. 11-S-001.

activities, offering practical guidance for bicycle tourists and calling attention to the wide variations in road quality (fig. 852). Many of these maps and guides were compiled from the field observations of club members, lending an amateur quality to this early road mapping that contrasted strongly with the professionalism and marketing orientation of contemporary railroad mapping. During the 1890s commercial publishers such as George H. Walker & Company made a modest entry into road map publication as well, but their activity was largely confined to the Northeast United States and adjacent parts of Canada, where road conditions and high population densities made publication of large-scale maps for road travelers economically viable.

Within a few years of 1896 (traditionally reckoned as the time of the founding of the American automobile industry), motorcars pushed aside bicycles as the driving force behind the making and mapping of road infrastructure. There were nevertheless continuities between the brief era of bicycle mapping and early automobile road mapping in Canada and the United States. Commercial publishers found that maps they had previously published for bicyclists could be marketed to motorists with little modification beyond a title change. And motor clubs, which led the fight for road and highway improvements, became early innovators in maps and guides published for motorists. From 1905 to 1907, the Survey Map Company published a series of maps for the American Automobile Association (AAA) covering most of the Northeast United States. The rival Automobile Club of America endorsed its own editions of maps by George H. Walker & Company in 1907. Like bicycle mapping, these early automobile maps mostly supported local and regional travel, and mostly in the Northeast and outlying metropolitan regions, but by the 1910s the cartographic energies of commercial publishers and national organizations such as the AAA had shifted to the promotion of long-distance touring.

The persistent poor condition and poor marking of rural roads throughout most of North America before 1920

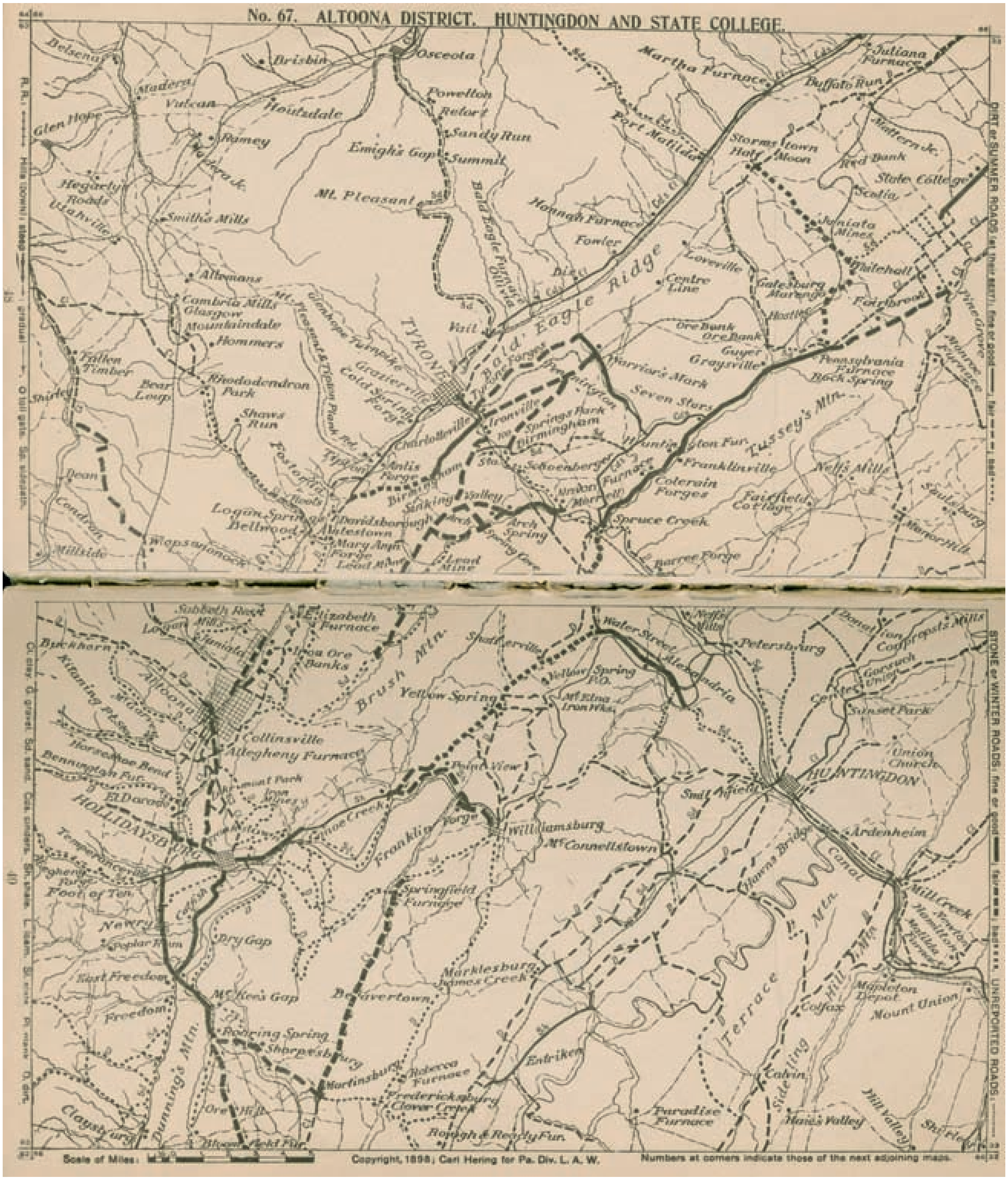
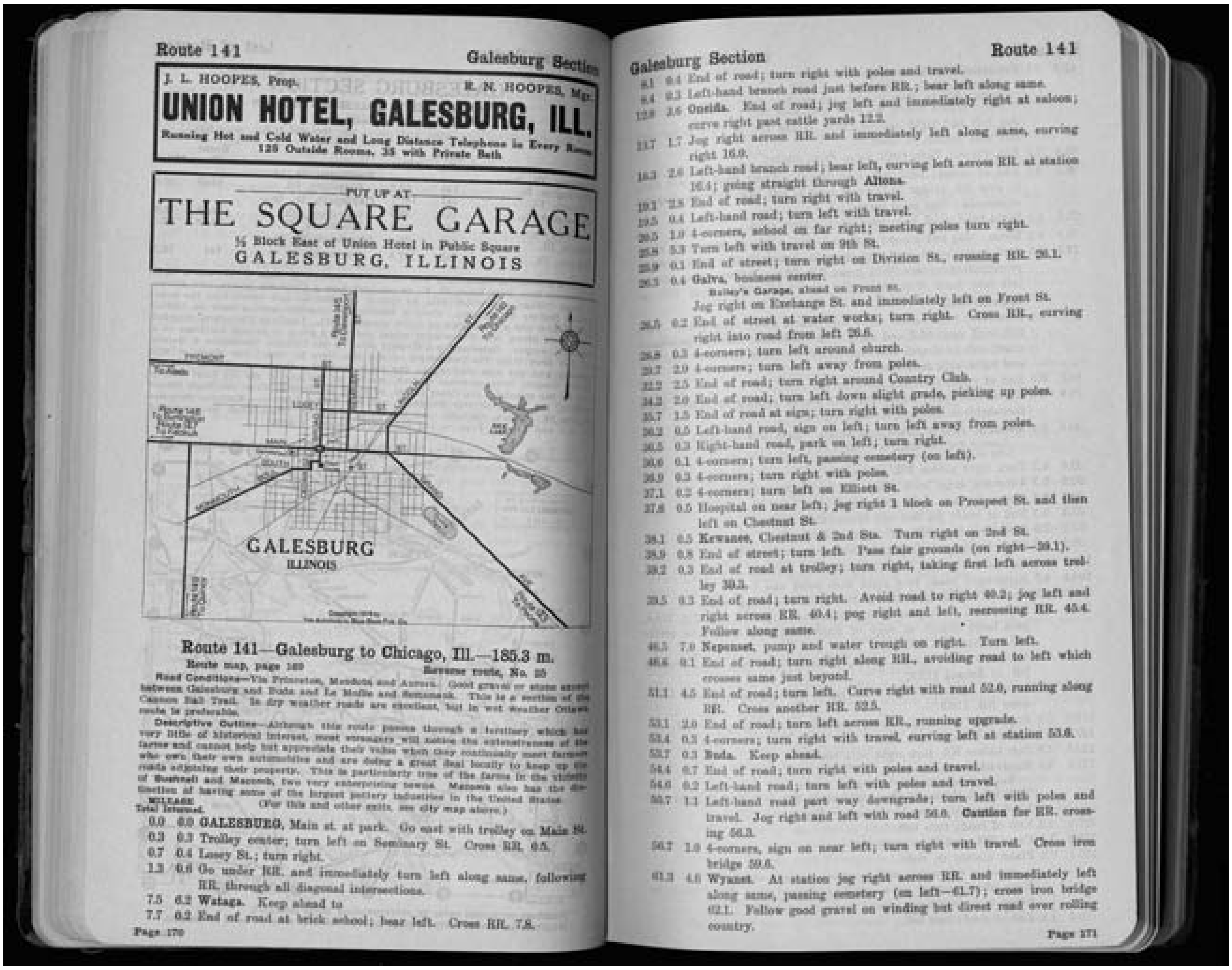


FIG. 852. *MAP NO. 67. ALTOONA DISTRICT. HUNTINGTON AND STATE COLLEGE*, 1898.
Size of the original: 21.5 × 18.3 cm. From *Road Book of Pennsylvania, Western Section*, comp. W. West Randall and Carl Hering (Philadelphia: Pennsylvania Division, League of American Wheelmen, 1898). Image courtesy of the Newberry Library, Chicago.



Route 141 Galesburg Section

J. L. HOOPES, Prop. R. N. HOOPES, Mgr.

UNION HOTEL, GALESBURG, ILL.

Running Hot and Cold Water and Long Distance Telephone in Every Room
125 Outside Rooms, 35 with Private Bath

PUT UP AT

THE SQUARE GARAGE

½ Block East of Union Hotel in Public Square
GALESBURG, ILLINOIS

GALESBURG
ILLINOIS

Route 141—Galesburg to Chicago, Ill.—185.3 m.

Route map, page 169 Reverse route, No. 25

Road Conditions—Via Princeton, Mendota and Aurora. Good gravel or stone roads between Galesburg and Buda and Le Moille and Somonauk. This is a section of the Cannon Ball Trail. In dry weather roads are excellent, but in wet weather Ottawa route is preferable.

Descriptive Outline—Although this route passes through a territory which has very little of historical interest, most strangers will notice the attractiveness of the farms and cannot help but appreciate their value when they continually meet farmers who own their own automobiles and are doing a great deal locally to keep up the roads adjoining their property. This is particularly true of the farms in the vicinity of Bushnell and Macomb, two very enterprising towns. Macomb also has the distinction of having some of the largest pottery industries in the United States.

MILEAGE (For this and other exits, see city map above.)
Total Intervl.

0.0 0.0 **GALESBURG**, Main st. at park. Go east with trolley on Main St.
0.3 0.3 Trolley center; turn left on Seminary St. Cross RR. 0.5.
0.7 0.4 Losey St.; turn right.
1.3 0.6 Go under RR. and immediately turn left along same, following RR. through all diagonal intersections.
7.5 6.2 **Wataga.** Keep ahead to
7.7 0.2 End of road at brick school; bear left. Cross RR. 7.8.

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Galesburg Section Route 141

8.1 0.4 End of road; turn right with poles and travel.
8.4 0.3 Left-hand branch road just before RR.; bear left along same.
12.0 3.6 **Oneida.** End of road; jog left and immediately right at saloon; curve right past cattle yards 12.2.
13.7 1.7 Jog right across RR. and immediately left along same, curving right 16.0.
16.3 2.6 Left-hand branch road; bear left, curving left across RR. at station 16.4; going straight through **Altona.**
19.1 2.8 End of road; turn right with travel.
19.5 0.4 Left-hand road; turn left with travel.
20.5 1.0 4-corners, school on far right; meeting poles turn right.
25.8 5.3 Turn left with travel on 9th St.
25.9 0.1 End of street; turn right on Division St., crossing RR. 26.1.
26.3 0.4 **Galva,** business center.
Bailey's Garage, ahead on Front St.
Jog right on Exchange St. and immediately left on Front St.
26.5 0.2 End of street at water works; turn right. Cross RR., curving right into road from left 26.6.
26.8 0.3 4-corners; turn left around church.
29.7 2.9 4-corners; turn left away from poles.
32.2 2.5 End of road; turn right around Country Club.
34.2 2.0 End of road; turn left down slight grade, picking up poles.
35.7 1.5 End of road at sign; turn right with poles.
36.2 0.5 Left-hand road, sign on left; turn left away from poles.
36.5 0.3 Right-hand road, park on left; turn right.
36.6 0.1 4-corners; turn left, passing cemetery (on left).
36.9 0.3 4-corners; turn right with poles.
37.1 0.2 4-corners; turn left on Elliott St.
37.6 0.5 Hospital on near left; jog right 1 block on Prospect St. and then left on Chestnut St.
38.1 0.5 **Kewanee,** Chestnut & 2nd Sts. Turn right on 2nd St.
38.9 0.8 End of street; turn left. Pass fair grounds (on right—39.1).
39.2 0.3 End of road at trolley; turn right, taking first left across trolley 39.3.
39.5 0.3 End of road; turn right. Avoid road to right 40.2; jog left and right across RR. 40.4; jog right and left, recrossing RR. 45.4. Follow along same.
46.5 7.0 **Neponset,** pump and water trough on right. Turn left.
46.6 0.1 End of road; turn right along RR., avoiding road to left which crosses same just beyond.
51.1 4.5 End of road; turn left. Curve right with road 52.0, running along RR. Cross another RR. 52.5.
53.1 2.0 End of road; turn left across RR., running upgrade.
53.4 0.3 4-corners; turn right with travel, curving left at station 53.6.
53.7 0.3 **Buda.** Keep ahead.
54.4 0.7 End of road; turn right with poles and travel.
54.6 0.2 Left-hand road; turn left with poles and travel.
55.7 1.1 Left-hand road part way downgrade; turn left with poles and travel. Jog right and left with road 56.0. **Caution** for RR. crossing 56.3.
56.7 1.0 4-corners, sign on near left; turn right with travel. Cross iron bridge 59.6.
61.3 4.6 **Wyanet.** At station jog right across RR. and immediately left along same, passing cemetery (on left—61.7); cross iron bridge 62.1. Follow good gravel on winding but direct road over rolling country.

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FIG. 853. LOG DESCRIBING ROUTE 141, FROM GALESBURG TO CHICAGO, ILLINOIS, 1914.
Size of the original: 23.5 × 27 cm. From *The Automobile Blue Book*, vol. 4, *The Middle West* (Chicago: Automobile Blue Book Publishing, 1914), 170–71. Image courtesy of the Newberry Library, Chicago.

limited the navigational utility of road maps describing interregional routes to North American motorists. Route guides, which used textual step-by-step instructions to guide motorists between cities and towns, were more reliable (fig. 853). The Automobile Blue Book Company published the most authoritative series of route guides between 1901 and 1929, enjoying the endorsement of the AAA after 1905, but there were many competitors and variations. In 1905 H. Sargent Michaels published a series of four *Photographic Runs* using photographs of key intersections to guide motorists from Chicago to nearby destinations (fig. 854). Though absorbed and expanded to twenty-seven titles by Rand McNally between 1907 and 1909, these "photo-auto guides" did not apparently meet with widespread success (Karrow 2008, xiv). They point nevertheless to the experimental and amateur character of early North American road mapping, hampered as it was by the poor quality and marking of the roads it had to work with. At its heart route log preparation involved the labor of a single intrepid motorist or small party traversing and logging rural roads in search of the most direct or least problematic routes. Self-styled "pathfinders" such as A. L. Westgard and W. D. Rishel made a living surveying and logging routes, but their memoirs reveal that they were equally motivated by a sporting passion typical of early motorists (Westgard 1920; Rishel 1983; Akerman 2000).

Pathfinding was also a political act that not only demonstrated the potential of automobile travel and the need for automobile highways but also gave motorists the means to follow the lead of the pathfinders. One of the many well-publicized pathfinding journeys undertaken by Westgard in 1911 became one of the first sets of strip maps published by the AAA. Rishel's many pathfinding expeditions under the auspices of the *Salt Lake Tribune* yielded a popular guide, *Rishel's Routes*. When the Lincoln Highway Association (LHA) completed its work blazing and marking on the most renowned of early transcontinental highways in 1915, linking New York to San Francisco, the press fanfare was accompanied by the publication of the route guide, intended to support navigation of the route (Hokanson 1988). Hundreds of associations like the LHA were formed in the 1910s and early 1920s to promote the marking, improvement, and promotion of specific transcontinental and regional routes. Most made some effort to mark their routes, often in affiliation with local authorities and motor clubs. While a few published elaborate route guides, many offered little more than small-scale maps showing the general course of the route. These maps, for example those published by the National Highways Association, often showed the routes as bold lines, in the manner of railroad maps, conveying a sense that the highways were capable of supporting rapid cross-country travel (fig. 855). Yet most of these routes were highways in name only. They were inconsistently marked on the ground, almost entirely unpaved, and nearly impassable in many stretches.

The growing commitment of state, provincial, and federal authorities to the development of a continental system of trunk highways with uniform marking and designation during the 1920s coincided with a dramatic

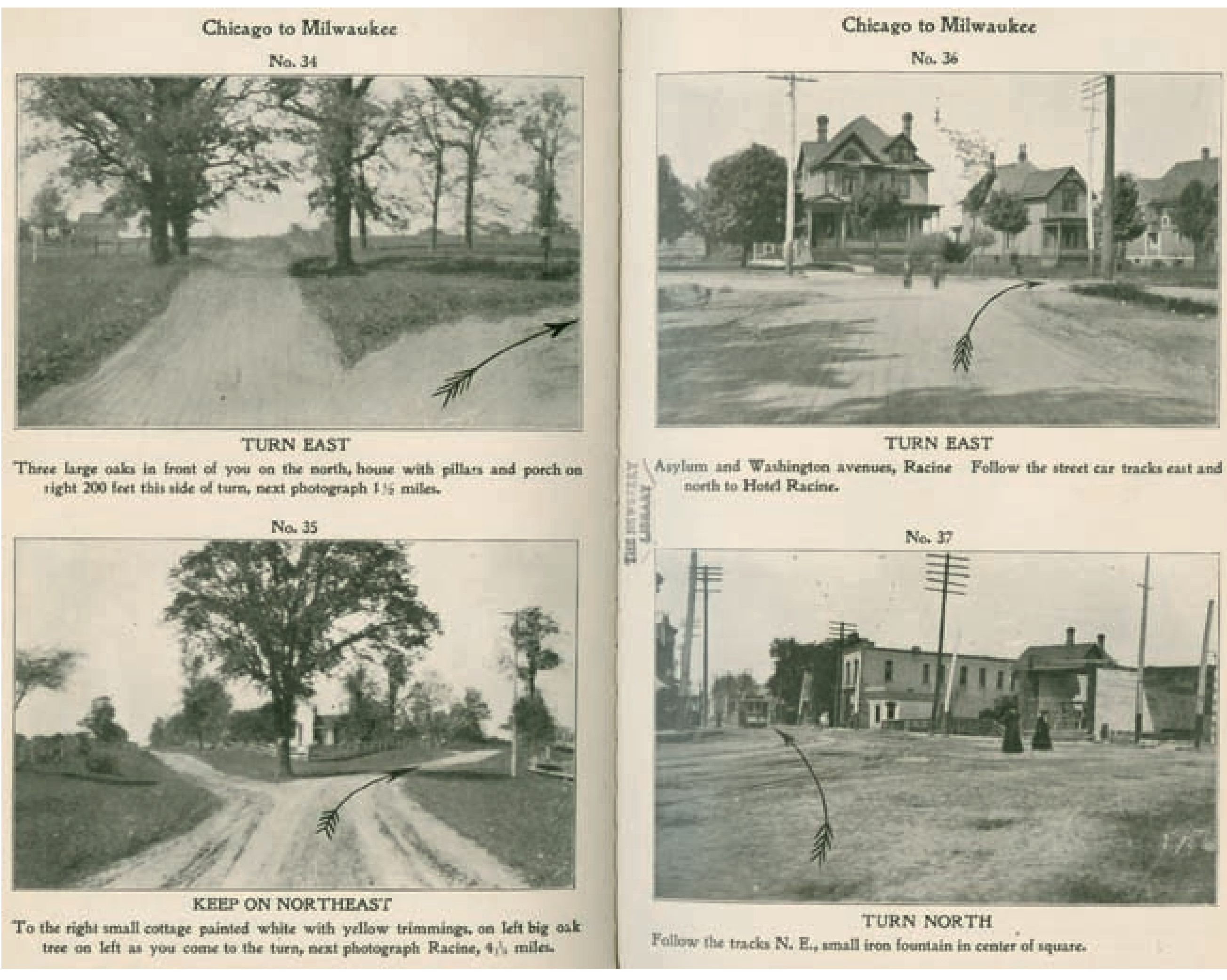


FIG. 854. PHOTOGRAPHS WITH DRIVING DIRECTIONS, PORTION OF CHICAGO TO MILWAUKEE ROUTE, 1905. Size of the original: 20 × 24 cm. From H. Sargent Michaels, *Photographic Runs, Series A: Chicago to Milwaukee* (Chicago: H. Sargent Michaels, 1905), photographs 34–37. Image courtesy of the Newberry Library, Chicago.

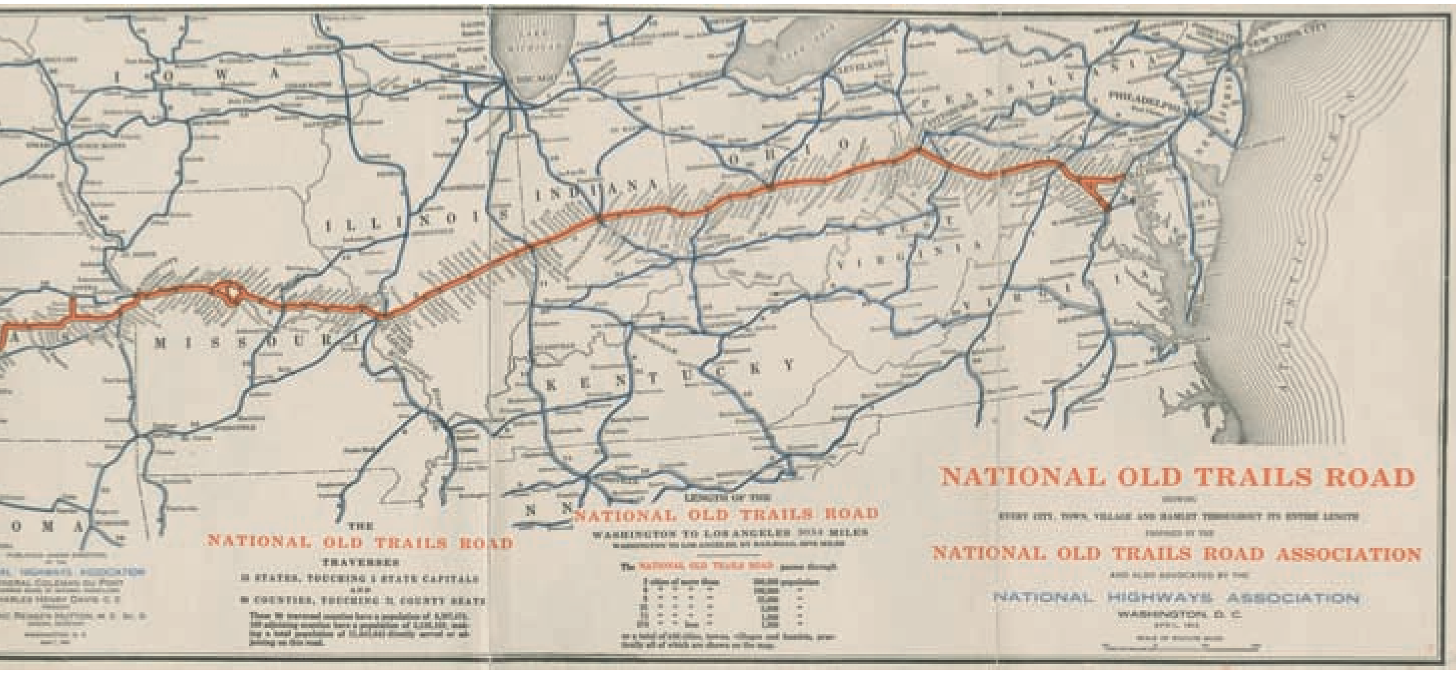
FIG. 855. *NATIONAL OLD TRAILS ROAD . . . PROPOSED BY THE NATIONAL OLD TRAILS ROAD ASSOCIATION AND ALSO ADVOCATED BY THE NATIONAL HIGHWAYS ASSOCIATION.* Washington: National Highways Association, 1915.

Size of the original: 21 × 92.5 cm. Image courtesy of the Newberry Library, Chicago.

rise in automobile ownership and travel. New forms of commercial infrastructure, such as motor camps and motels, gasoline service stations, and roadside restaurants and attractions, catered to the needs of motor tourists and made it possible for them to travel farther in greater comfort (Jakle and Sculle 1994; Belasco 1979). As both the social and geographical scope of motoring expanded, so too did demand for road maps. The new highway systems greatly reduced the navigational burden previously borne by detailed local maps, strip maps, and verbal guides. It was now possible for motorists to find their way on trips extending hundreds of miles with the aid of a single map providing little more than the general courses and numbers of trunk highways within a given state, province, or region. Route guides, strip maps, and local maps did not disappear entirely, but they were pushed to the margins of the North American road map marketplace by a cheaper and more flexible format that was ideally suited for the promotional needs of roadside commerce: the idiomatic North American road map showing highway networks (see fig. 851 above).

Early examples of this new style of road map included those issued by Gulf Oil, tire manufacturer B. F. Goodrich, and the AAA in the mid-1910s, but use of these was hampered by the still-poor road system and the lack of uniform marking. Goodrich's map series required the company to set up its own route markings and the consumer to use accompanying verbal road guides. Momentum for the development of the network road map increased after 1917, when Rand McNally launched its Auto Trails map series, which based its navigational strategy primarily on the many named association highways then in existence. Rand McNally marketed these maps partly by obtaining subscriptions from roadside businesses in return for listing them in the accompanying booklet and—perhaps more importantly—including their name and location on the map itself (fig. 856). In the mid-1920s Rand McNally also began preparing custom issues of Auto Trails maps for specific clients (Akerman 1993). By the late 1920s the firm had fully embraced the publication of map series customized for commercial clients, chiefly oil companies.

In the 1920s the fierce competition among North American petroleum companies for their share in the rapidly expanding consumer market for gasoline and motor oil set the stage for the ascendance of the free oil company road map. Automobiles powered by internal combustion engines required frequent refueling, making visits to the local gasoline service outlet a regular occurrence. Since gasoline itself varied little from one retailer to another, establishing brand loyalty among consumers was important, and the provision of travel



information, including maps, was an effective way of promoting goodwill (Jakle and Sculle 1994). The cheap, idiomatic North American road map was ideally suited to these purposes—so much so that a number of established cartographic publishers and several new firms entered the trade by the late 1920s, most notably General Drafting Company and H. M. Gousha, which with Rand McNally became the "big three" that dominated the gas map market until the 1970s. In most instances these firms sold maps in bulk to their oil company clients, which in turn gave the maps to their customers on demand and free of charge. Hotels and motel chains, insurance companies, and tire companies were also significant corporate distributors of free road maps, but the oil company map dominated the practice from the late 1920s through the mid-1970s. Throughout this period the basic design and house styles of the major publishers remained essentially unchanged, although the nearly constant expansion and modernization of the highway system required annual revisions. The adoption of four-color offset printing by the major map publishers facilitated piecemeal revisions to the base maps and supported the rich use of color in promotional illustrations and cover art customized to the specifications of each client. Corporate logos and slogans, prominent throughout the maps, reinforced brand identities and promoted specific products and services. Attractive cover illustrations, echoing the rhetorical strategies deployed in other printed media, associated automobile use (particularly for travel) and the consumption of petroleum products with a host of positive qualities thought important to mid-twentieth-century consumers, including wealth, vigor, freedom of movement, modernity, stable marital and family life, and patriotism (fig. 857) (Akerman 2002, 181–85; Yorke and Margolies 1996).

By the late 1920s the new state and provincial agencies created to oversee the construction and maintenance of trunk highway systems became major sources of free road maps as well. Initially, most were utilitarian and monochrome productions prepared by in-house draftsmen and emphasized progress on highway improvements. By the mid-1930s, however, many had evolved to include colorful and polished designs similar to oil company maps, featuring promotional artwork, photography, and text promoting the scenic, cultural, and historical attractions of the state or province as well as the modernity of its highways (fig. 858). Publication of official highway maps continued into the twenty-first century, long after oil companies had abandoned free maps, an indication of their perceived value as tools for economic development despite the contraction of state and provincial budgets (Akerman and Block 2005).

Motor clubs routinely provided maps and travel advice to their members since the first decade of the twentieth century. Shortly after the AAA established its own cartographic operations in 1911, it began to issue state and regional maps of highway networks. These were rudimentary publications at first, but by the late 1920s their design was comparable to the maps issued by oil companies, states, and provinces. Regional clubs also

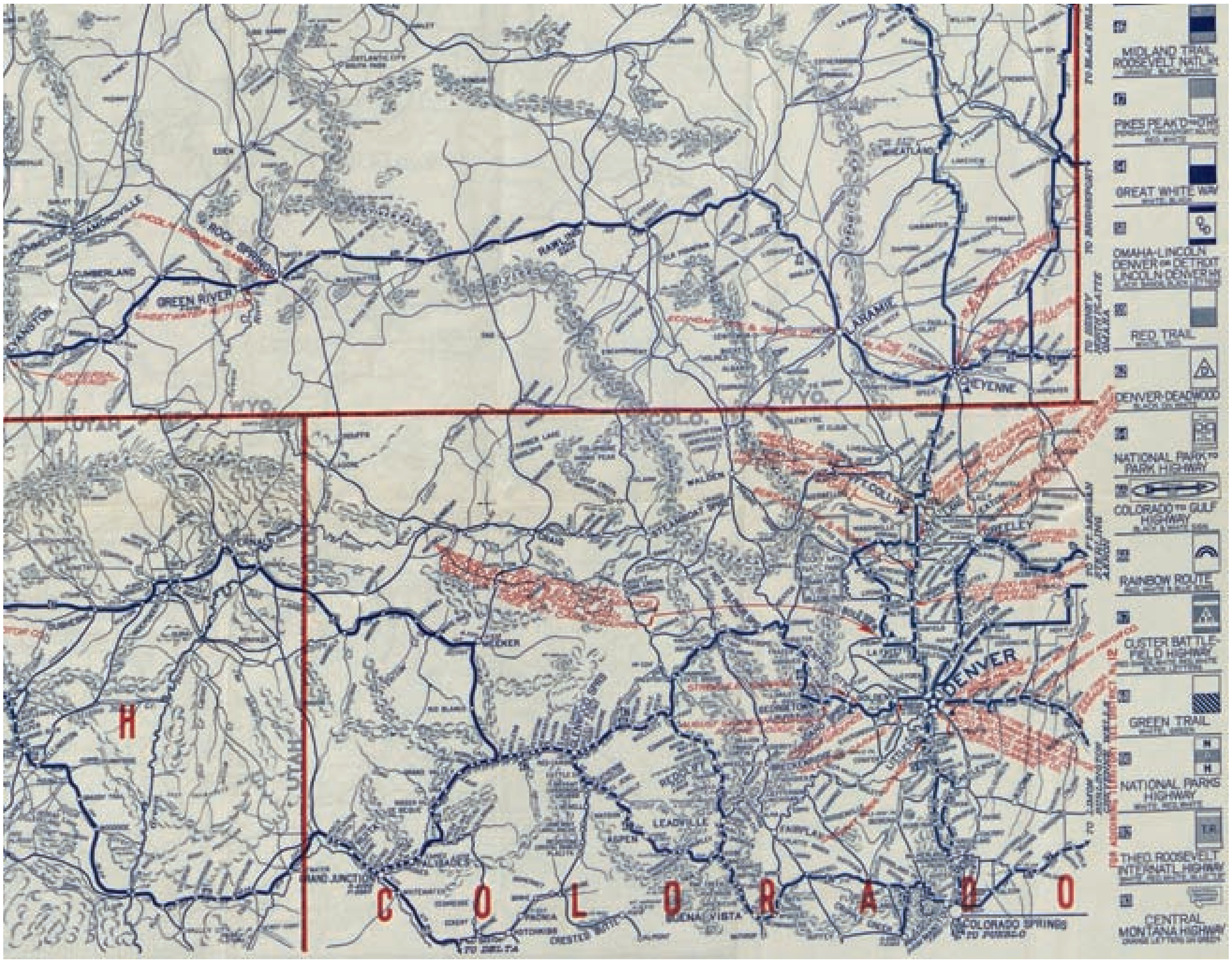


FIG. 856. DETAIL OF WYOMING, UTAH, AND COLORADO, AND KEY TO ROUTES, 1921.
Size of the entire original: 52.8 × 40.3 cm; size of detail: 19.1 × 24.5 cm. From *Rand McNally Official 1921 Auto Trails Map, District No. 13* (Chicago: Rand McNally, 1921). Image courtesy of the Newberry Library, Chicago.

began issuing similar maps during this period, prepared either by their own touring bureaus or by commercial publishers (see fig. 33). In 1926, the AAA abandoned the endorsement of Automobile Blue Books that it had maintained since 1906, yet the provision of detailed verbal cartographic itineraries of specific routes remained a popular service among automobile club members. Throughout the 1920s and 1930s many local clubs issued customized bundles of preprinted route cards to members. And in 1937 the AAA launched its series of strip maps called TripTiks—customized travel atlases about the size of a folded road map and assembled to order for club members—which the AAA and CAA (Canadian Automobile Association) continued to publish into the twenty-first century (see fig. 34).

Working with their cartographic partners, several oil companies also established travel bureaus that supplied walk-in or mail customers with maps, news and reports on current road conditions, brochures, and travel advice. Socony (Standard Oil of New York; later Mobil) and General Drafting established the earliest of these in New York City in 1927. The most innovative product published by any oil company travel bureau may have been the Touraide developed by H. M. Gousha and Continental Oil Co.'s (Conoco) travel bureau in 1936. Each Touraide was a spiral-bound atlas (31 × 23 cm) assembled on demand to describe an itinerary specified by the customer. Like AAA TripTiks, a suggested route for the proposed journey of the trip was delineated on sectional maps in bright colors by hand, but the Touraides had a much more significant textual component, with descriptions of sites and attractions, accommodations, and restaurants (fig. 859). From a purely navigational perspective, these custom cartographic products may have been largely unnecessary supplements to general highway maps of the standard idiom. Their attraction as custom products rested not only on their explicit guidance for the specific, and personal, journeys they charted but also on their value as mementos of these trips (Akerman 2000, 35–38).

North American production of free oil company maps expanded dramatically in the first decades after World War II, which saw massive investment in the construction of superhighways and automobile-oriented infrastructure, highlighted by the ascent of automobile-oriented suburbs and shopping centers (Jakle 1990). Road map cover art from this period expressed the prevailing enthusiasm for cars and highways by promoting the family car trip (Rugh 2008; Yorke and Margolies 1996) and the construction of the continental system of limited-access superhighways (fig. 860).

By the late 1960s, however, the car culture was under attack, and the free oil company road map became a casualty. Growing awareness of the pollution caused by the combustion of hydrocarbon fuels, the socio-economic disruption of central cities and suburban sprawl fostered by metropolitan dependence on the automobile, and expanding dependence on "foreign oil" caused many North Americans to rethink their automobile habit. Competition from jet age air travel made the family car trip itself less desirable as well. Finally, a shift in petroleum marketing from full-service to self-service stations doubling as convenience stores reduced the attraction of free maps as marketing tools. Esso, which

FIG. 857. COVER ART, *IN KANSAS LOOK FOR DERBY PRODUCTS*, 1931. *Central States—State Map* (Chicago: Rand McNally for Derby Oil Co., 1931).

Size of the original: 23 × 30.5 cm. Image courtesy of the Newberry Library, Chicago. Map © Rand McNally; R.L. 11-S-001.

had distributed nearly 34.5 million maps in 1965, issued only about one-fifth that number in 1979. By the late 1980s the free oil company map had almost entirely disappeared (Akerman 2002, 189). The commercial firms that once served the oil company market continued to publish maps under their own imprint, a practice that Rand McNally had pursued with great success since the late 1920s with its annual road atlas. Rival firms H. M. Gousha and General Drafting emphasized their own branded maps series or atlases. All three firms also continued to fill contracts for free maps issued by smaller businesses, motor clubs, or local governments, but these smaller contracts were not enough to sustain all three of them as independent firms. In 1992 the General Drafting Company was absorbed by the American Map Company, a subsidiary of the international Langenscheidt Publishing Group. Four years later Rand McNally purchased H. M. Gousha.

The volume and diversity of road and street maps issued by local authorities, chambers of commerce, small businesses, and roadside attractions is difficult to summarize either quantitatively or qualitatively. The number of these issues likely eclipsed the combined number published by oil companies, state and provincial governments, and motor clubs. Local in orientation, mostly undistinguished cartographically, and ephemeral by design, they might be seen as the foot soldiers in the use of paper maps to facilitate and promote automobile travel and its dependent economy. County governments had issued plain and functional maps of their local county road systems for most of the century (fig. 861). Banks and consortia of local businesses issued maps of streets

FIG. 858. *HISTORICAL TEXAS*, PROMOTIONAL ILLUSTRATIONS AND TEXT.
Size of the original: 71 × 90.5 cm. From *Texas: Official Highway Travel Map, 1952* (Austin: Texas Highway Department, 1952). Image courtesy of James R. Akerman. Permission courtesy of the Texas Department of Transportation, Austin.

FIG. 859. DETAIL FROM CONOCO TOURAIDE, 1939. The Touraide contains a general routing map (portion shown here), mileage and expense record, sectional maps, guide text, and photographs.

Size of the original: 30.5 × 61 cm; size of detail: 19.3 × 28 cm. From "Conoco Touraide Prepared Especially for Miss Jessie Wieseman" (Chicago H. M. Gousha for the Continental Oil Company, 1939). Image courtesy of the Newberry Library, Chicago. Map © Rand McNally; R.L. 11-S-001.

and local highways, often heavily laden with advertising. Most maps incorporated in brochures issued by roadside attractions, restaurants, motels, parks, historic sites, and tourist traps were simple, schematic designs intended merely to guide passing motorists to the sponsoring facility or attraction. But regional organizations established to promote travel to major touring destinations often invested in handsome examples of promotional art (fig. 862). Businesses and communities arrayed along specific routes also published maps reminiscent of those published by the early highway associations. National, state, and provincial parks and forest agencies published a wide variety of maps oriented to motoring tourists.

The late-century decline of the iconic oil company road map did not result in the full eclipse of the North American road map. State and provincial highway and tourism authorities continued to issue paper road maps, as did the AAA and CAA. And local commercial interests continued to issue free promotional maps. Among post-1980 newcomers, the larger-scale atlases featuring topographic contours by the DeLorme Map Company were popular among motorists favoring a more leisurely and in-depth exploration of the countryside off the main roads. Paper road maps persisted in North America despite the emergence in the 1990s of digital road mapping, sold in CD formats for use on personal computers, offered on the Internet by services such as MapQuest and Google Maps, and in GPS-enabled in-car navigational systems or smart phones. Digital formats offered mapped information flexibly and at multiple scales for a nearly unlimited number of places and areas, far exceeding what could be provided by standard map series and road atlases. On most platforms users had the option of presenting an overview of the road or street network in the area or focusing on the navigation of

FIG. 860. COVER PANEL, *OFFICIAL 1965 ROAD MAP, ONTARIO* (TORONTO: DEPARTMENT OF HIGHWAYS, ONTARIO, 1965).
Size of the original: 21.5 × 11.5 cm. Image courtesy of the Newberry Library, Chicago. © Queen's Printer for Ontario, 1965. Reproduced with permission.

specific routes or itineraries. Though this flexibility was novel, these options essentially replicated the navigational choices between itinerary style strip maps and maps of road networks. The ability of modern digital road and street maps to display on demand the location of roadside businesses and services similarly brought a new and powerful technology to what was nevertheless an old motivation for making road maps in Canada and the United States: directing motorists to places and businesses that stood to benefit from their patronage.

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SEE ALSO: American Automobile Association (AAA); Hammond Map Company (U.S.); H. M. Gousha Company (U.S.); MapQuest.com (U.S.); Rand McNally & Company (U.S.); R. R. Donnelley (U.S.); Wayfinding and Travel Maps

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Road Mapping in Latin America. Road mapping in Latin America was patchy at best throughout the twen-

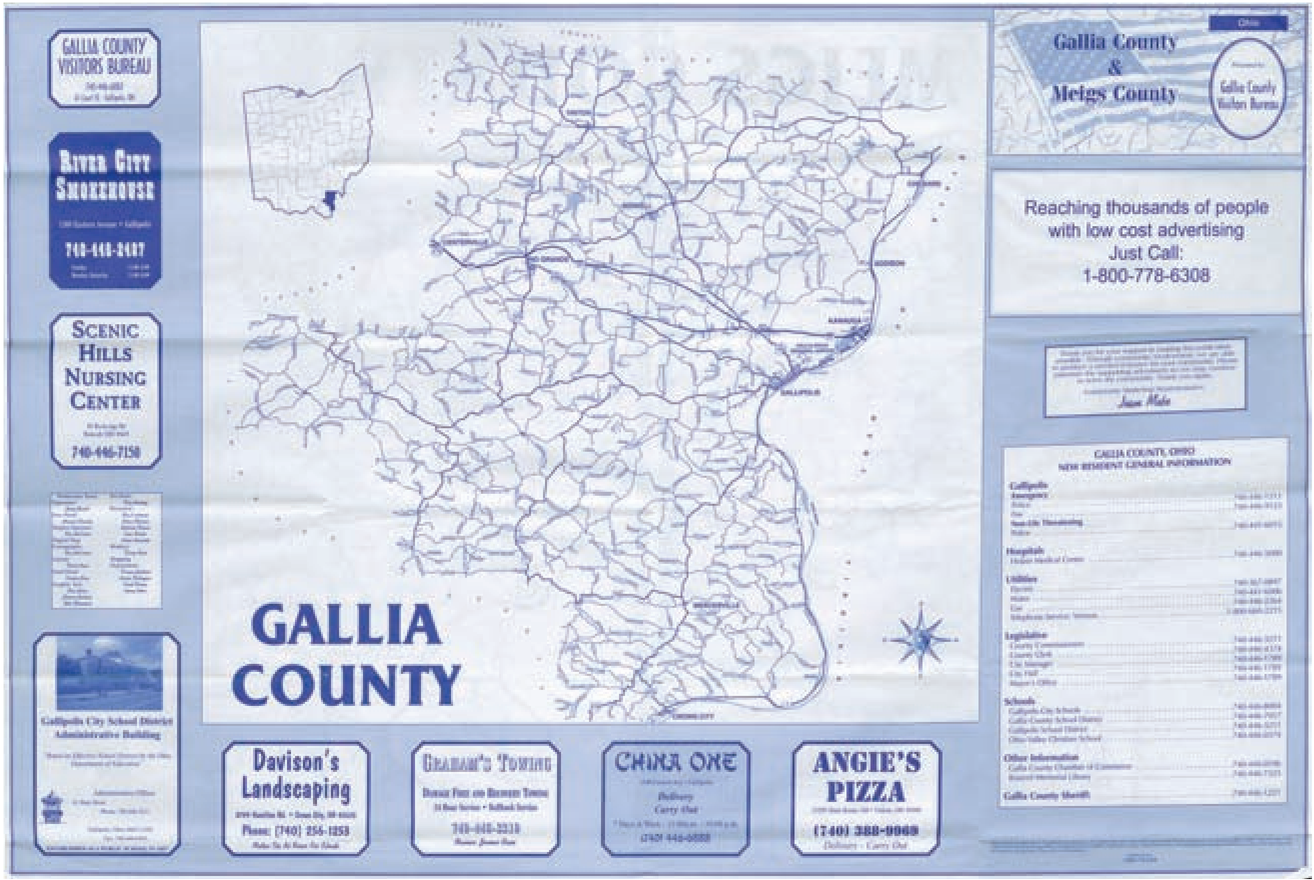

FIG. 861. *GALLIA COUNTY*, OHIO, PROBABLY LATE TWENTIETH OR EARLY TWENTY-FIRST CENTURY. Size of the original: 57.5 × 88.5 cm. From *Gallia County & Meigs County* (Gallipolis: Gallia County Visitors Bureau, n.d.). Image courtesy of James R. Akerman.

tieth century. Although the region's size and large number of political units as well as a paucity of published research on the topic preclude a comprehensive overview of road mapping in Central and South America, it is clear that oil companies produced most of the highway maps intended for public consumption, and that production increased, not surprisingly, as the number of cars and miles of paved road increased. As in the United States and Europe, the advent of the automobile in the early 1900s generated a demand for maps catering to motorists. Road mapping focused initially on urban areas because only cities had paved streets, and even in cities few routes were initially available, making the car very much a novelty in the century's first two decades—not yet a necessity, or even a convenience (Wolfe 2010).

Many early cartographic products came from highway map publishers in the United States, most notably, General Drafting Company (founded 1909), which produced maps of various Latin American countries for Standard Oil of New Jersey (later Esso), beginning in 1923, with a traveling audience in mind. H. M. Gousha (founded 1926) also produced free "oil company maps," which became particularly common during the boom years of motoring after World War II. Rand McNally (founded 1868) prepared road maps for Texaco. Its Central America series, for example, included maps of Nicaragua (1971, 1974, 1976, and rev. ed. in 1978); map scale varied modestly, from 1:1,140,480 (1971, 1978) to 1:1,150,000 (1974, 1976). Rand McNally also produced road maps of Costa Rica (1972), the Dominican Republic and Haiti (1955, 1959, 1971), Jamaica (1952, 1973), Honduras (1971, 1974), and Puerto Rico (1956), among others. In addition, regional guides of Central America included tourist maps useful to motorists (Dym 2004, 355).

Road mapping occasionally reflected a larger corporate strategy. General Drafting published its first map of Cuba in 1932, and maps of Venezuela and Puerto Rico followed in 1941 and 1942, respectively (Akerman 2011). From the standpoint of petroleum producers eager for new supplies of oil, all three countries were of great interest. By the 1950s, General Drafting was

FIG. 862. CLAUDE GEORGE PUTNAM AND ARTHUR WOODWARD, *RIDE THE ROADS TO ROMANCE ALONG THE GOLDEN COAST AND THRU THE SUNSHINE EMPIRE OF SOUTHERN CALIFORNIA.* San Bernardino: Roads to Romance Association, 1958. Size of the original: 54 × 87 cm. Image courtesy of the Newberry Library, Chicago.

publishing more than twenty maps of Latin American countries (Cangelosi 2002, 52). Examples can be found at the Newberry Library, Chicago, which acquired General Drafting's company archives. An inventory of these holdings includes six Chilean maps (1949–85); thirty-nine for Mexico (roughly 1930–50); twelve for Puerto Rico (1942–80); three for Peru (1949–58) (fig. 863); and twenty for Central America (1947–60). Other General Drafting clients with a Latin American focus included the Caribbean Tourism Association; Creole Petroleum Corporation in Venezuela; Esso's subsidiaries in Colombia, Brazil, Chile, Uruguay, and the Caribbean; General Motors Overseas Operations; and International Petroleum Co., Ltd., in Peru.

Perhaps the twentieth century's most iconic road project in the Western Hemisphere was the Pan-American Highway, spanning over 25,000 miles from Alaska to Tierra del Fuego. Its origins date back to failed attempts during the nineteenth century to build a transcontinental railway. On 5 October 1925, the first Pan-American Highway Congress met at Buenos Aires and road construction began shortly thereafter (Silverstein 2006, 71). Mexico was the first country to complete its stretch in 1950, a seventeen-year effort. A first account of the highway, published in the late 1940s, described the state of the road in each country from Mexico to Panama and included maps (Stephens 1948). The U.S. Bureau of Public Roads also produced maps of the proposed highway. Central American oil company road maps of the late 1940s and 1950s anticipated the completion of the highway long before it became a reality, making parts of the cartography imaginary (Dym 2004, 356).

The Automóvil Club Argentino (ACA), founded in 1904, became an important cartographic producer (fig. 864). In 1926, the club formed a department of highways to chart road construction. Since then, it has been one of the principal map producers, not least because of its 1936 agreement with Yacimientos Petrolíferos Fiscales (YPF), Argentina's then state-owned oil company. YPF began building service stations, which were featured on the ACA's maps, which in turn were

FIG. 863. DETAIL FROM *MAPA DE CARRETERAS DE LA REPÚBLICA DEL PERU*, GENERAL DRAFTING COMPANY, [1950]. Detail of the area around Lake Titicaca.
Size of the entire original: ca. 66.5 × 57.5 cm; size of detail: 17.3 × 13.1 cm. Image courtesy of the Newberry Library, Chicago, General Drafting Company Archives (Geographical series Peru).

given out at service stations, a common practice in the mid-twentieth century.

In 1993, de Dios Editores of Buenos Aires entered the Argentine map market producing maps in Spanish and English but not limited to Argentina. Laminated foldable maps of Argentina's provinces and areas such as Tierra del Fuego were produced at various scales. Not all automobile clubs, however, were concerned with providing road maps; many were purely recreational, formed only to promote racing and rallies.

Colombia formed its Ministerio de Transporte in 1905 to promote road construction. However, serious highway construction efforts did not get under way until the 1950s. In 2001, the Instituto Nacional de Vías became the country's highway agency and assumed responsibility for road mapping. Cartur Mapas, a commercial map publisher founded in 1966, has designed and published tourist maps of Colombia, including road and city maps. The maps were updated every six months, and scales varied between 1:200,000 (for a countrywide road map) and 1:20,000 or 1:25,000 (for city street maps). The Instituto Geográfico Agustín Codazzi, Colombia's national geographic institute founded in 1932, first published road maps with financial help from the Automóvil Club de Colombia in 1970.

El Salvador's Instituto Geográfico y del Catastro Nacional, founded in 1946 as the Oficina del Mapa, has produced with help from the Inter-American Geodetic Survey a variety of map products including road maps. At the end of the century El Salvador still relied on the U.S. National Imaging and Mapping Agency (renamed the National Geospatial-Intelligence Agency in 2004) and other international organizations to aid its mapping efforts.

In Mexico, despite the upheaval of its revolution in 1910, the first *Atlas Geográfico de la República Mexicana* was published in 1919 at a scale of 1:200,000 (Mendoza Vargas 2000, 177). Engineer and topographer Pastor Rouaix and geographer and mining engineer Pedro C. Sánchez led the Dirección de Estudios Geográficos y Climatológicos, formed in 1915 with responsibilities for mapping and surveying. The *Atlas* was not updated until 1942, and a completely new edition was published in 1949 (Mendoza Vargas 2000, 178–79).

Guía Roji, Mexico's predominant map publisher, was founded in 1928 by Joaquín Palacios Roji Lara, who walked the streets of Mexico City to collect street names for an indexed street map of the city. The company has published city guides as well as the *Atlas de Carreteras de México* at a scale of 1:100,000. All of its map products have been updated annually. The publisher has also sold highway maps covering the United States, Guatemala, and Belize, and its Internet site allowed users to search for streets in Mexico City, Guadalajara, and Monterrey by entering a postcode. The federal government's Secretaría de Comunicaciones y Transportes provided free cartographic products of Mexico's thirty-one states and its road network, as well as maps of toll roads, first introduced in the 1950s.

Brazil's vastness explains the slower development of its highway network. Like its counterpart in Argentina, the Touring Club do Brasil, founded in 1923, became not only a provider of maps, but also an influential lobbyist for road construction (Wolfe 2010, 96–97). Even so, there was no official tourist guidebook to Brazil until 1942 (Wolfe 2010, 229n22). The automobile industry, and with it road construction, began to flourish during Juscelino Kubitschek's presidency, from 1956 to 1961, and the 4,800-kilometer Transamazonian highway opened in 1972, enabling settlement in the once-impenetrable interior (Wolfe 2010, 113–20, 152–55). The publisher Editora Abril, founded in 1950, produced road and street guides: the *Guia rodoviário* and the *Guia* *de ruas*. General Drafting Company published three road maps of Brazil between 1952 and 1956, prior to many of the country's large-scale highway projects (fig. 865). In addition, *Quatro rodas*, an automobile racing magazine, began publishing a tourist guide in 1965 (Wolfe 2010, 167).

There were, of course, numerous small local road map publishers, but most of their products, with text only in Spanish or Portuguese, were not sold outside of their respective countries. Although downloadable maps disrupted the existing marketplace at the close of the twentieth century, North American and European map publishers continued to dominate road mapping in Latin America, where many countries continued to rely on foreign assistance for up-to-date road maps and current information about the state of roads and highways.

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SEE ALSO: Wayfinding and Travel Maps: (1) Road Atlas, (2) Road Symbols

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FIG. 864. TWO DETAILS FROM *MAPA DE LA REPÚBLICA DEL PERÚ: RED GENERAL DE CARRETERAS*, 1946. Collaboratively published by the Dirección de Caminos y Ferrocarriles del Perú and the Automóvil Club Argentino. Cartouche (left) and southern Peru around Lake Titicaca (right). Size of the entire original: 91.9 × 64.5 cm; size of each detail: 19.3 × 14.6 cm. Image courtesy of the Arthur H. Robinson Map Library, University of Wisconsin–Madison.

FIG. 865. TWO DETAILS FROM *SÃO PAULO E SUL DO BRASIL*, GENERAL DRAFTING COMPANY, 1956. Portion of the legend (left) and area around São Paulo (right). Size of the entire original: ca. 81.7 × 60.2 cm; size of each detail: 17.7 × 11.6 cm. Image courtesy of the Newberry Library, Chicago, General Drafting Company Archives (series 01/E85/1956).

Waters, Wendy. 1999. "Re-mapping the Nation: Road Building as State Formation in Post-revolutionary Mexico, 1925–1940." PhD diss., University of Arizona.

Wolfe, Joel. 2010. *Autos and Progress: The Brazilian Search for Modernity*. Oxford: Oxford University Press.

Road Mapping in Africa. The earliest road maps of twentieth-century Africa were produced by the mapping agencies of colonial governments. These maps were based on sketch maps of roads and tracks drawn by European explorers, settlers, and colonial administrators. Africans contributed to road mapping, notably as laborers and surveyors. The Survey School of the Gold Coast graduated twenty-three African surveyors by 1927 (Maxwell 1928, 193). They were employed by the Survey Department to do cadastral and topographic mapping that was important to the department's road maps.

Colonial road maps served as tools of administrative rule and commerce by revealing the location of population centers, markets, and economic corridors. They contributed to state formation by organizing space and knowledge in ways that made complex human geographies more legible, if not more manageable (Scott 1998, 25–33). The dense fabric of road networks appeared to integrate and civilize newly acquired colonies. They conveyed a sense of occupation and development of a territory to the ostensible benefit of both colonizers and the colonized. Colonial roads and thus maps were an expression of the power of colonial officials to force local populations to build roads (Hailey 1938, 611–13). The fact that most roads were of poor quality and not easy to travel suggests that a primary aim of road maps was to further state authority by constructing space in a way that made it seem more accessible and thus easier to control people and resources (Sack 1986, 30–34).

Road maps are easy to distinguish from other maps by their basic elements. These include a reference to roads or road travel in the map title (*Road Map of Egypt*, *Shell Motorists Map of the Sudan*); numbers that refer to route numbers or distances between major towns and cities; lines of different color and thickness that differentiate road types (all-weather roads, secondary roads, scenic routes); symbols for gas stations, hotels, and post offices; indexes of cities and places of interest; and a table that allows map users to determine the distance between major cities. These signs and symbols reveal the intentions of the mapmaker to produce a map that will assist road travelers whether they are merchants, administrators, tourists, or soldiers.

Three types of road maps were produced in Africa: general, tourist, and automobile club. General road maps were typically drawn by government mapping agencies. In the absence of commercial map companies, these maps were intended for sale to the general public as well as for public administration (fig. 866). When commercial mapmakers existed in a country, they commonly used general road maps as their base maps. The privately produced *States of Nigeria—Road Map* (1:1,500,000), published in Lagos in 1977 by Adeniji Maps, is based on the general road maps of the Nigerian Federal Survey.

The historical development of commercial road mapping in twentieth-century Africa was closely tied to tourism. Both government tourist bureaus and private companies produced road maps with the automobile tourist in mind. These maps characteristically highlighted scenic routes and sites of historical interest. Government tourist offices often collaborated with private firms in making such maps. For example, in 1968 the Commercial Bank of Ethiopia (CBE) published the *Tourist Map of Ethiopia* (1:3,040,000) in association with the Ethiopian Tourist Organization. In addition to labeling tourist sites, the map shows the CBE's ninety-one branches in sixty-one localities.

Tourism is also a central theme of oil company maps, one of the most popular sources of road maps published in Africa. BP, Shell, Mobil, Caltex, Esso, and Total produced road maps that blended tourism and petroleum products. Along with scenic routes and useful travel information, these maps often display the location of company gas stations throughout a given country. The *Cartoguide Shell Sénégal* is characteristic of this type of road map that marries tourist travel information with gasoline consumption (fig. 867). Oil companies contracted with firms located in the United States (General Drafting Company), the United Kingdom (George Philip and Son), and Africa (MapStudio) to produce their maps.

Automobile clubs produced the third type of road

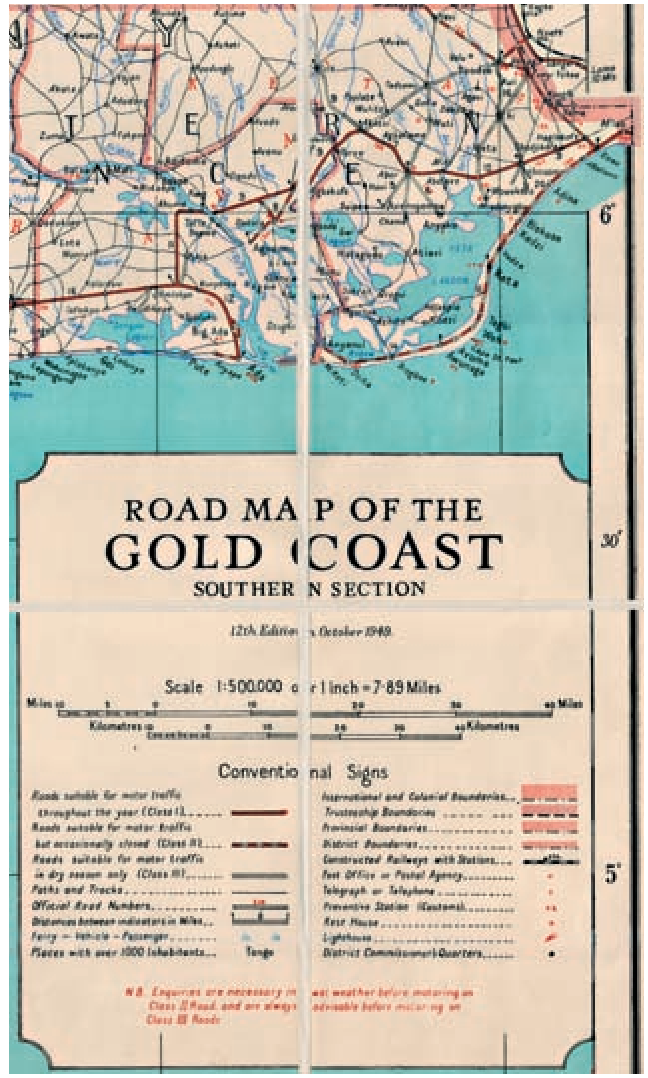

FIG. 866. DETAIL FROM THE *ROAD MAP OF THE GOLD COAST: SOUTHERN SECTION*, 1949. This twelfth edition sold for eight shillings mounted on linen and folded. The less economically important northern half of the country was only in its sixth edition at this time. This map gives the number of the auto route in red numbers and the distance between locations in black numbers. Produced by the Survey Department of the Gold Coast; scale 1:500,000.
Size of the entire original: ca. 77.3 × 101.3 cm; size of detail: 36.2 × 21.5 cm. Image courtesy of the University Library, University of Illinois at Urbana-Champaign.

map, the automobile association map. The Automobile Association (AA) of South Africa, for example, published a six-sheet map of the country in 1975–76. Their signature two-color maps are easy to read and contain much information on scenic routes, hotels, road conditions, camping areas, and historic monuments.

The AA of South Africa also compiled and published route books for the intrepid transcontinental trav-

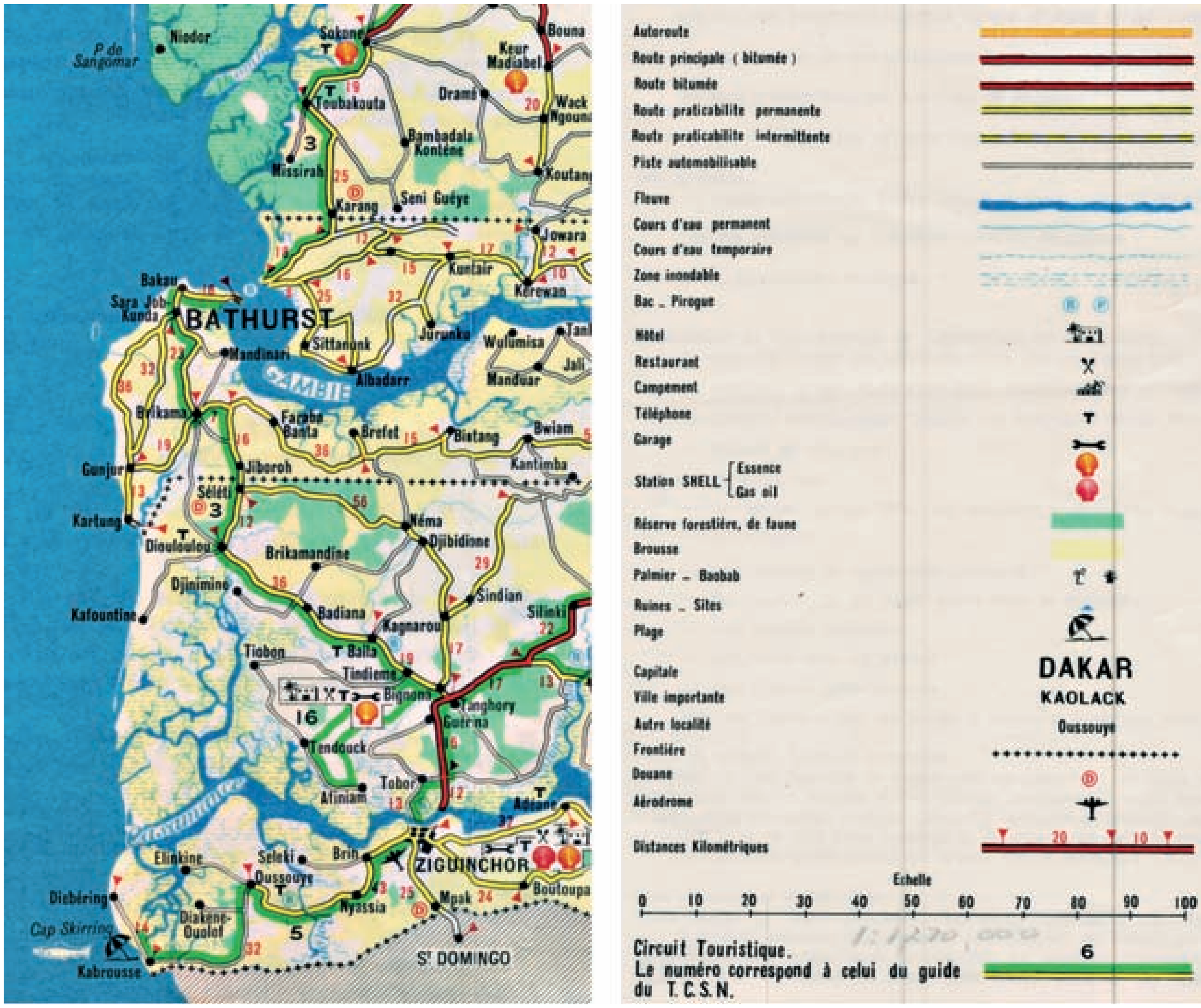

FIG. 867. TWO DETAILS FROM SHELL OIL COMPANY'S *CARTOGUIDE SHELL SÉNÉGAL*, 1963. Published by the Institut géographique national (IGN)–Annexe du Sénégal, Dakar; scale 1:1,270,000. Legend (right) and portion of Senegal south of Dakar around Bathurst (left).

Size of the original: ca. 45.5 × 58.6 cm; size of each detail: 14.3 × 8.4 cm. Image courtesy of the University Library, University of Illinois at Urbana-Champaign. Permission courtesy of the Cartothèque, Institut géographique national.

eler. *The Road from Cape to Cairo* (ca. 1938), *African Throughways* (1939), and *Trans-African Highways* (1949 and later editions) give distances and road conditions along sections of the main highways of Africa. These books include one-color strip maps of road routes on one page and directions for traveling these sections on the facing page (fig. 868). The itineraries include tips to travelers on the location of gas stations, ferries, and rest houses. More than a road guide, the AA's route books form part of the cultural identity of a nation in which the Cape-to-Cairo route figures prominently in its imperial imagination (Merrington 2001; Wolf 1991). Mining magnate Cecil Rhodes's vision of British rule extending from the northern to southern tips of the continent is inscribed section by section in these route books.

The spatial and temporal spread of roads was influenced by administrative jurisdiction and capacity, the geography of resource extraction, and the diffusion of motor vehicles among white settlers. There were just sixteen motor vehicles in French West Africa in 1916. By 1943 there were more than 10,000 (Great Britain, Naval Intelligence Division 1943, 356–57). In British East and Southern Africa, the spread of tourism and the number of motor vehicles among white settlers led to demands for all-weather roads in the 1920s and 1930s (Hailey 1938, 1556–57). Road development quickened

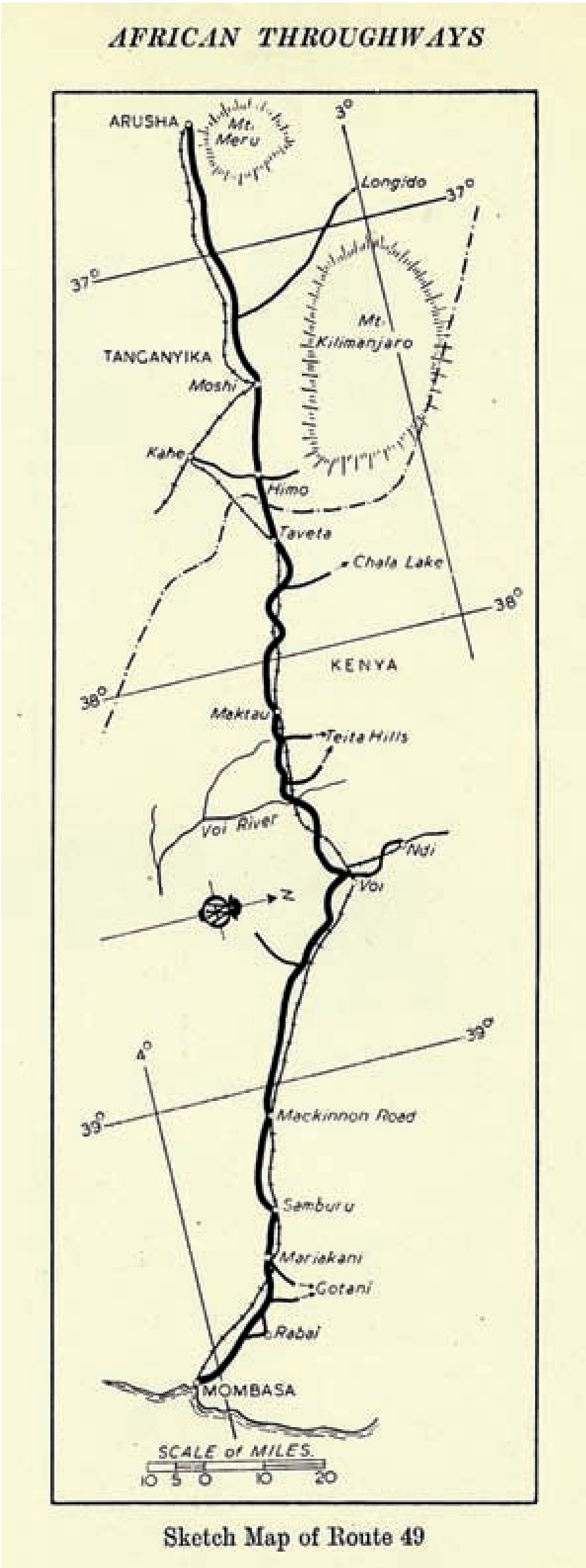

FIG. 868. A STRIP MAP FROM *AFRICAN THROUGHWAYS* SHOWING THE ROAD BETWEEN MOMBASA, KENYA, AND ARUSHA, TANZANIA.
Size of the original: 18.9 × 6.5 cm. From Alexander Freudenberg, *African Throughways* (Johannesburg: Automobile Association of South Africa, 1939), 164. Permission courtesy of the Automobile Association of South Africa, Johannesburg.

in the post–World War II era with the influx of settlers and tourists. Elsewhere roads were developed to connect colonies of the same European power and to facilitate the flow of exports from the interior to coastal ports. The French developed a network of intercolonial and imperial roads that linked its western and northern African colonies without passing through another foreign power's territory (Great Britain, Naval Intelligence Division 1943, 374). In this way, road maps functioned as a "vehicle of imperial integration" (Wolf 1991, 114).

Government expenditures on roads concentrated on zones of economic importance such as the coffee and cocoa belt of West Africa and the copper belt of the Congo and Zambia. The concentration of good roads in the southern export cropping zones of the Ivory Coast, Nigeria, Uganda, and Malawi illustrate this dynamic of uneven regional development of infrastructure. Colonial governments also favored areas of European settlement, which, more than coincidentally, tended to be in the most favored economic zones. In Kenya, government expenditures on trunk roads were four times higher in European- than in African-settled areas (Hailey 1938, 1557).

In 1960 the AA of South Africa published the first of many editions of its popular *Road Atlas and Touring Guide of Southern Africa*, which contained over 100 regional and city maps. By the end of the twentieth century, MapStudio stood out as the preeminent road mapping company within Africa. Established in 1958 in Johannesburg, the company purchased aircraft and photogrammetric plotters in the early 1960s, introduced orthophoto mapping into South Africa in the early 1970s, and computer cartography in 1980 (Eugene Gerald [Bill] Buckley, personal communication, 2007). In 2002 the production section of MapStudio moved to Cape Town. MapStudio's *Illustrated Road Atlas of Africa* (2002) achieves high standards of accuracy and clarity. It also stands out for being compiled, printed, and published in Africa. The company introduced its pocket-sized (14.5 × 10.5 cm) and cardboard-covered eaZimap series in the late 1990s. The cover of the *eaZimap of Botswana* featuring a nearly naked San hunter with a taut bow string superimposed on a map of the Okavango Delta (fig. 869) emphasizes wildlife and exotic peoples to entice the traveler to "one of the last unspoiled areas of Africa" (MapStudio 1997). As at the beginning of the twentieth century, road travel at the turn of the twenty-first century "is neither a breeze nor a walk in the park, and must be approached with due care and preparation" (MapStudio 2002, IV). Road maps opened up the continent by organizing space for an assortment of map users who depend upon the cartographer's craft to arrive at their multiple destinations.

THOMAS J. BASSETT

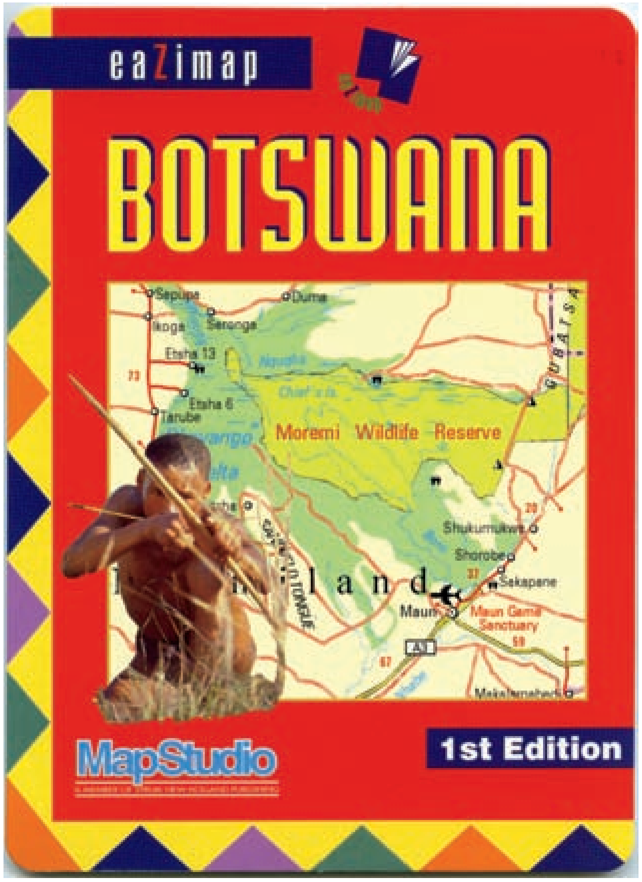

FIG. 869. THE COVER OF MAPSTUDIO'S *EAZIMAP OF BOTSWANA*, 1999, LURES THE TOURIST. Cape Town: MapStudio.
Size of the original: 14.5 × 10.5 cm. Permission courtesy of MapStudio, Cape Town.

SEE ALSO: Wayfinding and Travel Maps: (1) Road Atlas, (2) Road Symbols

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Sack, Robert David. 1986. *Human Territoriality: Its Theory and History*. Cambridge: Cambridge University Press.

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Wolf, James B. 1991. "Imperial Integration on Wheels: The Car, the British and the Cape-to-Cairo Route." In *Literature and Imperialism*, ed. Robert Giddings, 112–27. New York: St. Martin's Press.

Road Mapping in Europe. The term *road map* was used with different meanings over time and even within the twentieth century. In the first decades road maps often had supplemental titles "for motorists and cyclists" indicating the intended audience, but the word "road" was not always included within the title, which was often just *Map of* . . . From about midcentury, a road map was understood more and more as intended for motorized users only. This corresponded to the use of the word "traffic" as a synonym for motorized individual traffic and "map" for road map.

Of course the emphasis was on roads and their representation on the map, but in addition road user information and road usage conditions were important map features. Topographical information often served only as background and contour lines and relief representation were frequently omitted. Specific content for road users and especially motorized users differed over time. At the beginning of the twentieth century, road map content was similar to cyclists' needs: important features were distances, gradients, and road conditions (fig. 870). There also was information about forbidden roads—motor cars were not allowed generally on roads before 1908 in all of the German Reich. In Switzerland it took even longer; it wasn't until 1925 that the Grisons became the last canton of Switzerland to allow motor cars on roads (fig. 871). Until then, cars had to be pulled by oxes over the passes of the Alps. Although forbidden roads were highlighted at the beginning of the century, maps eventually focused on recommended roads. With increased horsepower in cars, gradients became less important except for very steep mountain passes. With better tires and suspensions and due to extensive use of asphalt surfaces on most Western European roads, specific information on surface conditions could be omitted as well.

At the beginning of the century, European countries differed greatly with respect to both the development of their road systems and their road maps. General topographical maps were not always in existence or at least not yet widely available to the public. Many road maps had cyclist maps as predecessors; others were newly developed as general road maps not initially intended for specific user groups. Typical scales were 1:200,000 to 1:500,000 depending on the country and road network density. Overview road maps at 1:4,500,000 covering all of Europe were published for trip planning purposes. Detailed studies from various countries provided many examples (Koeman 1983; Lierz 1990a, 1990b; Nicholson 1983). Based on these and other studies, and especially on studying thousands of maps personally, T. R. Nicholson (2004) gives the most comprehensive country-by-country overview of all Europe. The following summarizes some general aspects.

There were various types of publishers. Road maps

FIG. 870. DETAIL FROM *RAVENSTEIN'S RAD- UND AUTOMOBILKARTE*, 1912. Sheet 32, *Köln, Düsseldorf und Aachen*, scale 1:300,000. Originally a cyclist map with only limited automobile information added in orange ("most advantageous/beneficial automobile roads"). Red pin-shaped symbols denote distances; red bullets denote dangerous points. Size of the entire original: 70 × 48 cm; size of detail: ca. 6.8 × 17 cm. Image courtesy of Wolfgang Lierz.

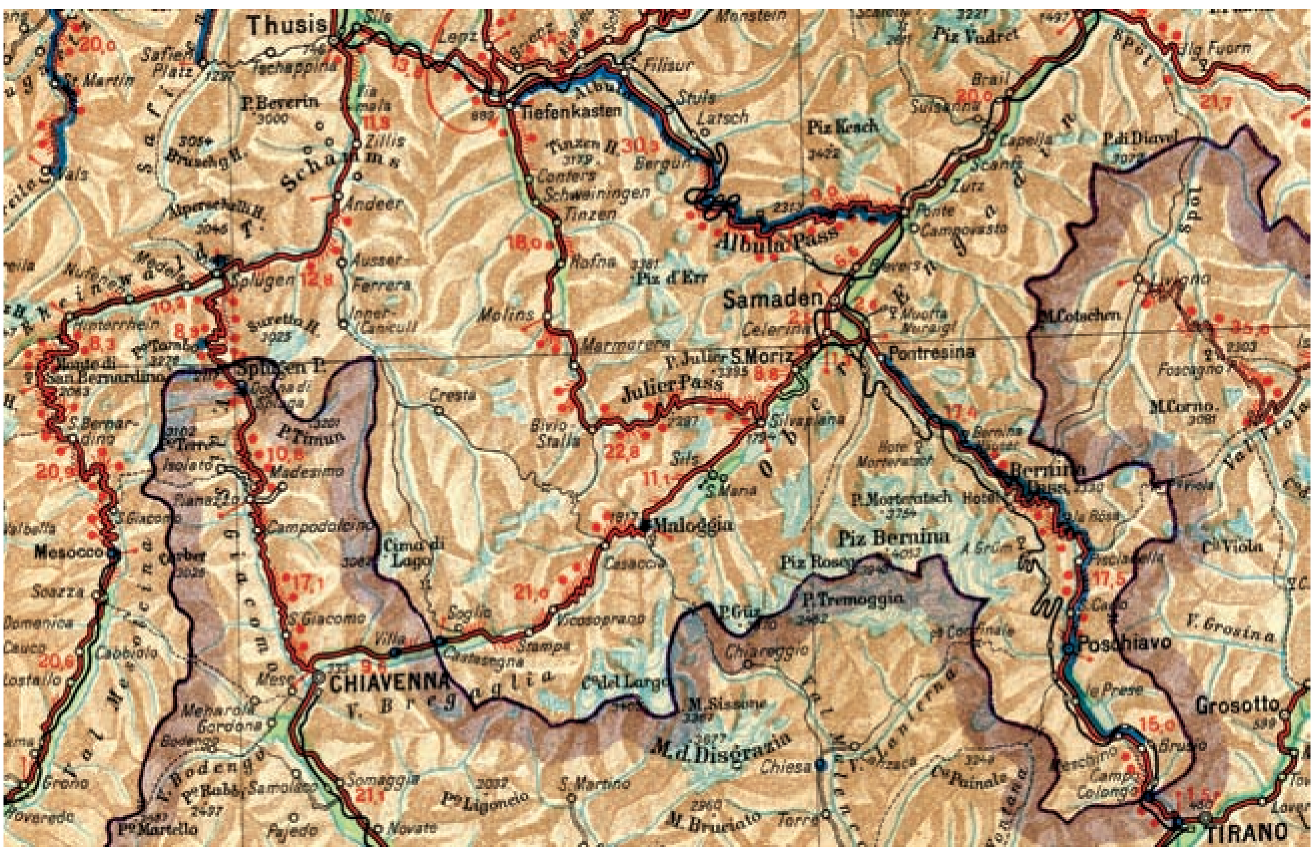

FIG. 871. DETAIL FROM *RAVENSTEIN'S RAD- UND AUTOKARTE*, 1928. Sheet 72, *Schweiz*, scale 1:500,000. After opening roads in the Grisons for cars 1925, main passes (like Julier Pass) are shown as open, but the smaller passes (like Albula and Bernina) are still shown with a blue line indicating they are forbidden for cars. Red pin-shaped symbols denote distances; red bullets denote dangerous points.
Size of the entire original: 60 × 80 cm; size of detail: ca. 11.1 × 17.3 cm. Image courtesy of Wolfgang Lierz.

FIG. 872. DETAIL FROM *ANWB TOERISTENKAART*, 1990. Sheet 1, *Noord-Holland noord*, scale 1:100,000. Red pin-shaped symbols denote distances on major roads. For easier orientation in flat areas, blue numbered Y-shaped signs are shown, which correspond to numbered signposts on the road. Size of the entire original: 87 × 54 cm; size of detail: ca. 20.4 × 29.3 cm. Image courtesy of Wolfgang Lierz. Permission courtesy of ANWB, the Hague.

were always an important field of publishing activity for most (national) cyclists' clubs and later automobile clubs that often emerged from cycling predecessors. Some of them, like the royal Dutch touring club Algemene Nederlandse Wielrijdersbond (ANWB) and the Touring Club Italiano (TCI), published road maps throughout the century and beyond (fig. 872). Oil companies like Shell cooperated with large commercial map publishers such as Mair in Germany, and tire companies such as Michelin in France were very important map publishers. Less frequently, national mapping authorities, like the Institut géographique national (IGN) in France, the Ordnance Survey (OS) in Great Britain, or swisstopo in Switzerland, took on that role. In some countries, for example Germany, road maps were explicitly in the realm of private publishing and not part of official administrative mapping.

Based on previous experiences with cyclist maps, some typical signature styles became more or less common for road maps. Typical for visualizing gradients were, depending on steepness, one or more arrows across road line symbols showing uphill portions, sometimes with numerical values and other hints added for trailer drivers. Distances were shown with pin-shaped symbols between road crossings, differently sized and colored for smaller and larger distances. Coloring was intensively used for road classes, especially for officially classified and numbered roads, and for numbered or named exits on motorways. Already a cartographic convention for cyclist maps, the color red (with shades from orange to violet) was mainly used as a road outline fill to differentiate major and minor roads. Green lines to the side of the road line symbol denoted roads of touristic interest.

Many road maps were published as series of several sheets. Systems with rectangular sheets of equal size

FIG. 873. DETAIL FROM *DIE GENERALKARTE BUNDESREPUBLIK DEUTSCHLAND*, 1988/89. Mairs Geographischer Verlag, sheet 10, scale 1:200,000. Relief shading is almost entirely gone (compared to first edition, 1952–57). Red pin-shaped symbols denote distances on motorways (orange) and other roads (red).
Size of the entire original: 45 × 104.5 cm; size of detail: ca. 12.7 × 12.3 cm. Image courtesy of Wolfgang Lierz. Permission courtesy of MAIRDUMONT GmbH & Co, Ostfildern.

were most common, with or without overlapping areas, but special sheets for border areas with varying formats often had to be used. Various folding systems corresponding to the sheet systems were developed. Most appropriate for use within a car was Leporello folding in landscape (horizontal) orientation so the driver and passenger could easily handle and look at the map.

Many series originally covering a single country were soon extended beyond national boundaries, long before so-called globalization, and existed over many decades. For example, in Scotland, England, and Wales, *Bartholomew's Revised Half-Inch to Mile Map for Tourists* (later *Motorists*) *& Cyclists* (1890–1903, 66 sheets at 1:126,720) introduced colored contour layers. *Quarter-Inch to Mile* (1:253,440) editions followed; scales were transformed into metric (1:125,000 and 1:250,000) only after 1980. The ANWB's *Atlas van Nederland* (1894, 36 sheets at 1:200,000) was not a bound atlas but a series of loose small-format map sheets in a box; in 1930 it was revised and retitled *Autokaart van Nederland* (Koeman 1983, 20–27). In Germany, *Ravenstein-Liebenows Rad(fahrer)- und Automobilkarte von Mittel-Europa* (1899–1908, 164 sheets at 1:300,000) soon dominated the market, especially in various larger-sheet formats as *Ravensteins (Grosse) Rad(fahrer)- und Auto(mobil) karte* (1900–55, over 50 sheets at 1:300,000 and other scales). Ravenstein introduced the color red to emphasize roads. The Touring Club Italiano's *Carta d'Italia* (1907–14, 59 sheets at 1:250,000; see fig. 1034) was one of the first European road maps not mentioning a special user group in its title. The *Carte Michelin* of France (1910–13, 47 sheets at 1:200,000) was especially successful, and soon Michelin extended the coverage of its sheets from France to many other European countries. After World War II, Mair's (Shell) *Deutsche Generalkarte* (1952–57, 26 sheets at 1:200,000) became the dominant road map in Germany (fig. 873) and, like Michelin, it soon covered many other countries. It served as a basis for the very successful *Große Shell-Atlas* (1960–), which for decades could be found in almost every German car (Mair 1963). So map users from France and Germany, for example, could use a map in the style of their favorite publisher even abroad. Language was not an issue in these cases; explanation of signs was frequently given in several languages, and toponyms were often given in the corresponding national language—as shown on traffic signposts—with common exonyms added (Roma–Rome–Rom). Eastern Europe before 1990 was not covered completely with publicly available road maps.

Road maps in the form of strip maps played only a minor role as a holiday service for members of automobile clubs (Lierz 2002). Toward the end of the century, computer-based route planners again drew on this concept. During the first decade of the twenty-first century, classical road maps and road atlases were almost totally replaced by car navigation systems based on the Global Positioning System (GPS). Also, road maps could easily be printed from map websites such as Google and MapQuest.

Although road maps were one of the most frequently produced kinds of maps during the twentieth century, they were not of much interest to academic cartography. Overview articles and studies about road maps did not appear until after midcentury (Castiglioni 1959; Mair 1963). Attempts at classification of roads and road maps and some standardization were achieved (Gill 1993; Morrison 1966; Schiede 1968), but there was not much evidence that publishers took notice.

WOLFGANG LIERZ

SEE ALSO: Esselte Kartor AB (Sweden); Michelin (France); Ravenstein Verlag (Germany); Touring Club Italiano (Italian Touring Club); Wayfinding and Travel Maps

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Road Mapping in Australia and Oceania. Twentieth-century road map publishing in Australia was shared by automobile associations, government tourist bodies, commercial map publishers, and oil companies. In New Zealand the large number of automobile associations showed early interest in publishing maps, and they along with the oil companies dominated the market.

Road maps were specifically designed to show distances, surface conditions, and facilities enroute for travelers. Although they first appeared during the Victorian gold rush in 1853, the impetus for the genre to develop was the bicycle. In Australia the cycling associations became important publishers of both maps and guides, particularly the *Austral Wheel* series in Victoria and the *Cyclists' Handbook and Guide to the Roads of New South Wales* by the New South Wales (NSW) Cyclists' Touring Union. *George R. Broadbent's Road Map of Victoria* (1895) (fig. 874) and Joseph Pearson's *Cyclists' Touring Map of New South Wales* (in Pearson's *Cyclists' Touring Guide*, 1896) (Fitzpatrick 1982, 52–53; 1980, 20–21; Nicholson 2006, 5–7) led the surge into the 1930s and the 1950s, respectively. In New Zealand *Green's New Zealand Road Book* (1898) and *Green's Motor and Cycling Map of New Zealand* (1906) by J. E. Green were significant, while the Cyclists' Touring Club planned to issue maps by 1897 (Hargreaves 1984, 6).

The publisher Robinson's of Sydney dominated the New South Wales and Australian market early. They teamed up with Pearson starting in 1905 to produce road maps, guides, and strip maps from information collected by Cecil Gregory, who eventually formed Gregory's Guides and Maps (1934). Another notable publisher was Clive Barrass, who started his business in 1933 and worked with map publishers as well as oil companies. Universal Business Directories (UBD), later Universal Press, started business in Sydney in 1940 and became a major player in all states. Universal Press took over Barrass, Gregory's, and UBD in 1984, Robinson's in 1986, and R. A. Broadbent in 1989, and published maps of all the states (Bowden 2000, 20, 22, 26–27, 31).

In Queensland the first cycle map of the Brisbane district was published by the Office of the Surveyor General in 1896. Kenneth Craigie began producing early maps of Queensland in the 1920s. Nine oil companies produced maps from the 1930s to the 1970s, while Gregory's produced road maps for the state automobile association from the early 1950s to the mid-1970s. Hema Maps, started in Brisbane in the early 1980s, is now a significant publisher in Australia, New Zealand, and the southwest Pacific islands (Bowden 2000, 22, 74).

In South Australia publishing was promoted early (1897) by the two Adelaide newspapers, but the market was dominated by *The Tourist's Road Guide* (1903–26?) of W. K. Thomas and *W. G. Fuller's Road Guide to South Australia* (1921–55?). Both maps went into many issues. In the Northern Territory early mapping was by oil companies and Robinson's (1920s onward), UBD and Gregory's (1950s onward), and Hema in the 1990s.

The first Tasmanian maps were produced by a Victorian cycling magazine, the *Austral Wheel*. It was followed in 1897 by a map by Walch & Sons of Hobart, a well-established local publisher (Fitzpatrick 1980, 24–25).

In Victoria George R. Broadbent linked up with the automobile club and extended his mapmaking beyond the state. His company dominated road mapping until the late sixties, when it became part of Robinson's. Western Australia seems to lack cycling maps altogether, and the oil companies and the automobile club directed publication apart from Gregory's, UBD, and Hema.

Oil company mapping appeared early in all countries of the region. Over twelve companies operated in Australia during the century from the second decade. Atlantic and Shell were the earliest to produce road maps in the twenties. Similarly, in New Zealand five oil companies—Atlantic, Shell, Caltex, Mobil, and BP—issued maps. Shell has been the most prolific and enduring in both countries.

The peak period for oil maps was the 1950s and 1960s. By the 1970s the number of oil companies producing maps was declining, while the publishing format became the road atlas rather than the road map. The automobile clubs regained some dominance as the oil company maps disappeared. However, a number of

FIG. 874. *GEORGE R. BROADBENT'S ROAD MAP OF VICTORIA*, 1895–96. Compiled by F. Hamilton Nicol (Melbourne: George Broadbent, [n.d.]). One map in two sheets joined. Size of the original: 50.8 × 75.1 cm. Image courtesy of the Map Collection, University of Melbourne Library, Melbourne, Australia.

new commercial publishers appeared during the 1990s, including book publishers issuing road atlases, such as Penguin, Random House, and Reader's Digest. A similar publishing pattern in New Zealand saw new cartographic publishers such as Minimaps and Pathfinder Publications.

In Papua New Guinea, road mapping was produced by Caltex, Leigh Mardon, Shell, South Pacific Post, and UBD from 1952 onward. In 1992 South Pacific Maps, a division of Hema, started publishing maps of the southwestern Pacific islands.

DOROTHY F. PRESCOTT

SEE ALSO: Wayfinding and Travel Maps: (1) Road Atlas, (2) Road Symbols

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Nicholson, T. R. 2006. "On the Road Down Under: Some Australian Maps and Guides for Cyclists and Motorists, 1895–1961." *IMCoS Journal* 104:5–25.

Robinson, Arthur H(oward). Arthur H. Robinson was arguably the most influential cartographer of the second half of the twentieth century. His PhD dissertation changed the nature of cartographic thought, his textbook dominated cartography classrooms, his map projection was widely used, his scholarship profoundly influenced geography and cartography, and many of the cartographers in academic and other positions are direct academic descendents (fig. 875).

Born in Montreal of American parents in 1915, Robinson attended elementary and high school in Minnesota, Ohio, and England. He earned a bachelor's degree in history from Miami University of Ohio in 1935, a master's degree in geography from the University of

FIG. 875. ARTHUR H. ROBINSON AND THE ROBINSON PROJECTION, CA. 1985.

Image courtesy of the University of Wisconsin–Madison Archives.

Wisconsin–Madison in 1938, and a PhD in geography/cartography, with a minor in geology, from Ohio State University in 1947. His pursuit of the PhD was interrupted by World War II, when he served as chief of the Map Division of the Office of Strategic Services (OSS) in Washington, D.C. At the OSS he faced the problems of producing thematic maps that would carry a message to the people directing U.S. participation in the war. He became profoundly aware of the lack of training and research that would have helped in making design decisions, in organizing the mapping process, and in reproducing the product. The experience led to his dissertation, which was published as the philosophical and questioning *The Look of Maps* (1952), a slim volume that shifted attention from map content and encoding to that of the map as a designed object that ultimately interacts with the mind of the user. It was not a book of answers. The foreword says it was "to impart an appreciation of what and how much we do not know" (vii). One of the later developments from his shift in cartographic focus was a research genre that involved human users of maps. The phrase that captures the transition reflected in the book and subsequent developments is "the map as a communication device," a concept so ingrained in cartographic thinking by the end of the century that it was hard to conceive it as ever having been innovative. The influence of World War II on cartography, then, was not limited to the production of more maps and the development of new technologies; it changed how we think about maps.

Only a year into his academic career, Robinson published the first edition of his textbook *Elements of Cartography* (1953). It included chapters on drafting and reproduction of maps, design, lettering, and distribution mapping, all having been challenges at the OSS when neither he nor the people working under him brought appropriate background to the task (Robinson 1979). The textbook would continue, with coauthorship, through five more editions, in 1960, 1969, 1978, 1984, and 1995. By the last edition, topics included digital databases, remote sensing, color, and animated and interactive mapping. Over the half century of its publication, the text, or material influenced by it, was used in virtually all cartography classrooms.

At the University of Wisconsin, where he spent his entire academic career, from 1946 to retirement in 1980, Robinson developed several cartography courses and was founder of a highly functional cartographic laboratory that produced maps for scholarly books and papers. His convictions about the importance of cartography and his scholarly success paved the way for expansion of the program, and eventually he and his colleagues initiated both an undergraduate and master's program within the geography department that were explicitly labeled cartography. The names and separate identities of the programs varied over the years as geographical information systems came to the forefront and the relationship between geography and cartography was reconceived, but the strength of the cartographic components in the department were enduring contributions to the education of students going into mapping companies and agencies with the tools, updated for the times, that Robinson had so longed for when he was in the OSS.

Robinson's influence was not entirely associated with cartography. Drawing from his background in geology as well as geography, he coauthored general and physical geography textbooks early in his career. Geography students in introductory and physical geography courses in the 1950s and 1960s were as familiar with his name as those in cartography. Also during the first two decades of his academic career, he published articles on quantitative maps and methods of analysis, helping to usher in the use of quantitative approaches in the field of geography.

With a strong interest and background in history, Robinson began to publish work on the history of cartography in the late 1960s. His book *Early Thematic Mapping in the History of Cartography* (1982) not only expounds upon numerous early examples but explains how the maps were made, the messages they convey, and the context of their making, marking a change from historical approaches in the past. His strongest contribution to the history of cartography, however, was what he taught his students. His own and other graduate students who took his classes acquired a broad appreciation of the subject, and those who focused on the history of cartography have been leaders in extending and transforming the way in which we understand the past. The role of one of his students, David Woodward, as cofounder of the *History of Cartography* is testament to Robinson's accomplishments in inspiring and giving early guidance to scholars of the history of cartography.

Robinson's interest in what maps represent, beyond the obvious what and where of their content, led eventually to *The Nature of Maps* (1976), coauthored with Barbara Bartz Petchenik. An expressly philosophical and decidedly nontechnical volume (like *The Look of Maps*), it was a complement to his broad range of research articles and textbooks. It was arguably the turning point toward what would later be called critical cartography.

The accomplishment that would bring him to the attention of the general public was the Robinson projection. Developed in the mid-1960s for Rand McNally, it was adopted by National Geographic Society (NGS) in 1988 for its world map, which was distributed as a folded insert in the magazine to its roughly eleven million subscribers from all walks of life. It was suddenly a highly popular choice for a wide range of maps and one of the projections included in virtually every cartography class that included anything about map projections. After his death in Madison in 2004, scholarly obituaries (e.g., Morrison 2008) were complemented by journalistic obituaries that appeared in major newspapers throughout the country, reporting that the inventor of the Robinson projection had passed away.

Understanding the importance of an infrastructure that promotes interaction among scholars, Robinson served his discipline in numerous ways. He was chair of the Cartography Division of the American Congress on Surveying and Mapping (ACSM), the first editor of the *American Cartographer*, and president of both the Association of American Geographers (AAG) and the International Cartographic Association (ICA). Honors included the Earle J. Fennell Award (ACSM), the Carl Mannerfelt Medal (ICA), the John Oliver LaGorce Medal (NGS), and the O. M. Miller Cartographic Medal (American Geographical Society).

Robinson's legacy includes not only his publications but also the educational program that developed at the University of Wisconsin. The students who studied with him and, in turn, the generations of students produced by them and their students, think in patterns that can be traced back to his writing and teaching (Freundschuh 2005). Cartography has changed profoundly since Robinson retired, but he would embrace those changes. He is one of the people whose ideas set the changes in motion that led to the state of cartographic thought and education at the end of the century and indefinitely beyond.

JUDY M. OLSON

SEE ALSO: Academic Paradigms in Cartography; *American Cartographer, The*; Education and Cartography: (1) Educating Mapmakers, (2) Cartographic Textbooks; Histories of Cartography; International Cartographic Association; Office of Strategic Services (U.S.); Perception and Cognition of Maps: Subject Testing in Cartography; Robinson Projection

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Robinson Projection. The Robinson projection was created by geographer and cartographer Arthur H. Robinson in the early 1960s for the Rand McNally Company. It was first described in 1963, at the annual meeting of the American Association for the Advancement of Science, in Cleveland, Ohio, and was used throughout the 1970s and 1980s by Rand McNally, and for about ten years, starting in 1988, by the National Geographic Society. Rand McNally had asked Robinson to create a new whole-world map projection that would be appropriate for wall maps as well as small-scale atlas maps. The new projection was to be distinctly different from Goode's homolosine equal-area projection, a Rand McNally staple that interrupts the oceans to better preserve the shape of continents, as well as from the widely used Mercator projection, which greatly distorts area. Interruption was not allowed, but strict areal equivalence was not required—the relative sizes of continents merely had to appear to be approximately correct. Rand McNally's specifications differed from those normally associated with map projection and were more aesthetic than cartographic. For example, the graticule "should appear simple and straightforward," and "the system should be suitable for use by readers of all ages" (Robinson 1974, 148).

Robinson realized that these requirements called for a numerical procedure different from the traditional approach to creating map projections—a procedure that was artistic rather than purely mathematical. His description of how he designed the projection makes clear that when appearances and relative relationships are paramount and when absolute measurements typically associated with map scale are of no practical significance to the projection's use, the designer must first establish the "look" of the projection and then devise the mathematics able to describe it. To satisfy Rand McNally's requirements, in which appearance took precedence over the usual projection parameters, Robinson employed an iterative procedure, "a sort of graphic successive approximation" (Robinson 1974, 152), whereby he used a computer and plotter to map the graticule and continental shorelines, evaluated their appearance, adjusted the computer program to improve the look, and initiated a new cycle by making a new plot. These approximations, as Robinson called them, were continued until, "at least to the eyes of the author" (1974, 152), no further improvement could be made in the look of the projection. In this sense the projection is unique, requiring not a geometrical specification, but rather a large number of trial-and-error computer simulations that allow the cartographer some subjective flexibility in the location of lines of latitude and longitude. The final projection can be considered a type of pseudo-cylindrical—a compromise projection that is neither conformal nor equal-area (fig. 876). It is distinguished by an equator 1.9716 times as long as the central meridian and by flattened poles 0.5322 times the length of the equator (Snyder 1993, 216).

Rand McNally used the projection in various atlases, principally from 1969 through the 1980s, and in the

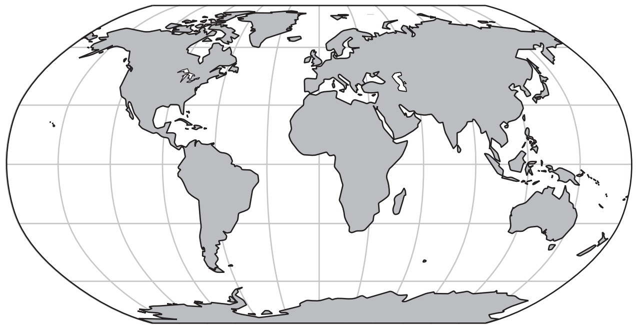

FIG. 876. ROBINSON PROJECTION.

RandMark Wall Map Series in the 1970s. In 1988 the National Geographic Society adopted it for a political map of the world but replaced it with the Winkel tripel projection in 1998. Although still in the repertoire of map projection software, its use had declined significantly by the end of the century.

JOHN W. HESSLER

SEE ALSO: Art and Cartography; National Geographic Society (U.S.); Projections: World Map Projections; Rand McNally & Company (U.S.); Robinson, Arthur H(oward)

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Route Map. Wayfinding maps can be classed into two broad and overlapping types, which have coexisted for centuries. Network maps offer a general view of pathways within a specific place or region and are usually smaller in scale than their counterpart route (or itinerary) maps. The latter are the conceptual descendents of ancient verbal navigational guides used by mariners or overland travelers to find their way along important routes. Even in the twentieth century, strip road maps were often designed as complements to written instructions and guides, a practice adapted to the digital age by online route-finding aids and in-car navigation systems. Richly illustrated maps and panoramas of major waterways and highways as well as simple graphic itineraries were produced in a variety of premodern and early modern contexts, but these were rare before the eighteenth century, except in cartographically prolific and mobile societies such as Britain and Japan (Delano-Smith 2006; Unno 1994, 422–26). The development of motorized watercraft, locomotives, automobiles, and aircraft revolutionized the pace and reach of travel during the nineteenth and twentieth centuries and encouraged the production of all types of wayfinding maps. As the infrastructure and habits of travel by these new modes matured, network maps became the standard maps of reference for most travelers, but route mapping remained an important cartographic strategy in the twentieth century whenever the emphasis on specific pathways and routes was desirable.

The planning and engineering of new routes required an enormous investment in cartography. According to its online inventory (accessed 26 November 2008), the U.S. National Archives and Records Administration preserves in Record Group 185 some 9,600 maps produced by French and American agencies that planned, constructed, and administered the Panama Canal from the late nineteenth century to 1960. These include general maps and profiles of proposed routes (fig. 877); detailed plans and profiles of locks, dams, and excavations; charts and harbor plans; maps documenting land acquisitions; and thematic maps concerned with the social and economic effects of the canal (see also Rhoads 1956). Comparable numbers of maps must surely have been created to facilitate the construction of other heavily capitalized route engineering projects, such as the Trans-Siberian Railway and modern superhighways.

Route planning maps were often personal and individual. Charles A. Lindberg famously blazed the transoceanic air route between New York and Paris in 1927 by preparing a simple but ingenious chart that would allow him to calculate carefully the periodic course adjustments needed to make European landfall with the minimum use of precious fuel (Lindbergh 1927, 201–3). Similarly, though less heroically, in the years before North American governments took responsibility for the improvement and marking of highways, amateur and professional "pathfinders," working alone or in small parties, surveyed informal interregional automobile routes (Akerman 2000).

On established routes, surveys and reconnaissance gave way to navigational and operational mapping. Pilot books and atlases of navigational charts of major inland water routes such as the Rhine and Mississippi Rivers were commonplace in the twentieth century, as were maps for railroad operators and travelers (Musich 2006, 111–13). The slow speed and difficulty of navigating on longer trips prompted the publication of strip-format route maps by North American motor clubs and commercial firms into the 1930s. Even after the general improvement of roads and route marking enhanced the utility of small-scale network road maps, many motorists preferred the explicit instructions offered by route maps, such as the customized TripTiks issued by the Ameri-

FIG. 877. DETAIL FROM *MAP SHOWING LINE OF PROPOSED LOCK CANAL WITH SUMMIT ELEVATION AT 85 FEET*, 1905. [Balboa Heights, Panama?]: Board of Consulting Engineers, Panama Canal.
Size of the entire original: 89 × 169 cm; size of detail: 12 × 16.6 cm. Image courtesy of the Newberry Library, Chicago.

can Automobile Association (see fig. 34), and their later digital counterparts. In addition, strip charts of single air routes were the wayfinding device most commonly used by early aviators to support the successful negotiation of longer trips into unfamiliar airspace in the era when airplanes had no radar and only limited aeronautical infrastructure (Ehrenberg 2006).

Maps showing the routes of walking or driving tours published in guidebooks and travel brochures constitute a distinct type of navigational route map. Though guidebooks richly illustrated with maps were already common by 1900, maps prescribing specific itineraries for tourists were mostly a twentieth-century phenomenon, a response in large measure to the emergence of automobile tourism. As roads improved and cars became more durable, most of the practical restrictions on the movement of automobile travelers disappeared in many parts of the world. While this freedom of movement was a major part of the appeal of motor touring, it also left its enthusiasts, somewhat ironically, in need of guidance. Most often this guidance had an explicitly promotional motive. In the first decades of the century, for example, Waterbury, Connecticut, hotelier Almon C. Judd published a guidebook and map of *The Ideal Tour* of New England, whose stages conveniently ended each night at the doorstep of a different hotel that cosponsored the publication. While the types of route map noted thus far usually described the navigation of a roughly linear and direct route linking termini separated from each other by considerable distances, tour route maps and their cognates (such as postal and bus route maps) described complex pathways linking points scattered about a locality or district. As often as not, these described a circuit, as in this example from a 1954 Michelin *guide verte* describing a scenic tour west of the southern French city of Grasse (fig. 878). Such maps connected places within a locality, creating a series of sites and experiences thought to be entertaining or meaningful to the typical tourist. While in one sense tour maps helped their readers navigate a route (telling them how to traverse a series of

FIG. 878. *EXCURSIONS AUTOUR DE GRASSE*, 1954. Adjacent text in this Michelin guide describes the routes and employs a star rating system ("Vallée du Loup**: panorama, gorges").
Size of the original: 9.7 × 13.8 cm. From *Côte d'Azur, Haute Provence* (Paris: Services de Tourisme Michelin, 1954), 74.

points of interest efficiently without getting lost), their primary purpose was to structure a traveler's experience of a place. Most often working with accompanying text, their selection and serialization of points of interest not only told tourists what to see along the way but also how to see it.

Tour maps could, of course, describe established routes as well, utilizing the classic format of the strip map. Ranging from crude sketches to elaborate panoramas, such maps promoted routes and passenger services, entertained travelers during the passage, and served as souvenirs of the journey after its completion. North American railroad companies had been active in this sort of publication since at least the 1860s (Musich 2006, 98–108; Modelski 1984). Similar promotional strip maps were published by associations of roadside businesses and communities with a vested interest in promoting specific highway routes, such as U.S. Route 66 and the "Golden Chain" (California State Route 49) linking former mining communities in the foothills of California's Sierra Nevada Mountains. Passenger airlines issued similar maps loosely based on early aeronautical charts to their customers in an era when planes flew low to the ground and air travel was novel. River routes popular with tourists were also mapped to support the traveler's appreciation of the passing landscape, notably the passage of the Rhine River through its famous gorges between Mainz and Cologne (fig. 879).

FIG. 879. DETAIL FROM *RELIEF PANORAMA OF THE RHINE*, [1930s?]. Cologne: Hoursch und Bechstedt.
Size of the entire original: 172 × 25 cm; size of detail: 53.4 × 25 cm. Image courtesy of the Newberry Library, Chicago.

The complex relationships between route creation, navigation, and promotion explain the enduring appeal of route maps in the twentieth century, even in navigational contexts that no longer seemed to require them. Route maps created to help plan canals, railways, urban expressways, or transatlantic air routes were not only essential to their technical realization, they also make these routes seem possible, desirable, and perhaps inevitable—even if they were not always so. Similarly, route maps facilitated the navigation of established pathways even as they attracted traffic to them. We cannot say that these qualities were first realized in the twentieth century, but in a century shaped by the explosive growth of tourism and worldwide commerce, mapmakers and map consumers alike found route maps useful tools for sorting out expedient or desirable pathways from among the almost endless possibilities.

JAMES R. AKERMAN

SEE ALSO: Wayfinding and Travel Maps: (1) In-Vehicle Navigation System, (2) Web-Based Wayfinding

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Royal Geographical Society (U.K.). One of the Royal Geographical Society's (RGS) principal goals upon its founding in 1830 was the dissemination of geographical information in cartographic form. Monday evening lecture meetings on scientific geography, exploration (land and sea), travel, contemporary research, historical geography, and the history of cartography were initiated with concomitant published accounts. Lectures, to which invited nonmembers were permitted, and other international progress reports and news were edited for publication in the *Journal of the Royal Geographical Society*. The *Journal* (1831 to 1880), the *Proceedings* and the *Proceedings*, new series (from 1855 and 1879 respectively), the *Supplementary Papers* (to the *Proceedings*, new series) (1882 to 1893), the *Geographical Journal* (from 1893), and the Society's other special publications were available to the general public in libraries and scientific institutions worldwide by mutual exchange, subscription, or donation. Foreign or corresponding honorary membership was conferred upon potentially useful geographers, nobility, and donors; thus, with exchanges of international news and publications, the RGS formed a growing multifaceted data bank of artifacts and manuscript and printed texts and graphics.

Its central London locations brought it close to geographical publishers and map trade practitioners, from whom it commissioned map engraving and printing. Map Room staff from 1854 made diagrams for the RGS's evening meetings, and the May 1878 appointment of an official in-house "chief draughtsman" improved map drawing facilities for its *Journal*. From 1885 to 1914 hand maps were compiled and printed for distribution at main lectures. After revision the hand maps were published two or three months later with the lecturer's paper in the *Proceedings* or *Geographical Journal*. Beginning in 1892 another RGS drafting skill was the preparation of maps and other diagrammatic illustrations for glass lantern slides for RGS lectures.

From its beginnings the policies, programs, and publishing activities of the RGS were formulated by an elected council supported by various specialist advisory committees, such as a Special Committee for Geographical Research (1903), whose program frequently encompassed cartography and required Map-Drawing Department (also called the Map-Drawing Office, Map-Drawing Room, and Drawing Office) input, and a Roman Coastal Map Sub-Committee (1956). Notable was RGS president Sir Clements R. Markham's support for the British National Antarctic Expedition (1901–4).

Markham prompted the RGS to initiate training from 1879 in courses of "practical astronomy, route-surveying and mapping" (Mill 1930, 245–46) for explorers, missionaries, army officers and colonial officials; this was normally a precondition for anyone wishing to borrow the RGS's surveying equipment (Collier and Inkpen 2003b). Under pressure from former Survey of India officers, particularly Thomas Hungerford Holdich, director of Frontier Surveys, between 1900 and 1914 the "character of the instruction was assimilated generally to the methods of the Survey of India and of the School of Military Engineering" (Mill 1930, 246). Early editions (from 1854) of the RGS's *Hints to Travellers* were largely concerned with surveying and mapping methods suitable for explorers. The eighth edition (Coles 1901) was in two volumes, of which the first was a textbook on surveying and practical astronomy together with the necessary computation tables. The eleventh edition

(1935–38) was last reprinted in 1947, by which time a wide range of other, more up-to-date texts were available. Specialist pamphlets were published from 1920 onward on such topics as the theory of map projections (Young 1920) and wireless time signals (Hinks 1925).

The RGS's resident staff was headed from 1892 by John Scott Keltie, who served as secretary and editor of publications. His appointment in 1884 as RGS's inspector of geographical education resulted in his influential *Report of the Proceedings of the Society in Reference to the Improvement of Geographical Education* (1886) and selection as librarian. Edward Ayearst Reeves became map curator in 1900 and also taught surveying and practical astronomy. At the time the Drawing Office consisted of a map draftsman, Henry Sharbau, assisted by Joseph W. Addison and Francis J. Batchelor.

Map draftsmen and -women were supervised by the map curator and directed by RGS's secretary until Reeves retired in 1933 and Arthur R. Hinks, who served as secretary from 1915, took direct control. Lectures and articles on theoretical aspects of cartography, most notably on projections, were a major concern of Hinks, and his personal influence maintained a scientific side to the Drawing Office's output. The nineteenth-century practice continued whereby RGS-compiled maps were loaned to outside institutions or commercial publishers (always with a credit to the RGS for permission to publish or reproduce). RGS maps were reused, for example, in the *Journal of the Manchester Geographical Society*, *Scottish Geographical Magazine*, and other periodicals as varied as *Game & Gun & the Country Estate: A Journal of British and Overseas Field and Stream Sport*, *Quarterly Journal of the Geological Society of London*, and *Alpine Journal*.

Hinks's artistic instinct and modernizing influence gave him control over the work of the Drawing Office, resulting in the distinctive RGS style that was similar to near-contemporary changes in the Ordnance Survey's (OS) medium- and small-scale mapping (Herbert 2010). It was first seen in two *Geographical Journal* maps published in December 1926 (fig. 880).

In 1935, Hinks and the RGS also influenced the work of the Davidson Committee, headed by Sir John Humphrey Davidson, which reviewed the capabilities of the OS to keep its maps current. Hinks's support of technological advances including the use of aerial photography in mapping led the RGS to recommend to the Davidson Commission that the OS form a photogrammetric research department (Collier and Inkpen 2003a).

In World War II both George S. Holland and Kenneth C. Jordan served as Royal Air Force mapmakers within the stereoplotting section of the Central Interpretation Unit at Medmenham, Buckinghamshire, and at Nuneham Courtenay, Oxfordshire. Holland was appointed as RGS chief draftsman in 1955. The Society's last full-time draftsman was Edward J. Hatch, who joined in 1961 and worked until the Drawing Office closed in 1990.

FIG. 880. "SKETCH MAP TO ILLUSTRATE VOLCANIC ACTIVITY NORTH END LAKE RUDOLF" [1926]. Original pen-and-ink manuscript by RGS Drawing Office's Charles Edward Denny. This version was later reduced by one-third for reproduction in W. Pennefather Holland, "Volcanic Action North of Rudolf in 1918," *Geographical Journal* 68 (1926): 488–91, map on 489. The second example (not shown here), by George S. Holland of the Crater of Kibo, Kilimanjaro, was published in the same volume in D. V. Latham, "Kilimanjaro and Some Observations on the Physiology of High Altitudes in the Tropics," *Geographical Journal* 68 (1926): 492–505, map on 495.
Size of the original: 18 × 16.5 cm. Image courtesy of the Drawing Office Archive, © Royal Geographical Society, London.

In 1947, under Lord Francis James Rennell Rodd's presidency (1945–48), Holland drew a specimen map for the Travel Association of Great Britain and Northern Ireland's *Local Information Sheets* series, edited by Edmund Vale; this envisioned commercial contract for 200 maps, each to carry "Drawn by the Royal Geographical Society," was fulfilled by some 45 maps by 1949. Six maps were also made for *British Military Administration of Occupied Territories in Africa, 1941–1947* (1948). RGS draftsmen Graham Mackay, Sharbau, Addison, Henry F. Milne, W. R. Rand, and Holland drew some thirty-seven maps for volumes published by the Hakluyt Society. The RGS, however, was not always able, nor was it always necessary, to produce its own maps. Occasionally, Admiralty charts were used and the Ordnance Survey, War Office, Survey of Egypt, and Survey of India also permitted map reproduction or they printed versions of their maps for RGS use. Before World War I, maps compiled and published by the RGS were displayed at international geographical, oceanographic, and general exhibitions. These included the Exposition Internationale d'océanographie des pêches maritimes et des produits de la mer in Marseille (1906), the New Zealand International Exhibition in Christchurch (1906–7) and, in London, the Franco-British Exhibition (1908), the Japan-British Exhibition (1910), and the Coronation Exhibition (1911).

During both world wars the War Office used the RGS as an information source and compiler of maps and texts. Following the outbreak of World War I work began immediately with civilian volunteers on the compilation of gazetteers of Belgium and France, based on the national map series, for Colonel Walter Coote Hedley of the Intelligence Division War Office to distribute to the British Expeditionary Force (Heffernan 1996). By June 1915 maps had been compiled of wheat and rye growth in Germany. The RGS made another important contribution through its work on sheets of the International Map of the World (IMW) at 1:1,000,000; the first ten sheets, covering Central Europe and the Balkans, were compiled and printed during 1914–15 (fig. 881) with further sheets covering western Russia and the Ottoman Empire produced later. At Hinks's suggestion, the RGS also compiled a thematic series of language and ethnicity maps of Austro-Hungary and the Balkans at 1:1,000,000, which were subsequently used in the Paris Peace Conference. By war's end the RGS draftsmen had compiled over ninety IMW-style sheets covering most of Europe and the Middle East (Heffernan 1996, 511, 519), and during World War II they were called on to do recompilations and revisions of the sheets covering the Arabian Peninsula.

Due to the military's great demand in World War I some of the RGS's maps, such as *Map of Eastern Turkey in Asia, Syria and Western Persia* (1910), grew in importance: by January 1921, there were eight revisions. After transfer of the lithographic stones to the Geographical Section, General Staff (GSGS) in July 1918, a full-color ethnographic overprint by the War Office was produced for the Paris Peace Conference in 1919 and was recommended as "the best general map of Mesopotamia" in the Foreign Office's Peace Handbook on Mesopotamia (Great Britain, Foreign Office, Historical Section 1920, 134).

From 1927 onward, under enthusiastic direction and editing by successive librarians Edward Heawood and G. R. Crone, scholarly memoirs with reproductions of early maps and charts were launched as a publishing enterprise. Much of the map publication concerned itself with reproducing some of the maps in the RGS's collection, not producing new cartographic products.

After World War II, exhibitions of maps at the RGS became more frequent as the Society's 1930 centenary extension of its headquarters included the Ambulatory, a three-sided exhibition space. One of the first exhibitions included demonstrations of military map compilation and printing arranged by the Directorate of Military Survey's Brigadier Sir Clinton Lewis, with lorry-borne equipment in the RGS's garden and a specially printed booklet, *The Making of a Map*, prepared by Lewis and published in 1945–46. It was followed in 1947 by "The World in Focus," which was chiefly on visual aids for the teaching and learning of geography and, with the Ministries of Civil Aviation and of Education and the British Airways Corporations, "Highways of the Air," showing globes and "new types of projections and air maps" (Anonymous 1947, 245). In 1948 the exhibition "Navigation though the Ages," showing portolan charts, was organized with the Institute of Navigation, and this was followed in 1949 by "Maps for Colonial Development," which exhibited the RGS's maps of Africa, including those by David Livingstone, and also publicized the work of the Directorate of Colonial Surveys. The RGS and Crone were largely responsible for planning "Cartography in Britain: A Course Arranged by the British Council" for foreign delegates and centered on London (including a visit to an official Festival of Britain exhibition at the RGS, in conjunction with the Institute of Navigation, "Development of British Maps and Charts"), Southampton, and Taunton in May 1951. Although such exhibitions became less frequent, in the autumn of 1998 the RGS had an exhibition commemorating the quadricentennial of Abraham Ortelius's death. Another RGS contribution to mapping generally and worldwide was supported by two benefactors: Sir Herbert George Fordham by his Fordham Bequest (1928) for the encouragement of cartobibliography, and the Michael Corbett Andrews Bequest (1934) for cartography.

FRANCIS HERBERT

SEE ALSO: Hinks, Arthur R(obert); International Map of the World; Permanent Committee on Geographical Names (U.K.); Societies, Geographical: Europe

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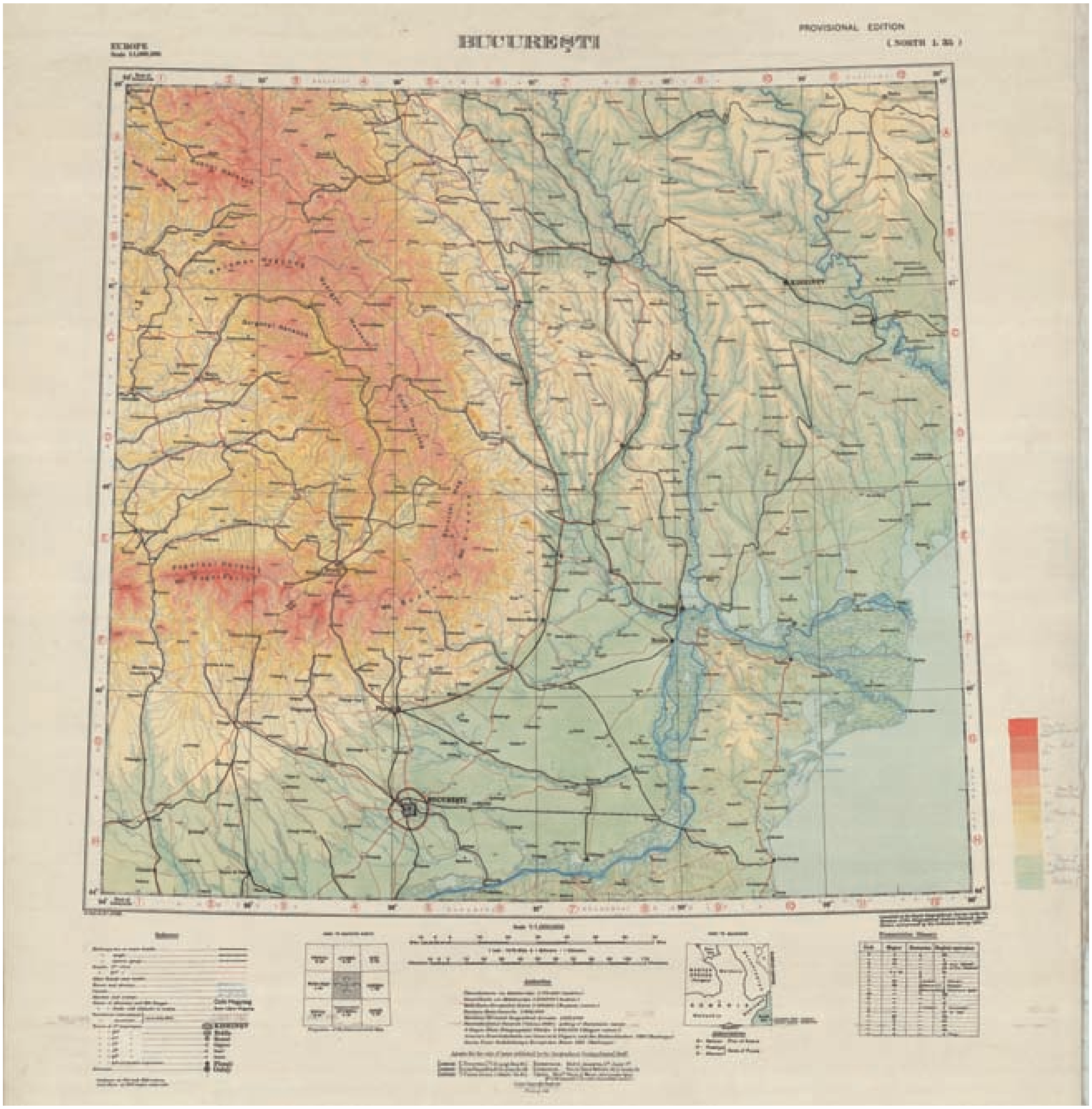

FIG. 881. *BUCUREŞTI* SHEET OF 1:1,000,000 MAP, CA. SEPTEMBER 1915. After the map was compiled at the RGS under the direction of the War Office's GSGS, drawn and printed as "provisional edition" in 1915 by the OS with only metric contours, the RGS applied experimental hand-colored layer relief. Shown here is one of the two variant color schemes applied to two identical printed base map sheets.
Size of the original: 65.5 × 59.5 cm. Image courtesy of the Drawing Office Archive, © Royal Geographical Society, London.

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***R. R. Donnelley & Sons** (U.S.).* R. R. Donnelley & Sons grew from its 1864 founding in Chicago to lead the nation in commercial printing in the 1960s, employing thousands at plants across the United States. Donnelley's venture into commercial cartography built upon resources and connections developed serving large accounts like Sears' mail-order catalog and *National Geographic* magazine.

In 1964 Donnelley hired Duncan M. Fitchet to produce road maps as advertising for oil companies, including Amoco, Mobil, and Shell. Fitchet, formerly with Rand McNally, was a founder and officer of the International Cartographic Association (ICA). The first maps made by his group at Donnelley (1965) covered southern New England but rapidly expanded to Delaware, Maryland, Virginia, West Virginia, and Pennsylvania, followed by other states. Donnelley described the maps as "revolutionary" in appearance and content, particularly details of interstate highways and feeder roads (fig. 882), and copyrighted them (Anonymous 1965, 28).

The road map operation became a separate division in 1969: R. R. Donnelley Cartographic Services; the name changed to Mapping Services in 1990. Headquartered in Lancaster, Pennsylvania, near a Donnelley map printing facility, it offered full custom cartographic work, from research to printing. Fitchet recruited expert staff and led Cartographic Services to an enviable reputation among academic, travel, and commercial publishers. A notable addition in 1975 was Barbara Bartz Petchenik, who did pioneering research on map design for children and became an officer of the ICA; in 1993 the ICA created its biennial children's world map competition in her memory. A major innovation was adding maps to telephone directories, of which Donnelley was already the major publisher. According to production supervi-

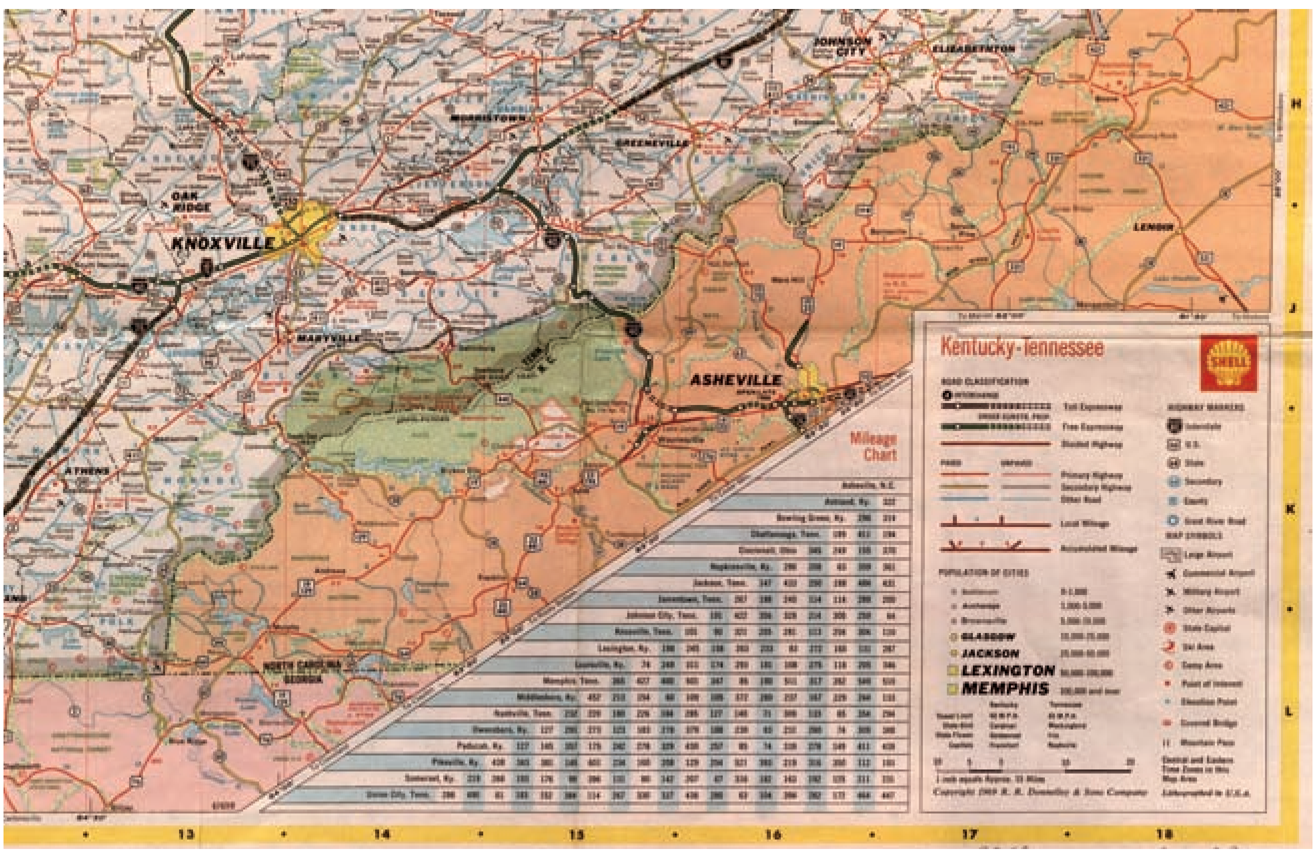

FIG. 882. DETAIL FROM R. R. DONNELLEY & SONS COMPANY, *KENTUCKY-TENNESSEE*, 1969, CA. 1:950,400. Detail of the legend and the area around Knoxville taken from a road map distributed by Shell.

Size of the entire original: 57 × 89 cm; size of detail: ca. 22 × 34.2 cm. Courtesy of the T. R. Smith Map Collection, University of Kansas Libraries.

sor Herwig Schutzler (personal communication 2006), Illinois Bell was first in 1976, followed by NYNEX and all other Bell companies except Bell West; by the 1980s Donnelley was producing 4,000 pages of maps for directories of seventeen Yellow Pages publishers serving 2,000 cities.

In the 1980s Donnelley computerized its cartographic work and began producing digital files for sale. It developed cartographic applications for Apple Computer, major textbook and directory publishers, and the U.S. National Park Service. In 1984, Donnelley won the first of several prizes from the American Congress on Surveying and Mapping. Donnelley Cartographic Services joined with Spatial Data Sciences of McLean, Virginia, in 1989 to create Donnelley Spatial Data, which in 1992 introduced GeoLocate Plus, a digital directory on compact disc. The next year it joined Cincinnati Bell in creating an electronic business directory with maps. At the Boston office of Avis it installed the first system to provide renters of cars with on-demand driving directions and maps.

In 1994 Donnelley Mapping Services was spun off as GeoSystems Global. By February 1996 GeoSystems Global had launched the first interactive mapping website for consumers, MapQuest.com. Four years later the firm changed its name to MapQuest.com Inc. and went public; in 2000 America Online (AOL) purchased the company for more than one billion dollars. Online services grew, and in 2006 Donnelley's cartographic services component finally broke off into two separate groups, GeoNova Group and Spatial Graphics.

JOHN H. LONG

SEE ALSO: Petchenik, Barbara B(artz); Road Mapping: Canada and the United States

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Russia and the Soviet Union, Fragmentation of. Even before the Russian Revolution of 1917, Russia was the largest country in the world. The general crisis World War I brought to Russia led to social unrest and uprising in the country. The workers' councils (soviets, of which the Bolsheviks were the majority faction), led by Vladimir Il'ich Lenin, took power in November 1917. After a period of civil war, the first socialist state in the world, the Soviet Union (Soyuz Sovetskikh Sotsialisticheskikh Respublik, SSSR; in English, the Union of Soviet Socialist Republics, U.S.S.R.) was founded in 1922. The new state was constitutionally socialist, politically and economically ruled by the Communist Party, the single party in the union of the Russian, Ukrainian, Belorussian, and Transcaucasian republics. Although nominally independent, the member republics were actually under the control of the highly centralized Soviet system. Due to large-scale modernization programs the Soviet economy developed quickly and basic life conditions improved. Mass education increased literacy, and the party supported Soviet culture as a medium of Communist propaganda. From the late 1920s the Georgian Communist leader Joseph Stalin gradually became the leader of the Communist Party and the country and started to build his signature totalitarian state. Due to its permanently developing industrial economy, the Soviet Union became a political and military power. Despite the German-Soviet nonaggression pact of 1939, which enabled the Soviet Union to occupy most of Eastern Europe, Nazi Germany attacked the Soviet Union in 1941. Eventually Soviet forces not only stopped the German invasion, but troops of the Red Army defeated the enemy in Eastern Europe and occupied Berlin.

In the post–World War II period the Soviet Union, now a superpower, kept its military, political, and economic control over the occupied territory. With Soviet support and assistance, Socialist countries, or so-called satellite states, were established in the Eastern Bloc. The expansion of the Communist world in Asia included Mongolia and China. During the Cold War period, the economy of the huge continental area operated separately from the rest of the world. At first the system worked well, and the Soviet economy could exploit the results of scientific and technological progress. However, political and economical difficulties became more apparent, and in 1985 Mikhail Gorbachev introduced substantial economic reforms (*perestroika*) as well as more democratic public policy (*glasnost*).

The weakening of the central government led to the gradual collapse of the union. The series of political events started in Baku, Azerbaijan, in January 1990, when Soviet troops attacked people demonstrating for independence and opposing the government. While some republics like Lithuania and Estonia wanted independence, in a 1991 union-wide referendum a majority voted for the retention of the Soviet Union. Although Gorbachev was anxious to maintain the union as a less centralized state, an unsuccessful military coup directed against him in August 1991 made its disintegration inevitable. On 21 December 1991 the former Soviet republics (except Georgia) signed the Alma-Ata Protocol, which confirmed the dissolution of the Soviet Union into fifteen independent republics, and by the end of the year (1991) all Soviet institutions had ceased operations. Due to a lack of information on other successor states, the changes discussed here relate mainly to those that took place in Russia.

With the dissolution of the Soviet Union, the Russian Federation, composed of eighty-three federal units (this administrative system was changed by presidential decree in May 2000), became the largest country in the world. Although not of equal status, these units included provinces, republics, territories, autonomous districts and one autonomous province, as well as two federal cities (Moscow and Saint Petersburg). More than three-quarters of the population was Russian, the remainder belonging to 161 ethnic groups. The rapidly changing international borders resulted in serious problems due to the lack of available official maps; mass media mapmakers in particular were eager to follow the political changes on their own maps.

The introduction of a market economy in the Russian Federation had several cartographic consequences. Cartography, like any other branch of social activity in the post-Soviet countries, was greatly influenced by the deep economic crisis, which was most dramatic in the 1990s. The social and economic crisis did not allow much technical development in the field, and thousands of former cartographers became unemployed.

The legal conditions for cartography were ensured by the federal geodesy and cartography law, O geodezii i kartografii, accepted by the Duma (federal assembly) and signed by President Boris Yeltsin in 1995. It must be noted that for historical reasons, cartography is closely associated with geodesy and surveying in Russia. In this context, cartography refers to the production of a cartographic image, ranging from large-scale cadastral plans to satellite images. According to the federal law, cartographic activities important to the government (e.g., production of topographic base maps, topographic mapping of Antarctica) were under the control of federal authorities. Private cartographic enterprises or citizens could produce and publish general maps for individual regions or cities; cadastral plans in connection with boundary marking, planning, and construction; general or thematic maps and atlases; or maps to be used for scientific research.

Federal surveying and mapping in Russia were executed by a massive governmental institution, Roskartografiya, with a staff of some 20,000. This federal service was responsible for geodetic and cartographic work on international borders and the provision of topographic map coverage of the country. Roskartografiya (and the federal security service) also controlled access to cartographic data. Topographic base maps with larger resolution than 1:200,000 were considered confidential by the Russian state. According to a Roskartografiya list in 1997, maps at a scale of less than 1:100,000 were considered public, but only if all secret objects and sites were removed. At the same time, on the basis of Order 055 (1996) of the ministry of defense, the 1:100,000 topographic map was declassified by the ministry of national resources. By the end of the century, the debate over state secrecy and topographic maps, including the distortion of topographic base maps, intensified. Printed topographic map sheets from the Soviet era were available abroad for most parts of Russia at scales of 1:100,000 and even 1:50,000. Cartographic activity in Russia was licensed by Roskartografiya, and commercial cartographic companies had to pay a fee for using topographic base maps (eventually available as digital data).

Among the larger cartographic projects the new Russian government financed was activity in connection with the demarcation and delimitation of a new state border. The approximately 72,000-kilometer international border of the Russian Federation had to be surveyed and mapped. These border demarcation activities were completed by 1992, and Roskartografiya started the topographic mapping of the border on 1:25,000 and 1:50,000 topographic sheets. Large areas were surveyed at the scale of 1:10,000, and revised topographic maps were produced for the border zone.

From the early 1990s the introduction of digital maps and geographic information systems (GIS) created new tasks beyond the more traditional ones. To meet the demands, a multipurpose integrated program on progressive technologies of surveying and mapping of the Russian Federation was run until 2000 by Roskartografiya. One of the most important tasks was to maintain and revise the topographic maps of the country. In Russia topographic scales are 1:25,000, 1:50,000, 1:100,000, 1:200,000, and 1:1,000,000, but urban areas are mapped at 1:10,000 or larger. According to Russian publications the whole country was covered at 1:25,000, which made Russia one of the most cartographically advanced countries in the world. To maintain and revise the topographic database the technological transformation of the system was of vital importance.

The first step toward an integrated database was the production of digital map series of 1:10,000 to 1:1,000,000. Digital mapping projects started in 1992 and in the following year regional centers for geoinformation were set up outside Moscow (RosGeoInform) in Saint Petersburg, Ekaterinburg, Irkutsk, Novosibirsk, and Habarovsk. The state center for geoinformation, GosGIScenter, was founded in Moscow in 1994. This leading research and production institute in the capital continued the digital mapmaking program that started decades earlier. In 1994–95 a digital cartographic database for Russia was created at the scales of 1:200,000 and 1:1,000,000, to be used for applications in support of the national economy. It is notable that both solutions were based on Russian standards, and the digital technology used domestic products, computers, and peripherals. By the end of the century, however, the GIS industry became international, and U.S–based companies like Environmental Systems Research Institute (ESRI) and Intergraph appeared in Russia, and RosGeoInform participated in international projects (e.g., in Finland and Canada).

The state system for the standardization of the mapping of the Russian Federation was put into operation in 1993, and the national standard for digital mapping was developed by the cooperating governmental agencies. The state standard "Geoinformatic Mapping—Metadata of Electronic Maps: Composition and Content" (GOST R 51353-99) was adopted in 1999. This standard provided a cartographic representation of the world based on an accurate geodetic basis and using remotely sensed images. The standard allowed spatial and temporal representation of the world, and the mathematical and semantic model was realized via distributed electronic cartographic libraries.

A subprogram aimed at educational institutions and the population of the Russian Federation resulted in new maps, atlases, and globes, already reflecting the political changes after 1991. In its first decade the technological development at Roskartografiya included new digital facilities, which were used for electronic map design and production. Global navigation satellite system (GNSS) methods for surveying using GLONASS (Global'naya Navigatsionnaya Sputnikovaya Sistema), digital photogrammetry, automatic color separation, and digital map printing were results of the implementation of this development program.

The production of cartographic material for the public was carried out by different Roskartografiya agencies and enterprises. Map printing plants were in Moscow, Omsk, Ekaterinburg, and Novosibirsk. The mapping association "Kartografiya" specialized in maps and atlases for the public. In the massive production of cartographic material (e.g., 2.887 million copies of school atlases in 1995), the emphasis was on maps representing the geography of the Russian Federation, but among its new products Roskartografiya also produced plastic globes.

The government of the Russian Federation decided to publish the national atlas of the country. The project started in 1994 by Roskartografiya with the cooperation of several institutions and ministries. The editorial plan was restructured by GosGIScenter in 2001, and maps were grouped in four atlas volumes, each consisting some 500 pages. Volume 1 of the *Natsional'nyy atlas Rossii* was published in 2005, an electronic version in 2006, and a web version in 2010.

To set up a single geographic database for the country the problem of geographical names was also dealt with and a joint committee was formed by government decree. The federal assembly ratified the federal law on geographical names in 1997. This provided a legal basis for naming of geographical objects and for the use of geographical names in Russia. The state catalog of geographical names, *Gosudarstvennyy katalog geograficheskikh nazvaniy*, was created and maintained partly by the federal cadastre service of Russia, Rosreestr (with over 400,000 geographical names).

During the Soviet era, the cadastral system set up in the nineteenth century was considered unnecessary. The agrarian reform of the Russian Federation, resulting in some forty-three million landowners, required a uniform land cadastre, which was created in the 1990s. The reappearance of private land property resulted in a rapidly growing land market after 1991. Cadastral registration and boundary marking tasks required more land surveyors and the number of high schools offering training in geodetic engineering increased.

Rosreestr, with a staff of about 19,000, was founded in 1994 and authorized to manage land resources at the state level. The service was centralized and controlled more than two thousand territorial and city administrative units. It had eighty-six federal land and cadastre offices and some one hundred research and production institutes and enterprises. Some state authorities (e.g., Roskartografiya and the ministries of nature and of property relations) also executed some land management functions.

In November 1999, after preparatory measures by the governmental committee on land tenure and management, the federal law on the state cadastre was accepted. In the following year the cadastral valuation of parcels started, based on governmental rules, and the resulting information was classified as open (with an unspecified category of limited access). The modernization of the analog database started in 1996, and an automated state land registry system, which included some 900 special offices in the country, was completed by the end of the century. The program budget exceeded 50 billion rubles, which reflected the importance of the project. The amount of collected land taxes steadily increased (18 billion rubles in 1999, 25.3 billion in 2002). In 2000 a federal law on state land cadastre was ratified and a new unified and digital land registration system began.

In 1993 the former Moskovskiy institut inzhenerov geodezii, aerofotos"yëmki i kartografii (MIIGAiK) in Moscow became an independent university, Moskovskiy gosudarstvennyy universitet geodezii i kartografii. Mapping specialists were also educated at the state university of land use planning, the Gosudarstvennyy universitet po zemleustroystvu in Moscow, and at several universities and technical schools in the country, including the former geodetic institute in Novosibirsk (NIIGAiK), which became the Siberian geodetic academy, Sibirskoy gosudarstvennoy geodezicheskoy akademii (SGGA), in 1994.

After the collapse of the Soviet Union and the declaration of the independence, the general economic crisis in the 1990s had a substantial effect on the cartographies in the new countries. Earlier, the well-established system was controlled and maintained by the central government in Moscow. Along with control the financial support disappeared and the post-Soviet states drastically reduced the budget for cartography. Under market conditions, commercial cartographic products received priority in the programs of both governmental and private enterprises. At the same time, digital cartography and geographical information systems were introduced and the new technology offered the new states the opportunity to transform their mapping systems into more independent and effective state cartography.

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SEE ALSO: Boundary Disputes; Cold War

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***Russkoye geograficheskoye obshchestvo** (Russian Geographical Society).* The Russkoye geograficheskoye obshchestvo (RGO) is a learned society founded on 6 August 1845 in St. Petersburg, Russia. Its name has changed multiple times over the course of its history (table 45). The Imperatorskoye Russkoye geograficheskoye obshchestvo (mid-nineteenth to early twentieth century) comprised four departments: physical geography, mathematical geography, ethnography, and statistics. Affiliated societies were established in the Caucasus (1850), Irkutsk (1851), Vilnius (1851), Orenburg (1868), Kiev (1873), and Omsk (1877), among others.

TABLE 45. Names of the Russian geographical society

1845–50	Russkoye geograficheskoye obshchestvo (Russian Geographical Society)
1850–1917	Imperatorskoye Russkoye geograficheskoye obshchestvo (Imperial Russian Geographical Society)
1917–26	Russkoye geograficheskoye obshchestvo (Russian Geographical Society)
1926–38	Gosudarstvennoye geograficheskoye obshchestvo (State Geographical Society)
1938–92	Geograficheskoye obshchestvo SSSR (Geographical Society of the USSR) or Vsesoyuznoye geograficheskoye obshchestvo (All-Union Geographical Society)
1992–	Russkoye geograficheskoye obshchestvo (Russian Geographical Society)

From the start the RGO's goal was to systematically expand and quantify knowledge of the vast—and still relatively unknown—Russian terrain. Geographical societies elsewhere (England, France, Prussia) were mainly concerned with general geography; homeland geography *(domashnyaya geografiya)* was of secondary concern. By contrast, the founders of the RGO were leading proponents of the nationalist reform movement that pervaded Russia in the mid-1800s. They emphasized Russia's special place in the world and its diversity of climates, languages, customs, and peoples.

The RGO carefully attended to exploration and mapping of the Russian Empire. The founders used several different methods including detailed questionnaires and circulars distributed to various government localities, methods well developed in the Russian geographical tradition of the eighteenth century. In 1847, the RGO sent out 7,000 copies of a questionnaire to collect data on ethnology; between 1848 and 1851, another 21,000 were sent to collect information on seasonal change. These questionnaires went to a wide array of offices: regional gentry, school directors, county presidents; bishops, abbots, and priests; foresters; and selected land owners. The RGO also published and distributed a variety of instructions and programs on such topics as geographical names and terminology (1848), internal trade (1849), weather (1870), lakes, sands, seacoasts (1888), earthquakes (1890), glaciers (1892), permafrost (1895), and anchor ice (1904). These reports appeared in 1905 in a reference book for travelers, which was expanded into a two-volume directory, *Spravochnik puteshestvennika i kraeveda* (1949–50), of over 1,500 pages.

One of the main tasks of the RGO was to update the general land survey of the Russian Empire, the General'noye mezhevaniye zemel', which began in 1765 and ended in the early 1800s. This update took place under the supervision of Lieutenant General Aleksandr I. Mende, who opened a special office at the Moscow land survey, Moskovskaya mezhevaya kantselyariya, to process the work of his staff. Under Mende, field surveys began in 1848 and continued until 1866, covering over 345,000 square versts, much of it interior Russian provinces never before surveyed in any detail. (One verst equals roughly 3,500 feet or 1.07 km.) Most of the survey maps were drawn at a scale of 1:84,000 (two versts to the inch), but some had scales of 1:126,000 or 1:168,000. Only atlases of Tver, Ryazan, and Tambov, and a handful of other maps were published at the time; most maps remained in manuscript. In 1926 Soviet cartographers published a landmark edition of 790 topographical map sheets on a scale of 1:100,000, based on the Mende surveys.

Mende's set of survey instructions set the standard for Russian field cartographers working in the twentieth century. Use of questionnaires continued. He also introduced exacting standards of accuracy carried forward to later times. For example, in his manual for verifying the atlas of Tver produced in 1848 (manuscript, Rossiyskiy gosudarstvennyi arkhiv drevnikh aktov [RGADA], Fond 1357, opis' 3, #10) he insisted on noting the "sources of brooks and streams and clearly and accurately marking the division and flow of waters on the map and making sure that hollows are not marked as brooks." The surveyors "should not show imaginary bends which do not exist in real life" on rivers, and were asked to clearly delineate roads, particularly those connecting one village to another. The Mende survey maps used special conventional symbols that were different from then-current symbols used in military topographic maps and land survey plans. The survey's 1853 guidebook for map symbols (RGADA, Fond 1357, opis' 3, #24) became mandatory for all maps of Russia until 1917.

In the late nineteenth and early twentieth centuries, the RGO sought to create a united topographic and geodetic service across Russia. As a first step, Aleksey A. Tillo, Konstantin N. Pos'yet, and Vladimir I. Vernadskiy suggested the creation of a coordinating and consulting geodetic council. This proposal was not implemented in prerevolutionary Russia, but it prepared the ground for the 1919 decree to organize a state geodetic service, Vyssheye geodezicheskoye upravleniye.

The RGO survived the Revolution of October 1917 and remained intact in the Soviet Union. Its role, however, changed dramatically. The Imperatorskoye Russkoye geograficheskoye obshchestvo had been the main state geographical research institution: it organized explorations; discussed, processed, and published its materials; and facilitated geographical research in different governmental bodies, especially in the military ministry. After the October Revolution, the Akademiya nauk became the main state scientific institution, encompassing research institutes in the humanities, technology, and science, some of them responsible for exploration and research in geography and ethnology. Initially the RGO played a leading role in outlining goals and formulating programs in the institutes. By the 1930s, scientific research institutes dealing with geographical topics were functioning in the Akademiya nauk, the Gidrometeorologicheskaya sluzhba, the Glavnoye upravleniye geodezii i kartografii (GUGK), and the ministries of water resources and agriculture. In addition, the geography departments of various Soviet universities carried on geographical research and exploration. In this diffuse system of institutions, the RGO become a kind of a platform for relatively free interdepartmental discussions on geographical theory and practices.

On occasion, these discussions conflicted with official Soviet policies. The RGO opposed the state's huge projects ruinous to the environment. When a pulp and paper factory was proposed at Lake Baikal, RGO officials argued it would pollute one of the purest and largest natural water resources of the world. Despite this opposition, the factory was constructed and still functions today. Another controversial project was the Northern and Siberian Rivers Water Transfer, which Soviet officials conceived to offset water drop-off in the Caspian Sea, as well as the loss of flow in the rivers across Central Asia. In this case, the RGO's opposition was heard, and the project was abandoned. In addition, the RGO has supported unorthodox and officially disdained thinkers like geographer and historian Lev N. Gumilev, who found the Moscow branch a convenient platform for his ideas on historical geography and complex relationships between different ethnic groups and landscapes across time.

The society was never formally connected with military intelligence during the twentieth century. Its traditions and rules forbid this kind of connection, and its meetings, archives, and library remained open to anyone interested in geography. Even so, many geographers participating in its activities were no doubt involved in confidential endeavors, which they were unlikely to discuss at the RGO.

Under the name Geograficheskoye obshchestvo SSSR, the society convened numerous congresses and awarded many medals for outstanding achievements. In 1949, it convened a very active scientific discussion, which resulted in publication of a special issue of proceedings, *Voprosy geografii*, devoted to the improvement of general geographical maps. By 1970, the society had published more than 2,000 monographs, paper collections, popular lectures, and other editions, including the annual *Zapiski* (from 1846) and its proceedings, *Izvestiya* (from 1865).

During the Soviet period the Geograficheskoye obshchestvo SSSR operated under the auspices of the Akademiya nauk, which provided most of its funding. Even so, the society was connected with the country's principal universities directly as well as through individual professors who actively participated in the society's activities. In addition, university geography departments often helped the society with modest contributions, mainly for publications. Officials of the society have been elected by delegates to the society's congresses, usually held once every five years, and include the members of the scientific council and an executive council called the Presidium, which includes the president and several vice presidents. These officials as well as the elected chairs of the various commissions are unpaid volunteers. Everyday activities are orchestrated by the scientific secretary, a paid employee with a PhD or Doctor of Science degree in geography. The scientific secretary supervises several other society employees, including an archives curator with one or two archivists, a library curator with several librarians, a museum curator, and various other employees responsible for the society's publications and its lecture programs for children and the general public. Additional staff are responsible for building security, cleaning, and maintenance.

The Geograficheskoye obshchestvo SSSR carried out its mission at congresses held every five years, semiannual general meetings of the scientific council, and occasional thematic and regional conferences as well as through the everyday work (meetings, expeditions, and lectures) of its departments, commissions, and seminars. The number of departments has varied, but physical geography, socioeconomic geography, history of geography and historical geography, polar geography, meteorology and climatology, and cartography and GIS have been among the most stable. By tradition, no department has paid employees, and all participants in department and commission activities meet on their own time, outside their job responsibilities as teachers, professors, or scientific research fellows at schools, universities, or scientific research institutes. RGO commissions have discussed ongoing cartographic research and publishing projects, and commission members have informed the work of practicing cartographers as well as the polices of GUGK. Meetings of the cartography and GIS commissions in Moscow and St. Petersburg have often attracted over one hundred participants.

The RGO has amassed an extensive library and archives—the only specialized geographical archives in all of Russia. Founded simultaneously with the RGO, the library includes some 400,000 books and more than 38,000 atlases and maps; the majority are manuscript originals surveyed during RGO expeditions. Besides daily records of RGO activities, the archives retain expedition diaries, albums of drawings and photos, questionnaire responses, papers presented to the RGO by various (including foreign) explorers and scientists, and a few manuscript maps and atlases. An extensive correspondence between the RGO and geographical societies and geographers all over the world offers a rich stock of geographical information.

ALEXEY V. POSTNIKOV

SEE ALSO: Societies, Geographical

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