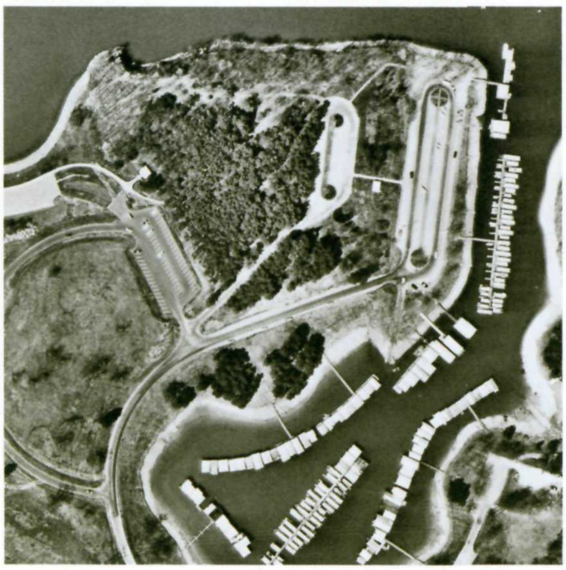
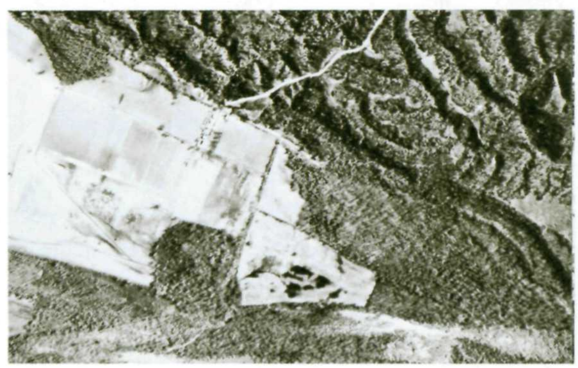
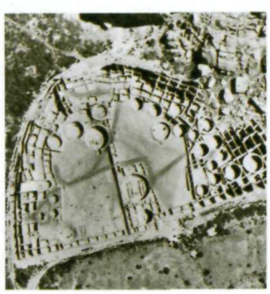
REMOTE SENSING

Aerial and Terrestrial Photography for Archeologists







Supplement No. 7

REMOTE SENSING

Aerial and Terrestrial Photography for Archeologists

Thomas Eugene Avery
Thomas R. Lyons

Supplement No. 7

to Remote Sensing: *A Handbook for Archeologists and Cultural Resource Managers*

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Preface

This supplement is designed for use with *Remote Sensing: A Handbook for Archeologists and Cultural Resource Managers,* by Thomas R. Lyons and Thomas Eugene Avery. The handbook may be obtained by writing the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

Within the next several months, the National Park Service will publish other supplements to the handbook dealing with regional applications of remote sensing for the archeologist and cultural resource manager. The reader may receive notification of these publications as they become available by writing the Superintendent of Documents (address above) and asking to be placed on mailing list N-557.

Contents

Illustrations

Tables

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The following organizations provided some of the aerial photographs used as figures in this volume: Bovay Engineers Inc., Albuquerque, New Mexico; Koogle and Pouls Engineering Inc., Albuquerque, New Mexico; NASA; University of New Mexico Photo Services, Albuquerque, New Mexico.

Section 1

Introduction

How Aerial Photographs Can Help

Aerial photography is a vital tool of archeologists, historical architects, geographers, and others who are concerned with the discovery, evaluation, and preservation of historic or prehistoric cultures and environments. Although many such sites are still being discovered by accident (e.g., during surveys for a new highway alignment), aerial imagery provides a systematic means of searching out features that may have gone unnoticed for centuries. Furthermore, the remote sensor imagery itself constitutes historical data; once acquired, it becomes a historical document of conditions that existed at a certain point in time and space.

In arid climates, the detection and delineation of archeological sites may be fairly simple, especially where vegetation is sparse or absent. By contrast, detection may be extremely difficult in high-rainfall regions such as tropical forests. Potential sites may not only be obscured by vegetation, but their ground scale alone may render them virtually invisible to terrestrial observers. The greater range and vertical perspective afforded by aerial photography thus provides a new dimension in the search for and delineation of archeological sites. Even when such sites are not clearly discernible, probable locales for detailed ground exploration may be *predicted* by image analysis of environmental and microenvironmental zones.

Aerial photographs are also useful for monitoring natural and human impacts on areas that have been set aside for public use. This is accomplished by scheduling sequential photographic coverage at various points in time. Finally, the proper planning and use of aerial photography can result in substantial savings, because airphoto techniques are often more economical to use than conventional field approaches.

Types of Aerial Photographs

Oblique Photographs. In the earlier days of aerial photography, most exposures were made with an aerial camera aimed somewhere between the horizon and the ground, resulting in an oblique view. If the horizon is included in such a photograph, it is referred to as a high oblique; if the horizon does not show up in the picture, the view is termed a low oblique. Oblique photographs provide a wide-angle, perspective view in areas of level terrain, but their usefulness is impaired by mountains or rough topography. As a general rule, obliques are best employed to show specific features at low altitude or as supplements to vertical exposures (fig. 1).

Vertical Photographs. The vertical photograph is taken with an aerial camera pointed straight down at the earth's surface. Where continuous coverage is specified, the photographic flight is planned so that consecutive exposures will overlap about 60 percent of their width along the line of flight and about 30 percent between adjacent flight strips. This pattern of overlapping exposures provides an image of each terrain feature from two different camera positions. As a result, any overlapping pair of exposures from a given flight line can be viewed three-dimensionally with a stereoscope (fig. 2).

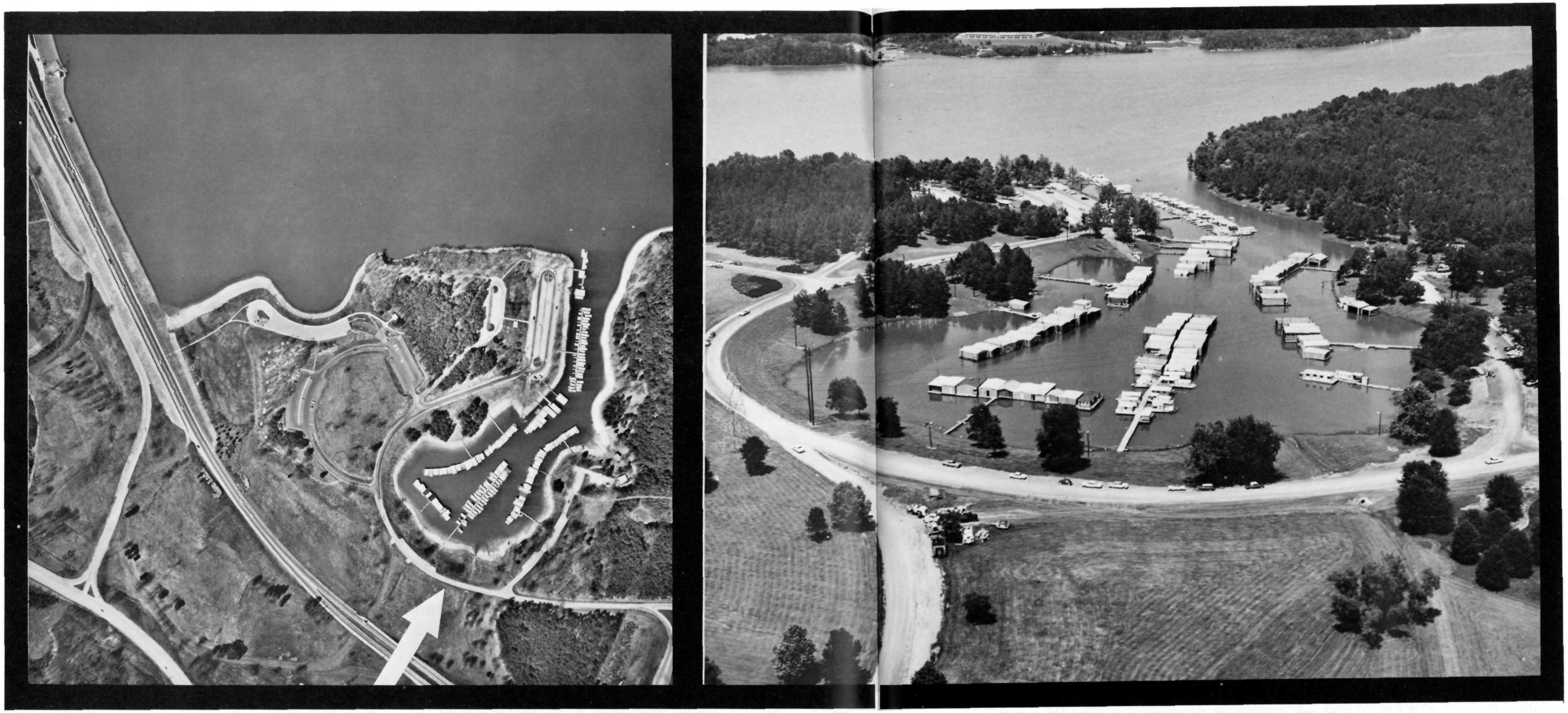

Figure 1 Vertical and low oblique views of Chickamauga Lake and Marina, Chattanooga, Tennessee. The arrow on the vertical print indicates the angle of the oblique view. Scale of the vertical photograph is about 600 feet per inch. *Courtesy Tennessee Valley Authority.*

Mosaics. Mosaics are composite pictures that are assembled by using only the central, non-overlapping portions of vertical prints. The individual photo centers are carefully trimmed, matched, and pasted together like a jigsaw puzzle to give the appearance of a single, large picture. A mosaic constructed with direct ties to ground survey points is termed a controlled mosaic; if ground control of linear distances is lacking, the mosaic is called uncontrolled. When professionally assembled, both types of mosaics will serve well for planning purposes. They are particularly useful if special transparent overlays are prepared to show such features as property boundaries, trails, soil types, or vegetation classes.

Figure 2 Mirror stereoscope with attached binoculars.

Orthophotographs. An orthophotograph is a reproduction, prepared from ordinary perspective photographs, in which image displacements due to tilt and relief have been entirely removed. When these unique photographs are subsequently assembled into an orthophotomosaic, the result is a picture-map, i.e., a photograph with both scale and planimetric detail of high reliability. When such mosaics are overprinted onto standard mapping quadrangles, they are referred to as orthophotoquads.

A Brief History of Aerial Archeology

Although it was demonstrated in the late 1800's that airphotos could be taken from captive balloons, it was the development of the airplane (circa 1903) that provided the main impetus for archeological applications. Archeologists, especially those in Europe and the United Kingdom, were well aware of the potential uses for aerial photography. During World War I and II, for example, many persons (including archeologists) were flying airplanes and photographing extensive areas of prehistoric and historic interest. Thus it was no accident that the first archeologists to use aerial photographs extensively were those who were wartime flyers or photo interpreters.

O.G.S. Crawford, an archeologist who was an early enthusiast of airphoto techniques, was a member of the Royal Flying Corps of England during World War I. Around 1922, Crawford demonstrated the value of using various ground markings to delineate archeological sites in the United Kingdom. His successes are exemplified by the fact that he discovered more Celtic, Roman, and "henge" sites in one year than had previously been found during a hundred years of ground reconnaissance. This work firmly established aerial techniques for archeological exploration in England.

Early aerial explorations in North America include coverage of the Cahokia Indian mounds in western Illinois and both visual reconnaissance and photographic flights by Charles and Anne Lindbergh over the American Southwest and the Yucatan peninsula of Mexico (fig. 3). Early flights over tropical areas produced only limited successes because of insufficient advance planning and dense, masking ground cover. Nevertheless, a few important sites were located, and the attendant publicity generated induced several foundations and universities to send archeological expeditions into Mexico and South America. Since 1934, most of the site discoveries in these regions have been made through aerial reconnaissance or photographic interpretation.

The following listing, though quite incomplete, provides examples of sites in the United States that have been discovered, delineated, or mapped through aerial techniques:

1921 — Mapping of Cahokia Indian mounds in Illinois
1930 — Lindbergh flights over pueblo ruins of Chaco Canyon, New Mexico
1932 — Photographic evidence of effigy sites (giant Indian intaglios) on bluffs above the Colorado River near Blythe, California, and delineation of Hohokam Indian irrigation canals in southern Arizona
1948 — Mapping of Zuni and Hopi Indian pueblos in Arizona and New Mexico
1953 — Detailed site mapping of concentric banks of earthworks (part of mound complex) near Poverty Point, Louisiana
1959 — Discovery of village sites in the Alaskan tundra
1965 — Discovery and delineation of fortified village sites along the Missouri River in South Dakota
1968 — Discovery of prehistoric Indian agricultural plots (by infrared scanning) in northern Arizona
1970 — Discovery and mapping of ancient roadways and Indian pueblos in the vicinity of Chaco Canyon, New Mexico
1976 — Monitoring of direct and indirect impact on a fragile archeological site in Chaco Canyon National Monument, New Mexico
1977 — Detailed photogrammetric mapping of Hidatsa Indian Village sites on the Knife River, North Dakota

In spite of technological advances, the applications of aerial archeology have been limited in the United States until the past few years. This may be a reflection of our greater interest in the present than in our ancestry, but there are

Figure 3 An oblique photograph of the Wijiji Ruin in Chaco Canyon National Monument taken by the Lindbergs in 1929.

probably other reasons also. Among these are (1) the feeling that the techniques is too expensive, (2) the feeling that many, if not most, sites have already been described, and (3) the attitude that more impressive sites are likely to be found outside United States boundaries. Whether these are valid generalizations can only be determined in the future.

Stereoscopic Viewing

When an object is photographed from two different points in space, the dual images that result may be viewed three-dimensionally with a simple and inexpensive stereoscope. The two photographic images, consisting of a left-hand and a right-hand view, are arranged under corresponding lenses of the stereoscope; the instrument "forces" the left eye to look only at the left-hand photograph, while the right eye sees only the right-hand view. The result is a somewhat exaggerated three dimensional effect created in the brain of the viewer.

The stereoscope was invented in 1832 by Sir Charles Wheatstone, a scientist whose reputation was established by his development of an electrical measuring device called the Wheatstone bridge. By the late 1800's, the popularity of the stereoscope had increased to the point where the hand-held "stereopticon" comprised the entertainment center in American parlors. The variety of three-dimensional viewing cards that were available by the turn of the century enabled rocking chair travelers to make personal tours to the pyramids of Egypt, the Great Wall of China, or the deserts of the Arizona Territory. Stereoscopes used today for studying aerial photographs are based on exactly the same principle as Wheatstone's original invention of 150 years ago.

When aerial exposures are to be studied three-dimensionally, the print centers or principal points should be pin-pointed as an aid in orienting the photographs under the stereoscope (Lyons and Avery 1977).

Neophyte interpreters should follow these rules to develop proper stereoscopic viewing habits:

1. Make sure that photographs are properly aligned, with shadows falling toward the viewer.
2. Maintain an even, glare-free illumination on prints or transparencies.
3. Keep stereoscope lenses clean and separated to your correct interpupillary distance.
4. At the onset, do not use the stereoscope more than 30 minutes out of any given one-hour period.

Section 2

Photographic Films and Filters

Black-and-White Films

Panchromatic Film. The two general types of black-and-white emulsions most frequently employed are panchromatic and infrared aerographic films. Panchromatic film, a negative material having approximately the same range of light sensitivity as the human eye, is regarded as the "standard" film for aerial mapping and for archeological investigations. Today's panchromatic emulsions provide good tonal contrast, a wide exposure latitude, good resolving power, and low graininess. Aerial panchromatic films have extended sensitivity in the red portion of the visible spectrum, thus permitting fast shutter speeds through haze-cutting filters (fig. 4).

Images on panchromatic film are rendered in varying shades of gray, with each tone proportional to the brightness of the object as seen by the human eye. Panchromatic film is thus useful for distinguishing objects of truly different colors, and it is recommended for such projects as reconnaissance surveys, topographic mapping, and locating old settlement boundaries. Since roads and trails are easily seen, panchromatic prints are also useful as field maps for the archeologist who must find his or her way through unfamiliar terrain. Most healthy vegetation appears imaged in similar gray tones on panchromatic film. Where only coniferous (needleleaf) trees are present, panchromatic film may be preferred for the classification of forest vegetation.

Black-and-White Infrared Film. If deciduous (broadleaf) vegetation is interspersed with coniferous trees, separation of the different types can be more easily accomplished by using a black-and-white infrared emulsion. This kind of film, sensitive to infrared radiation as well as to the blue, green and red portions of the visible spectrum, is especially suited for applications in forestry, geology, and archeological exploration. It is sometimes exposed through red or dark red filters; thus exposures can be made by red and infrared wavelengths only. Such photography is often described as "near-infrared", because most exposures utilize only a small band of infrared radiation ranging from about 0.7 to 0.9 micrometers (fig. 5).

Gray tones on black-and-white infrared film result from the degree of infrared reflectance of objects rather than from their visible reflectance. For example, broadleaf vegetation is highly reflective and therefore photographs in light tones; coniferous or needleleaf vegetation tends to be less reflective in the near-infrared portion of the spectrum and consequently registers in much darker tones. This characteristic makes infrared film the preferred black-and-white emulsion for delineating vegetative types in mixed forests.

Filters. 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, it 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 "minus blue" filter reduces the effect of haze by

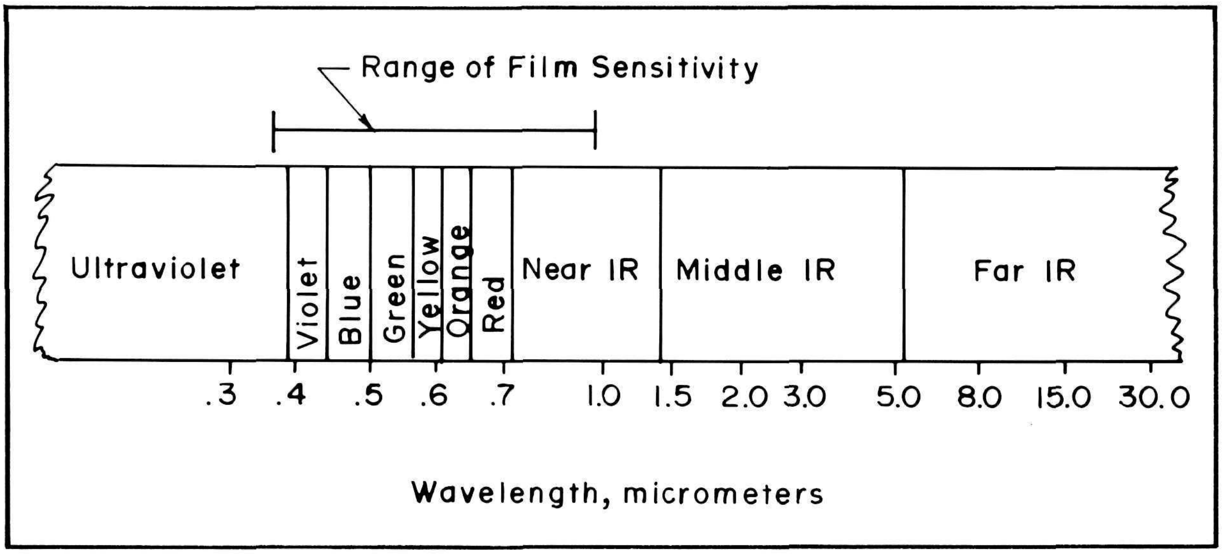

Figure 4 A portion of the electromagnetic spectrum.

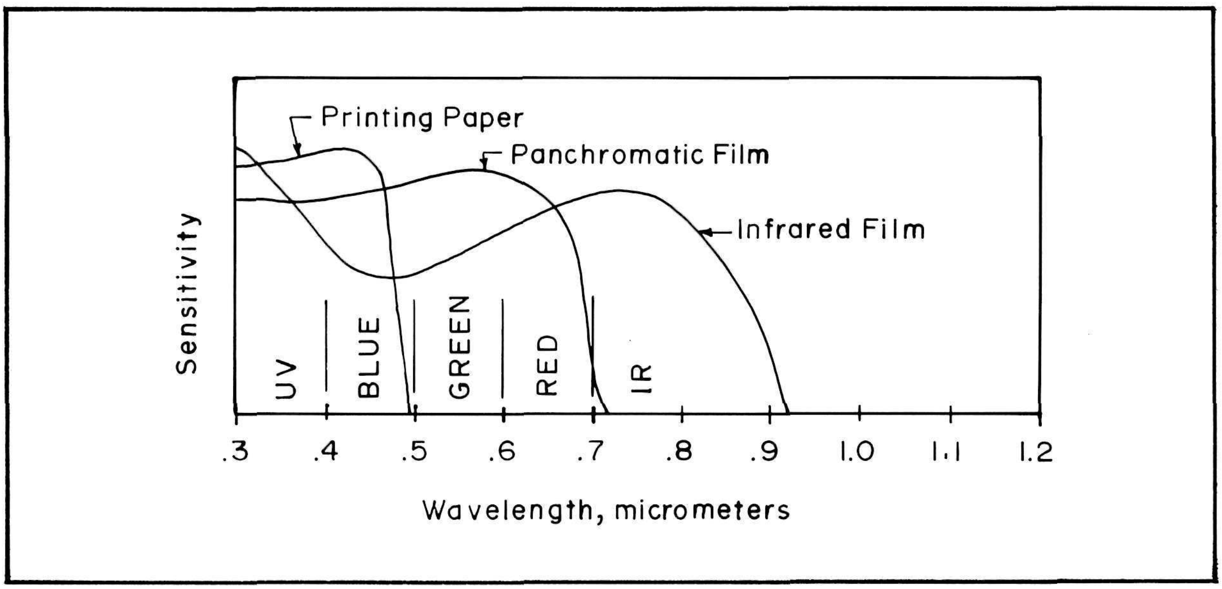

Figure 5 Approximate spectral signatures of two black-and-white films.

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 may be required. Infrared emulsions are generally superior to panchromatic films for reducing the effects of haze.

Color Film

The two most commonly used color films are normal color (conventional color rendition) and infrared color (false color rendition). These films are processed to produce color-positive (or color-reversal) transparencies that can be used for direct interpretation. In most instances, color photographs are superior to black-and-white pictures for detailed interpretation because the human eye can detect many more color variations than gray tones.

Conventional Color Film. The conventional color emulsion is an aerial color-reversal film designed for daylight exposure and is sensitive in the visible-spectral regions. It provides transparencies with natural color rendition when properly exposed and processed. This emulsion has proved especially valuable for identifying soil types, rock outcrops, and industrial stockpiles. Normal color film also has good qualities of water penetrability, and it is therefore useful for subsurface exploration, hydrographic control, and the delineation of shoreline underwater features. As is the case with most aerial films, correct exposures require conditions of bright sunlight.

Color Infrared Film. Infrared-sensitive color film is a false-color film that differs from ordinary color film in that the three emulsion layers are sensitized to green, red, and infrared radiation instead of the usual blue, green, and red wavelengths. When the film is correctly exposed, the resulting transparencies display colors that are false for most natural features. Infrared color film was originally designed to emphasize differences in infrared reflection between live, healthy vegetation and visually similar objects camouflaged with green paints (fig. 6).

Infrared color film has become especially valuable for a variety of survey projects such as the detection of disease and insect outbreaks in forests. Basic to such applications is the identification of tree species or vegetative cover types, a task that requires information on the infrared reflectivity of various types of foliage. Since healthy broadleaf trees have a higher infrared reflectivity than healthy needleleaf trees, their photographic images can usually be easily separated on infrared color film.

In summary, it may be concluded that no single film serves all purposes. Instead, the varied tones and patterns produced by different ranges of film sensitivity complement each other, and the maximum amount of information can be extracted when several types of imagery covering the same area are studied simultaneously. The interpretation of comparative photographic coverage representing two or more regions of the electromagnetic spectrum is known as multispectral reconnaissance.

Filters

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 have filter factors of one, i.e., their density does not require exposure increases.

Kodak Aero-Neg Color Process

This approach is based on the use of a special Kodak film that is processed to a negative. From this single negative, additional processing techniques provide for the production of color prints, black-and-white prints, color diapositives, or color transparencies. These end products can be produced as enlargements, reductions, or as contact-scale photographs.

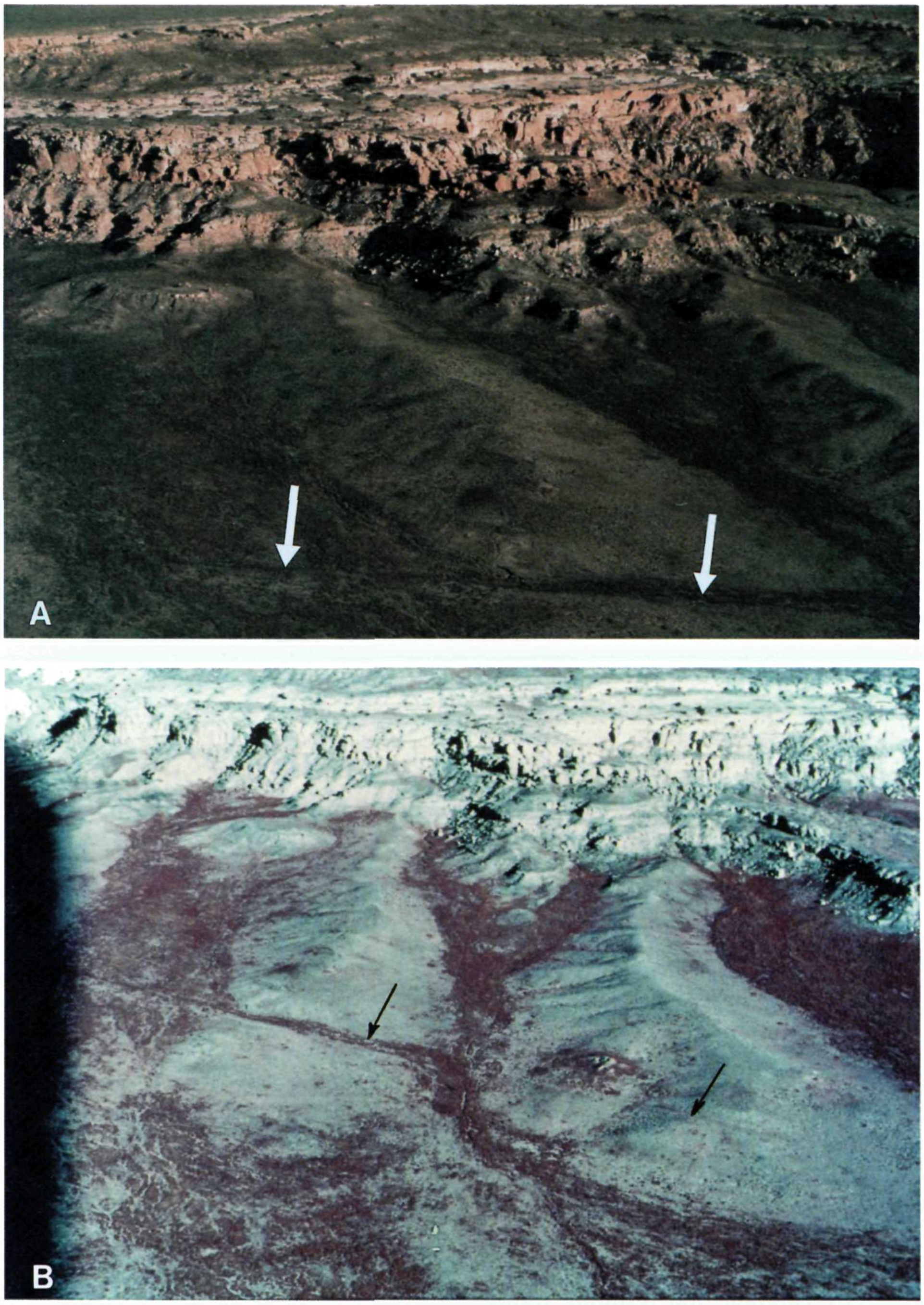

Figure 6 Comparative photo coverage of approximately the same area in Chaco Canyon National Monument showing contrast between normal color (A) and infrared color film (B). Arrow indicates trace of prehistoric road.

With this process, the interpreter has an opportunity of selecting a variety of image forms from one aerial exposure. The versatility of the Kodak Aero-Neg process should make it especially popular with archeologists who desire color photographs for office interpretation along with conventional black-and-white contact prints for field use.

Kodak Aerial Exposure Index

Because of the smaller range in subject luminance, atmospheric haze conditions, and other factors, the characteristics of aerial scenes differ considerably from those of ordinary ground views. As a result, the speed criterion used in the sensitometry of aerial film is different from the A.S.A. or D.I.N. ratings assigned to conventional roll and sheet films (Eastman Kodak, 1970).

The two-dial Kodak Aerial Exposure Computer provides the aerial photographer with a quick and convenient means of determining the exposure parameters for Kodak black-and-white and color aerial films anywhere in the world. Of course, proper exposure will still depend, to some extent, on the aerial photographer's judgment of such factors as atmospheric haze conditions, amounts of tolerable image motion, and selection of filters. For example, the photographer must remember to take the filter factor into account when determining the exposure setting for an aerial camera equipped with an antivignetting filter.

Seasons for Aerial Photography

The optimum season for scheduling photographic flights depends on the nature of features to be identified or mapped, the film to be used, and the number of days suitable for aerial photography within a given period. Since optimum weather conditions may not prevail during the season when photography is desired, it may be necessary to ascertain the average number of "photographic days" for a locality during each month of the year. A photographic day is defined as one with 10 percent cloud cover or less; this kind of information may be obtained from periodic reports issued by the National Weather Service. Other factors being equal, aerial surveys are likely to be less expensive in areas where sunny, clear days predominate during the desired photographic season.

Archeological Exploration. For the detection and evaluation of most archeological sites, drier seasons of the year are generally preferred over wetter periods, because the loss or retention of moisture by various soils provides more striking tonal contrasts during dry seasons. Density and condition of covering vegetation is an additional seasonal factor for consideration. It is obvious that growing-season photography is required for the detection and evaluation of crop or plant marks, for example (fig. 7).

Reconnaissance flights over humid regions are likely to be more successful when masking deciduous plants are leafless. And soil marks are most readily discernible after plowing but prior to the establishment of an agricultural crop. In summary, the photographic season must be selected on the basis of specific project objectives; there is no single period of the year that is "best" for all forms of archeological exploration.

Topographic Mapping Photography. For topographic mapping, aerial photographs are usually made either in spring or fall when deciduous vegetation is bare and the ground is essentially free of snow cover. Only during these periods in many environments can terrain features be adequately distinguished and contours precisely delineated. As differences in vegetation are rarely of significance in topographic mapping, photography is commonly made with panchromatic film. Similar coverage would be specified by geologists interested in stratigraphic mapping and by engineers concerned with proposed highway routes. Although summer photography may suffice in an emergency, dense canopies of foliage greatly inhibit the efficient evaluation of ground detail, thereby increasing total project costs.

Vegetation Mapping. Interpreters interested in vegetation analysis will ordinarily specify aerial photography made during the growing season, particularly when deciduous plants constitute an important component of the vegetative cover. When it is essential that deciduous trees, evergreens, and

Figure 7 7A is a black-and-white aerial photograph of a portion of Ninety Six National Historic Site taken in January 1978. Arrow indicates the location of the clearly visible Star Fort during season of barren deciduous tree cover. 7B is an infrared color photograph of a portion of Ninety Six National Historic Site taken in the spring of 1977. Arrow indicates location of Star Fort obscured by vegetation.

mixtures of the two groups be delineated, either black-and-white infrared or color infrared film is frequently specified. In regions where evergreen plants predominate, however, panchromatic or conventional color film may be used with equal success.

Scale Expressions for Vertical Photographs

The scale of a vertical aerial photograph is dependent on the focal length of the camera em-

ployed and the height of the aircraft above the ground. Photographic scales are commonly expressed as representative fractions, e.g., 1:4,800. In a representative fraction, the "1" refers to units on the photograph, while the denominator (4,800 in this case) denotes units on the ground. Thus the implication is that one inch on the photograph is equal to 4,800 inches on the ground. This is merely another way of saying that one inch on the photograph is equal to 4,800/12 or 400 feet on the ground. Table 1 includes a wide range of scale conversions for maps and vertical photographs.

Table 1. Scale conversions for maps and vertical photographs.*

Ratio scale	Feet per inch	Inches per 1,000 feet	Inches per mile	Miles per inch	Meters per inch	Acres per square inch	Square inches per acre	Square miles per square inch
1: 500	41.667	24.00	126.72	0.008	12.700	0.0399	25,091	0.00006
1: 600	50.00	20.00	105.60	.009	15.240	.0574	17.424	.00009
1: 1,000	83.333	12.00	63.36	.016	25.400	.1594	6.273	.00025
1: 1,200	100.00	10.00	52.80	.019	30.480	.2296	4.356	.00036
1: 1,500	125.00	8.00	42.24	.024	38.100	.3587	2.788	.00056
1: 2,000	166.667	6.00	31.68	.032	50.800	.6377	1.568	.00100
1: 2,400	200.00	5.00	26.40	.038	60.960	.9183	1.089	.0014
1: 2,500	208.333	4.80	25.344	.039	63.500	.9964	1.004	.0016
1: 3,000	250.00	4.00	21.12	.047	76.200	1.4348	.697	.0022
1: 3,600	300.00	3.333	17.60	.057	91.440	2.0661	.484	.0032
1: 4,000	333.333	3.00	15.84	.063	101.600	2.5508	.392	.0040
1: 4,800	400.00	2.50	13.20	.076	121.920	3.6731	.272	.0057
1: 5,000	416.667	2.40	12.672	.079	127.000	3.9856	.251	.0062
1: 6,000	500.00	2.00	10.56	.095	152.400	5.7392	.174	.0090
1: 7,000	583.333	1.714	9.051	.110	177.800	7.8117	.128	.0122
1: 7,200	600.00	1.667	8.80	.114	182.880	8.2645	.121	.0129
1: 7,920	660.00	1.515	8.00	.125	201.168	10.00	.100	.0156
1: 8,000	666.667	1.500	7.92	.126	203.200	10.203	.098	.0159
1: 8,400	700.00	1.429	7.543	.133	213.360	11.249	.089	.0176
1: 9,000	750.00	1.333	7.041	.142	228.600	12.913	.077	.0202
1: 9,600	800.00	1.250	6.60	.152	243.840	14.692	.068	.0230
1: 10,000	833.333	1.200	6.336	.158	254.000	15.942	.063	.0249
1: 10,800	900.00	1.111	5.867	.170	274.321	18.595	.054	.0291
1: 12,000	1,000.00	1.0	5.280	.189	304.801	22.957	.044	.0359
1: 13,200	1,100.00	.909	4.800	.208	335.281	27.778	.036	.0434
1: 14,400	1,200.00	.833	4.400	.227	365.761	33.058	.030	.0517
1: 15,000	1,250.00	.80	4.224	.237	381.001	35.870	.028	.0560
1: 15,600	1,300.00	.769	4.062	.246	396.241	38.797	.026	.0606
1: 15,840	1,320.00	.758	4.00	.250	402.337	40.000	.025	.0625
1: 16,000	1,333.333	.750	3.96	.253	406.400	40.812	.024	.0638
1: 16,800	1,400.00	.714	3.771	.265	426.721	44.995	.022	.0703
1: 18,000	1,500.00	.667	3.52	.284	457.201	51.653	.019	.0807
1: 19,200	1,600.00	.625	3.30	.303	487.681	58.770	.017	.0918
1: 20,000	1,666.667	.60	3.168	.316	508.002	63.769	.016	.0996
1: 20,400	1,700.00	.588	3.106	.322	518.161	66.345	.015	.1037
1: 21,120	1,760.00	.568	3.00	.333	536.449	71.111	.014	.1111
1: 21,600	1,800.00	.556	2.933	.341	548.641	74.380	.013	.1162
1: 22,800	1,900.00	.526	2.779	.360	579.121	82.874	.012	.1295
1: 24,000	2,000.00	.50	2.640	.379	609.601	91.827	.011	.1435
1: 25,000	2,083.333	.480	2.534	.395	635.001	99.639	.010	.1557
1: 31,680	2,640.00	.379	2.000	.500	804.674	160.000	.006	.2500
1: 48,000	4,000.00	.250	1.320	.758	1,219.202	367.309	.003	.5739
1: 62,500	5,208.333	.192	1.014	.986	1,587.503	622.744	.0016	.9730
1: 63,360	5,280.00	.189	1.000	1.000	1,609.347	640.00	.0016	1.0000
1: 96,000	8,000.00	.125	.660	1.515	2,438.405	1,469.24	.0007	2.2957
1: 125,000	10,416.667	.096	.507	1.973	3,175.006	2,490.98	.0004	3.8922
1: 126,720	10,560.00	.095	.500	2.00	3,218.694	2,560.00	.0004	4.00
1: 250,000	20,833.333	.048	.253	3.946	6,350.012	9,963.907	.0001	15.5686
1: 253,440	21,120.00	.047	.250	4.00	6,437.389	10,244.202	.0001	16.00
1: 500,000	41,666.667	.024	.127	7.891	12,700.025	39,855.627	.000025	62.2744
1: 1,000,000	83,333.333	.012	.063	15.783	25,400.050	159,422.507	.0000062	249.0977

* From *Aerial-Photo Interpretation in Classifying and Mapping Soils,* Agriculture Handbook 294, Soil Conservation Service, U.S. Department of Agriculture, Washington, 1966.

Obtaining Aerial Photography

Alternatives for Consideration

Aerial photographs may be obtained by purchasing prints of existing photography, by taking the necessary pictures yourself, or by contracting for new coverage through a private aerial survey company. Each solution has its own advantages and limitations. For example, existing photography has the advantage of low cost, but it may be outdated or available only as black-and-white prints. Do-it-yourself photography is often sufficient for small areas or spot coverage, but the amateur rarely has the equipment and professional expertise to photograph large land areas with required standards of precision. And contracting for a special aerial survey, the choice most likely to result in superior pictures, may be rather costly for small or irregularly-shaped land areas.

Existing Photography from Government Agencies

Most of the United States has been topographically mapped with the aid of aerial photography, and imagery taken since the mid-1920's exists in the files of a number of government repositories. In addition to this, private firms have flown diverse areas at useful scales for archeological investigation.

The National Cartographic Information Center (NCIC), established in 1974 by the U.S. Geological Survey, Department of the Interior, provides a national information service to make cartographic data of the United States more easily accessible to the public and to various Federal, State, and local agencies. At present, more than 30 Federal agencies collect and prepare cartographic data. Existing data include more than 1.5 million maps and charts, 25 million aerial and space photographs, and 1.5 million geodetic control points. The address of NCIC is:

National Cartographic Information Center
U.S. Geological Survey
507 National Center
Reston, Virginia 22092

NCIC does not obtain all of the cartographic data from present holders; rather it collects and organizes descriptive information about the data, tells where they are located, ensures their availability, and provides ordering assistance. Existing government and private data centers will continue to hold and distribute cartographic data. Some of these centers will also provide for local users direct access to NCIC information through their existing public service facilities. The principal affiliates in the NCIC network are the Geological Survey and the National Oceanic and Atmospheric Administration. As a rule, most aerial photographs purchased through federal agencies range in scale from about 1:12,000 to 1:40,000. Panchromatic film is commonly used, although national forests and adjacent lands may have coverage with infrared black-and-white film. Also, there is an increasing amount of high-altitude color photography (scale 1:60,000 to 1:125,000) available from some agencies.

The age of existing photography usually varies from about two to eight years, with agricultural regions, urban areas, and large reservoirs being rephotographed at the most frequent intervals.

Much of the existing photography is held by the Agricultural Stabilization and Conservation Service (ASCS), the Forest Service, or the Soil Conservation Service, USDA. Inquiries relating to this coverage should be addressed to:

Aerial Photography Field Office
ASCS/USDA
P.O. Box 30010
Salt Lake City, Utah 84125

Ordering Photography from ASCS/USDA/EROS

Photo index sheets or index mosaics, showing the relative positions of all individual photographs within a given county (fig. 8) can be examined at local offices of the Agriculture Stabilization and Conservation Service or the Soil Conservation Service. The number of index sheets per county varies from one to six or more. It is possible to visit an ASCS office, select desired photos from an index, and order them on the spot.

Forest Service indexes are usually available for inspection in local supervisor's offices or in ranger districts. Instead of conventional photographic indexes, the Forest Service now uses "spot indexes," i.e., maps showing the locations of photo centers.

If you are interested in aerial photography of a distant county, you may wish to purchase an index of that county and make your selection. Again, your own county ASCS office will help you order the index and will provide assistance in selecting the photos that will suit your needs. Prints are identified by a county symbol (or by a special state and county code), and by film roll and exposure number. Other items to specify are date of photography, scale, and type of reproduction (print size, weight, finish, contrast, etc.).

Special order blanks and current price lists may be obtained through local ASCS offices. Orders must be accompanied by advance payment, and 3 to 4 weeks should be allowed for delivery.

If you do not have access to the appropriate index sheet, an alternative is to outline the area of interest on a reliable map. This map can then be sent to the Aerial Photography Field Office in Salt Lake City with your inquiry.

Although EROS is principally an agency for collecting and archiving Landsat data, it is also a source of much Federal aerial photography. The address is:

EROS Data Center
Sioux Falls, S.D. 57198

Aerial photo negatives from 1941 and earlier were transferred to the National Archives. To order any of these older photos, write to:

National Archives and Records Service
Cartographic Archives Division
General Services Administration
Washington, D.C. 20408

Existing Photography from Private Firms

A wide selection of photographic negatives are held by private aerial survey companies in the United States and Canada. As a rule, prints can be ordered directly from these companies after obtaining permission of the original purchaser. A large share of the available coverage has been obtained on panchromatic film with aerial cameras having 6-inch focal lengths. As a result, prints are well-suited to stereoscopic study because of a high degree of three-dimensional exaggeration. Scales are often 1:15,840 or larger for recent photography. In addition to contact prints and photo index sheets, most aerial mapping organizations will also sell reproductions of special atlas sheets or controlled mosaics. These items may be useful for pictorial displays and administrative planning.

Prints purchased from private companies may cost more than those from public agencies, but they are sometimes more recent or taken at larger scales —factors that may offset any price differential. Quotations and photo indexes can be obtained by direct inquiry to the appropriate company. Names and addresses of leading photogrammetric concerns are available in current issues of *Photogrammetric Engineering and Remote Sensing,* the journal of the American Society of Photogrammetry.

Figure 8 Portion of an aerial photo index sheet. *Courtesy Forest Service, U.S. Department of Agriculture.*

Taking Your Own Aerial Photographs

If oblique or near-vertical photographs taken with hand-held cameras or cameras on handmade mounts are sufficient for reconnaissance of small sites, the do-it-yourself approach may be a satisfactory solution for archeological reconnaissance. An unobstructed side view can be obtained from most high-wing monoplanes, and even better visibility is provided if the aircraft door can be removed during photographic flights. For oblique views, a standard 4 × 5 press camera works very well, and most aerial film emulsions are available in this size.

Where the camera must be exposed to the aircraft slipstream or where near-vertical coverage is desired, a rigidly designed aerial camera should be used instead. Such cameras may be rented, or they may be purchased at relatively low cost through military surplus outlets. Hand-held military reconnaissance cameras such as the K-20 have been employed by a number of scientists for making periodic aerial surveys of scattered sites. (Hint: Check with your film supplier regarding the availability of films in various sizes before purchasing an aerial camera which might have a non-standard negative format.)

Exposures made with hand-held cameras are satisfactory for oblique views and for spot coverage with a near-vertical camera orientation. However, if continuous strips of overlapping exposures are needed for stereoscopic study, a camera mount must be devised and constructed for best results. It is assumed here that most rented aircraft will not have camera ports or cargo hatches incorporated therein; consequently, most improvised camera mounts are designed to hold the photographic apparatus outside the airframe, usually on the passenger's side.

Handmade camera mounts have been designed in a wide array of configurations, since each must be adapted to a particular airframe and camera. To combine light weight with maximum platform stability, most camera mounts are constructed of plywood and aluminum; vibration problems are often minimized by employment of foam rubber shock absorbers (fig. 9).

Two common problems with low-altitude, do-it-yourself photography are (1) the difficulty in determining exact altitude above ground for scale calculations, and (2) poor camera stabilization, which may result in blurred or nonvertical imagery. In spite of these limitations, however, the technique is ideally suited for spot photographic coverage where low costs and exact timing of flights are chief factors of concern.

Contracting for New Photography

The ideal imagery for complete data recording is that which allows maximum recovery of many classes of archeological data. This criterion may imply high resolution color photographs at scales of 1:5,000 or even larger. In many circumstances, existing aerial photography does not meet essential standards for archeological fieldwork. As a consequence, there may be an interest in contracting with private firms for obtaining new aerial photography.

This is the preferred method of obtaining photographic coverage, since specifications such as film, filters, scale, and season can be placed under the control of the buyer (fig. 10). As a rule, the cost per square mile for special coverage decreases as photo scales become smaller and as land areas become larger. For coverage at a scale of 1:15,840 (four inches per mile), a good camera crew can photograph 750 to 900 square miles in five to eight hours of flying time. Thus the cost of photography of small land areas is dictated more by the cost of relocating the photographic aircraft and crew than by the actual flying time required.

The purchaser of special photographic coverage should negotiate only with a reputable aerial survey firm. Names and addresses of such firms can be obtained locally through consulting engineers, city managers, or by contacting photo interpretation specialists at various universities. Addresses and activities of major aerial survey companies are described annually in the "Yearbook Issue" of *Photogrammetric Engineering and Remote Sensing.*

When there is a choice to be made among two or more aerial survey companies, the purchaser is advised to request photographic samples from each company. Such print samples provide useful guidelines to the quality of work that may be expected. Purchasers who feel unqualified to evaluate sample photography should retain the services of a special

Figure 9 Photograph of do-it-yourself camera mount emplaced in the open doorway of an aircraft.

consultant to assist in drawing up photographic specifications, defining areas to be covered, and inspecting the finished product.

Aerial photographs that fail to provide the desired quantity and quality of information cannot be considered inexpensive by any standard. Therefore, when special flights are justified, contract specifications should be thoroughly discussed by buyer and contractor prior to actual flights. A few extra days of advance planning will sometimes alleviate the need for reflights and help to avoid subsequent disputes arising from differing definitions of stereoscopic coverage, exposure quality, or film processing deficiencies.

To illustrate the kinds of data commonly required in an aerial photography contract, some sample specifications from the U.S. Department of Agriculture (USDA) are included in the appendix of this booklet.

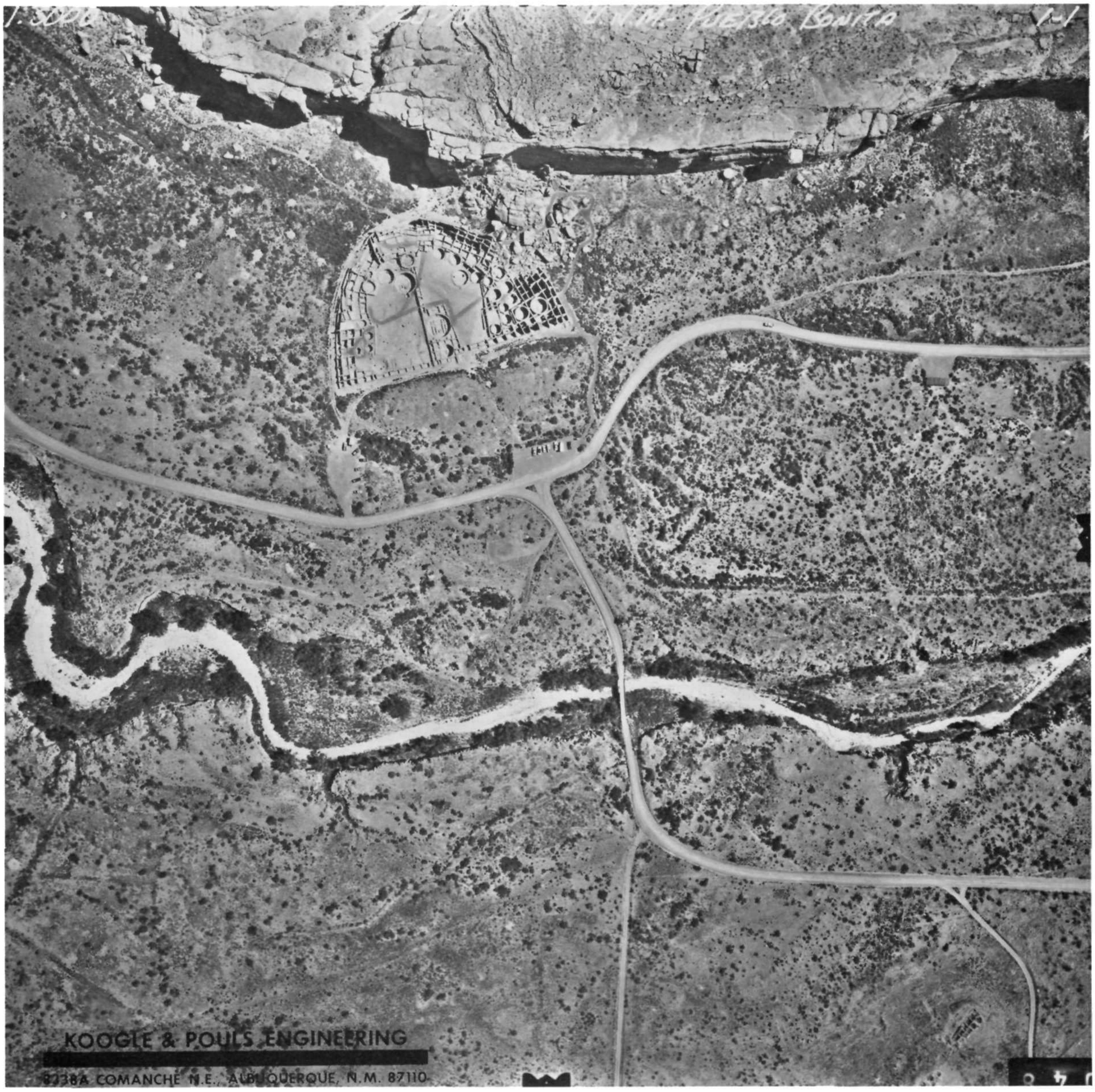

Figure 10 A high quality photograph of the Pueblo Bonito ruin, Chaco Canyon National Monument, taken by a private aerial firm at an original scale of 1:3000. Note annotations at top and bottom of photograph.

Section 4

Terrestrial Photography

Camera Platforms for Phase Mapping

Phase mapping is a technique that involves the systematic photographing of a site while excavation is in progress. Since photography is obtained at predetermined intervals during excavation (e.g., every six inches in depth), the technique provides permanent and acurate site information and can virtually eliminate the need for detailed site sketches and unrelated "busy work."

As a rule, site photographs are taken from established points or camera stations, and cameras are suspended and stabilized by the employment of platforms such as bipods, tripods, or tethered balloons. The bipod consists of two poles assembled into an A-frame and having a platform near the top to support a camera; the frame is held in place by two or more guy wires. The camera, preferably devised to operate by remote control, can thus be suspended 15 to 20 feet above the site for near-vertical exposures. Tripods, of course, are operated in a similar fashion. The arrangement makes it feasible to measure the exact height of the camera above the ground; hence, the photographic scale is readily determined (fig. 11).

For large sites where the camera must be elevated to heights of 50-100 feet or more, tethered balloons can be rigged to serve as camera platforms. As one might suspect, a major problem in camera stability is presented by wind fluctuations. Thus balloon photography may be more suitable for general coverage of entire sites rather than for precise photos of individual rooms or grids. Remotely controlled cameras are a must for efficient balloon photography; motorized cameras have been successfully employed in this connection.

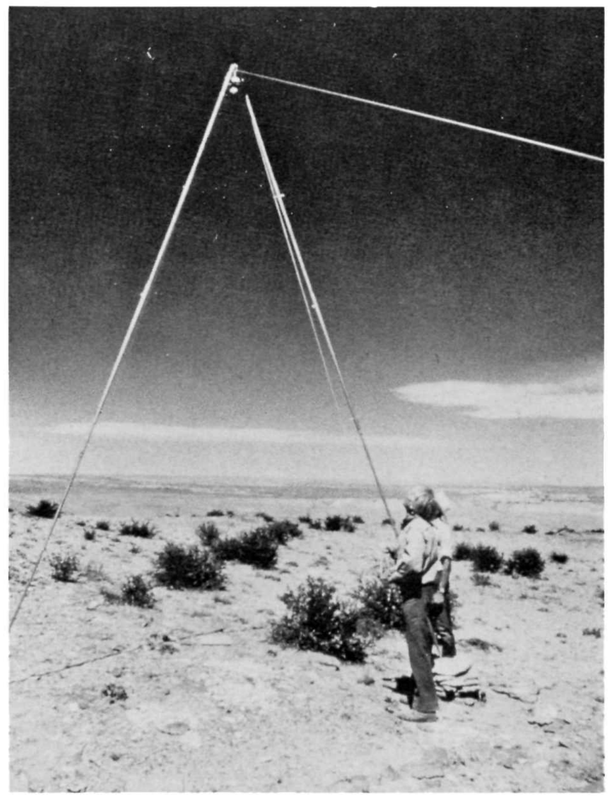

Figure 11 A bipod with attached 35-mm camera and guy lines over a small archeological site.

Cameras and Lenses

Most archeologists are skilled in the operation of hand-held cameras. Favored equipment includes 35-mm single-lens reflex cameras, 70-mm twin-lens reflex cameras and 4 × 5-inch sheet film view cameras.

Camera selection requires (1) selection of a suitable format, and (2) a comparison of various models available on the market. The camera must obviously be geared to the type of work planned; a camera designed for extreme closeup work may not be equally suited to general site photography. The complete archeological photographer will often wish to have cameras in two or more formats, focal lengths, etc. Therefore, cameras with interchangeable backs and lenses are generally to be preferred. A favored combination is a 35-mm system, along with a 4 × 5-inch view camera, including accessories.

For good archeological perspective, view cameras are almost indispensable. A good view camera can also serve as a copy camera for closeup work and for preparing scientific illustrations. The standard lens for most cameras has a focal length equal to or slightly longer than the diagonal of the image; for example, a 50-mm lens is considered normal on many 35-mm cameras and a 6-inch lens on many 4 × 5-inch cameras. Shorter focal length lenses will include a wider field of view, longer focal length lenses a narrower field. Many manufacturers are supplying as standard equipment on their 35-mm cameras a normal lens with a speed of at least f/2. With modern films, such a lens is adequate for nearly any photographic mission.

Stereo Photography

Ground sterograms are most easily made with a stereo camera equipped with negative film. When a stereo camera is not available, however, three-dimensional pictures can be taken with any good camera, provided the objects being pictured remain stationary long enough for two separate exposures to be made.

If ground stereograms are to be studied under a lens stereoscope, a camera having a negative format of 2¼ × 2¼ inches is ideal for stereoscopic photography. The technique is as follows:

a. Frame the desired view carefully in the camera viewfinder and mentally note the exact limits of the area photographed.
b. Move the camera several inches to the left or right and take a second exposure of precisely the same area. For later printing of views in their correct relative positions make notes on whether left-hand or right-hand negatives were exposed first on the film roll.
c. After the two 2¼ × 2¼-inch prints are mounted side by side, they are ready for three-dimensional study with a simple lens stereoscope.

It will be noted that when two separate exposures are taken for stereo viewing, the three-dimensional effect is heightened by increasing the lateral distance (photo base) between left and right exposures. As a general rule, this photo base should measure three to four inches for objects 100 to 200 feet away and four to ten inches for distant landscapes. For any given camera and subject, of course, the ideal separation is best obtained by trial and error.

Section 5

Applications

Site Discovery Principles

Although some archeological sites are (and will continue to be) discovered purely by accident, there are systematic means of searching for and finding sites in any physiographic region. Humankind's own brief, recorded history provides many clues into past settlement patterns and activities of earlier civilizations. The various factors that led ancient peoples to select particular sites for their villages, forts and burial grounds are still determinant forces today. This governing principle is especially apparent among agrarian, non-industrialized societies.

In aboriginal or tribal communities, the essential elements for the survival and perpetuation of a society were about the same as they are now:

1. A reliable source of water,
2. A means of finding game and edible wild plants, and/or the capability of growing food crops,
3. Shelter from the elements and protection from enemies,
4. Land or water access routes for transporting essentials to a selected habitation site,
5. A favorable climate, i.e., an acceptable environment in relation to other alternatives known to be available.

If a given physiographic region is systematically surveyed with the foregoing criteria in mind, it will become apparent where the most hospitable habitation areas are situated. As a minimum, the search can be appreciably narrowed by applying these controlling factors in a "convergence of evidence" (Lyons and Avery 1977:59).

It will be recognized that many of the controlling elements of human environments can be identified or inferred from the study of aerial photographs and/or nonphotographic imagery. Since the availability of water is the most critical requirement for habitation sites, preliminary searches should be concentrated near perennial streams and lakes. The hierarchical ranking of the other controls must be established on the basis of local considerations, because relative importance will vary from one archeological period or physiographic region to another. The use of aerial imagery, coupled with a well-conceived search rationale, can greatly improve the chances for site detection in relatively unexplored regions.

In a world faced with an ever-increasing population and accompanying food shortages, the unearthing of ancient civilizations can produce significant benefits to those who struggle for survival today. For example, the discovery of once-arable lands that supported earlier peoples may provide us with new insights on living in harmony with near-hostile environments. We can also derive valuable information on what *not* to do, *if* we are receptive to the lesson of history. There are numerous cases where formerly lush rangelands have been completely denuded by overgrazing. The signs are clear for those who can learn by observation.

Photographic Anomalies as Site Indicators

A photographic anomaly as here defined is an observed pattern on a photograph which is out of keeping with the imaged environment or a pattern which is in contradiction to one's expectations of the characteristics of the studied environment. There are numerous examples of such anomalies which an investigator familiar with the environment will recognize. Examples are linearities, unusual variations in pattern of drainage channels, geometric designs out of phase with the natural setting, soil color changes, soil blowouts and variations in vegetative cover patterns. Some anomalies encountered in a semiarid environment are illustrated in Figure 12.

Anomalies are identifiable on all photographic emulsions, black-and-white, color and color infrared. They may, of course, be more apparent on one type and scale than on another, and which type is best suited for a given environment can be determined only by experience in the use of the imagery in the selected area of study.

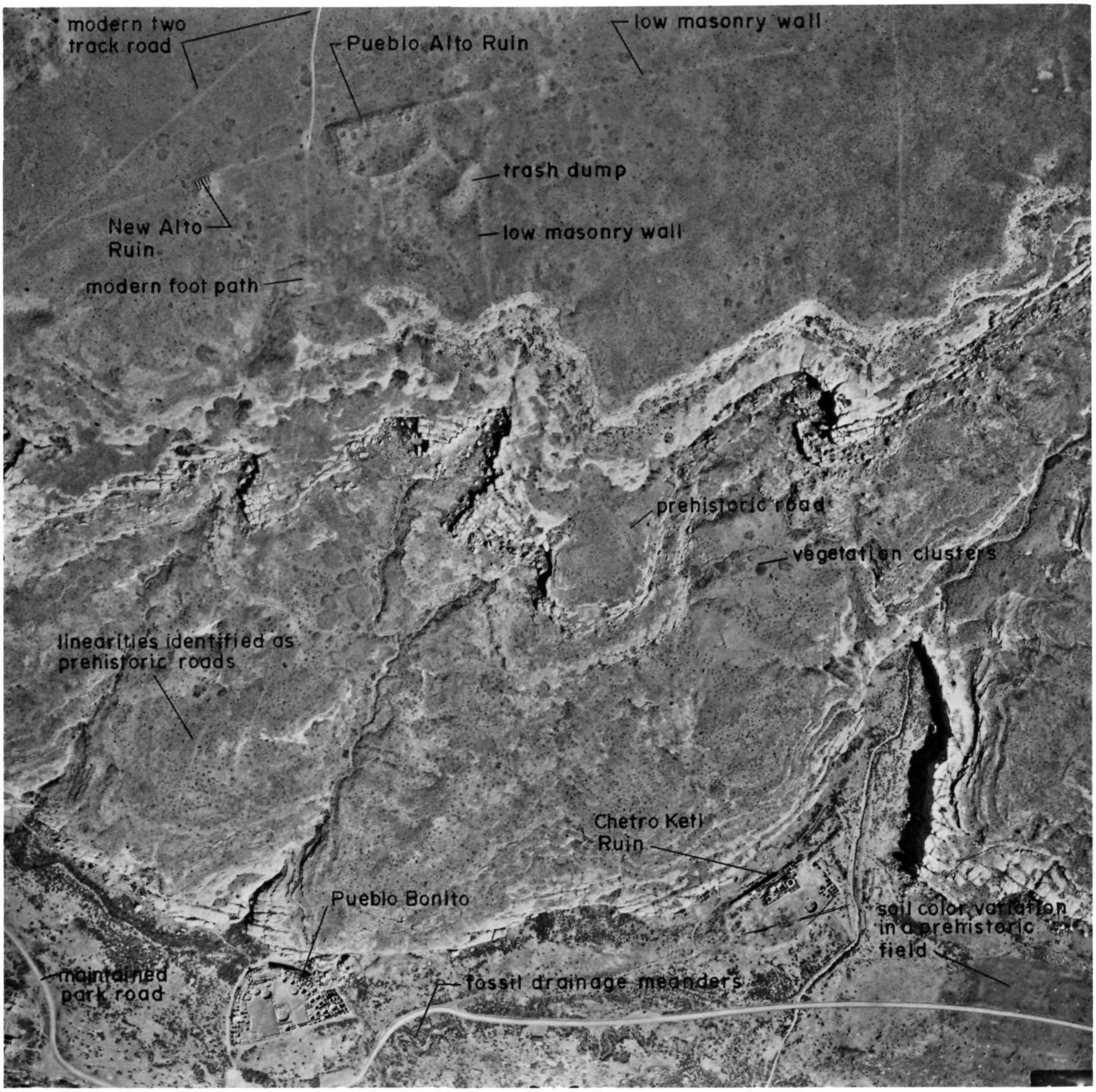

Figure 12 Vertical aerial photograph of a portion of Chaco Canyon National Monument identifying numerous anomalies in the landscape.

Direct Site Identification Techniques

Site Detection from Plant Marks. Faint indications of buried or obscured sites are sometimes directly discernible on aerial imagery. Subtle outlines of ancient features may be produced by plant-growth anomalies, soil variations, or shadow patterns. Unfortunately, these faint delineations may be registered only at certain times of the day or during limited seasons of the year.

Differences in the color, density, or height of agricultural crops or grassland will sometimes provide a clue to the existence of buried landscapes. And, the occurrence of different or unusual tree and shrub species may furnish additional evidence of subsurface features. A common explanation for these anomalies in plant growth is that the upper soil horizon has been disturbed and is no longer uniform, i.e., the zone of cultivation has become more fertile or less fertile due to subsurface change. Consequently, plant growth directly above the affected area will be either superior or inferior as compared to that on uniform, undisturbed soils.

Plant growth differences due to root-penetration variations may result from the remains of features such as filled-in ditches or buried foundations. If the buried feature lies below the normal plowing depth, the crop marks may reappear each growing season. A stimulation of plant growth over filled-in ditches results in *positive* crop marks; where growth is inhibited, the surface indication is a *negative* crop mark.

Positive plant marks are often well-developed on subsoils composed of compacted gravels, chalk, or silt; limestone and loose gravels are apt to be much poorer for producing positive marks. The kind of subsoil has a lesser effect on negative marks, because buried impervious materials nearly always inhibit the growth of plants directly overhead (fig. 13).

Grains such as wheat are the best kinds of crops for producing distinctive marks, although native grasses are also good indicators. Vertical photography is preferred for registering crop marks that result from differences in plant density. Oblique views with a low sun angle may be more desirable for detecting subtle marks that are based on plant height or color differences, however. Photographic flights over cultivated areas are ideally planned for dry weather as the crops are nearing maturity.

Site Detection from Soil Marks. When features such as ditches, depressions, or excavations are filled in, the result is an anomalous soil profile. In some cases, soils are mixed in such a way that the original subsoil appears at the surface. The variations in soil color, texture, or moisture can often be seen on aerial imagery as soil marks, even when such delineations are indistinguishable by terrestrial observation.

Soil marks may indicate the presence of buried archeological sites, although it will be recognized that similar markings can also result from more recent activities such as buried pipelines, underground utility cables, abandoned roads, or abandoned stream channels. The most striking soil marks are produced where there is a significant color contrast between the "normal" surface soil and the disturbed fill material. The marks usually show up best when the soils are drying out—two or three days after a heavy rain.

Where there is little difference in soil coloration, marks or delineations may still be found on the basis of differential moisture retention. For detecting these kinds of soil-moisture differences, it is usually desirable to utilize an infrared film emulsion.

Soil marks are most easily seen when they occur in cultivated areas, and they may be especially vivid right after the plowing of fallow fields. The marks may remain visible for hundreds of years, provided the buried feature or disturbed soil is below plowing depth. Of course, as surface soils become more uniform due to cultivation, the soil marks will gradually become less distinct and they may even disappear.

Soil marks are key diagnostic features in the aerial detection of covered archeological sites. The intelligent interpretation of unusual soil delineations has led to discovery of many burial mounds, walled cities, fortifications, and ancient irrigation systems.

Site Detection from Shadow Patterns. When the sun's rays fall obliquely on irregular terrain features, even minor surface configurations may be outlined by a distinct pattern of shadows. Such shadows can be useful site indicators of features that may pass unnoticed on the ground, e.g., eroded burial mounds, worn down earthworks, old hedge-

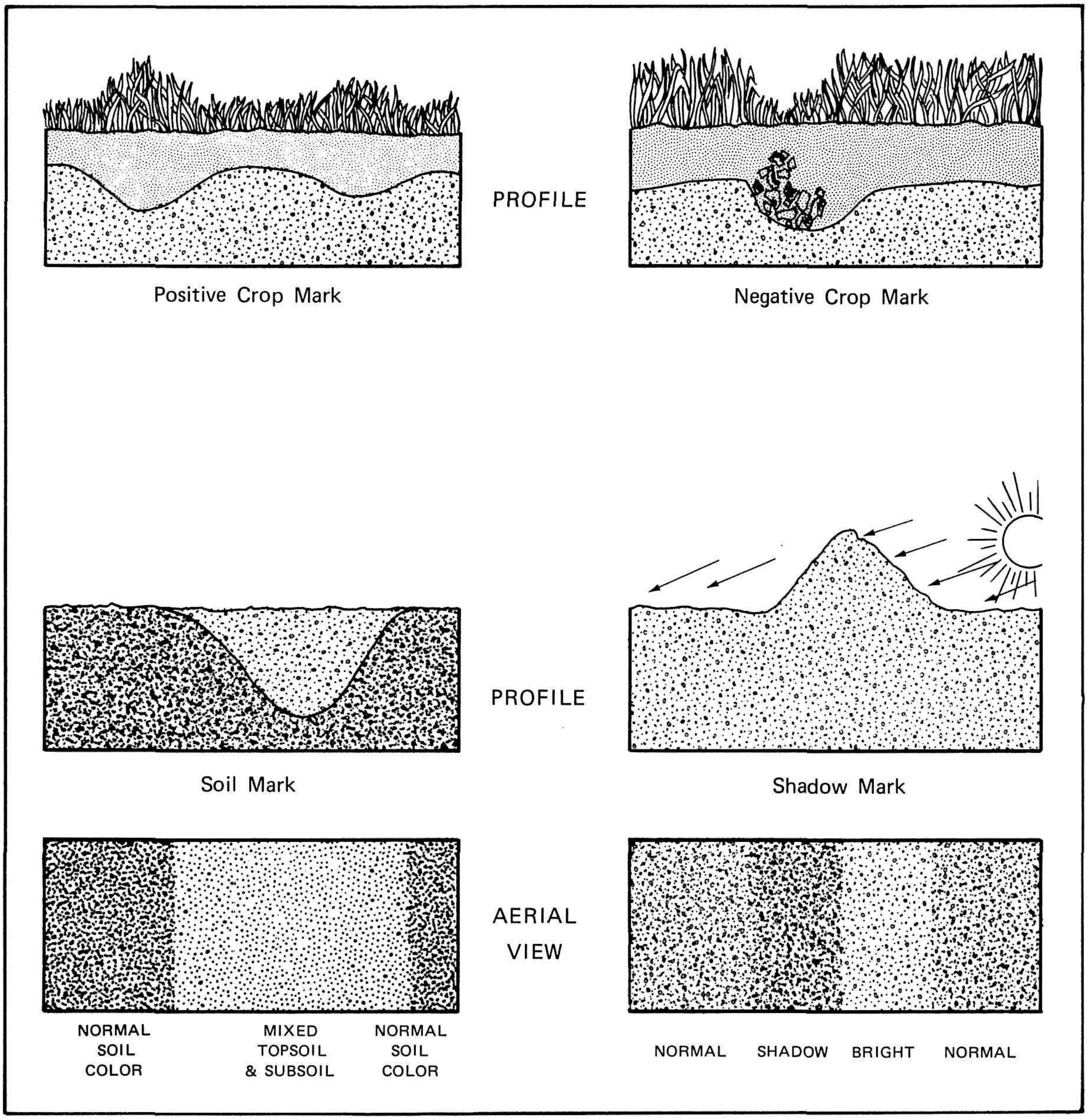

Figure 13 Terrain models showing crop marks, soil marks, and shadow marks.

rows, and wall fragments. These subtle relief differences are indicated by the contrasting tones of shadows, normal image shades, and highlighted zones.

Minor terrain irregularities require a low sun angle for the production of useful shadow patterns. Therefore, early-morning or late-afternoon flights may be essential for obtaining the desired image characteristics. The sun's direction, as well as its elevation, can be important in revealing diagnostic shadows. For example, linear patterns are most clearly seen when the sun's rays strike the terrain feature at right angles; the same feature may be invisible if it happens to trend in a parallel direction. For exploratory flights, it is therefore desirable to obtain imagery during different times of the day.

Interpretation problems may be caused by shadows of obscuring objects, such as hills, trees, or buildings. The masking of indistinct shadow patterns by vegetation can be partially overcome by photographing forest regions when deciduous plants are leafless.

Indirect Site Identification Techniques

Site Survey with the Aid of Aerial Photography. When sites cannot be seen or identified directly upon inspection of aerial photographs either monoscopically or stereoscopically (which is frequently the situation encountered), the photography can, however, be a useful tool for site surveys in the field (Loose and Lyons 1976; Morris and Manire 1976). The principal involved in the use of aerial photographs in the field is as follows. In regions where it is possible to discriminate between features on the ground, for instance in hilly country, in lands with exposures of rock outcrops, in areas of variable vegetative cover types and distinctive drainage patterns, it is often possible to locate on the photograph one's own position on the ground. This can be done by standing on a site when the site itself is not discernible on the image and is accomplished by a kind of visual or eyeball triangulation. The surveyor studies the terrain and the observable trees, rocks, drainage, etc. By reference to several of these features, the surveyor locates his position on the photograph, and if standing on a site, can pinprick the image to record precisely the site location. In addition, the image can also be used to provide a record of the environmental setting of the cultural remains. Trees, shrubs, grass, soils, rocks, water bodies, etc., together with their variable characteristics are often readily apparent. Only a minimal amount of note taking may be necessary to record relevant information while on the site, enabling the surveyor to move more rapidly, cover more territory in a given period of time, thus effecting an economy, and at the same time, securing detailed information.

Environmental Studies. On all four emulsion types discussed here, black-and-white, black-and-white infrared, color, and color infrared, a vast amount of data is recorded in the earth disciplines of pedology, geology, biology, and geomorphology. Frequently, such data are of use to the archeologists not only for determining site locations, but also for developing an interpretation and explanation of material cultural manifestations based on the recorded environmental factors. In addition to the detection of soil marks and soil types or boundaries between soil types, some notion of soil depth can be determined (fig. 14 and 15). Rock outcrops and rock types are of frequent interest to the field archeologist. In such areas as the arid Southwest where vegetative cover is sparse, this kind of information can be derived directly from a study of the aerial photography. Natural vegetative cover mapping is done with expedition and economy by using adequate scales and emulsion type. Vegetative cover type maps thus derived have led to reliable interpretations of land use in the historic and prehistoric past and to the partial reconstruction of the paleoenvironment (fig. 16).

A frequent concern of archeological investigations is knowledge of the paleoenvironment context. To arrive at the realities of the paleoenvironmental setting, it is necessary to understand the current ecological condition. By combining and analyzing data from environmental studies the current base for projections into the past can be prepared. An example of such a study is illustrated in Figure 15 and the process of analysis in Figure 17.

Water Resources. Photography obtained at regular intervals offers an efficient means of monitoring water levels and checking on periodic fluctuation in major rivers, tributaries, lakes, and reservoirs. Panchromatic and conventional color exposures are often utilized for water penetration analyses and

Figure 14 A stereogram of the Peñasco Blanco ruin in Chaco Canyon National Monument. Light areas in the lower portion of the images are sandstone outcrops devoid of soil and vegetative cover.

Figure 15 Color aerial photograph of the Chetro Ketl ruin on the floor of the canyon in Chaco Canyon National Monument. Note fracture patterns in sandstone and variations in soil color.

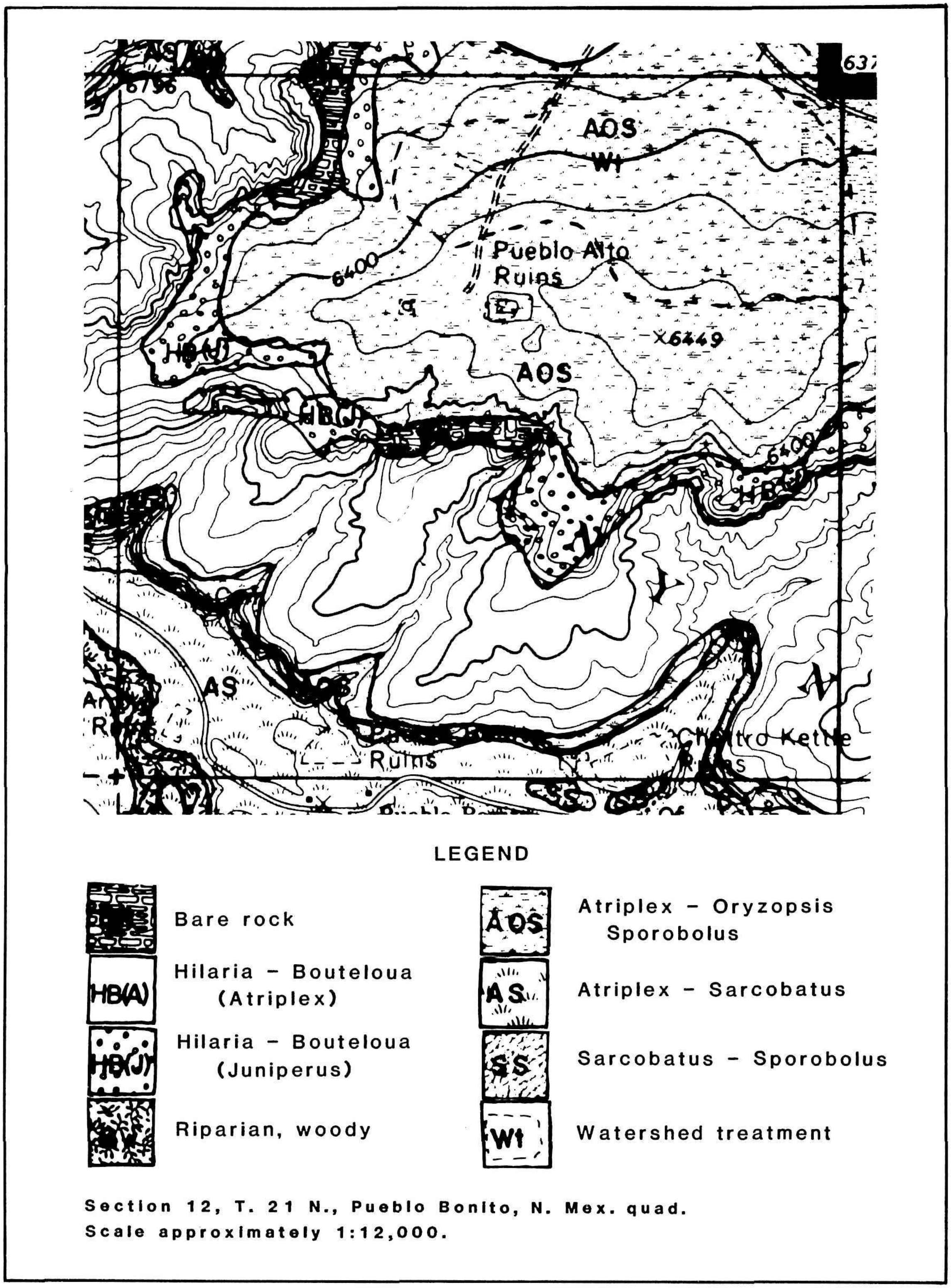

Figure 16 Example of vegetative type map. Taken from Vegetation Type Map of Chaco Canyon by Potter and Kelley, 1974.

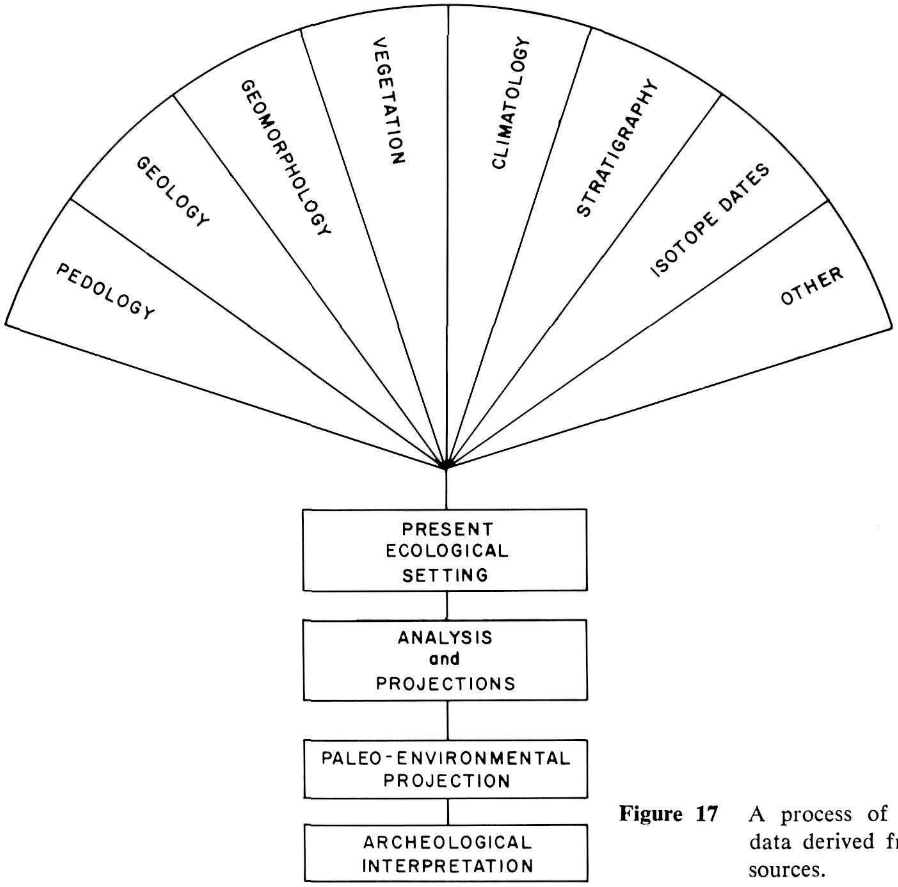

Figure 17 A process of environmental analysis using data derived from remote sensing and other sources.

for checking on siltation levels, while black-and-white or infrared color films are preferred for studies of shorelines, tidal marshes, and wetlands. Aerial photography is now a standard tool of the U.S. Geological Survey in continuing studies of the water resources of the nation (fig. 18).

Certain forms of water pollution can often be detected and assessed from aerial surveys. These include point sources of pollution such as sewage outfalls, dumping of petrochemical wastes into rivers, leaks from offshore or tidelands oil drilling and discharges of harmful acids and metallic salts from surface mines. In many situations, the type of industrial installation responsible for the pollution can also be identified by the photo interpreter. Maximum success in the detection and classification of water pollutants usually dictates a multispectral approach, i.e., photographic coverage with two or more different film emulsions. Special multicamera assemblies are now available so that simultaneous exposures can be made with four different films. Color infrared photography is especially useful in studies of water pollution.

Snow, an important source of surface water in northern latitudes, can be readily surveyed by aerial techniques if depth markers are strategically located in advance. Low-altitude oblique photographs can then be made at periodic intervals to obtain readings on the depth markers, and high-altitude vertical coverage is made to determine the area of the snow field. From such data, estimates of snow volume are obtained, and these estimates can be converted by hydrologists to the anticipated production of surface water from a given watershed.

Range Resource Surveys. Those scientists concerned with range management practices should be familiar with large numbers of native or introduced forage and browse plants that are favored by domestic and wild grazing animals. Comprehensive inventories of range resources may also include censuses of livestock or game animals, along with an analysis of soil types, water availability, and the range carrying capacity for various kinds of grazing animals. Aerial photography can be of

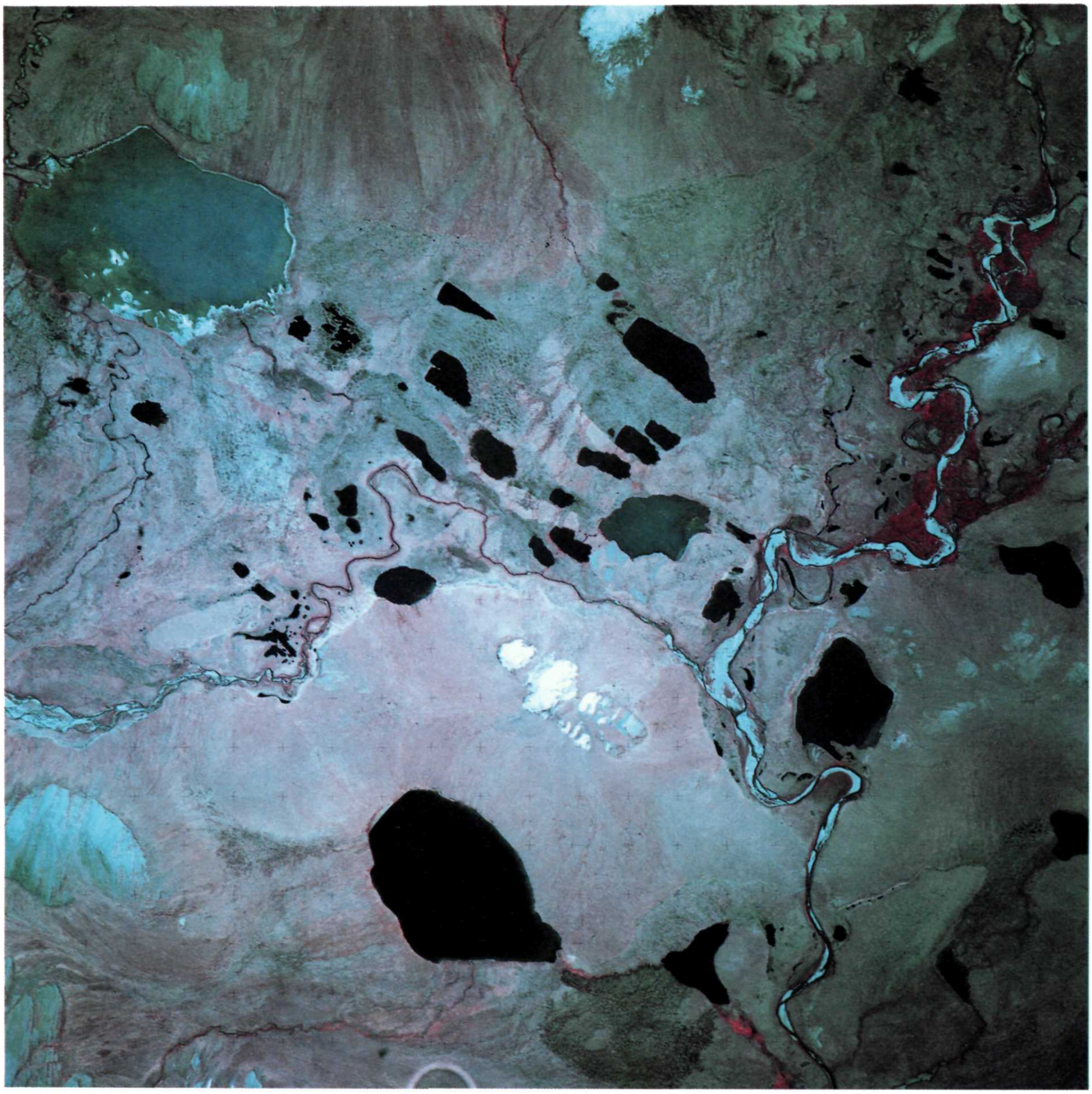

Figure 18 This is a color infrared aerial photograph of a portion of the north slope of Alaska. Color infrared rays are absorbed by water bodies and consequently water/land contacts are distinct, and varying hues in the water bodies indicate variable depth and/or materials in suspension.

valuable assistance for most of these tasks. Important grasses and shrubs can be identified from largescale color or infrared color exposures and carrying capacities (quantity of vegetation) may also be approximated; perennial streams and seasonal ponds or "stock tanks" can be quickly inventoried from smaller photographic scales.

Tests with both panchromatic and color photographs have shown promise in aerial classification of agricultural soils in which many archeological sites have been observed and mapped (Jones and Evans 1975). With color exposures at a scale of 1:5,000, it has been demonstrated that interpreters trained in standard soil survey techniques can recognize the soil grouping, soil series, and in some cases specific soil types. For agricultural soils, the best timing for photographic flights appears to be immediately after spring or fall plowing and during a period when soils are relatively dry. In forested regions where soil colors are obscured, a knowledge of the underlying geological structure, drainage pattern, and natural vegetation may enable interpreters to define the soil grouping or soil series by deductive processes.

Recreational Surveys. A preliminary recreational survey can be done almost entirely through photo interpretation. In effect, the objective is to locate potential recreational sites and transfer these areas to a base map of suitable scale. Sites are then checked on the ground to determine such information as past history and current land use, present ownership, potential availability, and possible undesirable features such as polluted water, excessive noise, or lack of all-weather access roads. After elimination of those areas that are unavailable or undesirable, a final report is prepared to summarize and rank the recreational potential of each site recommended. The report should be accompanied by both ground and aerial photographs which have been carefully annotated to emphasize salient features, needed improvements, and possible trouble spots.

Water-based recreation sites, in great demand around large cities, can be readily assessed and rated in terms of priority through the general procedures outlined here. *The Kodak Aero-Neg Color Process* is recommended for initial surveys of potential outdoor recreational areas; color transparencies are ideal for office interpretation, and the comparative black-and-white prints can be made available to field personnel for checking potential recreational sites and the archeological remains they may contain.

Recognizing Forest Cover Types. Identifying forest types or species associations is dependent on general familiarity with forest associations and plant ecology in the region to be mapped, because this knowledge permits the interpreter to mentally eliminate those cover types not likely to be encountered.

The chief diagnostic features used for recognizing forest cover types are photographic textures (smoothness or coarseness of images), tonal contrast, relative sizes of tree images at a given photo scale, and topographic location or site. When observed separately, these characteristics may constitute rather weak clues, but considered together, they will generally provide an essential link in the identification chain. In most regions of the United States, important forest types can be differentiated at photographic scales of 1:10,000 to 1:20,000. Black-and-white exposures are considered adequate for delineation of major forest cover types (fig. 19).

Guidelines for Aerial Surveys of Cultural Resources

Table 2 provides some generalized guidelines for aerial surveys. Since individual project objectives will vary from one locality to another, other combinations of films, seasons, and scales may be just as suitable as those recommended here.

Architectural Recordings with Aid of Controlled and Uncontrolled Aerial Photography

Of interest to both the archeologist and the historic architect is the mapped plan of cultural sites. Photogrammetric engineering firms located throughout the nation have the capabilities and skills to develop very precise and detailed planimetric and topographic maps of sites to fit the needs and specifications of scholars and resource managers (Pouls, Lyons, and Ebert 1976; Lyons and Avery 1977). Aerial photography obtained with horizontal and vertical control points visible on the imagery is a requirement for such accurate map development (Wolf 1974). However, if a high order of engineering accuracy is not a requirement, much useful information can be prepared in mapped form by inspection and the plotting of information on transparent overlays of the photos. An uncontrolled mosaic is readily constructed from aerial photographs by simply matching features on

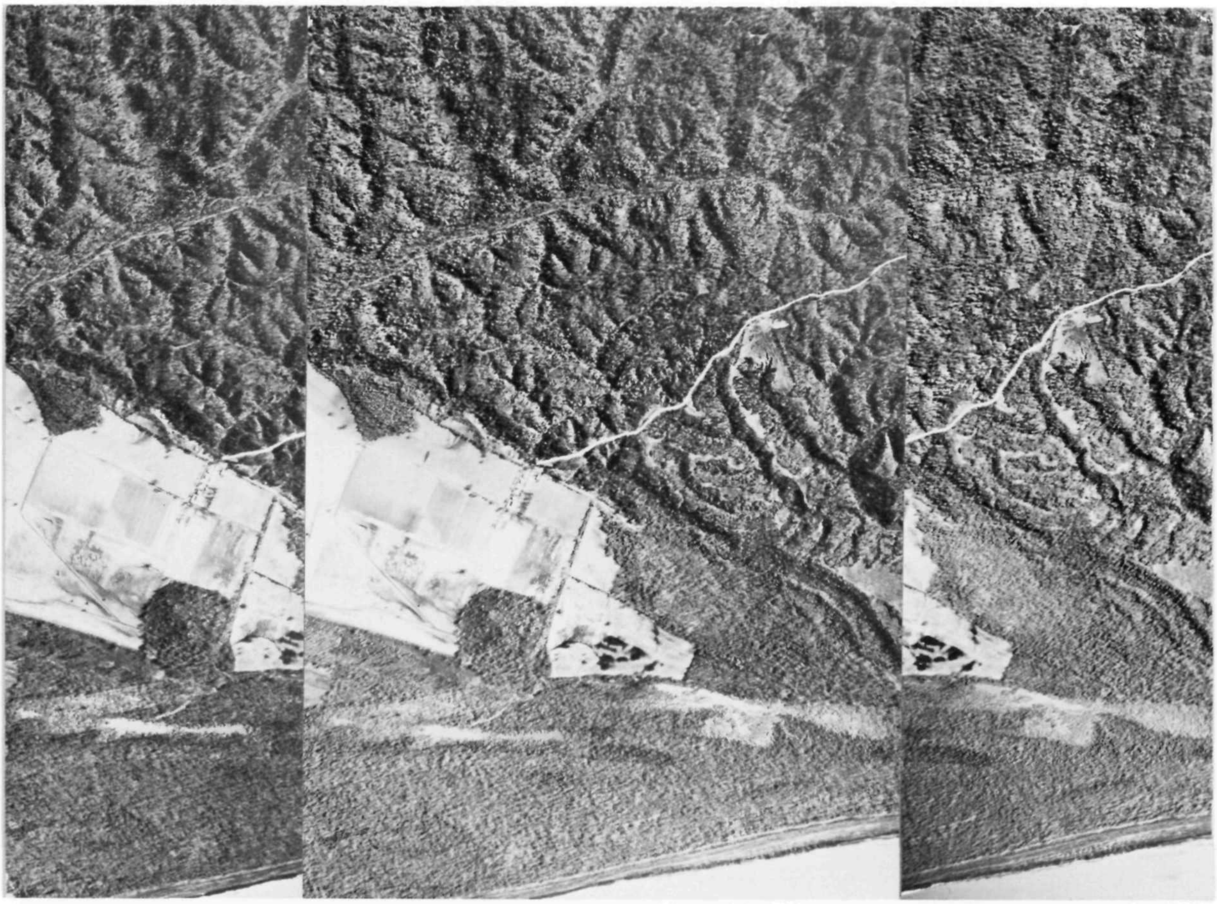

Figure 19 Stereo-triplet of an area near Natchez, Mississippi, showing an alluvial floodplain adjacent to dissected bluffs of loess (aeolian deposits). Vegetation on the flood plain consists of willows and cottonwood; the loess hills are largely covered with an oak-hickory forest type. Made on panchromatic film at a scale of about 1870 feet per inch. *Courtesy U.S. Department of Agriculture.*

overlapping photos along a flight line and between adjacent flight lines (Lyons and Avery 1977:32). Direct visual identification and sketching on overlays of features provide a useful product for a number of purposes (fig. 20).

For the development of precise architectural elevations, it is necessary to enlist the services of photogrammetrists skilled in what is termed terrestrial photogrammetry. On the other hand, a considerable amount of structural information can be obtained from photographs taken from terrestrial stations for the purpose of identifying and recording details such as masonry type, wall surfacing, window and door type, roof lines embellishment, etc. (fig. 21).

It should be noted that virtually all of the studies discussed on the documentation of archeological sites and of historic architectural features can serve as the basis for mitigation of threatened resources. Since mitigation is the recording of salvagable information, pictorial records contain much of importance for this purpose and sometimes is the only practical way of obtaining valuable data prior to land disturbances (Ebert and Lyons 1980).

Further, the maps, elevations and sketches constructed via photogrammetric techniques are of practical use for stabilization crews in the planning of restoration or preservation of historic fabric.

Table 2—Guidelines for aerial surveys of cultural resources *

Photo interpretation task	Type of film	Suggested season	Range of photo scales
Archeological reconnaissance and regional relations	Pan	Fall, winter	1:12,000 – 1:40,000
Water resources	Multiband	All seasons	1: 4,800 – 1:40,000
Soil surveys and mapping	Color	Fall, winter	1: 4,800 – 1:40,000
Resource management surveys	Color negative	Late fall, winter	1: 4,800 – 1:12,000
Surveys of wetlands or tidal regions	IR	All seasons—low tide	1: 4,800 – 1:30,000
Site location surveys	Pan	Fall, winter	1: 6,000 – 1:30,000
Rural studies	Pan	All seasons	1: 2,400 – 1:40,000
Urban studies	Pan	Late fall, winter	1: 2,400 – 1:10,000
Topographic and planimetric mapping	Pan	Late fall, winter	1: 2,400 – 1:10,000
Identifying plant communities	Color IR	Spring, summer	All scales
Forest mapping: conifers in Western USA	Pan	All seasons	1:12,000 – 1:20,000
Forest mapping: conifers in Eastern USA	Pan	Fall, winter	1:12,000 – 1:20,000
Forest mapping: mixed stands	IR	Late spring, fall	1:10,000 – 1:12,000
Locating property boundaries	Pan	Late fall, winter	1:10,000 – 1:25,000
Measuring areas	Pan	Late fall, winter	All scales

* It should be noted that black-and-white panchromatic photography has generally been regarded as the standard for archeological studies. In many instances, however, color photography can be used to greater advantage.

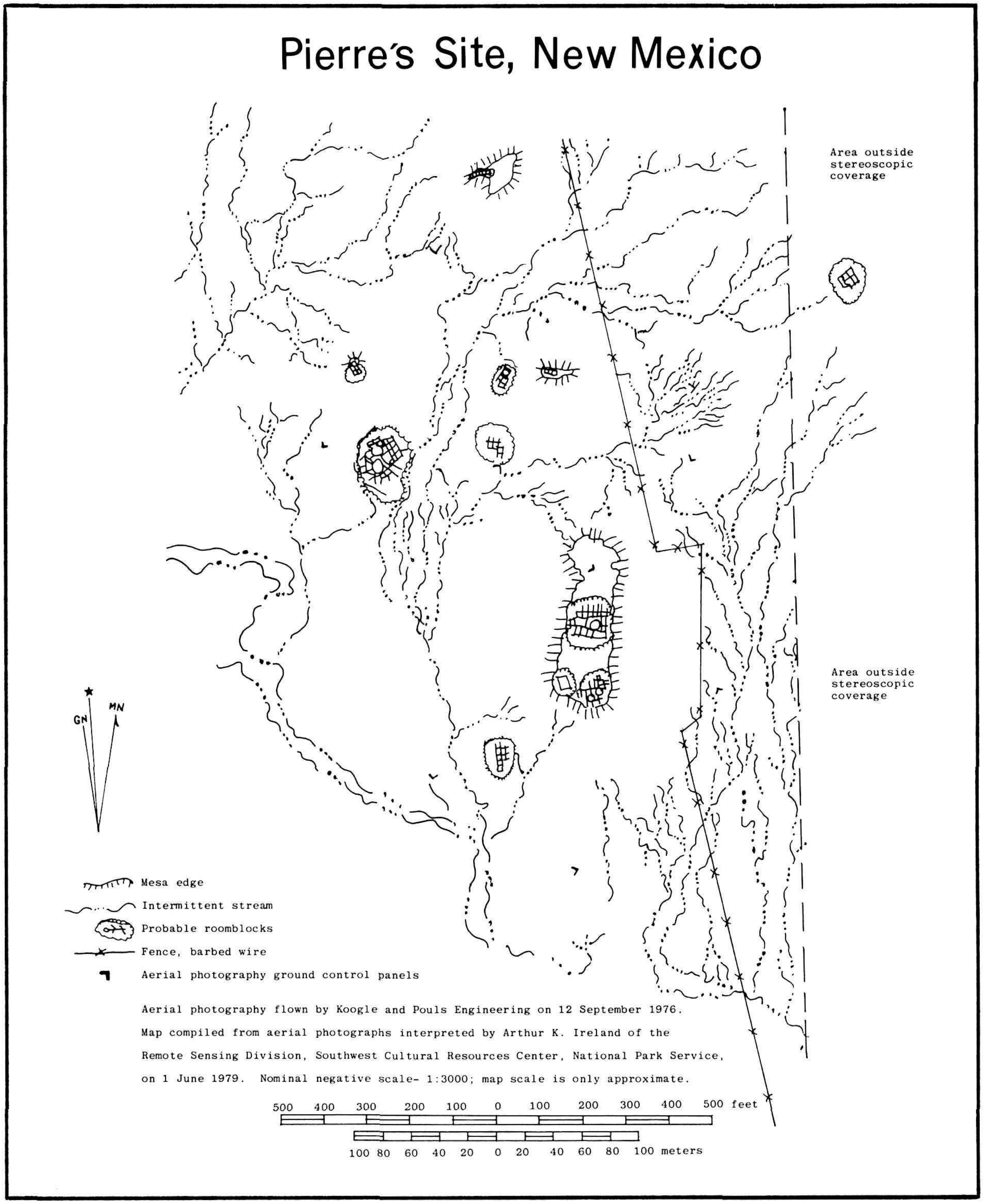

Figure 20 Overlay sketch map of a black-and-white aerial photograph at an original scale of 1:3000 of the Pierre's Site area in San Juan County, New Mexico. Note the rectilinear patterns of the numerous prehistoric architectural features.

Figure 21 Stereogram of Antelope House, Canyon de Chelly National Monument, Arizona. *Photograph by Myra Borchers.*

Relative Dating with Aerial Photography

Time-lapse aerial photography serves as a base for age dating of changes in the environment, both natural and man made. For instance, during the 1930's and later, government–contracted aerial photography of much of the United States was flown at nominal scales of 1:24,000 to 1:30,000. This imagery has provided a historic base against which changes can be identified and described over a relatively short period of time. Space photography taken from Gemini and Apollo flights also serves the same purpose. When the Shuttle becomes operational, it is probable that imagery secured from that space platform can be used to compare with the earlier space photography.

Examples of relative age dating can be found in Lyons and Avery (1977:62) and Parry (1978).

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Appendix

Technical Specifications for Aerial Photography from U.S. Department of Agriculture

310 EQUIPMENT

311 Aircraft

Each airplane shall have a service ceiling with operating load (crew, camera, film, oxygen, and other required equipment) of not less than the highest altitude specified in the Bid Schedule. When the flight plan and location of any item in the proposed coverage fall within positive-control airspace, the aircraft must contain the appropriate equipment to operate in such positive-control areas within the purview of FAR 91.97. The design of the airplane shall be such that when the camera is mounted with all its parts within the outer structure, an unobstructed field of view is obtained. The field of view shall be shielded from the exhaust gases, oil, effluence, and air turbulence. No window of glass, plastic, or other material shall be interposed between the camera(s) and the ground to be photographed unless authorized by the USDA. If necessary to interpose a window between the ground and the camera the window shall be of optical flat glass, free of scratches and blemishes, and shall not degrade the resolution or the accuracy of the camera. The physical characteristics of the window shall be reported to the USDA on or prior to the bid opening.

312 Laboratory

The contractor's laboratory shall be adequately equipped and staffed with sufficient personnel to facilitate the production of high quality photographic materials or shall have access to such facilities. All aerial film, black and white and color, shall be processed with proper sensitometric control.

313 Aerial Mapping Camera and Filter

Only camera systems which meet the requirements in Section 200 of these specifications as determined by a current USGS camera calibration test report shall be used. Focal length and filter will be specified in the Bid Schedule. USDA shall have the right to require the removal of a camera from use when deficiencies in photographic imagery attributable to the camera are found to exist. Any camera removed from use by USDA shall not be returned to use on USDA projects until the cause of the malfunction is corrected to the satisfaction of USDA. That determination will be based on additional acceptable samples as required under Paragraph 135 and an additional test by the Optical Calibration Laboratory of the USGS, if needed.

314 One Camera Requirement

Unless otherwise specified in the Bid Schedule, or unless prior approval has been obtained from the Contracting Officer, only one camera may be used to photograph an area.

320 PHOTOGRAPHIC CONDITIONS

Photography shall be undertaken when skies are clear, free from smoke, excessive haze, and well-defined images can be resolved. The ground shall be free from snow below timberline, standing water (other than natural or man-made ponds and lakes), and flood waters from streams which have overflown their banks. Photography shall be undertaken only during that portion of the day when the sun angle exceeds the minimum specified in the Bid Schedule. Photographic operations shall be limited to the time of year specified in the Bid Schedule or as otherwise provided in writing by the Contracting Officer.

321 Priorities for Photographing Project Areas

When required, certain projects listed under an item shall be photographed in the order directed by the Contracting Officer, weather and ground conditions permitting. All reasonable effort will be directed toward providing a schedule of operations favorable to both the government and the contractor.

322 Coordination of Photography With Ground Targeting

On certain projects where the ground control points are targeted prior to photography, photographic operations must be coordinated with the placing of targets on the ground so that minimum time will elapse between the targeting and photographic operations. These projects will be designated on the Bid Schedule. The contractor shall consult with the Contracting Officer before beginning photographic operations on these projects.

330 COVERAGE REQUIREMENTS

331 Areas to be Photographed

Location, size, and project names of the areas to be photographed are described in the Bid Schedule and delineated in approximate position on a map or maps attached thereto.

332 Flight Line

332.1 Maps

The successful bidder will be furnished three (3) sets of maps at the scale stated in the solicitation. One set of these maps will show the length, direction, location of each flight line, and the flight altitude of each line (or portion of line) above mean sea level (see Bid Schedule Exhibit I).

332.2 Coverage

Coverage shall be obtained to the terminal points of each flight line, as indicated by the tick marks on the flight line map(s) furnished the successful bidder. The beginning and ending photo centers must be exposed on or outside of each tick mark.

332.3 Breaks

If it is necessary to break a flight line when obtaining original photography, no more than one break shall occur in a flight line. The flight line resulting from the break shall have no less than 100% overlap at the break and shall not be less than 3 exposures in length.

332.4 Reflight Photography

Reflights for aerial photography shall be centered over the plotted flight line and shall consist of no less than three (3) exposures in length and with no less than 100% overlap at each break. All reflight photography shall be flown using the same camera system as used in the original photography.

332.5 Exposure Stations

Exposure stations, when required in the Bid Schedule will be designated on the flight line maps. Individual negative frames will be exposed so that the center of the exposure does not exceed the allowable deviation stated in the Bid Schedule.

333 Individual Counties or Areas and Block Flying

Each county or area shall be flown separately except where block flying is authorized in the Bid Schedule. Counties in a block shall not be flown separately unless specified in the Bid Schedule.

334 Deviation From Specified Flight Altitudes

Deviation from specified flight height shall not exceed 2% low or 3% high for all flight heights up to 12,000 ft. (3,650 m). Above 12,000 ft. deviation from specified flight height shall not exceed 2% low or 600 ft. (180 m) high. Deviations are computed using the flight height above mean ground elevation.

335 Horizontal Deviation

Deviation from the plotted position of the flight line in excess of eight (8) percent of the flight altitude above the mean ground elevation may cause rejection of the entire flight line.

336 Overlap

336.1 Endlap in Line of Flight

Endlap (overlap in line of flight) shall be approximately sixty-two (62) percent unless otherwise specified in the Bid Schedule. Any endlap of less than fifty-seven (57) percent or more than sixty-seven (67) percent may be cause for rejection of any, or all, of the photographs in the flight strip in which such deficiency occurs.

336.2 Sidelap

Sidelap will depend on the altitude, scale, and position of flight lines. Sidelap will be designed for a 30 percent average, 15 percent minimum, and a 45 percent maximum, unless otherwise specified in the Bid Schedule. Minimum sidelap for Analytical Aerotriangulation Aerial Photography shall be 25 percent.

337 Crab

Any series of two or more photographs crabbed in excess of five (5) degrees as measured between photographs in line and between adjoining lines may cause rejection of that particular flight line of negatives.

338 Tilt

Negatives made with the optical axis of the camera in a vertical position are desired. Tilt (departure from the vertical) of any negative exceeding four (4) degrees or relative tilt between any two successive negatives exceeding six (6) degrees may be cause for rejection.

339 Image Motion

Exposure shall be made at the fastest shutter speed possible using the optimum aperture setting for the lens based on the various factor involved. Total exposure time shall produce no more image movement during exposure than one-half the linear distance resolved on the film.

340 AERIAL FILM

341 Film Characteristics

Only medium or fine grained, unexpired, polyester base film of the type specified in the Bid Schedule shall be used. The film base, excluding the emulsion, shall not be less than .004" (0.10mm) in thickness and be 9½" (24.1 cm) wide. For color emulsion, the film shall not exceed 200 feet (61.0 meters) in length. For panchromatic and black and white infrared emulsions the film shall not exceed 250 feet (76.2 meters in length.
Color and panchromatic emulsions shall be sensitive to the entire visible spectrum plus an extended red sensitivity from 400 to 720 nanometers. Color infrared and black and white infrared shall be sensitive to the visible and near infrared spectrum from 400 to 900 nanometers.

342 Processing

All aerial film shall be processed under controlled sensitometric conditions. The processing conditions shall be properly controlled to achieve consistant and even development. Processing development gamma shall not vary more than 0.10 density units throughout the roll of film. All color and color infrared film shall be processed according to manufacturer's instructions. Prior to processing a 21-step sensitometric wedge (in 0.15 density increments) shall be exposed on both ends of each roll of film and shall remain in the roll when delivered to USDA. A leader of at least three (3) feet shall be attached to each end of the roll.

It is recommended that a minimum of five (5) frames be exposed at the beginning of each roll for the purpose of providing the processing laboratory with a test strip. These frames should be representative of the terrain and exposure conditions prevalent on the balance of the roll A 21-step sensitometric wedge should be exposed to this test strip to assist in determining the processing necessary to achieve the desired density and density range.

Extreme care shall be exercised to insure proper exposure and processing to minimize vignetting due to differential exposure This differential shall not exceed that which would result from a basic ¼ stop difference in exposure.

343 Film Density

Density measurements will be taken on negatives using a transmission densitometer with a 2mm probe for scales 1/36,000 and larger and with a 1mm probe for scale 1/36,000 and smaller. Readings will be made no closer than 1½" from the negative edge. Negative densities for panchromatic and black and white infrared film shall be as follows:

343.1 Base plus fog density shall not exceed 0.20 as measured between and at the edges of the negative frame.

343.2 The minimum usable density as measured on the original aerial negatives shall be no less than 0.25 and maximum usable density no more than 1.50 after deducting base plus fog density.

343.1 The average density range aim point should be 1.0. The minimum density range should be no less than 0.55.

344 Storage and Handling

Storage, exposure, and handling of all photographic materials shall be in accordance with the manufacturer's recommendation. The film shall not be rolled tightly on spools or in any way stretched, buckled, distorted, or exposed to excessive heat

345 Dimensional Stability

The dimensional change in any direction across a 9" distance shall not exceed 0.005" at 65-75 degrees Fahrenheit and 45-55 percent relative humidity.

346 Physical Quality

All aerial film shall be free from chemicals, stains, tears, scratches, abrasions, water marks, finger marks, lint, dirt, and other physical defects. The imagery shall be clear and sharp in detail and uniform in density. It shall be free from snow, clouds, cloud shadows, smoke, haze, light streaks, static marks, and other defects that would interfere with the intended purpose.

All film shall be thoroughly fixed and washed to insure freedom from residual silver, hypo, and other chemicals which might impair permanency. Film or prints found to contain an excess of residual silver or hypo by test procedures in Kodak Data Books J-1 and J-11, quoted below, may be rejected or returned to the contractor for refixing and rewashing.

346.1 Hypo Test HT-2

The concentration of hypo in either prints or film shall not exceed 0.04 milligrams per square inch. The color of the test area shall not exceed that of Patch No. 3 of the Kodak Hypo Estimator of EKCo. Data Book J-11.

346.2 Residual Silver Test ST-1

Follow the procedures for Test ST-1 as given in Eastman Kodak Data Book J-1. The color of the test area shall not exceed that of Patch No. 1 of the Kodak Hypo Estimator of EKCo. Data Book J-11.

347 Composition of Negative Roll

A roll of aerial negatives shall consist only of exposures made with the same camera system (lens, cone and magazine). Unless otherwise specified in the Bid Schedule no more than one area may be placed on a roll. Film spools having a flange diameter of approximately 13.3 cm (5¼ inches) shall be used, and only that length of film which can be wound on a spool without strain, leaving at least 3 mm (⅛-inch) of flange exposed, shall be placed on each spool. Three (3) feet of blank or unused film shall be left beyond the first and last used negative on each roll or segment to serve as leader and trailer. All film on any one roll shall have the same roll number.

348 Splicing Film

Splicing shall be accomplished with three-quarter (¾) inch pressure sensitive polyester base tape. The splices shall be of the butt-joint type with tape placed on both sides of the splice. Particular care shall be given to the alignment of the film when splicing, with care taken to trim all excess binding tape in order that the film will be perfectly straight after splicing.
A splice shall not be closer than twenty (20) inches from the image edge of any accepted negative.

350 CONTACT PRINTS

The Bid Schedule will specify types and weights of prints required. Prints must be properly developed and thoroughly fixed and washed. They must be clean and free from stains and blemishes, uneven spots, air bells, fog, and finger marks. Photographic papers of proper contrast must be used in making suitable contact prints to bring out all the details of the negative.
Contact prints from the aerial negatives or positives shall be made without mask on one of the following materials:

351 Black and White

351.1 White opaque, polyester base .007″ thickness, such as Dupont's Cronapaque or equal.
351.2 Low shrink resin coated paper such as Eastman Kodak Kind 1717, Kind 1594, Kodabromide or equal.

352 Color

Sandard commercial grade multilayer color photographic paper capable of yielding sharp images and proper color balance. The Bid Scheule will specify types of weights of prints required.

360 EDITING OF AERIAL NEGATIVES

361 Required Editing

Each aerial negative shall be clearly edited with the following data as shown by Figure 4.
361.1 Date (month-day-year in standard numeric notation).
361.2 Departmental designator (As specified in the Bid Schedule).
361.3 Scale (denominator of representative fraction expressed to nearest thousand, e.g., 1:15,840 will be 16).
361.4 State and County or National Forest Code as specified by the USDA in the Bid Schedule.
361.5 Roll (number in series) followed by the contract fiscal year designation specified in the Bid Schedule, e.g., 376.
361.6 Exposure (number in unbroken series beginning with 1, *Not 001* or *01*).
361.7 The first and last exposure in each strip and at each break in flight line shall also be edited with time (standard civil time of day of the exposure).

362 Type and Size of Characters and Application

The characters used in editing shall be of the Gothic Type 0.25″ high. They shall be sharp, uniformly applied, and easily read. The editing shall be placed on the non-emulsion side of the negatives and may be applied by use of a stamp. Use black non-flaking ink such as "Phillips Clear Print No. 7″ or equivalent. No smears or transfer of marking ink to other parts of the negative roll will be permitted.

363 **Location of Editing Characters**

Identifying data shall be placed in line along the most northerly, inflight (endlapped) edge of the aerial negatives of north-south flights and shall be placed along the western edge of negatives in east-west flights. Editing shall be positioned so that the characters are 1/10" from the image edge and 1/10" from the corner fiducials.

364 **Assigning Roll Numbers**

All rolls of film used in the photography of each project shall be numbered consecutively beginning with number one followed by the contract fiscal year designation specified in the Bid Schedule. In no instance will the same roll number of assigned to more than one roll in each area or block. Rolls of film used in the photography of reflights ordered by the USDA shall also be numbered consecutively starting with the next highest roll number as assigned to the original rolls. Entire rolls of rejected film shall not be assigned roll numbers.

365 **Rejected or Not Used Negatives**

Unused or rejected exposures need not be edited, however, if edited, stamp such negatives "Rejected" in the exposure number corner.

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. administration.