Third Edition

Interpretation of Aerial Photographs

Thomas Eugene Avery

Third Edition

Interpretation of Aerial Photographs

Thomas Eugene Avery

Burgess Publishing Company
Minneapolis, Minnesota

Cover photo: Low oblique view of Rothenburg, a medieval walled city in West Germany. This type of photographic documentation can be extremely valuable in the preservation and restoration of historic buildings and related landmarks. Courtesy Carl Zeiss, Oberkochen.

Frontispiece: Mount Egmont, New Zealand, a snow-capped cone rising 2,520 m above sea level. The boundaries of Egmont National Park are defined as a 9.65-km radius from the central cone; the circular pattern thus results from the contrast between native vegetation and cultivated farmland. Photographed from an altitude of approximately 9,100 m by New Zealand Aerial Mapping, Ltd.

Printed in the United States of America
Library of Congress Catalog Card Number 76-9253
ISBN 0-8087-0130-4

0 9 8 7 6 5 4 3

This book was set in Melior by Typographic Arts. The editors were Robert E. Lakemacher and Ann Seivert. The cover was designed by Joan Gordon; the layout was done by Cindy Anderson; new drawings were done by Mari Ansari. The book was printed by the Colwell Press and bound by Midwest Editions, Inc.

To
Philip R. Wheeler

Preface

In recent years, notable advancements have been made in the development of thermal and microwave sensors, earth-orbiting reconnaissance satellites, and automated image-scanning devices. Nevertheless, conventional optical imagery in the hands of human interpreters remains the working standard against which other systems tend to be evaluated. Therefore, as with the two earlier editions, this volume is devoted mainly to the "nuts and bolts" of human photographic interpretation.

This third edition includes new sections on flight planning, land-cover mapping, archeology, and nonphotographic sensors. All chapters have been revised or updated, and suggested problems are now provided at the end of every chapter. The appendix has been expanded to include metric conversion tables and a model outline for a short course in photo interpretation and remote sensing.

The International System of Units (metric system) has been emphasized throughout the text. English units of measure are used only when logical metric units and illustrative examples were unavailable. This should cause a minimum of difficulty, because cameras, films, and photogrammetric equipment have been calibrated in metric units for decades. As in the previous editions, many stereopairs have been purposely reoriented (e.g., with south at the top of the page) to make shadows fall toward the observer and thereby facilitate stereovision.

My primary objective has been to provide an interesting and readable introduction to photographic interpretation that will also serve as a useful reference handbook. Suggestions for future editions, including diagrams, illustrations, and problems, would be welcomed at any time.

Thomas Eugene Avery

Acknowledgments

I want to thank Robert G. Merrifield of Texas A & M University and Charles O. Minor of Northern Arizona University for their support during the preparation of this third edition. For contributions relating to technical matters, the following persons were particularly helpful:

James R. Anderson and Richard E. Witmer, U.S. Geological Survey
Piet van Asch and Don Trask, New Zealand Aerial Mapping, Ltd.
R. D. Bratton, National Aeronautics and Space Administration
Kenneth M. Campbell, Alberta Remote Sensing Center
Douglas E. Grant, Texas A & M University
Laurens C. Hammack, Arizona State Museum
Thomas R. Lyons, National Park Service
Robert D. Miles, Purdue University
Thomas Schafer and R. E. Kauffman, Abrams Aerial Survey Corporation
John J. Welsh, Eastman Kodak Company

Contents

Chapter 1

Photography, Films, and Filters

Remote sensing and interpretation

This book is concerned with remote sensing, i.e., with the detection, identification, and analysis of objects or features through the use of imaging devices (sensors) located at positions remote from the subjects of investigation. In other words, remote sensing may be regarded as reconnaissance from a distance—and that distance may range from a few metres to thousands of kilometres. More specifically, this volume centers on the branch of remote sensing that is concerned with the acquisition and interpretation of aerial photographs.

The process of image interpretation is highly dependent on the capacity of the mind to generalize. To learn to identify objects on aerial imagery, one needs to study known features on many photographs so that the characteristic clues of shape, size, tone, pattern, shadow, and texture become automatically associated with particular subjects. Eventually, mental processes permit the conscious abstraction of key features from known objects so that such information may be applied to the recognition of unknown objects.

The International System of Units

For many years, cameras, films, and photogrammetric equipment have been calibrated in metric units. Therefore, wherever feasible, the International System of Units (SI) has been used for numerical examples in this book. (In accordance with SI practice, the American word *meter* will be spelled *metre*.) In some instances, tabular material has been presented in both metric and English units; conversion tables are included in the appendix.

With the International System of Units, there are seven base units and two supplementary units that encompass all measurement problems; all other SI units are *derived* from these fundamental units. For example, area is measured in square metres (or square kilometres), vehicle speeds in kilometres per hour, and density in kilograms per cubic metre.

Each metric unit is related to another by multiples or submultiples of 10. For instance, there are 10 millimetres (mm) in 1 centimetre (cm), 100 centimetres in 1 metre (m), and 1,000 metres in 1 kilometre (km). Another advantage of SI units is that multiples and submultiples of various quantities are *named* according to a system of numerical prefixes. Thus a *milli*metre is 1/1,000 of a metre, while a *kilo*metre is equal to 1,000 metres. The more common prefixes are listed here.

Prefix	Symbol	Meaning
Tera-	T	One trillion times
Giga-	G	One billion times
Mega-	M	One million times
Kilo-	k	One thousand times
Hecto-	h	One hundred times
Deka-	da	Ten times
Deci-	d	One tenth of
Centi-	c	One hundredth of
Milli-	m	One thousandth of
Micro-	μ	One millionth of
Nano-	n	One billionth of
Pico-	p	One trillionth of

History of photography

An understanding of the photographic process is essential for full comprehension of photogrammetry and aerial photo interpretation. The origin of photography has been traced back to 1839, when Louis J. M. Daguerre, of Paris, invented a positive-image process for making portraits. The daguerreotype method utilized metal film plates that had been light sensitized with a layer of silver iodide. The early-day camera was often no more than a light-tight box with a pinhole or a simple glass plate comprising the lens. After a picture was taken, the photographic plate was removed from the camera, exposed to fumes of mercury, and then heated to produce a direct-positive image. These positive images, of course, could not be duplicated.

A few years after Daguerre's technique had been developed, an Englishman, William H. Fox-Talbot, introduced the negative-positive process that continues in use today. The early 1840's also witnessed a reduction in camera exposure time from several minutes to a few seconds. This was made possible by the development of new lenses and the discovery of the superior light sensitivity of photographic plates coated with silver chloride and, later, silver bromide. For all practical purposes, the photographic techniques devised by Fox-Talbot remained basically unchanged for more than a hundred years.

The simple camera

In design and function, a camera is not unlike the human eye. Each consists of an enclosed chamber with a lens at one end and a light-sensitive film (retina) at the other. The lens gathers light rays reflected from given objects and transmits them in an orderly fashion back to the light-sensitive area. A shutter assembly serves to regulate the amount and duration of light reaching the film when an exposure is made (*Figure 1-1*).

When a camera is focused at infinity, the distance from lens to film is known as the focal length, and the area in which the film is held flat during an exposure is referred to as the focal plane. Shutters may be positioned behind the lens, between elements of the lens, or in the focal plane immediately in front of the film. The focal plane shutter is analogous to a slitted curtain drawn across the area where the film is positioned. Intensity and length of exposure can be changed by variation of the width of the curtain slit and the tension of a spring-driven roller. Between-the-lens shutters are commonly characterized by a series of overlapping metal "leaves" that are rapidly opened and closed by an intricate gear chain (*Figure 1-2*). The diameter of the lens opening (effective aperture) can be varied by adjustment of a second set of thin, metal blades which comprise the iris diaphragm.

$$f/\text{STOP} = \frac{\text{FOCAL LENGTH}}{\text{LENS DIAMETER}}$$

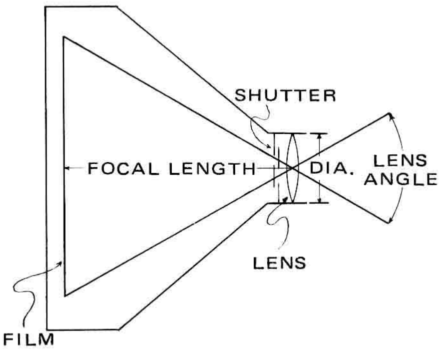


Figure 1-1. Nomenclature of a simple camera.

Figure 1-2. Camera lens with between-the-lens shutter. Note shutter-speed and f/stop settings. Courtesy Calumet Manufacturing Co.

Relative apertures

The ratio of the camera focal length to the diameter of the lens opening is known as the *f/stop*, an expression used to designate the relative aperture setting or "speed" of a lens system. For example, a camera with a focal length of 40 mm and a lens diameter of 10 mm at full aperture would have an f/4 lens. If the aperture were 20 mm instead of 10 mm, the lens rating would be f/2; conversely, a 5-mm aperture with a 40-mm focal length would result in a lens rating of f/8. Thus the smaller the f/rating, the "faster" the lens, i.e., the more light admitted through the lens opening.

While the focal length of a camera is normally fixed, the iris diaphragm can be used to regulate the effective aperture, with accompanying changes in f/stop values. When an f/4 lens is "stopped down" to f/8, it simply indicates that the effective *diameter* of the lens opening has been cut in half. More explicitly, the *area* of the lens opening is only one-fourth as large. Similarly, a lens setting of f/16 admits only one-fourth as much light as a setting of f/8 and only one-sixteenth as much as a setting of f/4.

A complete system of relative apertures begins at f/1, and multiplication of any aperture by 1.4 (i.e., the square root of 2) yields the succeeding smaller aperture. Thus, the sequence of full-stop increments would be f/1, f/1.4, f/2, f/2.8, f/4, f/5.6, f/8, f/11, f/16, f/22, f/32, f/45, f/64, f/90, f/128, f/180, f/256. Each lens opening in the series transmits one-half as much light as the preceding lens opening (for example, f/5.6 transmits half as much light as f/4). Most lenses do not have a range of openings this great. Sometimes the largest opening for a lens is less than one full f/stop from the next marked lens opening. Examples are f/3.5, f/4.5, and f/6.3.

The more commonly used aperture settings and corresponding shutter-speed ratios are as follows:

Relative aperture or f/stop	Larger lens openings — — — — — Smaller lens openings										
	f/2	2.8	4	5.6	8	11	16	22	32	45	64
Index number for shutter speed	Faster speeds — — — — — — — — — — — — Slower speeds										
	1	2	4	8	16	32	64	128	256	512	1,024

These relationships are well known to most camera enthusiasts. Simply stated, changes in aperture settings must be accompanied by adjustments of shutter speeds if a constant exposure is desired. For instance, a lens setting of 1/100 second at f/4 admits the same amount of light as a setting of 1/25 at f/8 or 1/400 at f/2. These paired relationships are the basis for light value systems featured on many cameras; when the iris diaphragm is coupled with the shutter-speed selector, a change in either value results in an automatic adjustment of the other.

Camera viewing angles

The angle of view encompassed by a camera lens is a function of the focal length and the diagonal measure of the film negative. When these two distances are approximately equal, the angle is roughly 45° to 50°, and the lens is referred to as *normal angle*. The distinction between normal and wide lens angles is somewhat arbitrary. For aerial cameras, lens angles of up to 75° are considered normal, those with angles of 75° to 100° are termed *wide angle*, and those that exceed 100° are designated *ultrawide*. As will be seen later, the choice of a proper camera focal length and lens angle is of prime importance in planning photographic surveys.

Lenses may vary from a single curved piece of glass to multielement, distortion-free designs that are little short of optical perfection. A thorough evaluation of camera lenses is beyond the scope of this volume, but it should be noted that lens quality is the major factor to be considered in the purchase or use of any camera.

Photographic film

Photographic film is ordinarily composed of a cellulose acetate or polyester base that has been coated on one side with a light-sensitive layer known as the *emulsion*. On the other side of the film base is the anti-halation backing, a light-absorbing dye that prevents the formation of halos around bright images. A simplified film cross section is illustrated in *Figure 1-3*. The prime ingredient in the film emulsion is metallic silver, generally in the form of silver halide crystals suspended in a gelatin vehicle. During the split second when the camera shutter is open, light reaches the emulsion and a latent image of the scene viewed is recorded on the film. The image is made visible to the human eye by subsequent processes of film development and printing.

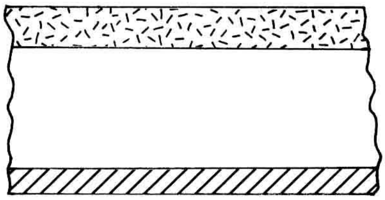


Figure 1-3. Simplified cross section of photographic film, greatly enlarged.

Emulsions for photographic films possess varying degrees of sensitivity to light waves, and knowledge of a particular film's "speed" is essential to obtaining a correct exposure. "Slow" films may require bright sunshine or artificial light for proper exposure, while "faster" films permit good pictures under minimal light conditions. A disadvantage of high-speed film, however, is that resultant negatives and prints are apt to be excessively grainy, i.e., coarsely textured.

In the United States, the American Standards Association rates each film emulsion on a relative scale of light sensitivity. The A.S.A. exposure index, as it is called, provides a uniform classification system that can be applied easily under changing light intensities. Black-and-white films most commonly used have exposure ratings of 50 to 300, although extremes may range from around 8 to 1,000. The larger the A.S.A. rating, the greater the sensitivity of the emulsion. Many black-and-white aerial films are rated at 80 to 200, and such speeds provide a reasonable latitude of exposure with a minimum of graininess. In West Germany and other European countries, film speeds are rated on a D.I.N. (Deutsche Industry Norm) scale of sensitivity. Most camera exposure meters provide settings for either A.S.A. or D.I.N. film ratings. As noted in later sections, however, *aerial films* are not usually rated according to these sensitivity scales.

Developing and printing

When a roll of exposed film is removed from a camera, it must be protected from light, extremes of temperature, and humidity until it is processed. Briefly, the step-by-step darkroom procedure in the production of a film negative is as follows:

1. **Developing:** Immersion of film in a chemical solution to produce the photographic image recorded during exposure. Image highlights take the form of heavy metallic silver deposits; medium tones are characterized by lighter silver deposits. Negative tones are the reverse of those on a positive print.
2. **Short-stop:** Immersion of film in dilute acetic acid to stop the developing reaction.
3. **Fixing:** Removal of unaffected silver salts from the emulsion.
4. **Washing:** Agitation in running water to remove all processing chemicals.
5. **Drying:** Hanging of film on clips and drying by natural air circulation or in special film-drying ovens.

Positive prints are produced by a series of steps similar to those followed in film development. A sheet of sensitized photographic paper is placed over the negative and "exposed" by light from underneath. The exposed paper is then subjected to a developing solution, followed by a short-stop bath, fixing, washing, and drying. If a hard, high-gloss photographic surface is desired, the print is dried on heated stainless steel rollers or platens, a process known as *ferrotyping*.

Resolution and spectral sensitivity

Among the image characteristics contributing to the recognition of features on aerial photographs are qualities that are dependent on the type of photographic film selected, the type of filter used, and the season of exposure. Of special interest here are the factors of resolution and light sensitivity of the film.

Resolution, or *resolving power*, refers to the sharpness of detail afforded by the combination of film qualities and the camera lens system. In photographic terms, it is commonly expressed as the maximum number of lines per millimetre that can be resolved or seen as individual lines. Any magnification beyond that required to make the line-count for the resolution of the final print will only decrease the image quality and interpretation possibilities of the photographs.

The light sensitivity of a film implies more than an indication of its "speed," or exposure index. Of additional importance is the range of light wavelengths to which the film responds. Light wavelengths are measured in micrometres, and the portion of the spectrum visible to the human eye includes wavelengths of about 0.4 to 0.7 μm *(Figure 1-4)*. However, film emulsions may be sensitized to a wider or narrower span of wavelengths to produce varying tonal contrasts on the finished print.

It is apparent that the image quality or photographic tone is dependent on both the spectral reflectance of an object and the degree of film sensitivity to different wavelengths of reflected light. Thus, if it is desired to differentiate between various types of healthy vegetation, a knowledge of foliage reflec-

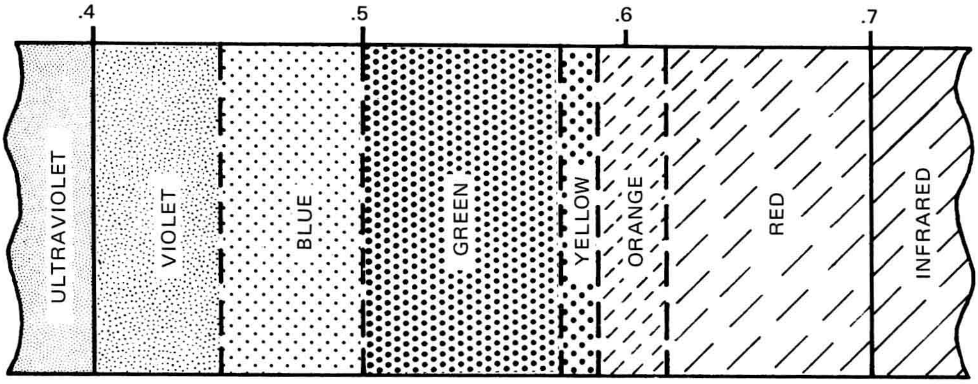


Figure 1-4. Schematic diagram of the visible spectrum. Color divisions are for illustrative purposes only; hues actually blend continuously from one wavelength to another.

tance characteristics under varying light conditions is essential (*Figure 1-5*). Photo interpreters are ordinarily limited to two basic types of black-and-white film (panchromatic and infrared) and two variants of color emulsions (conventional color and infrared color). Nevertheless, when these films are correctly exposed through proper filters, a wide range of light sensitivity can be made available for producing desired tonal contrasts.

Haze filters for black-and-white films

Aerial films are usually exposed through haze-cutting filters placed in front of the camera lens. Such filters are essential, because small dust and moisture particles in the air scatter light rays, preventing distant images from registering on the film. Scattering of light rays also destroys fine detail on the photographs. The effect of haze increases with the height of the air column that must be penetrated; therefore, the effect of haze is significantly greater in high-altitude photography. Due to their short wavelengths, blue light rays are scattered to a much greater extent than green and red rays. A yellow or "minus-blue" filter reduces the effect of haze by absorbing the short rays and transmitting only the longer wavelengths to the film. Because haze-cutting filters remove part of the available light, longer film exposures are required. The ratio of the increased exposure to the normal exposure is known as the *filter factor.*

The following tabulation includes several colors of filters that might be used for black-and-white photography. Filter factors will range from 1.5 to 4, depending on prevailing light and atmospheric conditions.

Filter color	Colors of light absorbed
Medium yellow	Violet, most blue
Deep yellow	Violet, all blue
Blue	Red, some yellow, some green
Green	Red, some blue
Red	Violet, blue, and most green

Haze filters for color films

Filters used with color films are different from those employed with black-and-white emulsions, because all colors of light must be taken into consideration. Scattering of the short, invisible wavelengths of ultraviolet light increases the haze effect on color film; thus, a desirable filter should absorb all ultraviolet and as much blue light as required for a correctly balanced color transparency. Such filters are usually colorless (ultraviolet) or pale yellow (minus-blue).

As a rule, haze filters for color films are less dense than those for black-and-white films; this is essential for maintaining a proper color balance. If excessively dense filters are used, aerial color transparencies may assume an overall hue similar to that of the filter. And, since excessive filtration of color film reduces the contrast of all other hues normally present, filters must be carefully selected and employed. Where ultraviolet filters are used, they will ordinarily have a filter factor of 1; i.e., their density will not require exposure increases.

Panchromatic film

The principal film used for aerial mapping and interpretation in Anglo-America is panchromatic, a black-and-white negative material having approximately the same range of sensitivity as that of the human eye. Standard speed panchromatic film provides reasonably good tonal contrast, a wide exposure latitude, satisfactory resolving power, and low graininess. *Pan* film, as it is called, has slightly higher than normal sensitivity to red light, thus permitting greater speed through haze filters (*Figure 1-6*).

Images on panchromatic photographs are rendered in varying shades of gray, with each tone comparable to the density of an object's color as seen by the human eye. Panchromatic film is superior for distinguishing objects of truly different colors, but its lack of high sensitivity to green light makes separation of vegetative types (e.g., tree species) difficult. A yellow haze filter is generally used for exposures on panchromatic film.

High-speed versions of standard panchromatic aerial films are also available (e.g., Kodak Tri-X Aerographic film), and these are intended for exposure under lesser light conditions. These films typically are about twice the speed of standard panchromatic aerial films. They are exposed through similar haze filters and, except for increased graininess, produce comparable tonal renditions.

Infrared film

Infrared black-and-white film is primarily sensitive to blue-violet, red, and near-infrared light radiations. It is sometimes exposed through red filters; thus, exposures can be made by red and near-infrared wavelengths only. This type of photography is best described as near-infrared, for most exposures utilize only a small band of infrared wavelengths ranging from about 0.7 to 0.9 μm.

It has been generally assumed that the gray tones on infrared film result from the degree of infrared reflectiveness of an object rather than from its true color. According to this theory, broad-leaved vegetation is highly reflec-

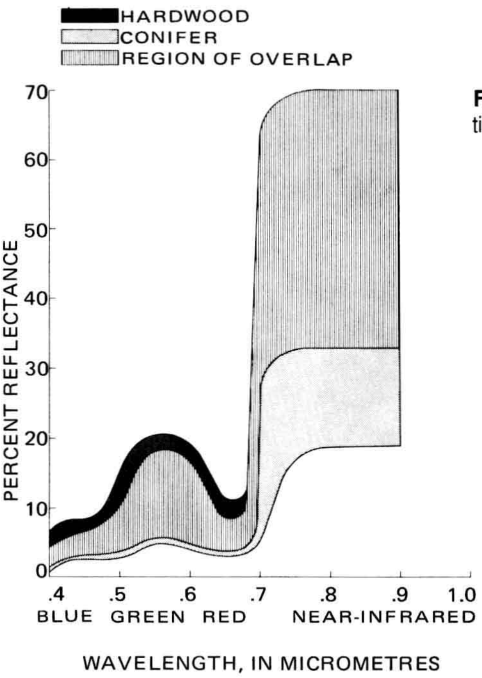
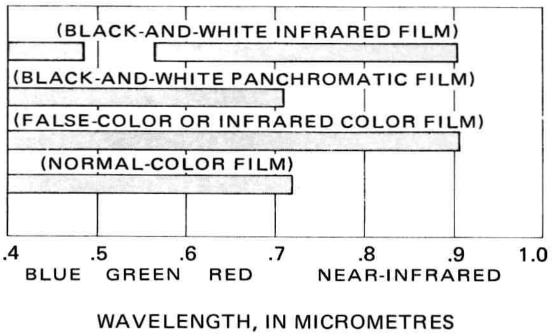


Figure 1-5. Generalized reflectance pattern from vegetation. Courtesy P. A. Murtha and Canadian Forestry Service.

Figure 1-6. Approximate wavelength sensitivities of four common aerial film emulsions. Courtesy P. A. Murtha and Canadian Forestry Service.



tive and therefore photographs in light tones; coniferous or needle-leaf vegetation tends to absorb infrared radiation and consequently registers in much darker tones. Whether this reasoning represents a true cause-and-effect relationship is somewhat uncertain. Nevertheless, the characteristic vegetative tones rendered on this film make it especially valuable for delineating timber types and for detecting camouflage when noninfrared reflective green paint or cut vegetation has been used.

Bodies of water absorb infrared light to a high degree and usually register quite dark on the film (unless they are heavily silt laden). This rendition is useful for determining the extent of river tributaries, tidal marshes, shorelines, and canals. On the other hand, the dark tone often inhibits detection of such underwater hazards as reefs, shoals, and channel obstructions. In some cases, the unusual tonal rendition of infrared photography blends light objects such as dirt roads with light-toned vegetation. Furthermore, the dark (black) shadows on infrared prints are a source of annoyance in the interpretation of ground detail.

Infrared photography normally penetrates haze better than panchromatic photography, but it will not penetrate extremely dense haze or moist clouds. When infrared film is exposed through yellow haze filters, the resulting compromise in tonal contrast is sometimes referred to as *modified* infrared. Exposure with red filters greatly increases contrast, especially among types of vegetation, but often at some sacrifice of image sharpness. *Figure 1-7* illustrates comparative panchromatic and infrared photography of an area in West Germany. Close inspection of these exposures confirms the fact that neither film has a clear-cut superiority over the other. When a choice of the two emulsions is available, the selection will depend mainly on the objectives of interpretation.

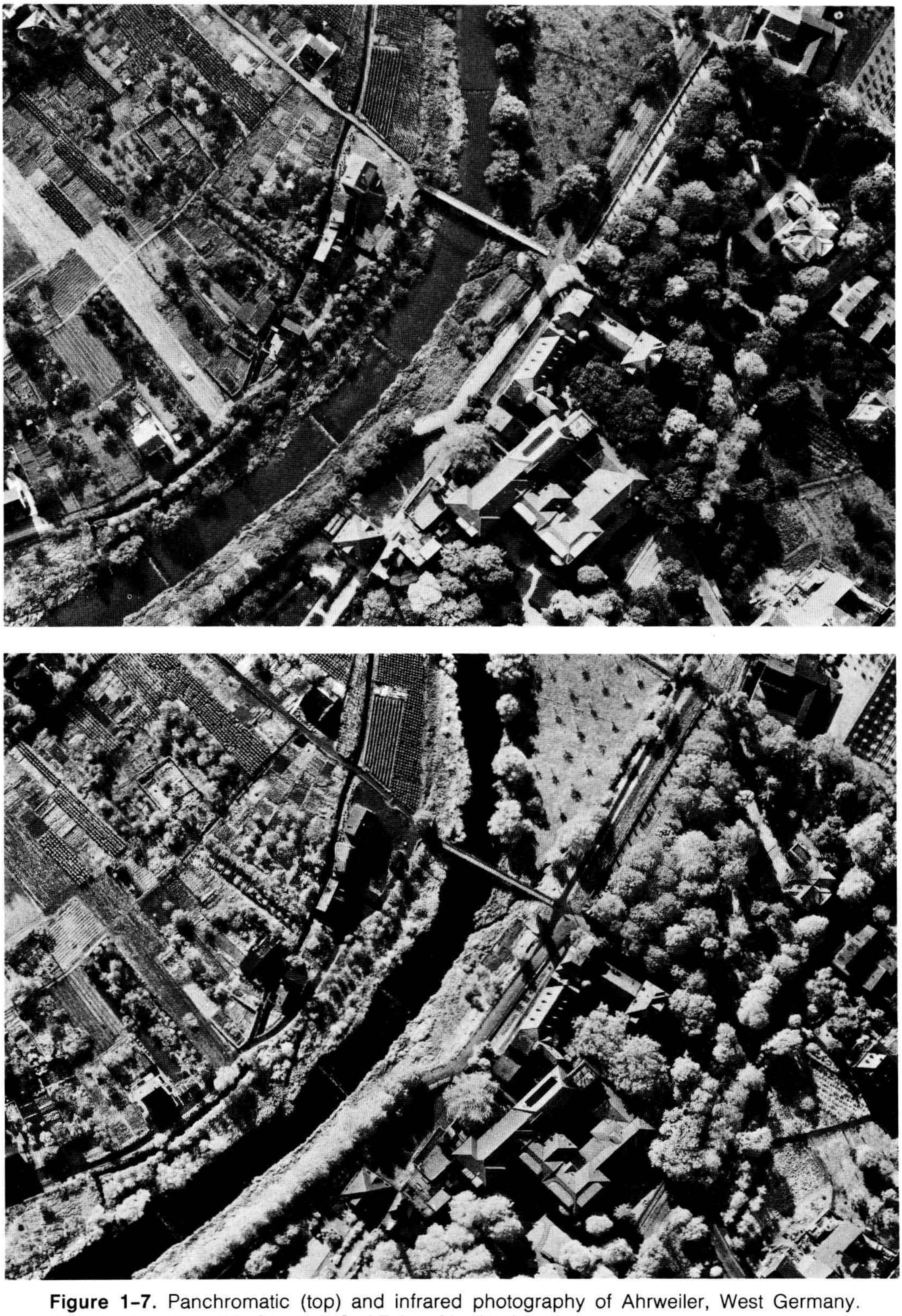


Figure 1-7. Panchromatic (top) and infrared photography of Ahrweiler, West Germany. Scale is about 1:2,500. Courtesy Carl Zeiss, Oberkochen.