The Historical Role of Photomechanical Techniques in Map Production

Karen Severud Cook

ABSTRACT: From the 1880s until the 1970s, photomechanical techniques played an important role in map making. Images created by and for photography were manipulated to form the printing image(s) from which the map was reproduced in multiple copies. After experiments in mapmaking in the 1860s, photomechanical techniques gained acceptance by the 1880s and, thereafter, increasingly dominated mapmaking until their rapid decline after the 1970s, as the shift to computers and electronic technology occurred. When they replaced earlier manual methods in the nineteenth century, photomechanical techniques caused the tools and materials of map production and the roles of personnel to change. Control over image production shifted from the printer to the cartographer as pen-and-ink drafting and associated collage techniques developed in the early 1900s, and even more so when scribing came into general use in the 1960s. Having thus assumed more direct responsibility for the end product (the printed map), the cartographer also adopted methods of predicting and controlling its appearance, such as standardized tools and materials, drafting specifications, flow charting, and color proofing. Through the faster and cheaper production of maps whose graphic presentation of information was enhanced by tonal effects and color printing, photomechanical production techniques also contributed to the growth of the map trade and of map use during the twentieth century.

KEYWORDS: Photomechanical map production; map design; map reproduction; production tools; production techniques; production materials; pen-and-ink drafting; photographic halftone screen; photographic tint screen; stick-up; negative scribing; technical pens; photolithography; photoengraving; collage techniques

Introduction

For about a century (from the 1880s until the 1970s), photomechanical production played a significant role in mapmaking. After several decades of initial experimental development in various branches of the graphic arts, photomechanical techniques began to find use in map production from the 1860s onward. Continuing technical innovations enhanced the graphic capabilities and cost effectiveness of photomechanical production techniques until their use in mapmaking peaked in the 1970s. By that time, advances in computer techniques for map production were offering new alternatives, and the focus of innovation shifted in that direction. By the 1990s electronic technology had almost entirely supplanted photomechanical technology in map production.

As employed in mapmaking, photomechanical production techniques involve the creation of images for and by photography that ultimately form the printing image(s) from which the map is reproduced in multiple copies. They combine the ability of photography to create images automatically (by the action of light on a light-sensitive emulsion) with the ability of relief, intaglio, or lithographic printing processes to reproduce multiple copies by repeated impressions of the inked printing image (Nadeau 1990, p. 377).

Faster, cheaper, and increasingly competitive graphically with alternative non-photographic techniques, photomechanical techniques became ever more important in map production from the 1880s until their decline after the 1970s. When they replaced earlier manual methods in the nineteenth century, photomechanical techniques caused a change in the tools and materials of map production and the roles of personnel. Through the faster and cheaper production of maps enhanced by halftone effects and color printing, they also contributed to the growth of both the map trade and map use in the twentieth century. This essay traces the historical rise and fall of photomechanical techniques in map production and explores their far-reaching impact on cartography.

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Photomechanical Production in the Cartographic Process

Map production is but one step in the complex cooperative process by which mapmakers take data about the spatial environment and turn it into published maps that inform the spatial thinking and behavior of map users. The cartographic process is often modeled as a sequence of stages. At each stage, a different combination of techniques, tools, materials, and personnel interacts to prepare the spatial information for transfer to the next stage. The sequence of stages may vary but generally progresses from initial concept through data collection, compilation, graphic design, production, printing, publication, and use. A change in one element at any stage of the cartographic process affects the other elements of that stage and, in turn, affects the other stages in varying degrees. Systematically following changes that occur in the cartographic process over time, as this essay does, is a useful approach for studying the history of cartography (Woodward 1974).

Map production, the subject of this essay, is the stage that turns the cartographer's rough compilation into a ready-to-print image. In the photomechanical era this usually meant tracing or otherwise copying a compiled worksheet to produce one or more camera-ready images, the number, form, and sequence of which varied according to the production techniques being employed. Photomechanical techniques in map production must be considered in relation to the production personnel, their tools and materials, and the nature of the camera-ready images they produce. The links between map production and the other stages of the cartographic process are also important. For example, the choices of production and reproduction techniques made at the preceding stage of map design influence the appearance and cost of the printed map product.

Rather than discuss all the stages and elements of the cartographic process, this essay will concentrate on photomechanical production techniques and their connections with other elements and stages. For example, although photographic technology has been important throughout the cartographic process, only those aspects relevant to map production are discussed in detail. This narrow focus is valid because the cartographic uses of photography have fallen into three distinct categories: data recording, photomechanical production, and map format. These three categories have developed and functioned separately in cartography, as shown by the historical summaries below.

1. *Data recording*. Photographic data recording for mapmaking usually means collecting environmental data in the form of photographs from which point locations, relief, and other map information can be compiled. Although the idea of photographic surveying had been suggested in 1839, it was not until the 1850s that topographic surveyors began to experiment with ground-level photography. The use of photography in topographic surveying, especially in difficult terrain, became accepted by the 1880s. From the 1850s onward, ideas for aerial photographic surveying (from balloons and kites) were also put forward but with limited progress until after the invention of the airplane in 1903. Its development for military purposes accelerated by World War I, aerial photographic surveying also found increasing civilian use from the 1920s onward. Aerial photographic technology and expertise developed further during World War II and replaced ground surveying for most mapping purposes by the 1950s. Since the beginnings of satellite photography in the 1960s, remote sensing has also developed, like aerial photography, into a largely separate field of activity of data collection, analysis, and interpretation. Aerial photography and remote sensing supply both raw and processed spatial data and imagery for cartography and GIS.
2. *Photomechanical production*. In map production, the role of photomechanical techniques is usually to copy an image from one surface to another and often to modify it (by scale change, reversal, halftoning, etc.). The exposure is sometimes made by contact printing, sometimes with a camera. The result may serve as a guide image, a transfer image, or an image for direct use in the next step. Isolated photomechanical experiments to produce fine arts and scientific illustrations were made in France and England during the 1820s and 1830s. A flurry of innovation from the 1850s onward, some within cartography but even more adopted from commercial art, brought photomechanical techniques into general use in map production by the 1880s. Thereafter, cartographic use increased over time as new techniques caught on, such as halftone in the 1890s, four-color process in the early 1900s, and scribing in the 1960s. When the digital shift began in the 1970s, the challenge of matching photomechanical effects and image quality with computer software and hardware caused the transition to computer production to lag behind that for data collection. Computer graphics production has succeeded in cartography, like photomechanical production before it, by adopting and adapting technology developed for the graphic arts in general.

3. *Map format*. Photographic technology also affected the format of maps and, consequently, their storage, preservation, and use. Before the introduction of wood-pulp paper in the nineteenth century, the biggest threat to the continued life of a map (printed on handmade rag paper) was the wear and tear of use. In any case, the copper plates on which most maps were engraved could be stored and reprinted for decades. Today, map overlays prepared for photomechanical production only a few decades ago have become unusable due to dimensional instability, perished adhesives, degraded colors, and brittleness. Additionally, maps printed on the machine-made wood-pulp paper have become acidic and brittle. A partial solution for this problem is that photographic negatives and positives, including microfilm and microform, offer formats for compact, relatively long-term storage of maps in archives and libraries. However, archival-grade film is more expensive than ordinary film and still does not last forever. While making it easier to copy maps and store them for later use, photography has contributed to the problem of rapid obsolescence associated with modern technology.

At the same time, photography has accustomed map users to new presentation formats. The lantern slide (and its successor, the 35mm slide), transparencies for overhead projectors, microfilm, movies, and television have introduced audiences to virtual maps, visible as light images but without substance or permanence. Although stereoscopic maps (such as anaglyphs printed in two colors for three-dimensional viewing through colored spectacles) have not been circulated widely, specialist users in the military forces, engineering, and earth sciences rely upon stereoscopic viewing of overlapping aerial photographs. From the late nineteenth century onward, this succession of photography-based techniques for producing light images prepared viewers for the transition to three-dimensional visualization and animation in late twentieth-century computer mapping. Like photographic data recording, photographic technology for different map formats developed separately and can be left out of this discussion of photomechanical map production.

History of Photomechanical Map Production

The historical starting point for this essay falls in the nineteenth century, because it is impossible to fully appreciate the role of photomechanical production in twentieth-century cartography without knowing its origins. The late nineteenth century lies beyond the living memory of today's cartographers. In addition, rapidly changing technology has diminished continuity of technological knowledge from previous generations of cartographic practitioners. Consequently, this research has relied mostly upon the techniques of documentary historical research.

A search for secondary sources about this subject soon reveals that general histories of cartography concentrate on earlier periods and barely mention twentieth-century photomechanical production techniques. Exceptions worth noting include Monmonier (1985, pp. 145-158) and Wallis and Robinson (1987, pp.306-307). In contrast, general histories of photography extend up to the present but emphasize artistic and documentary photography. The lack of coverage of sci-tech photographic applications in otherwise excellent histories of photography, such as Newhall (1969), Rosenblum (1997) and Hulick and Marshall (1998), has been pointed out by Ray (1999, p.1). Eder (1945, pp. 591-638) and Sipley (1965) say more than most about photomechanical processes but barely mention map reproduction. Even the best studies of the history of graphic production and reproduction seldom make the connection with mapmaking (Jussim 1974; Kainen 1951; Kissel and Vigneau 1999; Nadeau 1990; Newhall 1983; Twyman 1970). No comprehensive history of photography in cartography exists either. There are published biographies and corporate histories of cartographic organizations, as well as accounts of cartography in and of different countries and regions and of cartographic activities during significant time periods, but relevant information has to be extracted piecemeal from such sources. Historical research specifically about photomechanical map production techniques is limited but can offer valuable insights into the subject and its sources (Koeman 1975; Mumford 1972; Mumford 1999).

So much primary source material about photomechanical map production abounds that finding, selecting, sorting, and evaluating the huge amount of information available requires major effort. Research for this essay has selectively sampled different types of primary sources, each with its pros and cons. The sources consulted have provided general background knowledge for this research and have been cited when used as sources of specific information.

Although the physical characteristics of maps and atlases betray their manner of production, identifying the techniques employed to produce printed maps requires considerable technical knowledge and an educated eye. Map libraries are often arranged by geographical region, subject, and date, and this often throws together maps with varied production and reproduction techniques and publishers as they change over time. Collections of production material, proof copies, and record sets of printed maps created by individual cartographers or mapmaking organizations, some of which have been deposited in libraries and archives, allow technical changes to be traced in a more controlled context.

Information that complements the physical evidence provided by map products is to be found in technical literature about cartography, graphic arts, photography, and printing. These range from sources likely to be found in libraries, such as technical manuals, textbooks and articles in professional journals, conference proceedings, and patent literature, to more ephemeral information, such as sales catalogs, manufacturer's instructions, advertisements, and technical newsletters. When using any such material, it is important to consider the author and intended audience and judge the information accordingly. Ephemeral technical literature and obsolete equipment, tools, and materials may have been preserved in some historical collections but are equally likely to be found gathering dust in disused darkrooms and storage cupboards of cartographic facilities now converted to digital technology.

Firsthand accounts by practitioners of past technologies are also valuable when they can be found. These may include recorded and transcribed interviews as well as published and unpublished autobiographical and biographical accounts and obituary notices. The latter often appear in trade journals, which often report news of current activities and new technical developments. Archived personal and business papers are other sources of information about map production personnel and organizations. Writings by contemporary observers who were not practitioners can also be useful. These include encyclopedia articles about photomechanical production and reproduction techniques, accounts of visits to mapmaking organizations, and magazine or newspaper articles about mapmaking.

Data Collection and Map Compilation

From their earliest introduction, photomechanical techniques offered the possibility of bypassing professional map design and production and going direct to the stage of reproduction. Sometimes photomechanical reproduction gave the copy a new veracity not attainable by hand copying, as in the facsimile reproduction of old maps and plans

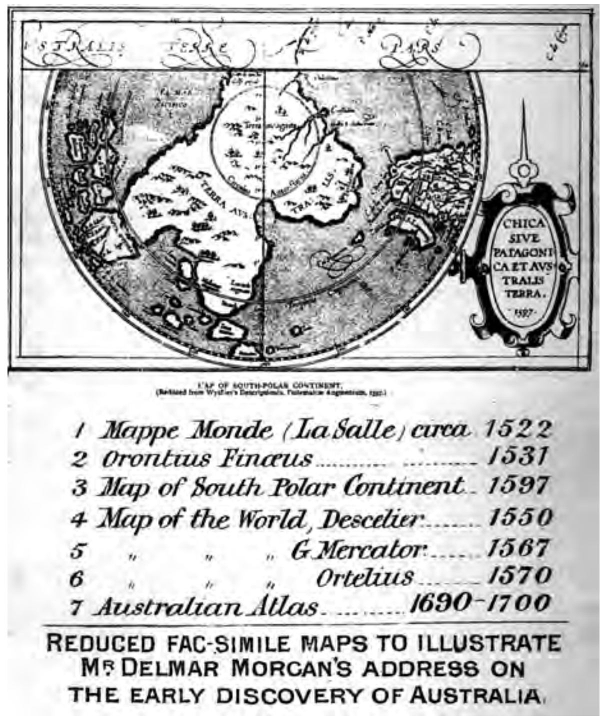


Figure 1. Much reduced photolithographic facsimile of early printed map (Morgan 1892, facing p. 238).

(Figure 1). By the late nineteenth century, contemporary maps not originally intended for reproduction, such as display maps and relief models, began to be reproduced photomechanically. An advantage of photography was that it could also reduce such maps to fit a smaller format, although excessive reduction often resulted in illegibility. As aerial photography became common after World War I, single photographs and composites were reproduced photomechanically and used directly as cartographic documents. Relief models and aerial photographs were also used as base information for maps onto which place names and symbols were compiled, but that additional step called for map design and production.

Map Design

Map design, like map production, had traditionally been based in the printshop. Before photography, it was a craftsman who translated the hand-drawn compilation into a printable image on a copper plate, wood block, or lithographic stone. An author who sketched a topographic view or a route map took it to a copper engraver or a lithographic draftsman, who copied it onto the printing surface, usually improving the consistency of its representation in the process. For example, the engraver who incised a map on a copper plate fol-

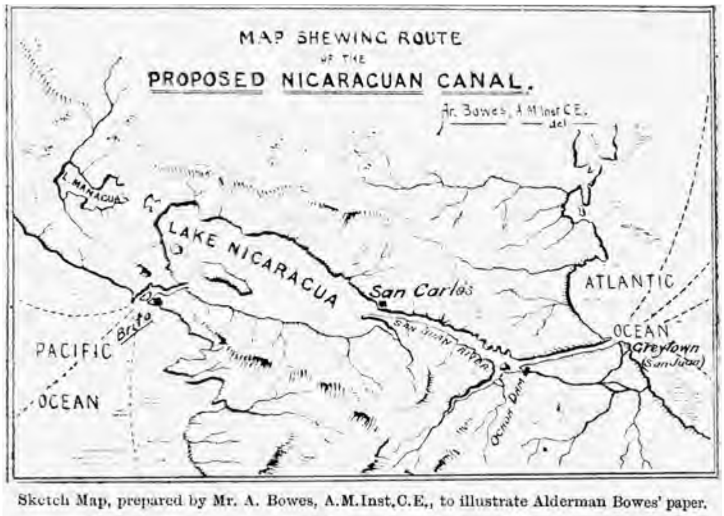


Figure 2. Sketch map drawn with pen and ink, photoengraved and relief printed (Bowes 1896, p. 150).

lowed established design conventions for symbols suitable for intaglio printing.

After 1860 photomechanical printing made it possible to reproduce pen-and-ink drawings directly, but eliminating the engraver created graphic problems. Sketch maps amateurishly drawn began to appear as illustrations (Figure 2). Another design problem that emerged was that photomechanical reduction was often excessive, resulting in illegible lettering (Mayer 1930, pp. 1664-1666). The development of map design as a separate activity preceding production was a response to these problems.

In 1874 Henry Blackburn formed a professional "Illustration Studio" in Britain to produce maps and other illustrations for photomechanical reproduction. He must have been drawing upon that experience in 1901, when he wrote in his textbook, *The Art of Illustration*, that:

> The artist who draws for reproduction by chemical and mechanical means is thrown upon his own resources. …[A]s we cannot often have good wood engraving, as it is not always cheap enough or rapid enough for our needs, we draw on paper what we want reproduced, and resort to one of the photographic processes described in this book.
>
> I do not think the modern illustrator realizes how much depends upon him in taking the place, so to speak, of the wood engraver. The interpretation of tone into line for the type press, to which the wood engraver gave a lifetime, will devolve more and more upon him (Blackburn 1901, pp.70-71).

As time went on, the illustrator's methods of designing and drafting for photography became formalized. Instruction books for professional illustrators and draftsmen, which began to appear, emphasized the need to draw well spaced solid black lines for photography (Blackburn 1901, p. 99; Cameron-Swan 1913, p.109). After the Survey of India adopted photography for map production in 1862, wash shading and colored inks that did not photograph well were replaced by pen and black ink (Waterhouse 1878, p.10). A new design strategy that soon became standard was to draft for photographic reduction. If pen drawings were reduced to 50-75 percent of original size, lines would become finer and imperfections less noticeable.

Reduction required careful planning, though, and a reducing glass was often used to visualize the final effect and check the design (Roberts 1924, p. 98). Other methods of reducing the guesswork in designing for

Figure 3. Type reduction sheet for designing U. S. Geological Survey illustrations (Ridgway 1920, facing p. 54).

reduction were developed. Specimen sheets of lettering and symbols at different sizes were introduced (Ridgway 1920, p. 55) (Figure 3). Ruling pens used for map drafting rarely had marked settings for line widths (Hambly 1988, pp. 58-63) (Figure 4). Around 1930, Graphos and other technical pens in standard widths came into use (Hambly 1988, p. 64).

The development of standard styles and sizes of templates and of preprinted lettering and symbols also occurred from the 1920s onward. Standard colors of printing inks (cyan, magenta, yellow, and black) adopted for process work helped the map designer to plan ahead, as did the development of tint screens at preset percentage increments. As the overprinting of tints to create colors became common, charts of sample colors became standard equipment for the graphic designer (Gamble, 1931a) (Figure 5). These innovations were intended for graphic illustration in general, but cartographers quickly took them up. Using such design aids, geographers compiling maps during World War II could select and specify lettering, symbols, and colors for draftsmen working in another building (Raisz 1948, p. 229). Later cartographic manuals began to include instructions for outlining and specifying the steps in the map

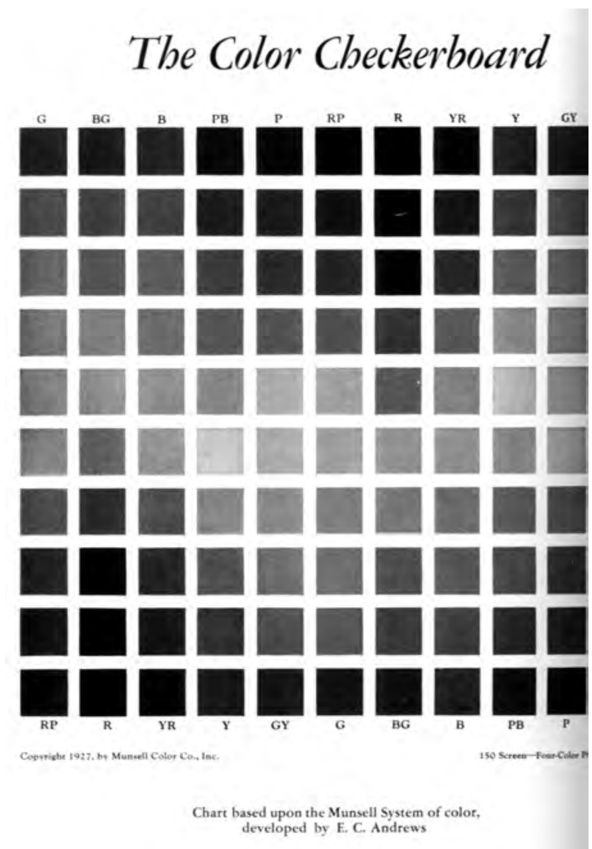


Figure 5. Color chart for graphic designers (Flader 1927).

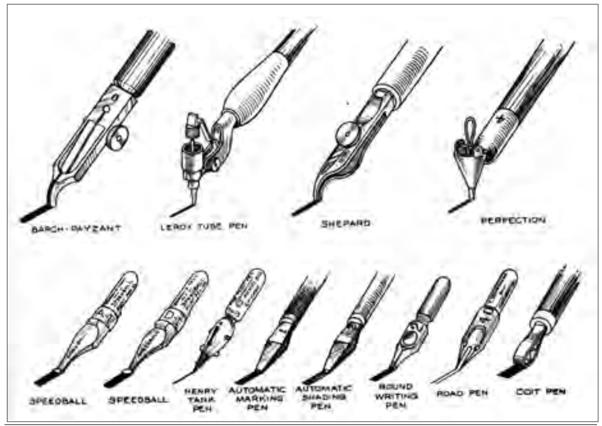


Figure 4. Lettering pens manufactured in standard sizes (Giesecke 1933, p. 57).

production and reproduction process in a systematic fashion (Keates 1973).

At first maps intended for photography were drafted entirely in ink, but a new collage approach to map production developed in the 1920s. The juxtaposition of different applied materials, shiny or matte, thick or thin, made it hard to visualize the effect of the printed map. It became even more important for the map designer to be able to preview the final product as the practice of working on registered overlays or separations developed. When the artwork for a complicated map consisted of numerous pieces, often both positive and negative, the combined effect remained guesswork until the final map was printed. Press proofing is expensive. Articles in printing journals about advances in photomechanical color separation during the 1930s complained that color proofing methods badly needed improvement (Gamble 1931d; 1932). Photographic proofing methods subsequently developed ranged from basic single-color materials used for checking content to expensive, multi-color systems that simulated the look of the final map (Gamble 1930, pp. 97-98; Nadeau 1990, pp. 75-76; Robinson and Sale 1969, pp. 327-335).

In order to make cost-effective production choices the designer had to understand the relative advantages, requirements, and costs of both production and reproduction techniques (Kranz 1962, p. 50). This design approach was followed at George Philip and Sons in England in 1924:

> Before work is commenced upon an atlas or a single map the Editorial Department exercises its selective and critical faculties, so that the best sources of information can be drawn upon, the most suitable method of production employed, the question of the colour scheme and lettering settled, etc.; work, which, like the foundations of a bridge, is never seen, but

upon which the superstructure is built (*British & Colonial Printer & Stationer* 1924, p. 37).

Since the mid-nineteenth century, general advances in reproduction technology have also greatly expanded the graphic options available to the map designer. Comments here will be brief, leaving more detailed discussion for the section on reproduction. Until about 1850 the printed map was primarily a black-line image on white paper, sometimes enhanced by hand color. However, the development of lithography, a new printing process invented just before 1800, led by the mid-century to mechanical innovations in image production and reproduction (tonal techniques, image transfer, and color printing). Cartography, along with other types of graphic illustration, was profoundly affected. As a result, flat and varying tones, area patterns, and colored symbols became increasingly common on maps after the mid-nineteenth century.

Soon photomechanical techniques began to play a part in this trend. Although they were not the only experimenters with photolithographic transfer, mapmakers in Australia and England led in making the technique successful by 1860. Photolithography could only reproduce line images satisfactorily at first. The development and use of the halftone screen in monochrome printing in the decades before 1900 first allowed photomechanical processes to join in. As with pre-photographic lithography, the halftone screen and its combination with color printing after 1900 entered mapmaking from general graphic reproduction. During the first half of the twentieth century halftones, flat tints, and color became common on both topographic and thematic maps and expanded their design possibilities.

Map Production

The Line Image: Guide Image, Ink Drafting, and Collage

Map production turns the map compilation into a print-ready image. Production by and for photography may generate one or more preprinting images leading up to the print-ready image. At first, this was more likely to be a guide image for hand copying. By 1857, photographic negatives were being printed onto sensitized woodblocks as guide images for the wood engraver (Nadeau 1990, pp. 384-385). In pictorial illustration, some wood engravers were inspired to alter their techniques to replicate the tonal effects of photographs (Jussim 1974). Although cartographers also used photographic guide images, maps remained primarily line images for the time being. Photographic guide

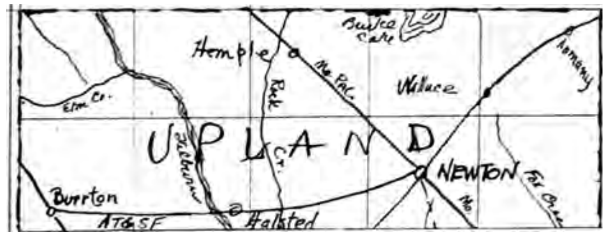


Figure 6. Rough pen drawing photographed to form guide image for wax engraving (Hackleman 1924, p. 377).

images for maps were also used in wax engraving (Figure 6), a relief printing process used mainly in the United States from the 1840s until the 1930s (Benedict 1912, p. 206; Woodward 1977).

Another early use of photography in both map and pictorial illustration was to create a guide image that a draftsman could draft over in black ink. This use continued into the twentieth century. Sometimes the guide image was a photographic print that could be bleached away after drafting, but it could also be printed in blue or other light-colored ink that would drop out when photographed (Nadeau 1990, p. 47; Waterhouse 1878, p. 8). Additional copies of the same guide image could be used to draft separations for printing in color, a practice that became common after 1900.

Mechanical transfer of images from one surface to another had been made possible by lithography in the nineteenth century and was used for text, maps, and pictorial drawings. During the 1850s, experimenters, including mapmakers, sought to make transferable photographic images. Successful photographic transfers of line images for lithographic map reproduction were achieved separately in Australia and England by 1860 (Mumford 1999, pp. 168-178; Nadeau 1990, p. 374). Thereafter, such transfers were often used to create preprinting images for relief and intaglio reproduction processes, as well as lithographic printing images.

The quality of even the best photographed line image was inferior to hand engraving, but the fact that drafting maps in pen-and-ink cost much less than copper or wood engraving was compelling (Karnahl 1935, pp. 259-260; Kranz 1962, pp. 44, 47; Twyman 1970, p. 32). Maps not originally intended for photography often ended up in front of a camera and needed to be touched up, as some early drafting instructions recognized (Waterhouse 1878, p. 12). In 1938, Erwin Raisz observed philosophically that "Maps can now be made by geographers and not necessarily by highly skilled engravers. The resulting maps may be less perfect technically, but they will more informally express geographic ideas" (p.70).

Before 1920 it was usual to draft the map as a line image in ink. Mechanical area patterns were usually added to the printing plate after photographing the line image. Ruling machines could engrave patterns directly on the plate, although transfer of patterns from master-ruled plates became more common after the mid-nineteenth century. The Ben Day tint frame, invented in the United States in 1878, held celluloid sheets with raised patterns (fine patterns were called tints) that could be inked and pressed onto printing plates (Figure 7). The graphic artist or cartographer marked in non-photo blue on the drawing to show the printer where the Ben Day tints should be added. The addition of such tints to the printing plate remained a standard printshop "make-ready" operation until the mid-twentieth century (Figure 8). Working indirectly through the printer not only made it hard for the cartographer to visualize or control the final effect but also raised production costs (*Process Engraver's Monthly* 1931, p. 221).

During the 1920s a new collage approach inspired by photography came into use in both fine and commercial art. The European Cubist and Dada schools of art adopted collage and photomontage for expressing avant-garde views about society, politics, and war (Rosenblum 1997, pp. 393-400). Even if there were no direct connection, the simultaneous adoption of similar techniques in commercial art indicates the societal pervasiveness of the new photographic technology. Map production, like commercial art, combined collage techniques with pen-and-ink drafting for photography for practical reasons and continued to use them until the 1970s. The obvious collage "look" usually did not carry over into the printed map because of the leveling and unifying effect of high-contrast photography and printing. In mapmaking circles, collage techniques are called "stick-up." The proliferation by the mid-twentieth century of techniques and materials intended for "stick-up" reflects the popularity of the collage approach.

Type printed on paper had been cut out and pasted down on maps intended for photography by J. Rodrigues of Lisbon as early as 1878, but the method did not become popular in America and Europe until around 1920 (Wallis and Robinson 1987, p. 257). The various adhesive backings included wax (burnished down), rubber cement (applied dry to a patch of dry cement), and Duco cement (brushed with acetone just before application) (Figure 9). Float lettering printed on paper and positioned before brushing it with adhesive that passed through the thin paper and could be drafted over, but patent restrictions prevented its wider use.

Area patterns and point symbols printed on adhesive-backed cellophane sheets began to be manufactured and sold commercially in the 1920s (*Process Engraver's Monthly* 1926, p. 18; Hutchinson 1926, p. 112) (Figure 10). After a time, more heat-resistant adhesives replaced wax. "Rub-down" wax

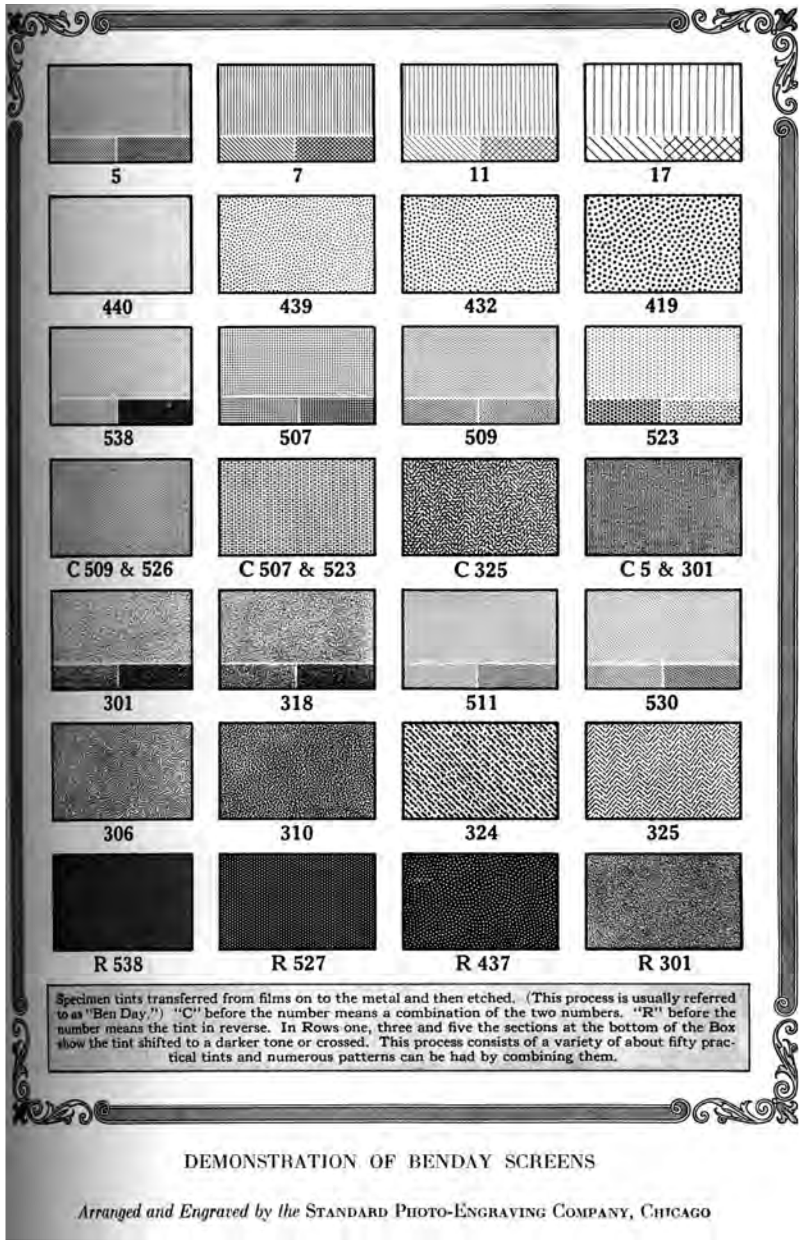


Figure 7. Sample Benday screen tints and combinations (Flader 1927, p. 129).

Figure 8. Laying Benday tints (Flader 1927, p. 126).

lettering and symbols that could be burnished off a backing sheet were also introduced in the 1920s (*Process Engraver's Monthly* 1930, pp. 164, 166; 1931, p. 68). Some drafting paper came with invisible area patterns that could be revealed after inking a drawing by brushing developer over selected areas. Adhesive line-symbol tapes also came into use. Most preprinted symbols and area patterns were intended for general use, but some were designed specifically for mapmaking. Preprinted sheets of letters in various fonts could be combined to form words, although job-specific type orders, whether produced in-house or by commercial firms, allowed faster placement of entire words and blocks of text.

The incorporation of photographic techniques into the process of typesetting reduced costs and enabled offset lithography to replace letterpress for printing newspapers, magazines, and books by the 1950s. In England, the Monotype firm had begun experiments with photocomposition in the 1930s. Subsequent experimentation and commercial production of phototypesetting equipment by firms in America and Europe occurred during the 1940s and 1950s. The technology developed from exposure of individual stationary characters on a negative to stroboscopic flash exposure through negative images on a constantly moving disk (Boag 2000, p. 58). Another approach introduced in the 1960s used electronically stored characters displayed and projected by cathode ray tube (CRT) onto light-sensitive paper or film. During the 1960s, many cartographers acquired their own phototypesetting equipment. Large cartographic organizations led the way in adopting top-quality equipment, such as the Monotype Photo-lettering machine. The introduction of cheaper models, such as the Varityper Headliner, made phototypesetting equally accessible to small cartographic operations. Even modestly priced phototypesetting equipment yielded good results and offered greater flexibility in sizing, styling, and positioning letters (Hodgkiss 1970, p. 104-106).

At the same time, pen-and-ink drafting for photography was becoming easier. Although ruling and "dip" pens, such as the crow quill, persisted in map drafting into the twentieth century, technical pens that would yield lines of standard width, both ruled and freehand, came into use. The Rapidograph, first introduced in the 1950s, and other brands of tubular reservoir pens kept improving in design and supplanted pens that had to be cleaned after each use. As well as being easier to use, they made design consistency easier to maintain.

Some pens were suited to dotting distribution maps (such as Barch-Payzant pens), while others intended for use with mechanical lettering devices also worked well for freehand and ruled lines (such as Leroy pens). Lettering templates, like stick-up lettering, decreased the use of hand lettering, although their mechanical look was often criticized (*British & Colonial Printer & Stationer* 1924, p. 37). Type lettering and symbols set in imprinters (special holders for hand stamping) were also used in map production until the mid-twentieth century. Stamped type had the advantage that it could not fall off as stick-up lettering was prone to do.

Other twentieth-century innovations include special papers, tracing cloths, celluloid, vinyl, polyester, and other supports for drafting (Raisz 1938, pp.

172-173; Raisz 1948, pp.148-149). The dual need for dimensional stability and transparency was met from the 1920s onward by new synthetic materials, for example in Germany by Zellon and Astralene. These improved upon celluloid which was highly flammable. Because traditional India ink did not adhere well to new synthetic surfaces, special inks, such as etching ink for drafting on plastic, were developed.

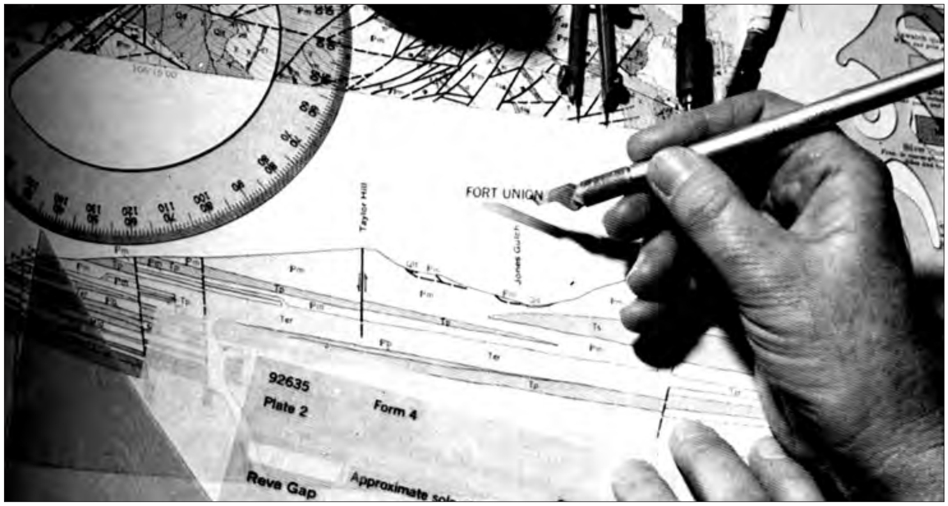


Figure 9. Applying stick-up lettering printed on adhesive-backed film (USGS 1977, p. 69).

The Tonal Image: Collotype and Halftone

So far the discussion of map production has largely concerned the creation of line images intended for high-contrast photography. There was also general interest in the graphic arts in rendering tonal images, such as photographs, printable. One tonal photographic reproduction method, collotype, was perfected in France by Alphonse Poitevin to a prize-winning state by 1867. This process produced superior tonal effects by means of a reticulated gelatine emulsion, but the fine-grained gelatine plates were too delicate to withstand reworking the image or large press runs (Nadeau 1990, pp. 73-75). It was used sometimes for reproducing relief models but was otherwise little used for maps.

Printable area images created with photographic screens proved to be more viable technically. Fox Talbot, who had sought to break up photographic images using gauze fabric, was followed by other experimenters seeking to make tonal photographs printable by a variety of methods (Gamble 1928, pp. 17-31; Kainen 1951; Nadeau 1990, pp. 121-123). One experimenter working in New York City, Frederick von Egloffstein, used wavy-line screens in 1865 to create printable intaglio images (including maps with halftone terrain shading), but his secretive methods prevented the spread of his process (Horgan 1926, pp. 48-50).

Glass halftone screens were perfected in America by Frederic Ives and by the Levy brothers and came into use in the 1890s (Kainen 1951, pp. 419-420). The Levy screen, an opaque grid with transparent openings, was formed by cementing together two sheets of glass in which black lines were set at right angles. Exposing the image through the screen broke up the tonal image into printable dots of graduated sizes, a process called halftoning (Figure 11). A disadvantage of halftoning was that it lowered contrast by reducing the entire image to shades of gray. Manually touching up the negative or the printing plate to add shadows and remove highlights was an early solution, although by the 1920s it became possible to add highlights photographically (Cameron-Swan 1913, p. 113; Durham 1927, pp. 357-360).

Cartographic application was immediate and widespread. In the late nineteenth century, halftoned photographs of relief models began appearing in atlases and on wall maps (Aitoff 1929, p. 552). Sometimes, the relief model was reproduced without additional information, but more sophisticated designs used the halftoned relief image as a gray middle ground to set off darker, lighter, or brighter lettering and symbols. Terrain relief shading executed in media such as pencil, wash, airbrush, and oil or acrylic colors was also in use by the early twentieth century. Halftoned photographs of relief models were still appearing on maps during World War II (Figure 12). In the beginning, halftoned relief maps were manually separated for color printing, but the development of photomechanical process color printing in the early 1900s made colored bird's-eye views much more common thereafter.

Other types of maps began to be halftoned, too. A 1917 graphics handbook recommends making dot distribution maps with bead-headed pins for halftone reproduction. Historic early maps and other maps not originally intended for printing could be turned into printable facsimiles by halftoning, although screening altered their graphic character by softening edges and lowering contrast. In the 1970s, the USGS began producing fully rectified

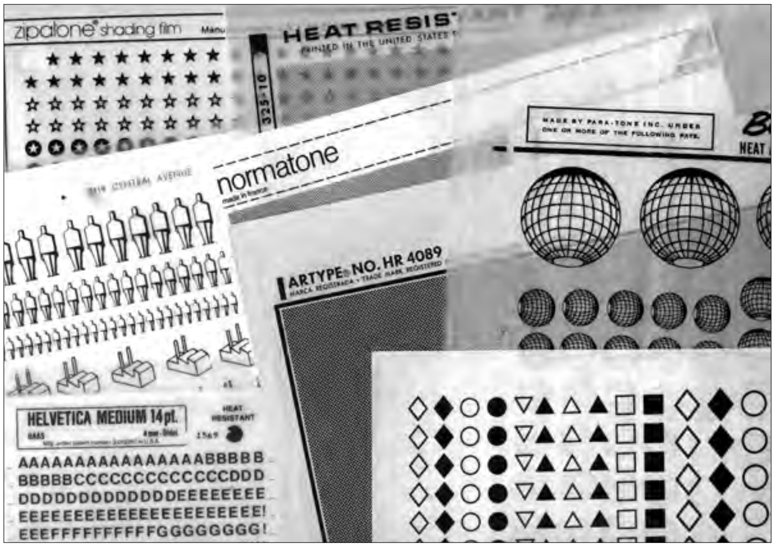


Figure 10. Different brands of rub-down (left) and stick-up (right) lettering,

aerial photomosaics, called orthophotographs, and used them as halftone backgrounds on topographic, soils, and geological maps (Thompson 1988, p. 134). Production of such maps was made even faster when movie-studio techniques for painting cartoon cels with acrylic colors were borrowed to create map overlays for photomechanical separation and printing in process colors.

Sometimes, photographic screens were used to create graded sequences of flat tints, such as layer tints. As early as 1870, a technique using masks to selectively expose areas and create a series of photographic tints was patented in England, although the patent does not mention maps (Window 1870). The idea of using halftone screens to produce layer tints may have developed out of earlier tonal processes sometimes used for map reproduction. Alternate masking and chemical etching were integral to aquatint etching, a pre-photographic process. Machine-ruled line patterns were much used on lithographic and wax-engraved maps. The Eckstein lithographic engraving process (used for map reproduction in The Netherlands from 1864-1910) started with a wet-collodion photographic guide image on three lithographic color stones, which were then machine-ruled and selectively etched to create 20 to 40 colored tints (Koeman 1975, pp. 146-149). A photographic technique for producing halftone layer tints for maps was patented in the United States by O. M. Miller in 1929 (*Process Engraver's Monthly* 1930, p. 196). The employment of photographic tint screens at preset percentages became more common as printers became more familiar with such work (Gamble, 1931b, p. 50) (Figure 13). Fine-textured screens contact-exposed directly onto the printing plate produced better quality images than photographed stick-up area patterns (Robinson and Sale 1969, p. 327). Pattern screens could also be made by photographing area patterns, and bold patterns could be tint screened to subdue them.

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

The Line Image Improved: Scribing

Scribing, a new technique for producing the line image, also grew out of photography. Originally called cliché-verre, this method of negative engraving on glass was used intermittently by artists in England and France from 1839 onward (Gamble, 1931c, pp. 177-178; Nadeau 1990, pp. 69-70, 381). In scribing pointed tools selectively remove an opaque layer

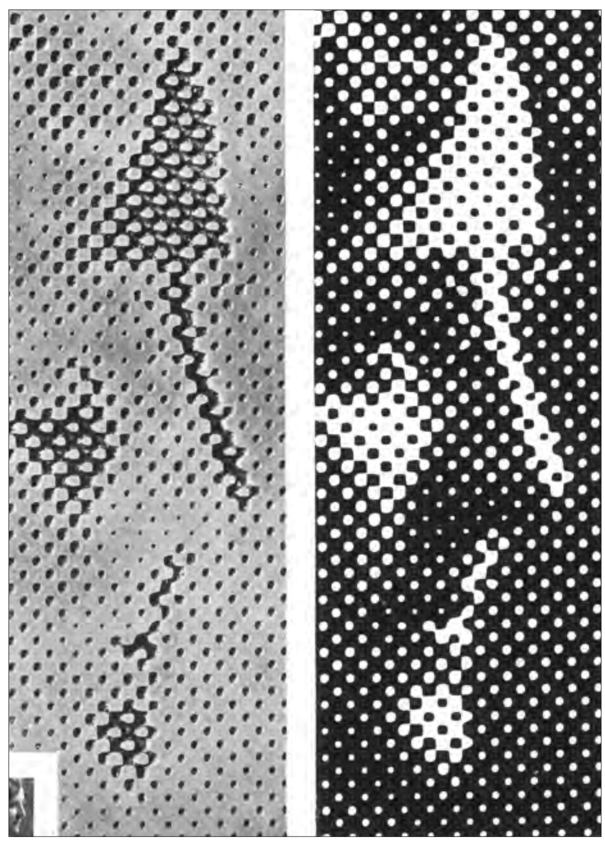
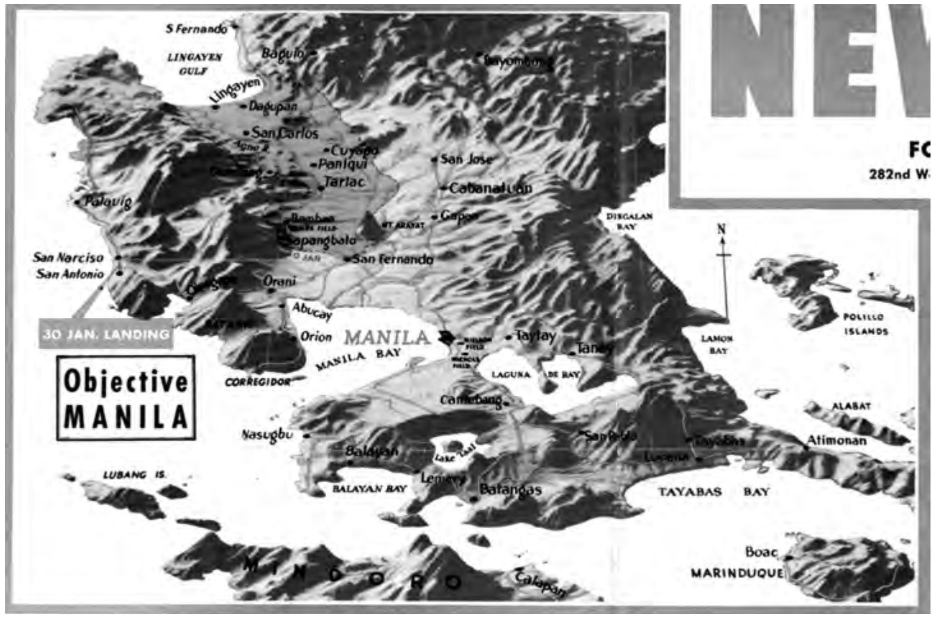


Figure 11. Enlarged negative (left) and positive (right) of photograph halftoned for relief printing (Hackleman 1924, p. 245).

from a transparent support material to create photographic negatives directly. Scribing may have been discovered accidentally by scratching a glass negative, but it also resembles pre-photographic intaglio etching and lithographic engraving in the removal of a superficial ground to expose an underlying surface.

Scribing on glass was used in map reproduction during the second half of nineteenth century, but the fragility of the glass support was a drawback. In 1913, C. H. Little suggested scribing on a flexible supporting material, but suitable transparent materials were not yet available (Little 1913). The introduction of synthetic base materials and concerted efforts by cartographers to develop scribing techniques led to the rise of scribing after 1940 (Figure 14). Improved tools and materials, such as strippable film for making open-window negatives, became available commercially. Punch register equipment facilitated registration of overlays. Point symbols and lettering could be scribed but were often added on separate positive overlays as stick-up. Because the map was created as multiple overlays, proofing both content and final appearance was of critical importance. Color proofing with the requisitioned German Ansco Printon process was introduced at the Army Map Service during World War II, and other color proofing systems were developed subsequently (Nadeau 1990, pp. 75-76). Scribing could produce lines more comparable in quality to copper engraving than any pen-drawn image, and more cheaply, because it eliminated some photographic steps. When the computer began to invade the field of map production in the 1960s, scribing was considered by many as the highest state of the art in map production (Kranz 1962, 44).



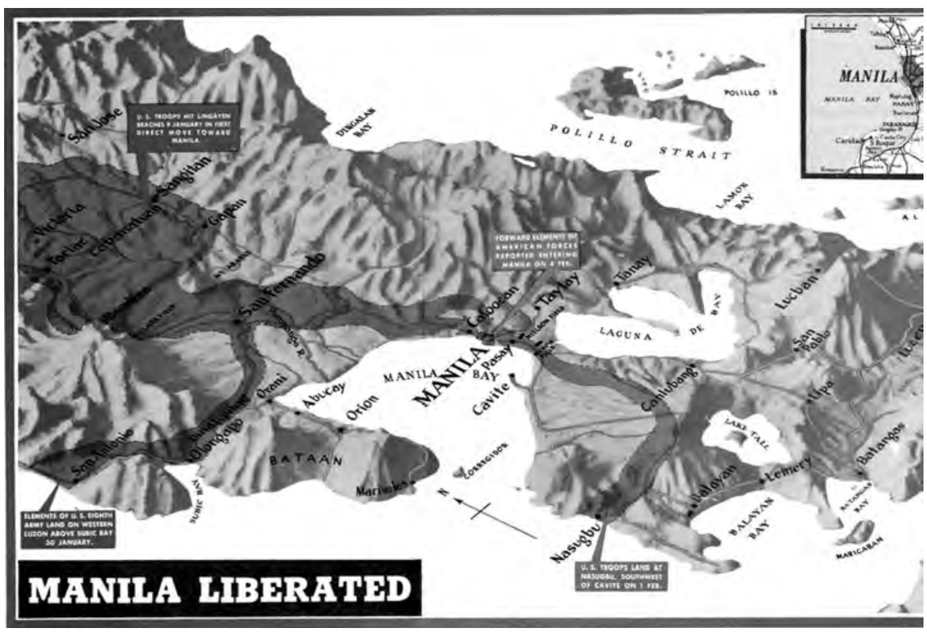


Figure 12. World War II Newsmaps "Objective Manila" and "Manila Liberated" show same relief model photographed from different points of view (*Newsmap* February 5 and February 12, 1945).

Map Reproduction

During the second half of the nineteenth century, while photomechanical printing processes were still emerging, direct photographic printing was used to reproduce small numbers of maps when

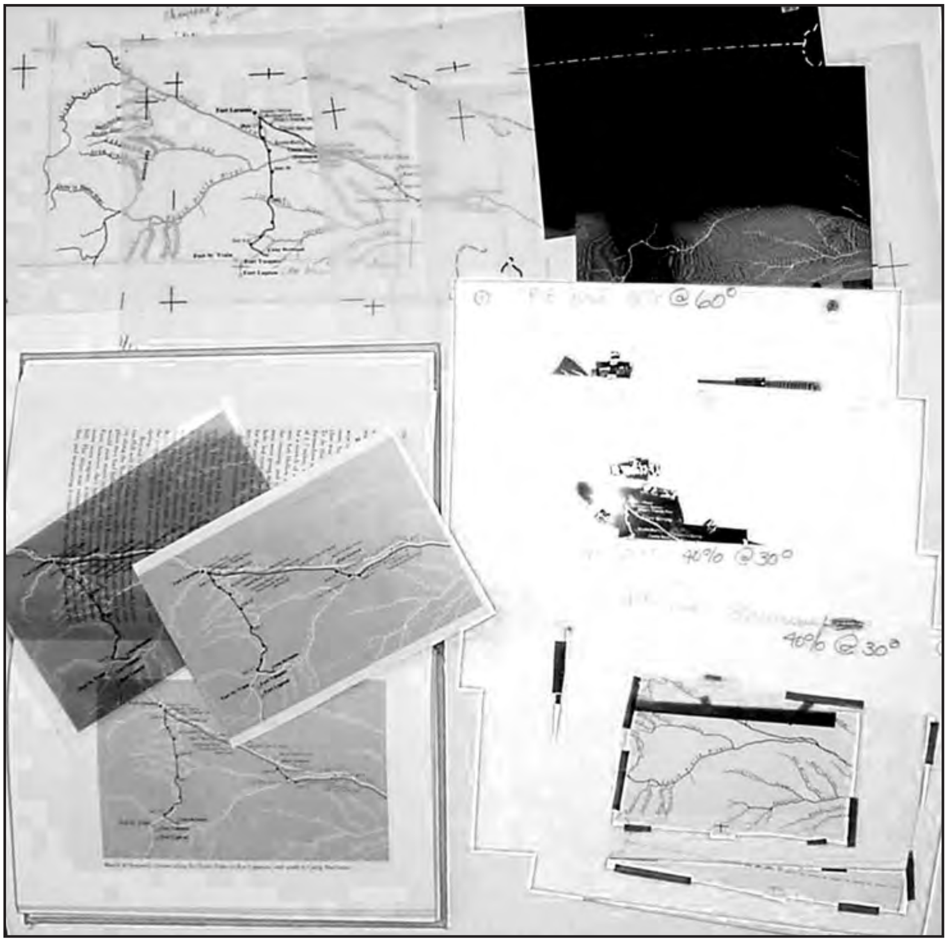


Figure 13. Artwork for a map (clockwise from upper left): Pen-and-ink drafting with stick-up lettering on Mylar film; film negatives for block out-positives; punch-registered film negatives and positives with tint screen percentages and angles marked on orange masking paper; photographic composites on paper and film; illustration in book (Chalfant 1989, p. 108, by courtesy of the KU Map Associates).

time or exact duplication was critical (Koeman 1975, pp. 140, 145). In 1859, for example, photographic reductions of Lieutenant Palmer's map of British Columbia were sent back to the Colonial Office for reproduction (Mumford personal communication, 2002). In 1866, Grenville Dodge's military map of Kansas was copied photographically for rapid issue to western officers (Akerman and Karrow 2001, pp. 62, 93). In 1869, photography was used in Russia to supply "identic" copies of a map of the Turco-Persian border to the countries involved in its survey (Chirikow and Williams 1869; Wilson 1914, p. 17).

Transparent supporting materials allowed drawings to be reproduced directly as negative or positive images. During the American Civil War (1861-1865), both sides in the conflict made quick photographic copies of maps by contact printing. Since then a variety of sensitized materials have been used to make one-to-one contact copies. They include the Vandyke, blue line, blueprint, and diazo processes, which were much used to copy architectural plans, reproduce low-demand map publications cheaply, and supply on-demand copies of utility plans from continually updated master plans. Cyanotype, described in 1842 by Sir John Herschel, came into general use as the blueprint process in the 1870s, following the development of "dry" ammonia vapor developing. Blueprint gave way to the black line and Vandyke processes around 1900, and they, in turn, were largely replaced by the diazo process in the 1920s and 1930s (Fishenden 1906-1907, p. 124; Kissel and Vigneau 1999, pp. 31, 38; Raisz 1948, pp. 162-163). Other uses of duplicating processes have included proofing map artwork and making overhead transparencies (Kissel and Vigneau 1999; Raisz 1962, pp. 142-144; Robinson and Sale 1969, pp. 298-303).

The albumen process, invented in 1847, was used to make glass lantern slides long after the process fell out of use for glass negatives (Nadeau 1990, pp. 26-27). Lantern slides of maps illustrated lectures and were also recommended as cheap alternatives to wall maps for classroom use (Raisz 1938, p. 222). They were succeeded by 35mm slides in the twentieth century, when microfilm and microforms also became map end products (Nadeau 1990, p. 416; Raisz 1962, p. 110).

Another early use of photography in map reproduction was to produce the image on the printing plate. The versatile photographic image could be produced on or transferred between different surfaces for reproduction by different printing processes. The choice of process depended upon image quality, cost, size of print run, and compatibility with other types of image, as well as available equipment and regional preferences. For example, the quality of the paper affected image quality, and cheap rough newsprint required coarser-textured lines and patterns than smooth coated paper for book illustrations.

Photolithographic transfer, developed by 1860, was still being used for map reproduction in the late 1870s, but flat-surfaced lithographic stones or metal plates could not be printed simultaneously with text set in metal type. After 1900, direct exposure of a light-sensitive emulsion on the printing plate became more common, but lithography was still limited to printing sheet maps or separate map plates for insertion in text volumes. (Fishenden 1906-1907, pp. 124-26). Heliogravure produced a higher-quality line image, but its use was even more limited because intaglio printing was relatively expensive (The Inland Printer 1902-1903, p. 201).

In the late nineteenth century, wood engraving had given way to photomechanical relief processes originally developed for general graphic reproduction which were also much used for maps in books and atlases (Benedict 1912, p. 208). These processes were used for newspaper, book, and magazine illustration well into the twentieth century, as long as metal type remained the chief method for printing text. The "make ready" operation of transforming the photographic image on the plate into a relief printing image involved a complicated sequence of chemical and mechanical steps. For example, photoengraving a pen drawing at the U. S. Geological Survey in 1920 involved camera reduction, negative stripping, contact printing, etching, routing, and proofing before the zinc plate could be mounted ready for relief printing with text (Ridgway 1920, pp. 73-74). Ben Day tints, added manually before etching the block, also raised costs.

As newspaper, book, and magazine printing shifted from relief printing to lithography by the mid-twentieth century, lithographic reproduction of maps for such publications increased, too. The development of power-driven, rotary offset multicolor presses, in combination with phototypesetting, tipped the balance in favor of lithography. Printshop "make-ready" for photolithography was also simpler than for photoengraving, especially after photographic transfer was replaced by direct exposure of sensitized printing plates in the early twentieth century (Ridgway 1920, p. 87). Photolithography also retained its superiority for printing large sheet maps in color (Ridgway 1920, p. 87).

Without the engraver who formerly served as an intermediary, the cartographer designing and drafting for photomechanical transformation into the printing image had to have some technical understanding of the printing process. The need for communication between cartographer and printer through the bidding process, instructions, and exchanges of proofs and corrections has increased rather than lessened as printing has become more automated (Kranz 1962, p. 51).

Figure 14. Scribing contour lines for topographic map by following photomechanical guide image on scribecoat with pen tool; rigid graver rests nearby on its side (USGS 1978, p. 67).

Map Publication and Use

The final stages in the cartographic process are map publication and use. Here photography, along with automation and other technical advances, has helped to make a wider range of maps available in greater numbers for different markets and types of use. Map production increased greatly from the mid-nineteenth century onward, partly as a result of photographic technology. Maps reached the general public, as well as specialist users, in the form of school atlases, road maps, magazine illustrations, topographic maps, or statistical maps. Military and other urgent needs could increasingly be met virtually overnight by using aerial photography or photographic copies of existing maps. Orthophotographs with topographic information added by contour lines or terrain shading combined the realistic pictorial detail of photographs with the positional accuracy of topographic maps. With increasing flexibility, the same map image could be photographed for reproduction at different scales or updated photographically for publication in new editions. Feature separations created for U.S. government maps and atlases and stored on photographic film could be purchased cheaply and used as base maps for thematic maps.

At the same time, photography made it easy to violate copyright regulations and duplicate someone else's map without permission. The variety of photography-based techniques and materials for printing both one-to-one and multiple copies (processes ranging in quality and cost from low to high) have made maps almost too accessible. Cheap maps and free maps whose publication has been subsidized by government agencies or commercial sponsors have encouraged popular disrespect of maps—a throw-away attitude reflecting ignorance of the enormous cumulative effort that has gone into creating them.

Conclusions

Photomechanical techniques made it possible for those who make maps to move the map image at will from one surface, printing process, or format to another. One important consequence was the shift of control over image design and production from the engraver and the printshop "make-ready" operation to the cartographer. Although the adoption of pen-and-ink drafting for photography resulted in a general drop in image quality, even after an array of standardized mechanical aids was developed in the early twentieth century to facilitate drafting, this could be justified on the grounds of economy. The rise of scribing in the 1940s was made possible by the development of transparent, flexible, and dimensionally stable plastic materials coated with easily incised emulsions. The direct production of photographic negatives by scribing made image quality once more comparable to copper engraving but accomplished it with greater ease. Cartographers took up scribing, producing artwork that could go to the printer and directly, photomechanically, onto the printing plate. Having done away with the middleman engraver, who formerly translated the compiled map into a printable image, the cartographer had also become responsible for ensuring the map's printability.

Collage-style drafting at larger-than-final size on separate registered overlays for halftone, tint, and pattern screening had made it harder, rather than easier to predict the appearance of the final product. This was equally true of scribing, with its mix of negative and positive overlays. Cartographers began to rely on charts of standardized lettering, symbols, patterns, and colors when designing maps. Systems of flow charting and specifying the steps in map production and reproduction were developed. The development of photographic proofing materials, including more expensive ones that closely simulated the look of the final map, assisted the cartographer to visualize the map product and offered the opportunity to make design changes and remedy errors before the map reached the printing press. These means for communication between the cartographer and the printer have helped to make the cartographic process more predictable, controllable, and successful.

As for map users, photomechanical production techniques changed the appearance of the maps they bought and used. Photographic halftone and tint screens made it easy to produce tonal images. The transition from hand to printed color had taken place earlier, in the mid-nineteenth century, when photomechanical techniques were still being used experimentally and only for black-and-white line images. By the early 1900s, though, photomechanical techniques were being used to prepare images for halftone and color printing. Photomechanical color separation and process color printing became routine. For the first time, the map designer could combine lines, tones, and colors at will. The maps that we see today have an enriched graphic vocabulary inherited from the era of photomechanical production techniques.

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