[redacted]

REPORTS
of the
CHACO CENTER

NUMBER TWO

AERIAL REMOTE SENSING TECHNIQUES IN ARCHEOLOGY

CHACO CENTER

National Park Service
U. S. Department of the Interior
and
University of New Mexico

Albuquerque

1977

Cultural Resources Management Division
Washington

REPORTS
of the
CHACO CENTER

NUMBER TWO

AERIAL REMOTE SENSING TECHNIQUES IN ARCHEOLOGY

Edited by
Thomas R. Lyons and Robert K. Hitchcock

CONTRIBUTORS

James I. Ebert
Melvin L. Fowler
George J. Gumerman
Elmer Harp Jr.
Robert K. Hitchcock
Laurence D. Kruckman
Thomas R. Lyons
Allan D. Marmelstein
William Meyer
Gary W. North
Henry T. Svehlak
Louis James Tartaglia
John A. Ware

CHACO CENTER

National Park Service
U. S. Department of the Interior
and
University of New Mexico

Albuquerque

1977

ROBERT H. LISTER

CHIEF, SOUTHWEST CULTURAL RESOURCES CENTER

ROSEMARY S. AMES

EDITORIAL ASSISTANT

Correspondence regarding the reports of the Chaco Center should be addressed to the Editorial Assistant, Chaco Center, National Park Service, P.O. Box 26176, Albuquerque, New Mexico 87125.

CONTRIBUTIONS

This report is Contribution No. 2 of the Chaco Center. Previous published contributions, as of January 1977 are:

1. *Lyons, Thomas R., Basil G. Pouls, and Robert K. Hitchcock*
The Kin Bineola Irrigation Study: An Experiment in the Use of Aerial Remote Sensing Techniques in Archaeology. Proceedings: Third Annual Conference on Remote Sensing in Arid Lands, Office of Arid Lands Studies, University of Arizona, pp. 266-283. Tucson, 1972.

3. *Lyons, Thomas R., ed.*
Remote Sensing Experiments in Cultural Resource Studies: Non-destructive Methods of Archaeological Exploration, Survey, and Analysis. Reports of the Chaco Center, Number One, National Park Service and University of New Mexico. Albuquerque, 1976.

6. *Siemers, Charles T. and Norman R. King*
Macroinvertebrate Paleoecology of a Transgressive Marine Sandstone, Cliff House Sandstone (Upper Cretaceous), Chaco Canyon, Northwestern New Mexico. New Mexico Geological Society Guidebook, 25th Field Conference, Ghost Ranch (Central-Northern N.M.), pp. 267-279. Albuquerque, 1974.

8. *Judge, W. James, James I. Ebert, and Robert K. Hitchcock*
Sampling in Regional Archaeological Survey. Sampling in Archaeology. James W. Mueller, ed., University of Arizona Press, pp. 82-123. Tucson, 1975.

9. *Lyons, Thomas R., James I. Ebert, and Robert K. Hitchcock*
Archaeological Analysis of Imagery of Chaco Canyon Region, New Mexico. ERTS-1, A New Window on Our Planet. U.S. Geological Survey Professional Paper 929. Richard S. Williams, Jr. and William D. Carter, eds., pp. 304-306. Washington, 1976.

10. *Hayes, Alden C. and Thomas C. Windes*
An Anasazi Shrine in Chaco Canyon. Collected Papers in Honor of Florence Hawley Ellis. Theodore R. Frisbie, ed. Papers of the Archaeological Society of New Mexico 2, pp. 143-156. Norman, 1975.

16. *Brugge, David M.*
The Horse in Navajo Rock Art at Chaco Canyon. Awanyu, Archaeological Society of New Mexico, Vol. 4, No. 4, pp. 34-46. Las Cruces, 1976.

FOREWORD

This set of assembled papers, resulting predominantly from a symposium on remote sensing in archeology, demonstrates the role that this technique is assuming in the acquisition and interpretation of archeological data. The articles, considered as a whole, relate much of the history of the use of various types of remote sensing techniques in archeological investigations, identify the instruments, equipment, and materials available to archeologists and interpretive specialists, and illustrate, through examples, the application of remote sensing to a variety of archeological circumstances and differing environmental settings. The economic feasibility of employing remote sensing and its incorporation into archeological research designs also are reviewed.

During the few years the National Park Service-University of New Mexico Chaco Center has been in existence, remote sensing has become a valuable tool to the Center and to other Park Service areas in many of their archeological and environmental investigations and in management studies. Additional applications of the technique to our problems dealing with cultural and natural resources are regularly being identified. Continued experimentation with remote sensing by individuals such as those who have contributed to this volume and by others, and refinements in instruments to enhance data gathering and explanation, will undoubtedly lead to still further, now unrecognized, ways remote sensing may contribute to research in archeology and related disciplines.

Robert H. Lister
Chief, SW Cultural Resources Center

PREFACE

In the fall of 1971 Robert Lister of the Chaco Center, National Park Service and University of New Mexico, suggested that we organize a symposium on the use of aerial remote sensing techniques in archeology for the annual meeting of the Society for American Archeology. William H. Sears, who was handling the arrangements for the meetings, agreed to put the symposium on the program and George Gumerman, then of Prescott College, agreed to chair the session. The symposium, entitled "Aerial Remote Sensing Techniques in Archaeology", was held Thursday, May 4, 1972, at the 37th Annual Meeting in Bal Harbour, Florida. This book is an outgrowth of that symposium.

There are many people and organizations to thank for their aid and generosity. Our debt to our friends and colleagues, Jim Ebert, Gretchen Obenauf, Dwight Drager, Doug Caldwell, Rosemary Ames, Jerry Livingston, and Gwinn Vivian is immeasurable. The EROS Program generously provided financial aid, and National Geographic Society Grant Number 1177 helped to support some of the Chaco Center research reported in this volume.

We acknowledge our debts to the many individuals with whom we have discussed remote sensing and its role in archeology. Without their interest and encouragement a compilation such as this would never have come about. These individuals, who include people in business, in government, in the military, and in academe, have provided us with insights into remote sensing technology and its applications. They have encouraged us and at the same time have not spared constructive criticism. We thank them all for their support.

Albuquerque, New Mexico
January, 1977

TRL
RKH

CONTENTS

ILLUSTRATIONS

FIGURES

TABLES

INTRODUCTION

Today the term remote sensing is generally understood as a technique for the acquisition of environmental data by means of non-contact instruments operating in various regions of the electromagnetic spectrum from air and space platforms. The resultant information may be in the form of a pictorial record or digitized data on tape. In a larger context, however, remote sensing can be considered as a discipline in and of itself with its own peculiar methods, objectives and goals. In this connotation, it is more fully understood as "an entire system including data acquisition, data reduction, interpretation and explanation" (Gumerman and Lyons, 1971:126). The papers presented in this compilation were selected to expand upon this broader concept and to demonstrate some of the applications and limitations of such a system to archeological research.

The organization of this volume was designed to provide a connected sequence of papers beginning with background information in a survey of electromagnetic sensing instruments currently employed in the field of remote sensing. Following this are an analysis of the overall potential of remote sensing for archeology, a selection of illustrative studies in widely different environmental settings including the sub-arctic, temperate, semi-arid, sub-tropical and marine zones, and finally a wrap-up discussion of research planning, theory, data sources, materials, and economics of remote sensing in archeology.

Perhaps the most singular aspect of remote sensing is not the system as just mentioned but rather its perspective for inquiry comparable in its probing capabilities and revelations to that of the microscope or the telescope. Other scientific disciplines have historically utilized remote sensing's instrumental and perspective capabilities to a fuller extent in research than have the archeologists who until recently employed aerial photography, for instance, principally as a tool of exploration and discovery. Important as this usage has been and will continue to be, other remote sensing potentialities for measurement, interpretation and explanation are being pursued with interest and vigor in anthropological science (Vogt, 1969; Vogt, ed., 1974; Lyons et al, 1972). Basically, it is recognized that this expanded use is methodologically feasible since not all archeological data is buried or hidden in the ground and retrievable only with the spade and trowel. Rather, the physical records of man's past activities and behavior are often still legible in alterations he left behind on the surface.

The scope of remote sensing in archeology includes not only functions of exploration and discovery, regional and intrasite analysis and quantitative data acquisition, but also a further property which increases in importance and value with the passage of time. An image once acquired, properly identified, annotated and accessibly filed becomes an historical document. Such references provide an easily legible comparative base for continuing investigations in the ever changing terrestrial habitat.

In archeology, a discipline which is developing in theory and methodology at a more rapid rate than ever before, due in large part to an awakening to the value and significance of our native cultural heritage, the economics of research have shifted accordingly. For many diverse purposes, remote sensing techniques provide more data and relevant information in a timely manner than can be obtained through some of the traditional approaches. Consequently, many investigations can profit from the employment of this technology and enjoy economies of time and funding as well as great quantities of specific and ancillary information.

By publishing this collection of papers, the editors and authors are expressing the strength of their convictions that remote sensing methodology is not the path to the solution of all archeological problems of discovery and spatial analysis, but rather is an economical and adaptable procedure for the broad study of prehistoric man and his environment. We consider remote sensing techniques to be a tool applicable to both earth and social sciences independently and interdisciplinarily.

TRL
RKH

LITERATURE CITED

Gumerman, George J. and Thomas R. Lyons
1971 Archaeological Methodology and Remote Sensing. Science 172:126-132.

Lyons, Thomas R., Michael Inglis and Robert K. Hitchcock
1972 The Application of Space Imagery to Anthropology. In Proceedings: Third Annual Conference on Remote Sensing in Arid Lands. Office of Arid Lands Studies, University of Arizona. Tucson.

Vogt, Evon Z.
1969 Some Unexpected Uses of Aerial Photography for Ethnographic Research in the Highlands of Chiapas. Paper presented at the 68th annual meetings of the American Anthropological Association, New Orleans, Louisiana.

Vogt, Evon Z., ed.
1974 Aerial Photography in Anthropological Field Research. Cambridge, Massachusetts. Harvard University Press.

AN INTRODUCTION TO REMOTE SENSING INSTRUMENTATION

BY

WILLIAM MEYER

PART I: INTRODUCTION

Remote sensing is the measurement of an object without the measuring device being physically in contact with the object. In its most common usage today, the term implies that the remotely sensed data are gathered from an aerial platform, either satellite or aircraft. The collection of data concerning the earth's surface from aerial platforms is not new. The first aerial photography was taken from a balloon prior to the Civil War, and aerial photography became an operational tool for mapping in the 1930's. However, the use of remote sensing as a viable measuring system for a large number of sciences did not begin until the early 1960's. Two characteristics that recommend it to the various scientific disciplines concerned with studying the earth's surface are (1) synoptic coverage of large areas at one time, and (2) the ability to measure phenomena in wavelengths undetectable to the human eye. The potential offered by the latter characteristic is especially useful for certain purposes such as temperature measurements and cloud penetration. A cornerstone of scientific knowledge is measurement, and the advancement of knowledge has followed closely man's ability to measure more precisely.

Knowledge of the instruments used to obtain remotely sensed data is essential to the successful application of remote sensing techniques to the measurement of features on the earth's surface. At the current state of the art, instruments are available that can collect data in nearly all portions of the electromagnetic spectrum, ranging from gamma rays to radio waves. A partial listing of such instruments is shown in table 1.

Archeologists working in remote sensing will most likely be interested in those instruments that obtain data in the wavelength span ranging from approximately 0.3 to 14 microns. The purpose of

Table 1. - Partial listing of sensors as they relate to the electromagnetic spectrum

Portion of Spectrum	Wavelength (μ) Sensed	Sensor
Gamma Rays	3×10^{-6} to 5×10^{-5}	Scintillation counters, gamma ray spectrometers
X-Rays	5×10^{-5} to 4×10^{-3}	" " " "
Ultraviolet	4×10^{-3} to 4×10^{-1}	Optical-mechanical scanners with filtered photomultipliers; image orthicon and cameras with filtered infrared film (>0.25μ).
Visible	4×10^{-1} to 7.2×10^{-1}	Film in cameras, television, optical-mechanical scanners with filtered photomultipliers.
Near infrared	7.2×10^{-1} to 1.5	Infrared sensitive film in cameras, television, solid state detectors in optical-mechanical scanners and radiometers.
Medium and far infrared	1.5 to 10^{3}	Solid state detectors in optical-mechanical scanners and radiometers
Microwave	10^{3} to 10^{6}	Radar, radio frequency (rf) receivers in imagers and radiometers.
Radio waves	10^{6} to 10^{11}	Electromagnetic pulse techniques.

this paper is to describe some of those instruments as well as to discuss some of the characteristics of the data obtained through their use. Some remote sensing instruments produce data of a large scale; side looking airborne radar, for example, produces data with a minimum scale of 1 inch equal to approximately four miles. Data such as these probably have limited utility for most present day archeological endeavors.

PART II: SELECTED REMOTE SENSING INSTRUMENTS

Some instruments normally used to collect data in the wavelength span 0.3 to 14 microns are continuous strip cameras, frame aerial cameras, multiband cameras, television, optical-mechanical scanners, and radiometers.

Continuous Strip Cameras

The continuous strip camera was designed to obtain low altitude, high speed aerial photography. The film is continuously exposed as the aircraft moves over the terrain. Image motion is compensated for by passing the film over a stationary slit in the focal plane of the lens at a speed synchronized with the ground speed of the aircraft. The resulting image can be either stereoscopic or non-stereoscopic, depending on the lens used in the camera. This kind of photography is very good for obtaining object height.

Frame Aerial Camera

Cameras in this category are those that obtain framed photography generally suitable for mapping. In using data obtained with frame aerial cameras as well as some other remote sensing instruments, one must keep in mind that certain features are important. These features include data format size, focal length, field of view, and film load length. The standard commercial and military mapping cameras built in the United States since the late 1930's contain lenses of 6-inch focal length covering 9 x 9-inch data formats. Other combinations are available, however. The KA-50A camera has a lens with a 1.75-inch focal length and a data format of 4.5 inches on a side. The RC-9 camera has a lens with a 3.5-inch focal length and a data format of 9 inches on a side. As of 1966, there were about 57 frame aerial cameras in use (Sewell 1966) and this number has grown. These cameras allow a wide range in data format size versus focal length. Length of film load varies both within and among camera types. Film lengths range from about 100 to 7,000 feet with the range 100 to 500 feet being normal. A normal field of view for frame photography is considered to be up to 75°. A wide angle lens would range from 75° to 100°, while a super wide angle lens is over 100°.

Multiband Camera

The basic purpose of multiband photography is to obtain color separation photography simultaneously. There are several versions of multiband cameras in use. One form employs separate films exposed through separate lens and filter combinations. The more common type employs only one film exposed through selected lens-filter combinations. The I^2S (International Imaging Systems, Inc.) multispectral aerial camera, for instance, contains four lenses, each of which can be selectively filtered. Individual exposures from each lens-filter combination are obtained simultaneously on one frame of photography. The individual lens directs the light upon separate portions of the photographic frame.

Television

Closed circuit television is the transmission of scenes by electronic means. In its most general sense, viewing is instantaneous; but through the use of magnetic tape the information can be stored and retrieved at any time. Light impulses are picked up by the television camera and by various electronic means. The original scene is then transmitted to a receiver and reproduced on a viewer. The image that is viewed is actually composed of individual lines, each of which is composed of minute elements of various light intensity. These elements are exposed along the line in an orderly fashion. The more lines per picture viewed, the more detailed the final image.

Optical-mechanical Scanner

The optical-mechanical scanner is variously referred to as an infrared scanner, scanning radiometer, imaging radiometer, ultraviolet scanner, and sometimes as a multispectral or multiband scanner. This is done partially because the same instrument can be used to obtain information from the ultraviolet through the visible, near infrared, and intermediate infrared wavelengths, or simply in the wavelength span from about 0.3 to 14 microns. The field of view of the detector in an optical-mechanical scanner is relatively small, while the field of view of the entire system is not. In order to increase the area "seen" by the detector, a mirror system is mounted in front of the detector and rotated. This mirror system reflects the incoming radiation waves optically onto the detector. Rotation of the mirrors allows radiation from successive portions of the ground surface on a line perpendicular to the aircraft flight path to be focused upon the detector in an orderly fashion. Fluctuations in the radiation received by the detector are translated into fluctuations of electrical current which are either recorded on tape or are converted into various light intensities which are recorded on film.

Radiometer

A radiometer is an instrument for detecting and measuring radiation due to thermal causes. Continuous chart recorders are most often employed for recording the data, although most radiometers come equipped with a scaled meter and pointer needle. The field of view of a radiometer is generally quite small with values on the order of 2^{o} to 3^{o}. The radiation from the area sensed is averaged and a single value of radiation intensity for the area is recorded by the radiometer.

PART III: SOME DATA CHARACTERISTICS

The previous discussion has briefly outlined some of the basic characteristics of a few of the instruments commonly used to collect data in the 0.3 to 14 micron wavelength span. What is probably of more direct utility to someone attempting to apply remote sensing techniques to a given problem, however, is a discussion of some of the characteristics of the data provided by these instruments. The data characteristics of most importance to the archeologist are (1) spectral range, (2) field of view, (3) resolving power and resolution.

Spectral range

Aerial film can be used to obtain data in the spectral range roughly bounded by the limits 0.3 to 1.0 micron. Through the proper selection of film-filter combinations, one can map either small selected portions of this wavelength band or nearly the entire band. Black and white aerial film such as Kodak Double-X aerographic film 2405 (estar base) has a spectral sensitivity range from about 0.72 to below 0.4 micron. Kodak Ektachrome MS aerographic film 2448 (color film on estar base) has a spectral range from about 0.72 to below 0.35 micron. Kodak Aerochrome infrared film 2443 (estar base) has a spectral wavelength range running from about 0.94 to below 0.35 micron. Kodak infrared aerographic film 2424 (estar base) has a spectral range from about 0.93 to 0.40 micron. These four negative films are some of the more frequently used films in aerial photography for applied remote sensing today.

In addition, there is a multitude of filters available. Kodak publication No. B-3 lists over 100 filters for technical uses, although not all of these are normally used in aerial photography (Eastman Kodak Company 1972). Filters can be used to select small parts of the visible and near infrared wavelength span. In general, however, multispectral photography in this region is generally obtained through the use of cameras such as the I^2S multiband camera or banks of four 70-mm cameras. These cameras allow simultaneous collection of data in the four wavelength regions 0.4 to 0.48 micron (blue), 0.48 to 0.6 micron (green), 0.59 to 0.7 micron (red), and 0.73 to 0.94 micron (near infrared). The ERTS-I and -II (Earth Resources Technology Satellite) television system is capable of collecting and recording data in comparable wavelength bands.

Television can be used to obtain data in the visible and near infrared portion of the electromagnetic spectrum as well. The spectral range of television is approximately 0.3 to 2.25 microns. As with aerial photography, television can be selectively filtered to permit detection of small wavelength spans within the spectral sensitivity of the instrument.

As mentioned previously, data in the wavelength span from about 0.3 to 14 microns can be obtained by some optical-mechanical scanners. A multispectral system consisting of two double-ended optical-mechanical scanners was recently used by the U.S. Forest Service to collect data in the wavelength spans 0.32 to 0.38 micron, 1.0 to 1.4 micron, 2.0 to 2.6 micron, 4.5 to 5.5 micron, and 8 to 14 micron (Weber and Polcyn 1972).

When a scanner is used in the thermal range 8 to 14 micron, absorption and radiation from the air mass underlying the instrument affects the recorded data; consequently, many scanners are now being filtered to allow the wavelength span 10 to 12 microns to be detected. This narrower span allows detection of surface radiation with minimum interference from the air mass existing between the surface and scanner.

Finally, most radiometers associated with remote sensing projects are sensitive to the wavelength spans 8 to 14 microns and 10 to 12 microns. The latter region is more desirable for the same reasons stated previously with regard to optical-mechanical scanners.

Field of View

In optics, field of view refers to the angular coverage of a lens system. Although not strictly a data characteristic in its own right, the field of view is an important concept in the collection of remote sensor data as it determines the total width of ground coverage by a remote sensing instrument for any given altitude. When the ground coverage is considered along with the width or length of the data base on which the data are being recorded, scale is fixed.

For a given field of view, ϕ, and a particular altitude above ground level, h (in feet), ground coverage (in feet) can be obtained from the relationship:

$$\text{ground coverage} = 2\ h \tan(\phi/2).$$

This equation applied equally well to all the various remote sensing instruments in use including cameras. For example, if the field of view of an aerial camera is 75° and data are obtained at 2,000 feet above the ground, then ground coverage is equal to 3,000 feet. For a camera with a given focal length f and width of film base (W), we can also say that:

ground coverage = (W/f) x h.

Scale can be obtained by dividing ground coverage by the width of the data base for scanned data and successively by the width and length of a frame of photography. In scanned data, the film is fed through the optical system at a speed correlated with the ground speed of the aircraft to prevent scale distortion along the length of the image; however, a perfect correlation of film speed to ground speed of the aircraft is not always obtained.

Resolving Power and Resolution

Resolving power is a lens definition and is usually stated as the maximum number of lines per millimeter that can be individually distinguished in a test image. Resolving power is a function of contrast of the test chart as well as its orientation, position, and shape. Resolution, in common usage, refers to the final produced image and is defined as the minimum separation between two objects for which the images appear distinct and separate, or it is the minimum size of a feature that can be detected. Because of the standardized method for measuring resolution, values given do not mean the size of the smallest object that can be seen. In photography, for instance, resolution is normally defined as the number of line pairs per millimeter recorded on a particular film under specified conditions that are just discernible by the human eye. The specified conditions in this case would consist of a standardized bar target wherein the ratio of the bar width to space between the bars is set, the ratio of the bar length to bar width is set, and the contrast between scene luminance to bar luminance is set. Changes in any of these factors will change resolution specifications. Thus, it can be seen that resolution is a function of such variables as object size, shape, arrangement, and contrast, as well as the experience and ability of the human observer. The term ground resolution, which is meant to represent the size or width of objects discernible on the ground in an image, is subject to the influences of the same variables.

The previous discussion concerns black and white imagery. When color imagery is introduced, additional factors become involved. For instance, the human eye can distinguish a nearly infinite number of colors, whereas it can only detect several hundred shades of gray.

In a recent article, Rosenberg (1971) discusses two other factors besides resolution which are of importance in determining what can be observed on an image. These are detectability and recognizability. Resolution, as discussed, can be quantified - detectability and recognizability cannot. As Rosenberg (1971:1257) states, "The latter (two) involve problems in visual perception, form recognition, gestalt theory and related areas in psychology and psychophysics - problems that are as yet poorly understood." Nevertheless, it is important to realize that objects can be detected that are smaller than the resolution of the system and that objects can be detected and resolved, but not recognized.

NOTE: Publication of this paper was authorized by the Director, U.S. Geological Survey.

U.S. Geological Survey

LITERATURE CITED

Eastman Kodak Company

1972 Kodak Filters for Scientific and Technical Uses. Kodak Publication No. B-3. Rochester, New York: Eastman Kodak Company.

Rosenberg, Paul

1971 Resolution, Detectability, and Recognizability. Photogrammetric Engineering XXXVII:1255-1258.

Sewell, E.D.

1966 Aerial Cameras. Manual of Photogrammetry. Falls Church, Virginia: American Society of Photogrammetry.

Weber, F.P. and F.C. Polcyn

1972 Remote Sensing to Detect Stress in Forests. Photogrammetric Engineering XXXVIII:163-175.

THE UNREALIZED POTENTIAL OF REMOTE SENSING IN ARCHEOLOGY

BY

George J. Gumerman and Laurence D. Kruckman

PART I: INTRODUCTION

The title of this paper has prompted a colleague to remark that it sounds much like the classic question asked of an archeologist, "How many undiscovered sites are there?" We therefore state at the outset of this article that the unrealized potential of remote sensing is a reflection of the archeologist's failure to use these techniques, and not a reflection of the current state of remote sensing technology. Some archeologists are becoming aware that remote sensing techniques may have application to their discipline, but a larger number might find solutions to many of their archeological problems if they knew of the resources available today in remote sensing methodology. The field is developing at a rapid rate, and it is impossible for the few archeologists currently using remote sensing to test all of the new or improved techniques. This paper was written, therefore, with the hope that it will prompt more archeologists to experiment with some of the powerful tools now available.

In order to encourage the greater use of remote sensing data, we also discuss in this article some means for obtaining and utilizing pre-existing data. Furthermore, we will present a description of the various techniques we discuss in as clear a manner as we can, so that the archeologist can comprehend the type of results he can expect. The user of remote sensing data need not be a technician, nor need he understand the detailed principles behind the various systems in order to utilize to best advantage remote sensing imagery or instrumentation.

We gratefully acknowledge John Caster for his many editorial comments which vastly improved the quality of this paper.

PART II: HISTORY

In some ways archeology and remote sensing grew up together, for, in the late 1800's and early 1900's when archeology was becoming a science, aerial photography was developing as an important scientific tool. Archeologists have long been aware of and used this earliest remote sensing technique. For example, archeologists at the Cahokia Mounds in Illinois employed aerial photography as early as 1921 (Solecki, 1960:718; Fowler, this volume). But World Wars I and II provided the real impetus for the application of aerial photography to archeology. It was during these periods that men, including archeologists, were flying in large numbers and photographing extensive areas, many of which included prehistoric and historic cultural features. It is no accident that archeologists who have used remote sensing to the greatest extent were either pilots during World Wars I or II or served in war departments that analyzed aerial photographs. O.G.S. Crawford, the man who did more than anyone to develop aerial photographic techniques for archeology, was a member of the Royal Flying Corps of England in France and Belgium during World War I.

Fortunately, remote sensing methodology began to experience a period of extreme growth and change about a decade ago parallel with the development of recent archeological theory and method. Therefore, many of the new techniques of remote sensing and instrumentation could be utilized to accomplish the new goals of archeology (for an excellent history of archeology and remote sensing, see Leo Deuel, 1969).

The impetus for the development of more sophisticated remote sensing techniques can be traced to the necessity for sensors which record different portions of the electromagnetic spectrum and to certain key inventions which came into use during the Korean and Vietnam wars. In addition, the techniques of photogrammetry developed along with these new sensing capabilities. Mechanical equipment capable of more efficiently depicting remote sensing data soon replaced the human hand, allowing expedient plotting of vastly increased amounts of information.

Unlike the advances in remote sensing, which are based on technological change, the recent changes in archeology can best be understood by examining the goals of the subdiscipline as they developed within the broader framework of anthropology. This article is not the place for a discussion of what is new in archeological theory. Nevertheless, a short statement is desirable in order to understand the potential of remote sensing to archeology. Many archeologists today take a theoretical approach to their discipline that requires a systematic view of culture. Culture is a system comprised of subsystems, such as technological, social, and ideological subsystems, all of which are highly integrated. In addition, culture is primarily conceived of as an adaptive mechanism which allows man to cope with his environment.

Briefly, many archeologists find it most productive to use an interdisciplinary team in the natural and social sciences in order to understand the various subsystems composing a culture and the culture's articulation with the environment. The archeologist then proceeds from an understanding of a particular subsystem, usually the technological or subsistence subsystem, to other aspects of the culture (for example, see Watson, LeBlanc and Redman, 1971; Hole and Heizer, 1973). Having adopted the view that culture is both a system and an adaptive mechanism, it has been frequently stated that much of modern archeology is indeed a social science, using the past as a laboratory for the analysis of cultural process and culture change, i.e., for understanding human behavior. Instead of asking primarily spatial and temporal questions, that is, who lived in an area, how, and when, the archeologist is now posing questions of broader significance, such as how does culture evolve; why are certain adaptations to specific environments more likely to occur than others; what is the function of warfare at different levels of sociocultural integration; and a host of similar questions.

Many of these questions are not, of course, new to archeology, but the recent developments in both theoretical structure and the available techniques demand, and at the same time permit, more sophisticated answers. It is no longer possible, for example, for an archeologist to do a cursory or even intensive survey and then excavate a single site, or even three or four, which seems to be representative of a specific culture at a particular time. More often, we now look at a whole range of sites representing different activities of the same culture, perhaps in different sub-environmental zones. Habitation sites may be on terraces above major water systems, defensive sites may be located in the woodland areas, and small farming settlements may be located along the floodplain where irrigation agriculture was practiced. In other words, those sites which serve separate functions are representative of different aspects of the same culture, and their relationship to one another must be examined if the cultural system is to be understood.

Although this approach of examining culture as a system through the relationship of the culture to its environment is theoretically very promising, a number of difficult logistic, administrative and financial hurdles stand in the archeologist's way. The archeologist must adopt a regional view and record sites in many hundreds, if not thousands, of square miles. He must not only know and understand the many variations in the environment over this large region, but must also attempt to extrapolate the character of the prehistoric habitats from the present environment. Quite obviously, this type of investigation requires a great deal more funding and more time than the archeologist has traditionally possessed. Some have suggested that a partial solution to the problem is through a statistical analytical approach; for example, the judicious use of random sampling of the study area in sub-environmental zones, in the selection of sites for excavation, and the selection of parts of sites for excavation (Redman and Watson, 1970). We feel that another partial solution is the increased utilization of remote sensing technology.

PART III: REMOTE SENSING IMAGERY

Photography

Black and white (BW) photography is the most basic film process. The film has an emulsion of silver salts which become black metallic silver when activated by light energy. The light that is recorded on the film is the selective reflection of sunlight from the various phenomena photographed through the lens. The quantity of energy reflected from an object is a function of the incoming energy as well as absorption and reflective characteristics of the object (Kiefer and Scherz, 1969:5). Therefore, the planning of archeological photography requires that light intensity and angle, altitude (hence scale and resolution considerations), and the angle and direction of the photography be properly specified. As an example, BW photo reconnaissance of the Estancia Valley in central New Mexico revealed Pleistocene and Holocene beach terraces of ancient lakes and site locations were successfully predicted because of their similarity to terraces known to be occupied by Paleo-Indian hunters and gatherers. However, if the angle of light and intensity from the terraces had happened to be parallel instead of perpendicular to the direction of photography they might have remained undetected. Fortunately, proper photographic parameters were specified and the location of Folsom and Sandia sites were successfully predicted (Gumerman and Lyons, 1971:127). Other cultural features can be distinguished on photographs because of short-term climatological phenomena, such as snow and frost marks, damp marks, and parch marks. Proper planning for some of these events is difficult because many such factors that enhance patterns on the ground, such as hoar frost, rarely occur and are short lasting. Snow and frost marks, however, often create patterns which remain long enough to be photographed and mapped. An English town in Oxfordshire, deserted because of the Black Plague, was located in this manner (Langer, 1964).

Some BW air photos reveal archeological patterns which may provide an insight into social and political organization, and also the way man changes his habitat. For example, the patterns of transportation arteries of the Romans, easily detectable on aerial photographs, were determined by the method of land partition, or centuriation, of farm land. Such patterns have appeared not only in southern Italy, but also in Tunisia, thus indicating similar settlement programs (Solecki, 1960:718). Another transportation system was delineated with black and white photography near Pueblo Alto in Chaco Canyon, New Mexico. Interpretation of these roads was improved by using photographs from different time periods, 1935 and 1959, and with different scales, 1:3,000 and 1:32,000 (Lyons and Hitchcock, this volume; Ware and Gumerman, this volume). Again, the delineation of the road networks provides important insights into inter-settlement interaction.

Agache (1964) demonstrated in France that black and white photography may efficiently record variations in soil color tones which are useful in detecting past agricultural activity. Prehistoric man, by altering the soil horizons, has also altered fertility and soil moisture acceptability. The patterns that result give clue to past agricultural areas as well as covered walls and structures. The site of El Purgatario in Peru is a fortified structure that was located from the study of these relationships (American Society of Photogrammetry, 1966:589). The Nazca Valley geometric designs, ca. 800 A.D., were also located from the air due to changes within the upper soil horizon. Vegetation marks identified from the air tend to be more easily recognizable in wet years, the most plausible explanation being that porous soils will dry out quickly, thus enhancing the tonal variations of the surfaces altered by man (Martin, 1971:353). Needless to say, this process works in reverse since ancient landforms, such as river courses, can be located and dated by association with previously identified archeological sites.

Color Film

By adding dyes and chemicals, the active silver salts in the emulsion can be made to react to varying wavelengths of light in the appropriate colors instead of shades of gray. For example, green-forming chemicals are activated by green wavelengths of 0.5 to 0.6 microns and are processed in such a way that part of the emulsion will become green in color. Normal three color film, which utilizes green, blue and red pigment, is often an improvement over BW film for the archeologist because factors of hue and chroma are included in the film, recreating near-normal vision. Since the eye tends to identify objects by color more than relative shade relationship, cultural features are more easily identified on color film. Color film is also more indicative of the natural environment and, therefore, is a valuable tool is survey work involving paleo-environmental factors.

Color and BW films are effective complementary sensors, and simultaneous recording of the same locale with both film types may provide advantages in archeological interpretation (Hammond, 1971: 511). For example, field patterns of possible Norse fortifications near Pierre, South Dakota, were discovered after a comparison of

BW and color photographs (Smith, 1968:386).

However, as useful as they are, conventional BW and color films are limited by their inability to detect wavelengths much beyond the visible portion of the spectrum, and thus record only a minute fraction of it. To use an analogy, if a graph of the entire electromagnetic spectrum were enlarged to three times the circumference of the earth, the portion representing that section to which the human eye is sensitive would be no wider than a pencil line. Normal photographic film is sensitive to wavelengths from 0.3 to 1.2 microns (fig. 1) and, although this is three times as sensitive as the human eye, it is still able to respond to only a small fraction of the information available in the entire spectrum. Therefore, other sensors must be used in order to even begin to explore the potential range of available data (Kiefer and Scherz, 1969:4).

Infrared (IR) Film

Infrared film in aerial cameras has both advantages and disadvantages when compared with normal BW and color film. The emulsion is sensitive in the red and near-infrared portion of the spectrum and also in the ultraviolet region below 530 millimicrons. By using a minus-blue filter (Wratten 12 or 15 or Kodak 89b) the ultraviolet region is blocked, leaving only the red and infrared wavelengths to be recorded. Under these conditions, the photometer or common exposure meter is of little value because the energy levels are beyond the registration levels of the meter. Therefore, as a guide, an ASA rating of 125-150 is recommended and under usual conditions a 35mm film, such as Kodak Aerochrome film 2443, should be exposed with an aperture setting of f8 at a speed of 1/250 second in the air or 1/125 second on the ground. Since the IR film records reflected sunlight, rather than heat emitted by the subject, it is regarded as a mid-day sensor and should be used between 10:00 A.M. and 4:00 P.M. A major limitation of Kodak 2443 35mm IR film is its three-day shelf life. Therefore, it is recommended that the film not be purchased from a retail store, but rather ordered directly from a distributor and kept on dry ice or frozen until used.

The value of black and white IR film for archeology is dependent on the differential tone rendering of vegetation and landforms. Green vegetation records much lighter than on BW film due to the absorption of chlorophyll in the IR portion of the spectrum. This high reflectivity results in the recording of vegetation as lighter shades of gray on black and white IR film compared to dark shades recorded on conventional BW film.

Because of an increasing need for an understanding of the

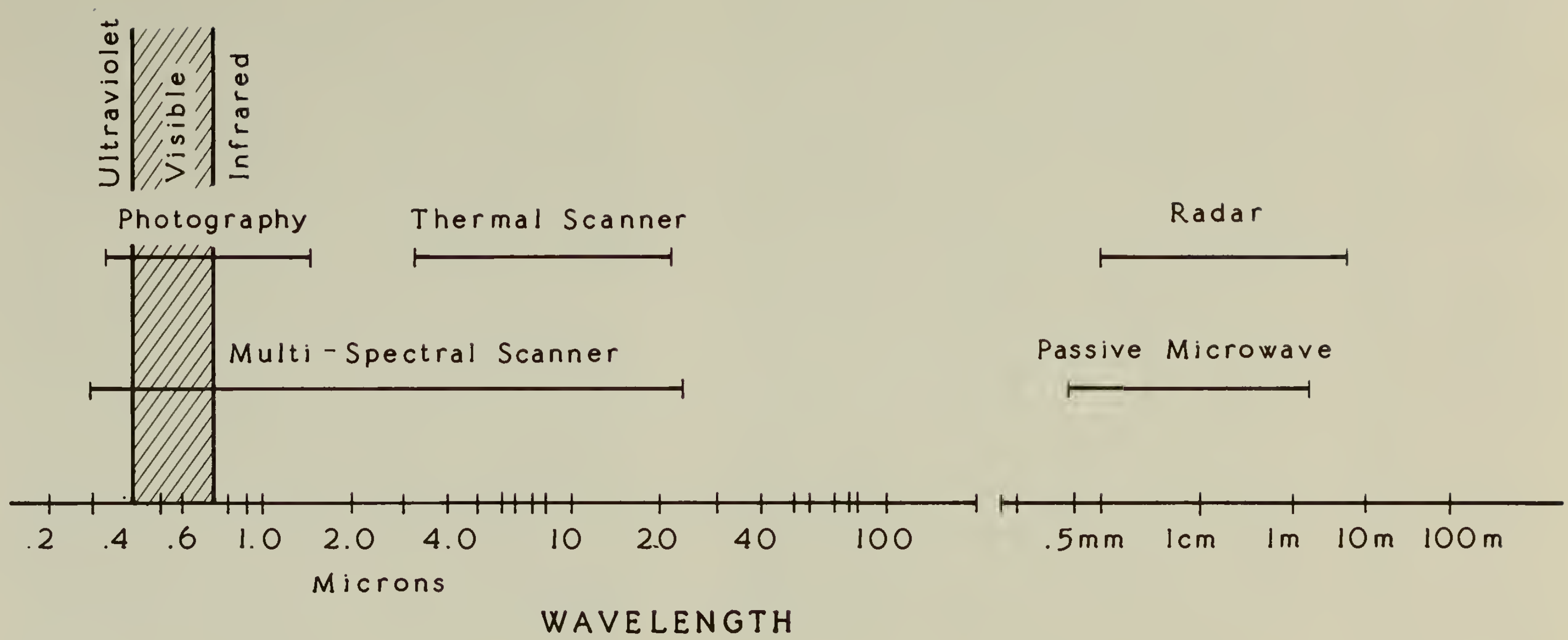


FIGURE 1 - Spectral Range (not to scale) for common remote sensing instruments
(Note the narrow range of the spectrum that is visually detectable)

contemporary environment as a means of reconstruction of past environments (Coe and Flannery, 1964; Struever, 1968), a method for easy mapping of environmental zones should be employed at a scale congruent with archeological needs. Certainly, no better means of quickly delineating major environmental zones as well as subenvironments can be found than with aerial color IR film or "false-color" IR.

Since color IR film transfers differential reflective levels of energy to distinctive "false" colors, contrasts between varying surfaces are improved. Vigorous plant growth appears in various shades of red and in arid or semi-arid regions this bright red contrast provides clues to subsurface water and former springs. From such evidence, preferred areas for habitation, e.g., former shorelines, ancient lakes and springs, have been located on IR film (Hammond, 1971:512). In a well-controlled test in the Tehaucan Valley of Mexico, where Coe and Flannery (1964) first utilized the concept of subenvironmental zones in archeology, it was possible to delineate quickly and accurately the different subenvironments that these authors had described earlier (Gumerman and Neely, 1972). No type of imagery tested so far gives such accurate delineation of small environmental zones. It must also be noted that color IR photography did not record cultural features well, especially in the more vegetated areas. The true value of color IR photography for the archeologist, therefore, is in the construction of quick, inexpensive and accurate environmental maps.

Thermal IR

Thermal IR instruments record energy in the 3-20 micron wavelength range. Since film emulsions are not sensitive to energy at this level, a thermal IR scanning device must be used. Any object with a temperature above absolute zero will emit radiation at a level proportional to its emissivity times the fourth power of its temperature. The emissivity of an object is a ratio between the object's radiation and that of a similar black body which is a surface that in theory completely absorbs all radiant energy. This ratio is altered by the filtering effect of the atmosphere. However, there are two regions or "windows" in the spectrum, 3-5 microns and 8-14 microns, that allow energy to pass through the atmosphere with only slight restrictions and hence print accurate detection of the actual emissions. The instrument uses a simple line-scanning technique similar to that used to form a television picture. As the aircraft moves forward, a rotating mirror scans the surface, one point at a time, and records the sequence of thermal intensities as fluctuations in the magnetic field on a recording tape. This is then used to reconstruct a two dimensional image on a cathode ray tube (CRT). The results may then be photographed from the CRT for a permanent record. Since the linear sequence of information stored on the magnetic tape can easily be converted to digital form, the data gathered by this technique is easily accessible to computer analysis.

Archeology has a great potential use for thermal emission data. To date, however, little use has been made of thermal scanning techniques. Where this type of imagery has been employed, it has proved extremely successful. Thermal scanning imagery was used in southern Italy to detect buildings and walls buried in sediment, but often such structures prove too deep to be accurately recorded (Steinmann, 1970:84). However, prehistoric garden plots located in central Arizona within a volcanic cinder area were greatly enhanced on infrared scanned imagery (Schaber and Gumerman 1969). The agricultural patterns not readily apparent on BW film were easily discernible on IR scanner imagery taken in the late afternoon. The cultivated areas exhibited a higher radiant temperature than the normal volcanic cinder and therefore became visibly enhanced. Subsequent field studies of the site produced corn and squash pollen which confirmed the agricultural nature of the prehistoric plots.

Using IR scanned imagery of the Nile Delta taken from a Nimbus I satellite, Jean Pouquet (1968) was able to map soils by organic content related to moisture capture and retention. Such soil changes were due to ancient human occupation and, therefore a paleo-pedological map permitted prediction of other site locations of similar occupation types.

Radar

Side-looking airborne radar (SLAR) differs from the previously discussed passive sensors because it produces its own electromagnetic waves. SLAR is effective in any weather situation, night or day. A frequency pulse is sent out from an antenna. Upon striking a target a portion of the energy is reflected back to the instrument where it is recorded. The returned energy is converted to a visible image on a cathode ray tube (CRT) and, by passing film across the tube at a proportional speed, a photo-like image is constructed.

Until recently, the resolution and pictorial quality of radar imagery has been inadequate for archeological purposes. However, recent advances in the technology of radar imagery have greatly improved the technique and, if at all possible, archeologists who can obtain radar imagery should test it for its potential. In all likelihood, its value would be in identifying natural features, especially soil, drainage and topographical differences, rather than defining cultural features on the landscape. It may prove particularly valuable in the tropics because areas never before photographed can be mapped since restrictive cloud cover does not affect radar (Kiefer and Scherz, 1969:26).

Multispectral Systems

Haralick and others (1970) have noted that many sensors produce more pictorial material per hour than can be analyzed by current methods in one year. With increased advancements in remote sensing, including more sophisticated optics, sensors and solid state electronics, implementation of automatic recognition systems will become necessary in order to analyze the large volume of data. Multispectral systems are suited to more advanced automatic analysis of data and consequently can be of value to the archeologist. Multispectral photography uses a camera which photographs different bands of the spectrum simultaneously. Multispectral photographs are usually taken in a 9" x 9" format with four or six different lenses utilizing different types of filters and film combinations to record only selected wavelengths from restricted portions of the spectrum. The resulting transparencies are then placed in a color additive viewer so that the information obtained, represented as arbitrarily chosen colors which vary in intensity, can be reconstituted into a composite image.

Alterations of the colors which represent different wavelengths can alter the emphasis given various aspects of the transparencies. For example, cultural features can be enhanced and natural features subdued, or vice versa. Few archeologists have experimented with this technique and those experiments which have been done have been of an extremely superficial nature (Ware and Gumerman, this volume). Thus, the true value of multispectral photography for the archeologist has, as yet, not been determined. One of the authors has observed that multispectral photography enhances prehistoric Hohokam canals in southern Arizona. Such positive results suggest that well-controlled testing of this system should be undertaken by archeologists.

Although multispectral systems with 26 channel formats have been tested, the expense is extremely high and archeologists would find testing two or four channel systems more practical. However, some companies, such as VTN, 6875 East Evans Avenue, Denver, Colorado 80222, market inexpensive cameras and projection systems where up to 26 color filters can be employed. These systems are available within the strict budget limitations of most archeologists.

PART IV: DATA PROCESSING INSTRUMENTATION

Although there have been a number of recent innovations and improvements in remote sensing technology, perhaps of even greater importance are the new developments in instrumentation for manipulation of data.

Few archeologists have investigated the potential of the microdensitometer. This instrument measures the density of the emulsion on any type of transparency and quantifies the light level on very narrow transects. Because the light density is quantitatively reproduced in graph form (fig. 2), it may be possible to use this instrument as a relative dating technique for land-use systems, such as terraces or agricultural plots, features which are notoriously difficult to place in even a relative chronological sequence. Initial investigations in the Tehaucan Valley of Mexico (Gumerman 1971) have demonstrated that agricultural terraces of different ages have characteristic signatures (fig. 2). These different signatures are a result of differential erosion or growth of grasses and brush on the terraces. Because of this differential growth or erosion, there are consistent differences in light density from terraces of different ages. These signatures will not permit absolute dating of land-use systems, of course, but they may be a method for the relative dating of such features by ordering according to degree of similarity. It will be necessary to revise the ordering sequence for the different types of signatures in each type of environmental situation because of regional variations in plant growth and soil cover.

Using the microdensitometer, we have thus far tried relative dating on terrace systems that are of obviously different ages. What will be necessary is a seriation of the different types of signatures on systems which appear to be visually similar.

Not only can the microdensitometer be used as a device for dating, but it may also be used as a means of discovery. Transects taken across transparencies may reveal slightly buried cultural features, such as irrigation canals, because of a slightly different density in the film emulsion, a density undetectable by the unaided eye. A number of transects across the transparency might reveal a characteristic light pattern, thereby emphasizing a linear effect. As a means for discovery, the microdensitometer would probably be most useful in finding cultural or physical features which are linear. Such a technique was used to map a prehistoric fort at New Madrid, Missouri, by the state archeological survey.

Another potentially useful device for photographic analysis is the isodensitometer. An isodensitometer is much the same as a microdensitometer in that it measures emulsion density. However, rather than plotting data from a series of linear transects, the isodensitometer translates areas of similar density in either a black and white or color transparency into distinctive color contours on a two-dimensional density contour map. The different tones of the transparency are plotted by this instrument to colored isolines which represent quantitative measurements of the emulsion density.

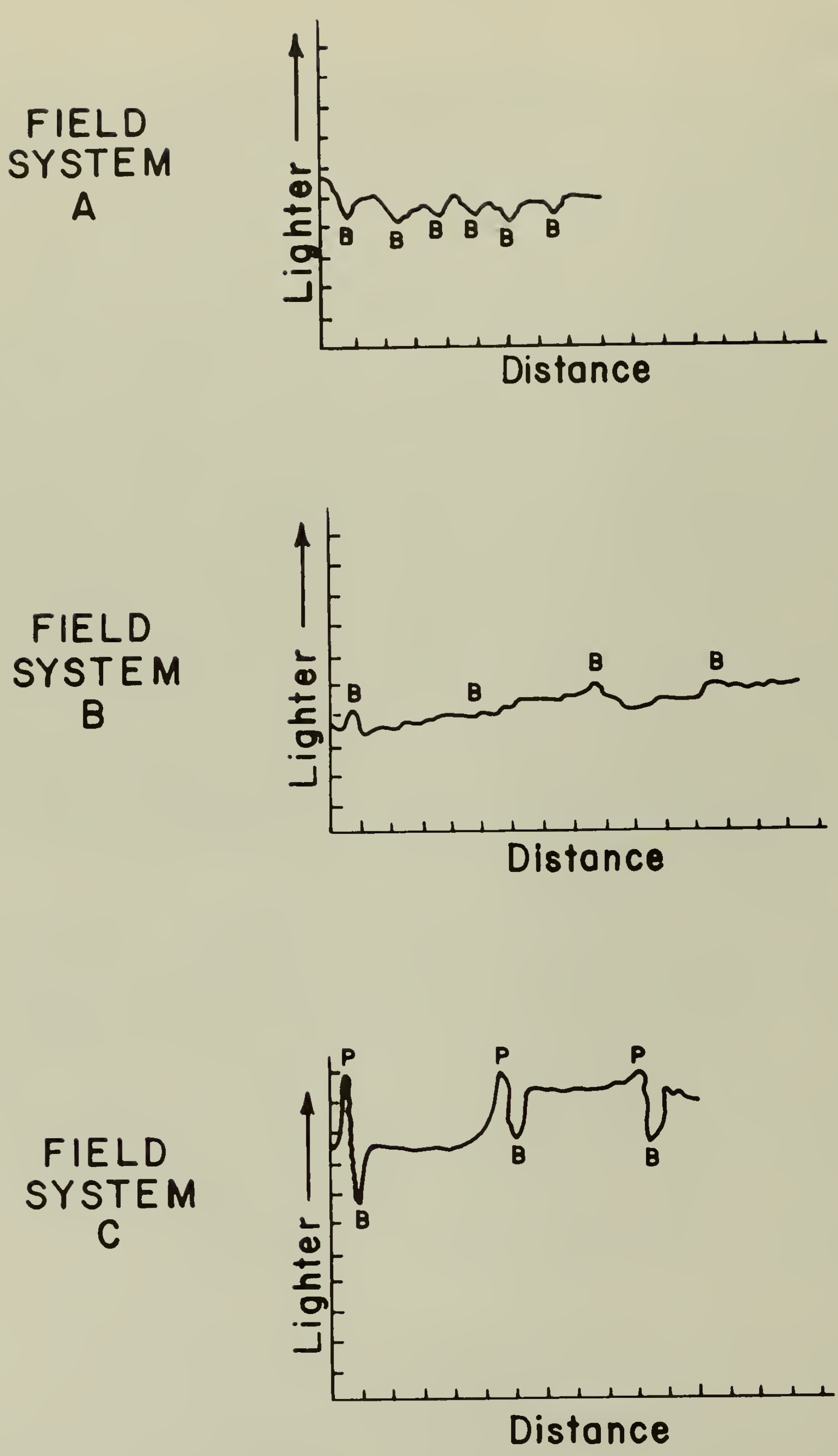


FIGURE 2 - Microdensitometer traces showing signatures of agricultural terraces in the Tehuacan Valley of Mexico.

Tests using this technique as a device for discovery have been superficial and in this instance not satisfactory (Ware and Gumerman, this volume). However, the isodensitometer is currently being refined and should be further tested under controlled circumstances.

Stereo plotters have been used by some archeologists as a quick and accurate means of obtaining a contour map of an area of study or a particular site. A stereo plotter, such as the Kelsh Plotter, can, with well-controlled transparencies or diapositives, draw contour maps with an interval of six inches or less. Not only can the stereo plotter be used as a mapping technique, but, again, like the microdensitometer and isodensitometer, it may be useful for the discovery of cultural features. For example, a prehistoric canal system may have a slightly higher or lower elevation than the soil or rock matrix. This elevational difference may be so slight that it is not easily detectable by visual inspection on the ground through the use of a stereoscope and conventional aerial photographs. Nevertheless, with the accuracy of a stereo plotter, it may be possible to delineate an entire canal system. (Since this paper was presented, Thomas Lyons has attempted this technique in Chaco Canyon, New Mexico, and has discovered a number of cultural features due to elevational differences detected by the plotter; see Lyons, Pouls and Hitchcock, 1972).

PART V: SOURCE INFORMATION

One of the major reasons archeologists have been reluctant to test aerial imagery and the variety of remote sensing instruments is the costs involved. If indeed the archeologist were able to bear the cost of collecting the type of data described in this paper, it would amount to a disproportionately high percentage of the budget, if not all of it. A solution to the problem is to search out data that has been obtained for other purposes, such as crop survey or highway construction. A number of potential sources are discussed below.

Aerial Photography

Air photos offer invaluable information to the user, but often they are avoided due to lack of familiarity. Unlike maps, photos present an actual view of the landscape and stereovision is possible due to the usual 60 percent overlap and 30 percent sidelap coverage. Inexpensive and easy to use equipment, such as height finders and stereoprets, allow almost anyone to construct maps from air photos with considerable accuracy. The major problem is in obtaining the appropriate photos. In the United States, several agencies distribute photos at reasonable prices (approximately $1.25 for 9" x 9" photos with a scale of 1:20,000). Many federal agencies are involved with remote sensing, but before the imagery can be ordered, the holding agency must be determined. To obtain this information without charge, write for the "Status of Aerial Photography," a 27" x 41" map of the U.S., from the U.S. Geological Survey, Department of the Interior, Washington, D.C. 20242. Once the federal agency which has the photography is identified, request an order blank and the name of the photo-index for the research area using the address on the back of the map. To receive the desired photo-index title, the research area should be described in detail, giving the county location, the latitude and longitude, and the major river boundaries. Then, following the directions on the order blank, request the photo-index sheets (usually $2.50 each). From the photo-index sheet order the specific photographs desired. The photo number, code, roll number, and scale can be obtained from the photo-index and must be specified on the order blank. Payment must be calculated and accompany the order.

Often anthropologists need air photos of foreign areas. Their procurement is usually time consuming and at times seemingly impossible. Before starting the search consult K. Stone (1961) for a list of useful sources.

Many collections from foreign countries are held by U.S. agencies because they took the photographs for foreign governments, and often it is possible to obtain them from the agency concerned. In addition, several institutions have special collections. For example, the University of Wisconsin at Madison has Italian coverage and the Aeronautical Chart and Information Center, Washington, D.C., has Mexican coverage. Also recommended for Latin American coverage is the set of volumes, "Annotated Indexes of Aerial Photography Coverage and Mapping of Topography and Natural Resources", published by the Pan American Union, Washington, D.C.

Other Remote Sensing Data

Most archeologists will find it more difficult to obtain and use remote sensing data other than photography. Innovation, ingenuity and dedication will be necessary to use such data fruitfully, but the major problem will undoubtedly center on procuring data in the first place. The U.S. Geological Survey and the National Space and Aeronautics Administration (NASA) are probably the most likely sources of the more exotic forms of remote imagery.

The USGS has established its central depository at the EROS Data Center, Sioux Falls, South Dakota 57198. This center distributes data from the EROS, ERTS, and SKYLAB programs. They also act as consultants and assist researchers with basic problems. The USGS - EROS program also has a library and information center where the researchers may obtain reprints, reports and papers generated by the EROS program. A list of publication holdings may be obtained from:

USGS-EROS Program, Room 1032, 801 19th Street, N.W., Washington, D.C. 20242.

NASA is still the major custodian of remotely sensed data, and it is possible to receive imagery and documents by writing: Earth Resources Research Data Facility, NASA/JSC, Houston, Texas 77058. For an excellent description of the various types of materials held by NASA and methods for retrieving data, consult Zeitler and Brattan (1971).

Other sources of remote sensing data may be private corporations such as Bendix, Barnes, Dames and Moore, Texas Instruments, and HRB-Singer. They all have been generous in distributing imagery. To discover what imagery is available is difficult, because these organizations are not oriented to processing commercial orders. Often they are willing to help, but the researcher will have to depend on interested individuals at the data source and the good will of the corporation. For a survey of 130 potential private sources of remote sensing data write: John McLaurin, Branch of Photogrammetry, USGS, 1340 Old Chain Bridge Road, McLean, Virginia 22101.

We also recommend inquiry with state highway departments, engineering consulting firms, Army and Air Force Units, and any company or government agency that might have a use for remote sensing.

In short, the cost of collecting remotely sensed data can be extremely high. Nevertheless, means are available to obtain data that have been collected for other purposes at nominal or no cost. The search, however, can often be long and frustrating. For information regarding data collection costs see Aguilar (1969).

PART VI: SUMMARY

We have attempted in this article to address ourselves to three major concerns related to contemporary archeology and remote sensing.

First, modern archeology is concerned with regional relationships rather than with the locality or the individual site. The focus on the large land areas has put strains on the archeologist's man power resources and on his budget. We have suggested that a partial solution to the problem lies in the effective use of remote sensing and data manipulation devices for examining large areas.

A second concern has been the continual improvement and increased sophistication of remote sensing methodology. Since most archeologists are unaware of these recent developments, we have described some of the available techniques with the hope that they will be tested for their archeological potential when the opportunity arises. The archeologist need not be a technician to test or use these remote sensing devices.

Thirdly, we have shown that although the cost of collecting remotely sensed data is exceedingly high, there are a number of sources available to the archeologist where data collected for other purposes can be obtained at little or no cost.

In summary, we feel that the archeologist has not realized the potential of remote sensing, and we hope this article will stimulate interest in an available, but greatly neglected resource.

Southern Illinois University

LITERATURE CITED

Agache, Roger
1964 Archeologie Derienne de la Somme. Recherches Nouvelles 1963-64. Amiens: Imprimerie Gogois.

Aguilar, A.M.
1969 Estimating Costs of Aerial Surveys. Civil Engineering 39:70-73.

American Society of Photogrammetry
1966 Manual of Photogrammetry. Falls Church, Virginia: American Society of Photogrammetry.

Coe, Michael D. and Kent V. Flannery
1964 Microenvironments and Mesoamerican Prehistory. Science 143:650-654.

Deuel, Leo
1969 Flights into Yesterday. New York: St. Martin's Press.

Gumerman, George J.
1971 Archaeology and Aerial Photography. Applied Remote Sensing of Earth Resources in Arizona: Proceedings of the 2nd ARETS Symposium, University of Arizona.

Gumerman, George J. and Thomas R. Lyons
1971 Archaeological Methodology and Remote Sensing. Science 172:126-132.

Gumerman, George J. and James A. Neely
1972 An Archaeological Survey of the Tehuacan Valley, Mexico: A Test of Color Infrared Photography. American Antiquity 37:520-527.

Hammond, A.L.
1971 Tools for Archaeology: Aids to Studying the Past. Science 173:511-512.

Haralick, R.M. et al
1970 Using Radar Imagery for Crop Discrimination. In Remote Sensing of Environment. New York: American Elsevier Company.

Hole, Frank and Robert F. Heizer
1973 An Introduction to Prehistoric Archaeology. New York: Holt, Rinehart, and Winston.

Kiefer, R.W. and J.W. Scherz
1969 Civil Engineering Applications of Airbourne Remote Sensing Technology. Unpublished paper presented at the American Society of Civil Engineers National Meeting, Washington, D.C.

Langer, W.L.
1964 Black Death. Scientific American 207:114-118.

Lyons, Thomas R., Basil G. Pouls and Robert K. Hitchcock
1972 The Kin Bineola Irrigation Study: An Experiment in the Use of Aerial Remote Sensing Techniques in Archaeology. Proceedings: Third Annual Conference on Remote Sensing in Arid Lands. Tucson: University of Arizona, Office of Arid Lands Studies.

Martin, Anne-Marie
1971 Archaeological Sites--Soils and Climate. Photogrammetric Engineering 37:353-358.

Matheny, R.T.
1962 Value of Aerial Photography in Surveying Archaeological Sites in Jungle Regions. American Antiquity 28:226-230.

Pouquet, Jean
1968 NASA Technology Note, TND-4603. Washington, D.C.

Redman, Charles L. and Patty Jo Watson
1970 Systematic, Intensive Surface Collection. American Antiquity 35:279-291.

Schaber, Gerald G. and George J. Gumerman
1969 Infrared Scanning Images: An Archaeological Application. Science 164:712-713.

Smith, John T., ed.
1968 Manual of Color Aerial Photography. Falls Church, Virginia: American Society of Photogrammetry.

Solecki, Ralph S.
1960 Manual of Photographic Interpretation. Menasha: American Society of Photogrammetry.

Steinmann, M.
1970 A Lost City Re-discovered: Space Age Instruments Unlock the Secrets of Sybaris. Science Annual. New York: Time-Life Books.

Stone, Kirk H.
1961 World Air Photo Coverage. Photogrammetric Engineering 27:214-227.

Struever, Stuart
1968 Woodland Subsistence-Settlement Systems in the Lower Illinois Valley. In New Perspectives in Archaeology, Sally R. Binford and Lewis R. Binford, eds. Chicago: Aldine Publishing Company.

Watson, Patty Jo, Steven A. LeBlanc and Charles L. Redman
1971 Explanation in Archaeology. New York: Columbia University Press.

Zeitler, E.O. and R.D. Brattan
1971 Uses of Earth Resources Data in the NASA/MSC Earth Resources Research Facility. Seventh Symposium on Remote Sensing of the Environment. Ann Arbor: University of Michigan, Institute of Science and Technology.

INFRARED ARCHEOLOGICAL RECONNAISSANCE

BY

LOUIS JAMES TARTAGLIA

PART I: INTRODUCTION

An investigation was conducted in the application of an aerial infrared photographic sensor to archeology. A comparative approach was undertaken using a series of infrared photographic experiments performed on several southern California coastal shell midden sites to test the usefulness of this remote sensor in data acquisition.

The purpose of the study was to give the archeologist insight into the sensor's capability in recording both physical and cultural anomalies which are invisible to the naked eye. Furthermore, the comparative data should enable the trained archeologist to predict specific types of features that can be detected by an infrared sensing system in a given area. The major aim of this project, then, was to determine the capabilities, limitations, and future potential of an infrared photographic sensor as a tool for the archeologist.

PART II: AERIAL PHOTOGRAPHY IN ARCHEOLOGY

The principal use of aerial photography in archeological research has been to look for sites not previously identified or to complete data on known sites by mapping, recording, planning, and demonstrating inter- and intra-site relationships. This paper is concerned with the development and utilization of an infrared sensor, in locating and analyzing archeological sites.

In order to obtain data from aerial infrared photography, the fundamental procedures for aerial photo interpretation must be used. It has been pointed out by a number of archeologists (see, for example, Riley 1944; Solecki 1957) that archeological sites are usually detectable on aerial photographs by three physically distinquishable features: (1) soil marks, (2) crop marks, and (3) shadow marks. Each of these features results from different kinds of conditions and aids the archeologist in locating and sometimes in identifying significant features.

Variations in texture, composition, color, and moisture retention of a given subsoil produce soil marks. These marks recur annually, but they progressively deteriorate until all signs of them have disappeared. Although weather does not appear to play a significant role in the detection of soil marks, weak marks are more clearly visible under dry conditions (Martin, 1971). A frequently occurring type of soil mark is a damp mark which results from differential rates of moisture absorption and retention of a given soil.

Crop marks are a result of differences in density, size, color, and moisture retention of plants, whether they are agricultural or non-agricultural in origin. Factors such as surface geology, plant type, and climate regulate the appearance of crop marks. Riley (1944) has divided crop marks into two categories: (1) positive crop marks which are the most common and result from sharp local variations in the depth of the soil caused by old cultural features such as ditches and pits that silt up; and (2) negative crop marks which usually occur as a result of prolonged periods of drought and are independent of the subsoil.

Shadow marks in an image are tonal variations due to contrasts in shadows and highlights of features on the surface. Optimum conditions for the detection of features by shadow marks exist when the angle between incident sun rays and feature alignment approximates 90 degrees.

Anne-Marie Martin (1971) has investigated the role that crop, soil, and shadow marks play in the detection of archeological sites by aerial photography. The results of her work indicate that more archeological sites will be detected in a dry year than a wet year. Secondly, she shows that it is possible to predict which soil types will show crop, soil, and shadow marks with some regularity. Porous soils, for example, show more sites in a wet year while chalk and gravel soils produce crop and soil marks in almost any year. Martin, too, stresses the point that in order for the desired aspects of crop, soil, and shadow marks to be captured by aerial photographs, operational requirements must be specified and aerial photographic planning done.

PART III: INFRARED AERIAL PHOTOGRAPHY IN ARCHEOLOGY

Unlike black and white and color aerial photography, infrared photography has not been used to a great extent in archeology. The first aerial infrared photographic mission in archeology was carried out by Ediene (1956). He was able to successfully detect surface details and buried features in Normandy, France, that were not discernible on conventional aerial photographs. Edeine employed Kodak black and white 35mm infrared film with a Leica camera at an average altitude of 120 meters and an air speed of 90-100 km per hour. Photographic analysis of the IR prints revealed traces of a Roman villa, foundation walls, and Roman roads. Furthermore, a circular burial feature, shaft tombs, and non-identified cultural anomalies were recorded only on the infrared film.

In 1958 H.L. Cameron commissioned medium altitude flight lines in an effort to detect surface and sub-surface features at a number of historical archeological sites in Nova Scotia. Black and white infrared film was employed in a Sonne camera which had a specially calibrated lens used without the attachment of filters. According to Cameron (1958), the infrared photographs proved excellent for mapping subsurface features such as buried foundation walls. One interesting anomaly recorded by the infrared film was a ring which did not appear on conventional photographic films used in the study. Subsequent excavation revealed hammer-trimmed flat stones which are believed to have been part of a circular walk in the Governor's garden. Moreover, the parade ground wall at the Louisburg site was recently reconstructed, but the infrared photographs, which delineated the former wall, showed that the rebuilt wall was not in its original position.

Infrared photoarcheology has been successful in detecting archeological sites along the Missouri River in South Dakota where a number of sites in the area, found previously by extensive surveys within the last fifteen years, were recorded on infrared film (Strandberg, 1967). In addition, new sites, including an aboriginal grave pit, were discovered.

Interpretive analysis indicates that the major advantage in using color infrared photography rather than black and white infrared is in the improvement in interpretation accuracy. This conclusion was confirmed in the Potomac River Basin where investigators using color infrared aerial photographs discovered some aboriginal fish traps (Strandberg, 1962).

The Data Analysis Center of the Itek Corporation conducted a field reconnaissance in the Missouri River Valley in an attempt to evaluate the effectiveness of various photographic and photo interpretation materials, techniques, and procedures in archeological exploration (Itek Data Corporation, 1965). Both black and white and color infrared films were tested to determine if variations in spectral reflectivity of vegetation types would act as indicators of subsurface cultural remains. Systematic analysis of both infrared films revealed that little if any supplementary information was obtained except for differences in soil moisture content which were clearly visible on infrared photos of several recently cultivated fields. The primary conclusion of the Itek investigators was that although infrared films failed to reveal any additional data when compared with conventional films, it is conceivable that infrared films might be beneficial in different geographical regions. One thing which this study did show, however, is that moisture differences in soil layers appear to be ideal indicators of the cultural landscape.

Harp (1958; 1968), working in an Arctic environment on the east coast of Hudson Bay, concluded that even though infrared films resulted in higher resolution, contrast, and shadow detail, they did not supply him with any significant improvement in information. Harp also points out the financial problems associated with obtaining aerial photography of different types in such remote areas.

As part of the USGS-NASA Geographic Applications Program, archeological air photo interpretation was investigated at the Asheville test site in North Carolina (Wray, 1971). Color infrared and nine-lens black and white multispectral imagery was used along with conventional color and panatomic films. These photographic sensors were successful in locating a former Indian trail, a drainage channel, and a possible Indian village. By interpretation of crop marks, an Indian cemetery, previously unknown, was outlined by infrared photography. Spring and fall missions were most successful in data acquisition. It is interesting to note that in this case infrared films were apparently more useful at higher altitudes (32,000 feet) than at lower altitudes (6,000 feet) (Wray, 1971).

Another aspect of color infrared photography is its assistance to the archeologist in reconstructing microenvironments, paleoclimatic conditions, hydrology, and pedology of historic and prehistoric sites. For example, Kent Flannery (1968) invested a considerable amount of time in mapping the microenvironments in the Tehuacan Valley, a dry highland valley in Puebla, Mexico. However, all of these natural zones were readily apparent on color infrared photographs and they were mapped in a short period of time with the aid of these photos by Gumerman and Neely (1972). From their investigation of the utility of color infrared photography in archeology, they learned that it was valuable not so much in locating cultural features as it was in delineating the ecological zones in which the features were located. It is, of course, possible to locate features not previously known, as is shown by the discovery of prehistoric agricultural fields near Sunset Crater in Arizona (Schaber and Gumerman, 1969).

PART IV: INFRARED PHOTOGRAPHIC EXPERIMENTS: A TEST STUDY

Although relatively few tests have been undertaken in the application of infrared photography to archeology, it is evident that infrared imagery can be of great utility both in terms of locating cultural features and in obtaining detailed ecological information. In order to further determine the capabilities, limitations, and future potential of infrared photography in archeology, a systematic investigation was conducted on several coastal shell midden sites in southern California. A series of infrared terrestrial photographs were taken in an effort to simulate conditions that would prevail during an aerial photographic mission. The purpose of this investigation was to determine the best infrared film-filter combination in detecting both cultural and natural anomalies. It should be noted that all references to anomalies pertain to tonal contrasts on an infrared print or transparency delineating patterns and features which are not recorded by conventional photographic procedures or discernible to the unaided eye.

The infrared field photography was conducted by the author from February 19, 1971, through August 26, 1972 at a tightly clustered group of archeological sites (fig. 3). These sites were selected because they were scheduled to be excavated during this period. Numerous photographic experiments were carried out on these three sites.

Infrared Photographic Procedures

The following procedures were employed in the field investigation:

1. The standard field equipment consisted of a Honeywell-Pentax Spotmatic 35mm single lens reflex camera.
2. A tripod was utilized to establish a fixed platform.

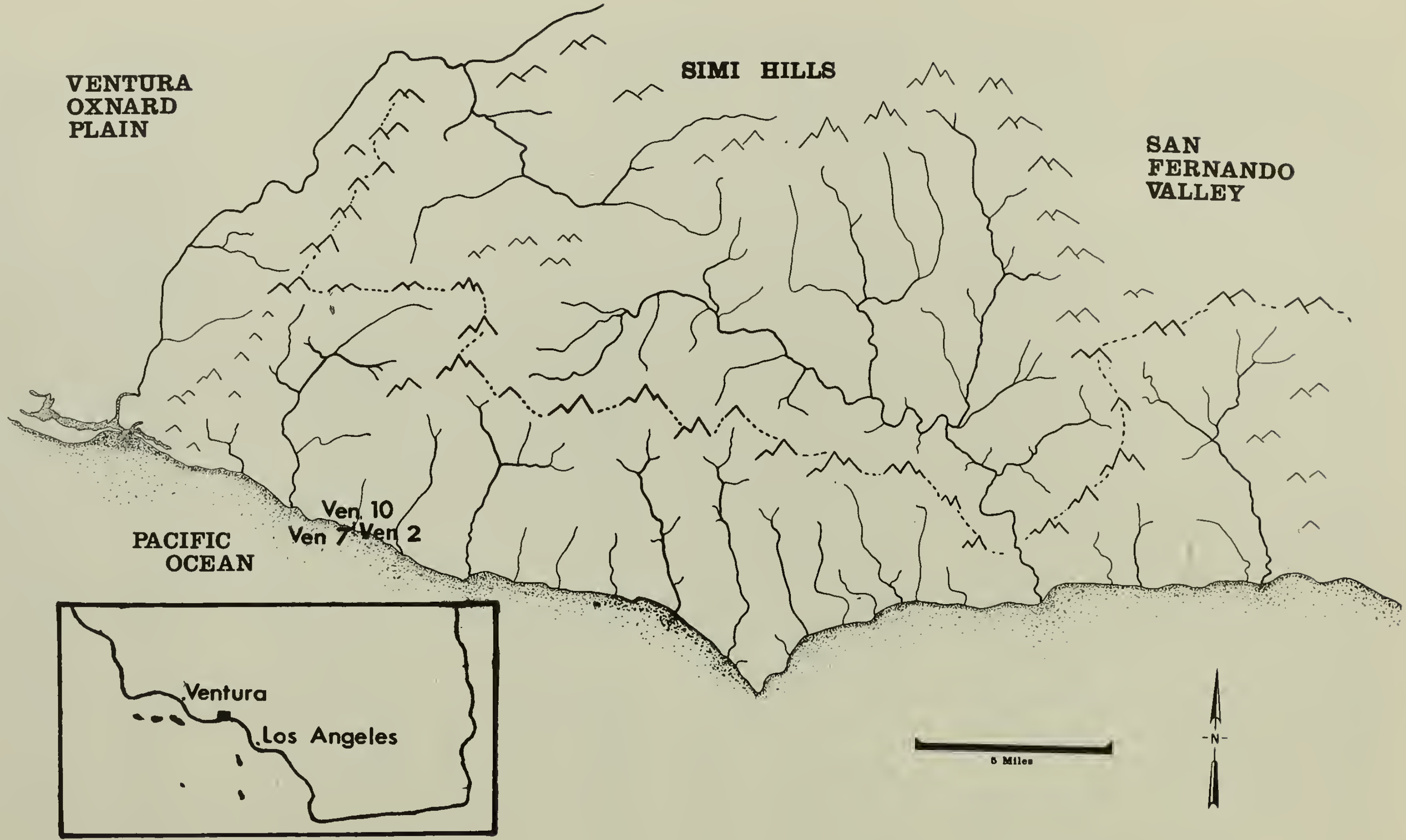
The following photographic films were used in this study:

<u>Conventional Films</u>

1. Kodak Panatomic X-32 was selected as the black and white standard because it is a fine-grained, high contrast film.
2. Kodak Ektachrome film was established as the color photographic standard because it has a similar base to Kodak's Ektachrome infrared film.

<u>Infrared Films</u>

1. Kodak's high speed infrared black and white film (HIE 135) is a moderately high contrast film sensitive through the visible regions of the electromagnetic spectrum and into the infrared. It has a maximum sensitivity from 770 mu to 840 mu (Kodak, 1970a).
2. Kodak's Ektachrome infrared film (IR 135) is a modified false color reversal film, designed to be exposed by daylight. The infrared sensitivity range of this film is



Modified from Leonard (1971)

FIGURE 3 - Area of examination in southern California showing the location of sites Ventura 2, Ventura 7, and Ventura 10, all in Ventura County, California

700 mu to 900 mu (Kodak, 1970b).

All infrared photographic films require the attachment of photographic filters to the lens of the camera to absorb undesired light. Thus, the selection of a specific filter or combination of filters is critical in determining desired results, since the solar energy reflected by any cultural anomaly and recorded on the film is controlled by the film-filter combination. Consequently, Wratten filters were investigated to determine the effectiveness of their detection capabilities and their specular enhancement qualities. The results of this experiment are listed in table 2 (consult this table for the best filter combination on the basis of "tonal contrast" and "remarks").

In order to apply the correct stop-factor for each wratten filter that appears in table 2, the following example is given. If a Wratten 11 filter - Wratten 15 filter combination is used with color infrared film, the correction factor is one and one-half (1½) stops down from the normal exposure setting. Thus, if the light meter reading (through the lens) is an F-stop of 8 (shutter speed 1/30 of a second) at an ASA of 100, then the correct exposure index is an F-stop of 16 (shutter speed 1/30 of a second) at an ASA of 100.

Since this technique cannot be applied to visually opaque infrared filters (Wratten filters 87, 87C, 88A, and 89B), a method was developed whereby a Wratten 70 filter (dark red) was used as a standard in taking light meter readings for all infrared filters. Then a correction factor for each respective Wratten filter was determined. The Wratten 70 filter was selected because its wavelength (200 mu to 620 mu) approaches the near-infrared portion of the electromagnetic spectrum and permits a through-the-lens light meter reading to be taken. For example, if an infrared Wratten 15 - wratten 88A filter combination is used with color infrared film, the correction factor is three and one-half (3½) stops down from the normal exposure setting obtained with the Wratten 70 filter (without any correction factors). Therefore, if the normal light meter reading (through the lens) for a Wratten 70 filter is an F-stop of 4 (shutter speed 1/30 of a second) at an ASA of 50, then the correct infrared exposure is an F-stop of 16 (shutter speed 1/30 of a second) at an ASA of 50. Furthermore, it must be stressed that for best contrast, resolution, and definition on an emulsion, a narrow aperture (F-stop of 16) is recommended since it decreases the amount of undesirable light which is recorded on the film.

Owing to the variable photographic properties associated with each film-filter combination, it is advisable that a data sheet accompany every series of infrared exposures since the correct exposure and respective effect of various filters on a given object cannot always be predetermined (table 3).

TABLE 2

Color Infrared Data Sheet

Filters	ASA	Stop Factor Down	Signature (Predominant Hue)	Tonal Contrast	Remarks
1A+15	100	1	Green	M	F.R.
6+15	100	1	Green	L	N.S.R.
8+15	100	1	Green	L	N.S.R.
11+15	100	1½	Blue	H	F.R.
15	100	1	Green	M	G.R.
15+PL	100	1½	Green-Red	H	G.R
25A+15	100	3	Yellow-Green	L	N.S.R.
29+15	100	3	Yellow-Green	L	N.S.R.
32+15	100	4½	Green	M	N.S.R.
32+44A	100	2	Purple	H	G.R.
15+32+44A	100	3½	Red	H	N.S.R.
36+15	100	1½	Magenta	M	N.S.R.
44A+15	100	2	Magenta	M	N.S.R.
70+15	100	3	Red	H	G.R.
80B+15	100	1	Green	H	G.R.
80C+15	100	1	Green	M	F.R.
81A+15	100	1	Green	L	N.S.R.
85+15	100	1	Green	L	N.S.R.
85B+15	100	1	Green	L	N.S.R.
87+15	50	3½	Red	H	N.S.R.
87C+15	20	3	Red	H	N.S.R.
88A+15	50	3½	Red	H	N.S.R.
89B+15	100	5	Red	H	N.S.R.

F.R. Fair Results
G.R. Good Results
N.S.R. No Significant Results

L Low Contrast
M Medium Contrast
H High Contrast

TABLE 3

Infrared Photographic Field Data Sheet

Area: Deer Creek
Date: February 12, 1972
Film: Color Infrared

No.	Site	ASA	Filter	F-Stop	Shutter Speed	Time	Compass Direction
1.	Ven-7	100	32+44A	11	15	12:30	N.W.
2.	Ven-7	100	15+80B	11-8	15	12:32	N.W.
3.	Ven-10	100	15+80B	11-8	15	12:33	N.E.
4.	Ven-10	100	11+15	11-8	15	12:34	N.E.
5.	Ven-10	50	15+87	11-8	15	12:36	N.E.
6.	Ven-10	50	15+87C	11	15	12:38	N.E.
7.	Ven-7	50	15+87C	11	15	12:39	N.W.
8.	Ven-7	50	15+87B	16	1 sec.	12:40	N.W.
9.	Ven-7	50	15+87B	16	5 sec.	12:40	N.W.
10.	Ven-7	50	15+87A	16	8 min.	12:41	N.W.
11.	Ven-7	50	32+15	16	15	12:50	N.W.
12.	Ven-7	100	15+44A	11	4	12:52	N.W.
13.	Ven-7	100	15+36	16	8	12:56	N.W.
14.	Ven-2	100	15+36	16	8	12:57	N.W.W.
15.	Ven-2	100	15+32	16	30	12:59	N.W.W.
16.	Ven-2	100	32+44A	11	15	1:01	N.W.W.
17.	Ven-2	100	15+44A	11-8	4	1:04	N.W.W.
18.	Ven-2	50	15+87	11	15	1:06	N.W.W.
19.	Ven-2	50	15+80B	11-8	15	1:09	N.W.W.
20.	Ven-2	100	15+PL	11	15	1:11	N.W.W.
21.	Ven-10	100	15+PL	11	15	1:12	N.W.W.

Infrared Archeological Site Detection

One of the basic principles involved in the aerial detection of an archeological site is the assumption that differential soil compaction, specific density, chemical composition, and the physical alteration of the surface are the main variables that affect the amount of absorbed and reflected solar radiation and thereby delineate cultural and natural anomalies. A combination of edaphic and vegetative conditions for site detection has been presented by Gumerman and Neely (1972). The amount of solar radiation (energy) absorbed, transmitted or reflected by a feature fluctuates according to the prevailing diurnal atmospheric conditions. Thus, another factor to consider when working with infrared photography is the occurrence of peak time intervals of optimum conditions. One must be aware of the cross-over periods in early morning and late afternoon when an object's surface will reflect light rays so evenly that no apparent fluctuation of surface texture is evident. Photographic experimentation has revealed that the optimum period for infrared photography in the coastal areas of southern California is between 10:30 A.M. and 1:30 P.M.

In order to extract spectral data for interpretive purposes from infrared reflectance of cultural features, all anomalies re corded by the infrared camera were subsequently field checked. The checking system was designed to achieve the following goals:

1. identification of cultural anomalies.
2. recognition signatures of respective cultural features.
3. prediction of the tonal-textural signatures of distinct phenomena.

Analyses were accomplished by comparing infrared transparencies and prints with conventional films that had been established as the photographic standards. The following method were employed in these analyses:

1. An eight-power hand lens was used in photo interpretation of black and white infrared proof sheets (8½"x11").
2. Color infrared transparencies were projected onto a screen and analyzed directly.
3. Composite color infrared transparencies were produced with a Spiratone dupliscope in order to acquire high contrast black and white prints.

Infrared Photographic Analysis

A series of infrared photographic experiments were conducted to test the effectiveness of this sensor for its practical application in detecting cultural anomalies. Photo interpretation of the infrared prints and transparencies revealed primarily two types of anomalies: 1) features that are visible to the unaided eye; and 2) features that are barely discernible or invisible to the human eye.

One infrared photographic study was conducted at the Deer Creek Drainage area, Ventura County, California, at an elevation of approximately 400 feet above the sites in an effort to evaluate this type of sensor's capability of revealing previously known archeological sites (Ventura 7 and Ventura 10) and other cultural anomalies. Since the sites selected for this investigation contained large amounts of shell, it is possible that this matrix factor is one of the primary variables to be considered in the infrared recording of the reflectance of solar radiation. This is due to the fact that the respective soil composition, compaction, and specific density have been considerably altered by man from the adjacent sterile soil. It is conceivable, then, that this factor facilitates the retrieval of spectral information indicating cultural remains in infrared aerial site detection.

As illustrated in figures 4-7, color infrared film proved superior when compared with both black and white infrared film and conventional films for archeological site detection in this particular area. Photographic analysis also revealed that the best site signatures were obtained with a Wratten 15 - Wratten 80B or a Wratten 32 - Wratten 44A filter combination (see table 2). An examination of site signatures on color infrared slides that were photographically induced by means of a Spiratone dupliscope revealed that a Wratten 80B - Wratten 15 filter combination or a combination of a wratten 15 filter and a polarizing filter provided the best results. Archeological site signatures were substantially reduced, however, with the attachment of visually opaque infrared filters.

Another application of infrared photography was to determine if disturbed areas within an archeological site could be revealed by the infrared sensor system. As shown in figure 7, the locations of pot holes and the back dirt associated with them (designated as X and Y on the photograph) were clearly exposed at Ventura 10. Moreover, it is evident that the infrared photograph provided greater definition of the outline and depth of each pot hole than did the conventional Ektachrome print. Also, another anomaly (designated as Z on the photograph) represents the back dirt piles from an earlier UCLA archeological excavation at the site.

Six months after the excavation of Ventura 7, a series of infrared photographs were taken to determine if former excavation units would be detected through tonal variations caused by differences in plant cover and moisture patterns. It has been noted by Gumerman and Lyons (1971) that vegetation is sometimes a reflection of subsurface water and can be used to locate and plot drainage patterns within a given river drainage area. However, since

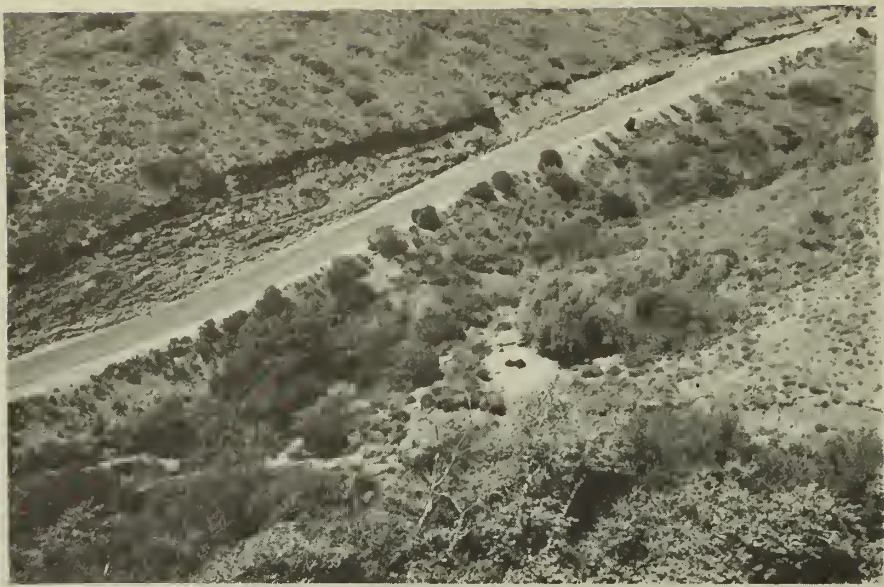


FIGURE 4 - A normal black-and-white
Panatomic print of Ventura 7

FIGURE 5 - An infrared Ektachrome print
of Ventura 7 (Wratten 15 and
polarizing filter combination)

FIGURE 6 - A normal Ektachrome print of Ventura 10

FIGURE 7 - An infrared Ektachrome print of Ventura 10 (Wratten 15 and 80B filter combination)

primary vegetation succession had not yet occurred, the infrared photographs failed to reveal any recent excavation pits at the site.

Photographic analysis of the infrared transparencies did, however, reveal some interesting ecological information. Hydrologic patterns are distinguishable on color infrared transparencies as subtle tonal contrasts representing poorly and well drained areas. It was possible, through photo interpretation, to determine that slope runoff and, possibly, periodic flooding had occurred at Ventura 10. This site is located on the flood plain of Deer Creek, whereas Ventura 7, which is only 25 meters to the northwest, is located well above the flood plain. Since archeological evidence indicates that Ventura 10 was only temporarily occupied while Ventura 7 was permanently occupied, it is postulated that environmental factors such as those indicated on the infrared transparencies played a major role in the periodic abandonment of Ventura 10. Infrared photo interpretation has thus provided an explanation for why one site was used only occasionally while another one right next to it was permanently occupied.

PART III: CONCLUSIONS

Infrared photography is a valuable tool for the archeologist in helping him detect both cultural and natural anomalies, but it has not been put to much use by archeologists. This study is an attempt to rectify this situation by showing that not only archeological information, but ecological information as well can be obtained. Some cultural features can be recorded by the aerial infrared sensing system. Furthermore, overlapping vertical aerial photographs permit stereoscopic viewing of these recorded features, enabling the photo interpreter to see greater detail.

Since only archeological sites in southern California were tested, many kinds of features such as house walls and canals were not encountered. As a result, the future potential of this remote sensing system, in terms of data acquisition, can only be fully determined through its application in other regions. Some experiments using infrared photography have already been undertaken in such places as the Tehuacan Valley, Mexico (Gumerman and Neely, 1972), the Missouri River Valley in South Dakota (Strandberg, 1967), and Nova Scotia (Cameron, 1958), and they have proved successful. Such demonstrations as these and the one presented in this paper illustrate the potential value of aerial infrared remote sensing in archeology.

University of California
Los Angeles

LITERATURE CITED

Cameron, H.L.
1958 History from the Air. Photogrammetric Engineering 24: 366-375.

Eastman Kodak Company
1970a Kodak High Speed Infrared Film 2481 - Data Release. Kodak Publication No. M-9. Rochester, New York: Eastman Kodak Company.

1970b Kodak Aerochrome Infrared Film 2443 - Data Release. Kodak Publication No. M-69. Rochester, New York: Eastman Kodak Company.

Edeine, Bernard
1956 Une Methode Practique pour la Detection Aerienne des Sites Archaeologiques, en Particulier par la Photographie sur Films en Couleurs et sur Films Infrar-rouges. Bulletin de la Societe Prehistorique Francaise 53:540-546.

Flannery, Kent. V.
1968 Archaeological Systems Theory and Early Mesoamerica. In Anthropological Archaeology in the Americas, Betty J. Meggers, ed. Washington, D.C.: The Anthropological Society of Washington.

Gumerman, George J. and Thomas R. Lyons
1971 Archaeological Methodology and Remote Sensing. Science 172:126-132.

Gumerman, George J. and James A. Neely
1972 An Archaeological Survey of the Tehuacan Valley, Mexico: A Test of Color Infrared Photography. American Antiquity 37:520-527.

Harp, Elmer, Jr.
1958 Optimum Scales and Emulsions in Air Photo Archaeology. Paper presented at the VIII International Congress of Anthropological and Ethnological Sciences, Tokyo, Japan.

1968 Anthropological Interpretation from Color. In Manual of Color Aerial Photography, J.T. Smith, ed. Falls Church, Virginia: American Society of Photogrammetry.

Itek Data Corporation
1965 _Archaeological Photo Interpretation_. Technical Report No. 65-8458. United States Department of Commerce Clearinghouse, Washington, D.C.

Martin, Anne-Marie
1971 Archaeological Sites--Soils and Climate. _Photogrammetric Engineering_ 37:353-358.

Riley, D.N.
1944 The Technique of Air-Archaeology. _Archaeological Journal_ 101:1-16.

Schaber, Gerald G. and George J. Gumerman
1969 Infrared Scanning Images: An Archaeological Application. _Science_ 164:712-713.

Solecki, Ralph S.
1957 Practical Aerial Photography for Archaeologists. _American Antiquity_ 22:337-350.

Strandberg, Carl H.
1962 Ancient Indian Fishtraps in the Potomac River. _Photogrammetric Engineering_ 28:475-478.

1967 Photoarchaeology. _Photogrammetric Engineering_ 33:1152-1157.

Wray, James R.
1971 _Locating Archaeological Sites by Image Interpretation_. Washington, D.C.: USGS/NASA Geographic Applications Program.

AERIAL PHOTOGRAPHY FOR THE ARCTIC ARCHAEOLOGIST

BY

ELMER HARP, JR.

PART I: INTRODUCTION

Aerial photography, if properly appreciated and employed, can be a significant tool for the archeologist in any part of the world. In general terms, it provides comprehensive data for the analysis of regional environments, and it can be used for the discovery of sites in previously unexplored country, for expedition planning, for site evaluation and settlement pattern analysis, and in some cases for photogrammetry and mapping. In any given environmental zone, the local characteristics of terrain, vegetation, climate, etc., will fundamentally affect the usefulness of such photography for archeological interpretation. The following discussion will be confined essentially to Arctic environments. More precisely, it will focus on my personal experience with air photo applications in southeastern Hudson Bay, an ecotone which encompasses both the southern fringes of the Arctic tundra and the northern edges of the sub-Arctic tundra and the northern edges of the sub-Arctic boreal forest zone (fig. 8).

Aerial photography is but one component in the complex technology of remote sensing, yet there can be no question that its visual images of the earth's surface comprise the archeologist's most effective tool in the full range of remote sensing instrumentation. This conventional photographic imagery normally covers the bandwidth of the electromagnetic spectrum detectable by the human eye and, of course, can be supplemented by imagery derived from other sophisticated sensors. For example, infrared photo emulsions slightly extend the visual bandpass, while true thermal sensors and radar read other segments of the spectrum. However, these and still other families of sensors only retrieve highly specialized fragments of information. Except in very limited circumstances, they are generally less effective than photography for the acquisition of broad archeological information. Moreover, there is a

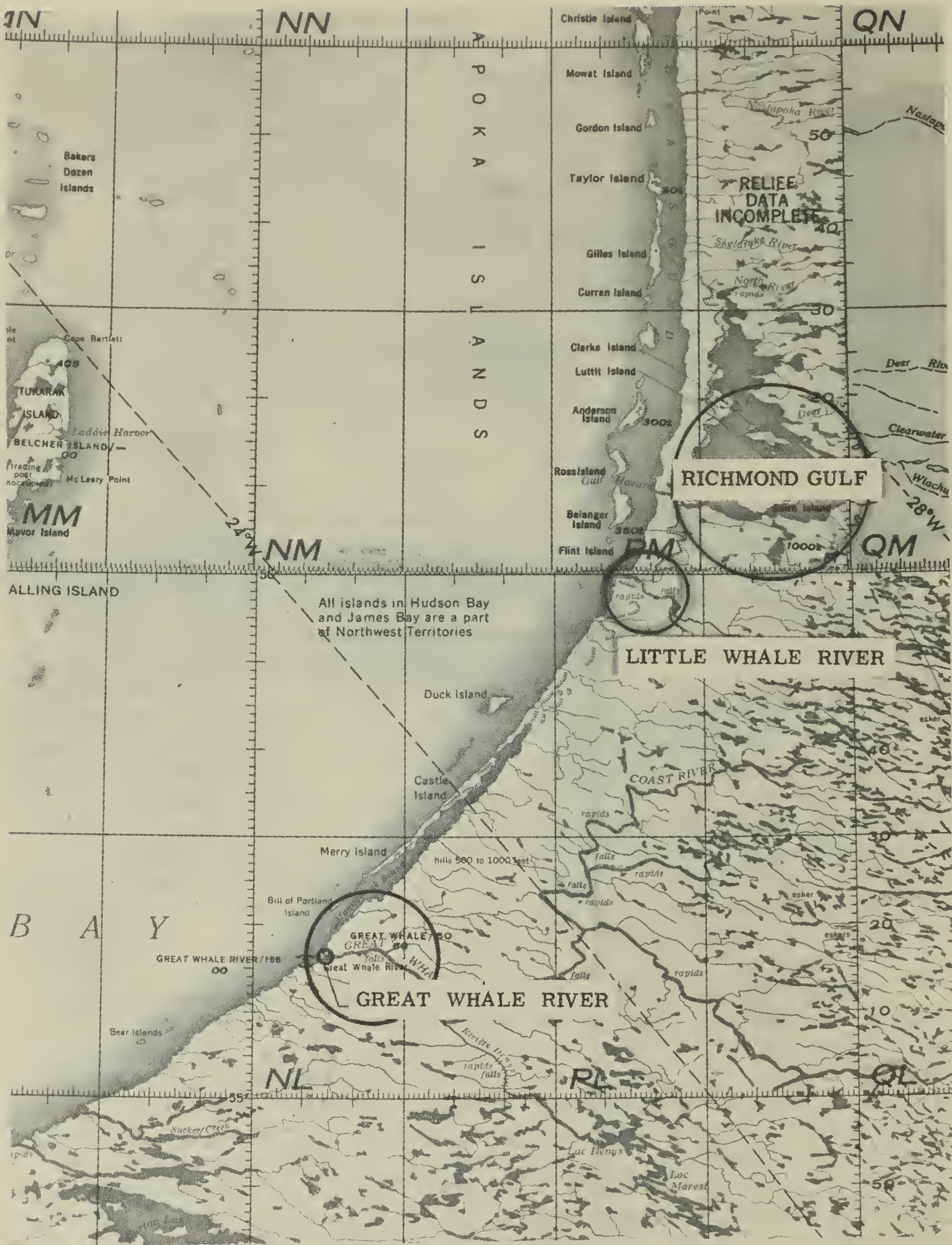


FIGURE 8 - Arctic and sub-Arctic areas covered by experimental aerial photography in the summer of 1966.

paramount economic factor involved in these kinds of remote sensors which should be a major concern to most archeologists, i.e., while photography can be very costly at times, operations employing extra-visual sensors often require massive financial support.

While serviceable aerial photography can be obtained from light planes or helicopters, it usually consists of a disconnected series of oblique shots which have no uniform ground scale, and which cannot provide blanket coverage of a sizable area. Such imagery may be very useful for the illustration of archeological sites or other cultural features, and sometimes for simple graphic photogrammetry, but it does not lend itself readily to systematic analysis and interpretation. Therefore, I intend here to consider the merits, as well as the drawbacks, of vertical aerial photography for survey or mapping purposes.

Vertical aerial photography is customarily taken in a 9 x 9-inch format, with 60 percent overlap of photos along the flightline, and about 15 percent overlap of adjacent flightlines. It has a constant ground scale, as determined by the needs of the mission, and it provides complete surface coverage over selected large areas. With this imagery, one can construct large photo mosaics, and, because of the overlap mode, features on the mosaic can be examined stereoscopically. The resulting three-dimensional effect is of inestimable value to the photo interpreter, for it vastly increases the amount of information that he could otherwise glean from two-dimensional planar photography (cf. Rinker, in press).

PART II: EXPLORATION FOR SITES

The preliminary examination of an air photo mosaic is normally a straightforward visual scanning, aided perhaps by a hand-held magnifying glass of moderate power. One looks for cultural, man-made features, whether of contemporary or prehistoric age; this essentially involves the discrimination of unnatural, anomalous forms or properties on the natural landscape. In the case of archeological sites, these will usually consist of changes in the vegetative cover, such as crop marks or deforestation, or there may be structures such as ruined buildings, walls, earthworks, or excavations such as house pits, ditches, etc. Anywhere that man has dwelt for a prolonged time or in significant community numbers, he will have left his mark. The more elaborate his culture and technology, the more extensive these signature traces will be. Of course, during the passing of millenia these traces may have been obliterated by erosion or cataclysm, but here we must assume that some vestigial signs remain and are amenable to detection and interpretation. However, at this point, we are confronted with a major disadvantage, one that is inherently a part of Arctic archeology.

Until our modern era, the Arctic, as well as the sub-Arctic and their mutual ecotone, were inhabited thinly by migratory hunter-gatherers, and the impact of such peoples and their cultures on the natural landscape was at all times minimal. Except for a very few food-rich locales in the western and eastern Arctic, Eskimo exploitation of that circumpolar zone was scattered and spotty. Extended family groups and seasonal band conglomerations of an impermanent nature were the social norm, and the archeological residues of such groups generally meager. I have previously characterized their landscape signatures in terms of "threshold indicators" (Harp, 1974).

The location of every hunter-gatherer site in the Arctic will first of all be determined by the availability of valued natural resources, particularly food. The size and complexity of the occupation clusters will be affected by several factors: the abundance or paucity of the food supply at any given time; the demographic character of the local population; and the level of hunting technology, which may emphasize either the lone operator or communal activity. The continuity of basic food supplies throughout a long period, perhaps several or more centuries, will also lead to the gradual enlargement of an archeological site, as people return to it seasonally in succeeding generations and construct new dwellings. Thus, Arctic sites may consist of the remains of a single dwelling, or of a cluster of dwellings numbering up to six or eight. If the grouping is more numerous, this fact almost certainly indicates a longer occupational span. Whatever pattern such a community may have is likely to be quite random. However, in coastal sites, the house units will frequently be strung out thinly and sporadically in alignment with a beach or terrace.

Obviously, such settlement sites do not represent large compositions or complex designs, and by virtue of these characteristics alone they will not be immediately recognizable in the preliminary scanning of an air photo mosaic. The overall dimensions of the community clusters can vary markedly. A two-house group might be encompassed in a space measuring 15 x 45 feet. The largest Eskimo site I have ever seen consisted of 36 house units in a space that measured approximately 250 x 700 feet. But it must be emphasized that these total settlement spaces are not discernible as human artifacts in air photos. They are not delineated by boundary walls, nor do they contain internal networks of streets or trails, or subsidiary enclosures. Man did not create these spaces, but simply located his houses or camps within them. Therefore, one must look directly to the individual dwelling units for traces of environmental disturbance. These are the fundamental anomalies that differ from the surrounding patterns of the natural landscape.

Virtually all the house types of hunting cultures in the far north were seasonal and temporary in nature, but some more so than others. Portable tents for spring, summer, or fall had pole frames and skin covers which were customarily held down against winds by rocks or small boulders which could be collected locally. At the time of abandonment, the poles and skin covers were hauled away, and the ring of stone weights left in place became archeological residue. We can, of course, disregard the snow houses of the central Arctic, but other forms of winter dwelling were more substantial. These were often partially excavated, or semi-subterranean, and lined with slab rock or driftwood to prevent slumping of the walls. As a general rule, such houses, whether for summer or winter use, averaged 15 feet in diameter, and they were subrectangular or circular in plan. Occasionally, there were ceremonial enclosures of larger size.

When this 15-foot linear measurement thus becomes the crucial unit for observation and recognition, the resolving power and the scale of the aerial photography are matters of extreme significance. I have examined these relationships before (Harp, 1968a), and in this paper I need only summarize my earlier findings. For discovering archeological sites in the Arctic, I have learned to use successfully an air photo scale of 1:15,000, and I have also found that is a viable scale in economic terms. At 1:15,000, each 9-inch photo portrays a plot of ground measuring 2.13 miles square; hence, 1 inch = 1250 feet, and 1 mm. = 49 feet. This means that with training and persistence, it is possible to observe 15-foot house rings directly, with the aid of a folding pocket model stereoscope with 2.5 magnification. Even better is a 7X measuring magnifier, such as one manufactured by Bausch and Lomb. This enables the photoanalyst to measure a linear distance of 0.1 mm. on the photo, or in the case of a 1:15,000 scale, 4.9 feet on the ground. Larger scales will obviously resolve smaller ground features, but this capability should not be carried to levels of absurdity. When site recognition has been satisfactorily achieved, it may then be time to enter the field and begin digging. Also, photo scales that are larger than necessary will involve increased numbers of photographs to be handled and analyzed, laboratory activity that is exceedingly time-consuming.

On the other hand, conventional mapping or survey photography available from several government agencies in Canada and the United States, generally has too small a scale to be useful for discovering hunter-gatherer sites. Canada, in particular, is covered mostly by 1:30,000 to 1:60,000 photography. These scales are perfectly usable for regional environmental analyses, and therefore may help the archeologist identify broad, potential site locales. However, at such small scales one cannot successfully register a 15-foot house pit or stone ring.

One other factor, image contrast, is very important in the photo analytical process of site discovery, especially in the Arctic, and that, in turn, relates to the varying capabilities of different photographic emulsions. Here, I refer specifically to the tone or color contrast between an object and its context or background, and I assume that all other factors relating to image quality (graininess, sharpness, resolving power, etc.) are optimum. Also, I purposely omit any consideration of the psychological and cultural factors which influence air photo analysis and interpretation.

In order to be seen, recognized, and interpreted, any cultural features must stand forth separately from its environment, and in a photographic image, this distinction can only be achieved through differences in color tone or three-dimensional relief. If we deal first with the problem of separation by means of color tone, it must be noted that most Arctic sites are distinguished mainly by drabness, or lack of strong color separation. The low-relief superstructures of house rings and house pits are constructed of immediately local materials. The house site may be a ring of boulders in a surrounding sea of other boulders and therefore virtually invisible both in a vertical photograph and at ground level. Also, although we never have to contend with the concealment of canopied forests, Arctic sites tend to become obscured by low-growing vegetation. The rate of their submergence will vary with geographic position and climatic factors. In the southeastern Hudson Bay region, for example, superficial rings will almost completely disappear within two or three centuries. Boulders in the peripheral ring soon become encrusted with lichens and blend under perfect camouflage with their environment. In my experience., this type of house site is impossible to distinguish in air photo analysis, even at impracticably large scales. Indeed, it can easily be missed during ground exploration.

Another variation of site disappearance occurs where surface growth of lichens, mosses, or sedges is thicker and richer, as on raised sandy beaches or river terraces. In such places, prehistoric house rings, whether Indian or Eskimo, generally are marked by a low, earthen perimeter ridge, originally heaped onto the ground flaps of the skin roofing to seal the dwelling and help hold it down. The interior space in Indian lodges is very slightly depressed below the surrounding ground level and will usually contain a raised hearth mound in the center. Eskimo houses of this superficial kind may have been excavated a bit deeper, but they lack the central mound. However, in either case, these rings will fade almost completely from view with the passing of a century or more. Portions of the outer rings will erode toward the lower interior, and finally the encroaching lichens and surface turf will stabilize and further soften the reduced contours of the original dwelling.

These shallow, saucer-like depressions are very difficult to perceive at ground level, and even an experienced archeologist who is not quartering the terrain with sufficient concentration may pass by them. Deeply excavated Eskimo winter houses with entrance tunnels, even though completely grassed over, are easier to see.

Despite the difficulty in observing such houses on the ground, they can sometimes be clearly seen in air photos. This may be due first of all to the three-dimensional effect inherent in stereoscopic viewing. Because of differences in the angles of parallax between the photo interpreter's eye base (interpupillary distance) and the photo base (distance between successive air photo exposures), the impression of depth in stereoscopic pairs is exaggerated, perhaps threefold or more. This means that the depressed or excavated interiors of prehistoric house sites are accentuated and appear much deeper than they really are. A depression of six inches may hardly be visible at ground level, but in a stereoscopic pair of air photos the enhanced depth effect of this feature will be immediately apparent to the analyst. Thus, optically induced vertical exaggeration is a tremendous asset to the archeological photo interpreter.

Secondly, unnatural or anomalous vegetation patterns can generally be seen more readily in air photos than at ground level. Ecological balances in the Arctic are most delicate, and apparently insignificant human acts, such as scraping up a low embankment around the edges of a skin-covered lodge, or scattering organic cultural debris within a house, alter and enrich the nutrient balance of these discrete areas. The result will often be a slight enhancement or thickening of the vegetation growing there, and in a photograph, this will serve to emphasize the shape or outline of the cultural feature, provided it contrasts sufficiently with the surroundings. If this suggestion of cultural form is linked with anomalous differences in ground level, the case for discovery is thereby strengthened. Elsewhere, I have shown with specific examples how these threshold indicators of Arctic and sub-Arctic sites can effectively be sorted out in the process of systematic air photo interpretation (Harp, 1968b; 1974).

PART III: FILMS RECOMMENDED FOR USE IN ARCTIC REGIONS

As for the use of various photographic emulsions, I have found through experimentation in the Arctic that panchromatic is best in terms of its information content per dollar of cost. It will consistently yield the results that I noted earlier in respect to matters of scale and contrast. Perhaps not all of the myriad gray tones on a panchromatic image may be immediately decipherable, but the major gradations will soon fall into meaningful relationships as stereoscopic analysis proceeds. It has the standard advantages of amenability to layout in regional mosaics, or the negatives can be converted to positive transparencies for viewing on a light table. It has the fastest emulsion speeds available and, therefore, with various filter combinations, can be used under a wider variety of weather conditions in the field.

Black and white infrared photography has the same general physical and handling characteristics as mentioned above, but I find it less satisfactory for use in Arctic photo interpretation (figs. 9 and 10). It minimizes the contrast values of many surface components, including broadleaf vegetation, and it does not permit rapid differentiation between certain types of rock and sandy areas. Water absorbs infrared radiation almost totally, and so this emulsion is good for separating dry from wet or water-logged surfaces. In other environments with more extensive archeological residues, particularly with buried remains that have affected the water retention capability of soils, this could be a superior emulsion for the detection of completely submerged sites. In the Arctic, however, these considerations do not apply.

The color film emulsions that are ordinarily reproduced in transparencies, but which may also be rendered in print form, include true color and Ektachrome infrared, or camouflage-detection film. Of these, the Ektachrome infrared is perhaps more interesting to use for analysis because of its startling color inversions (broadleaf vegetation appears red, red objects become green, green objects are blue, and blue becomes black). It records surface patterns in vivid contrast, but for its high cost, I do not feel that it adds significantly to the information one can obtain from the more commonplace panchromatic imagery. As for true color film that too is very costly and it very seldom exceeds panchromatic in its information-recording capability. After all, most archeological remains, certainly those in the Arctic, have long since lost any color which might formerly have had some cultural significance. In aerial photography, they usually are portrayed in the reflectance tones of the natural landscape, which can be seen just as easily and efficiently on panchromatic film.

PART IV: SITE EVALUATION

The preceding section suggests that air photo analysis can be an effective approach to site evaluation and settlement pattern analysis, but in the Arctic, the generally impoverished nature of prehistoric sites minimizes the value of this approach. One has the feeling that the job can be accomplished more efficiently on the ground. In many instances, the house units in the sites will not be visible at all in air photos, even at large scales, due to the lack of superficial structure and contrast. Nevertheless, if the ring clusters are apparent and recognizable, the photos reliably establish them in a full environmental context. Numerical house counts can be rapidly made and some notion of population or community size

FIGURE 9 - The modern settlement of Poste de la Baleine, Great Whale River, Quebec. Panchromatic 1:15,000

FIGURE 10 - The modern settlement of Poste de la Baleine, Great Whale River, Quebec. Black-and-White Infrared 1:15,000

tentatively stated. Occasionally, in the Arctic, it may be possible to read a sequence of occupations, as on a series of raised beachlines. All such observations, made to whatever extent possible, will surely help the archeologist to formulate theory and organize practical field strategy.

PART V: MAPPING AND PHOTOGRAMMETRY

The Arctic is not significantly different from other environmental zones or regions in respect to these functions. Its major advantage for air photo interpretation, the lack of canopied forests, seems almost entirely offset by a major disadvantage, the paucity and smallness of its prehistoric sites. Accurate plan maps of such sites can be constructed from vertical air photos, provided the scale is large enough to manifest all the visible traces of archeological features. Otherwise, I am confident that most archeological sites, wherever they may be, can best be mapped on the ground with conventional surveying instruments which simultaneously provide azimuth and elevation data.

If, in some instances, it is not possible to run an adequate ground survey for mapping purposes, sufficient data for later map construction can be acquired rather easily with photography (Williams, 1969). The four corners of a large, measured square should be staked out in the middle of the site, and the general area can then be photographed with any hand-held camera from some nearby, high vantage point, or even from a light plane. This produces a controlled oblique aerial view. The measured square is rendered as a trapezoid in the oblique photo, and one can graphically generate from this a large array of trapezoids covering the entire photograph. All pertinent features can then be plotted with a high degree of accuracy within this system or coordinates. Obviously, however, the Arctic bears no special relationship to this technique, although, in its austerity, it will never furnish the archeologist with a convenient tree to climb for such elevated photography.

PART VI: ENVIRONMENTAL ANALYSIS

It is most important, of course, for an archeologist to strive for a detailed understanding of the ecological context in which a site occurs, and then he must extrapolate this setting backward in time to the period of the site's occupancy. That is reason enough for intensive environmental analysis. However, if one's preliminary examination of an air photo mosaic has failed to detect any indications whatsoever of man or a cultural landscape, then environmental analysis necessarily becomes the primary research effort. Inasmuch as I have dealt with this topic fully in a recent paper (Harp, 1974), it need only be summarized here.

The rationale of this approach can be indicated as follows: Man is a part of nature and a full-time member of various ecosystems; he exploits his environment according to biological and cultural imperatives; if we can determine the constituents and properties of any given environment, we can then predict the range of man's cultural responses to it; in doing so, we can arbitrarily categorize the variety of possible responses in relation to levels of subsistence economy and technology; such different culture systems will exert variable impacts on the natural landscape; thus, different culture systems will leave distinctive signature traces.

The ensuing environmental analysis of the air photos cannot be haphazard, but must proceed systematically from regional to local levels and, ultimately, to stereoscopic examination of selected features. It should attempt to describe physiography, geology, drainage patterns and hydrology, land forms and erosion patterns, vegetation, signs of fauna, and all other indicators of climate. When that natural matrix has been thoroughly recorded in every possible detail, we may then pose relevant anthropological questions and inject man and culture into this scene. Thenceforward, the search for archeological patterns will focus on discrete locales. For further understanding of these analytical and interpretive procedures, I recommend study of Rinker and Frost (1968).

PART VII: EXPEDITION PLANNING

Environmental analysis sets the stage for the last, and by no means the least important, service of aerial photography in behalf of archeological research. It is an extraordinary aid in the planning of field strategy, particularly in areas that are new or strange to the investigator. Here, again, I make no claim that the Arctic differs from other environmental regions in its relationship to this function, but it will serve adequately here as a model.

After going through the intensive effort of environmental analysis, the archeologist is bound to have a new, extremely detailed appreciation of the area he proposes to explore. His attention has been concentrated on a set of locales which either have demonstrable sites or significant potential, and he has thereby ruled out of further consideration a large percentage of intermediate and surrounding countryside. This narrowing of focus will save substantial quantities of time in the field, for he can efficiently plan his movements from point to point, secure in the knowledge that in between stretches are likely to hold little of value. This reconnaissance of new country can be tightly related to the exigencies of terrain and drainage patterns. The easiest travel routes can be plotted, the most comfortable campsites preselected with attention to supplies of fresh water, wood, fish and game, or other natural resources. Precise distances and best paths for exploratory sorties on foot, horseback, or by canoe, can be calculated easily in advance. For travel by water, whether coastwise or through the interior, I have found this kind of analysis especially helpful. Air photos reflect water surfaces clearly, so that one can avoid areas of turbulence cause by tide rips, coastal currents, river rapids, etc. Panchromatic film also penetrates to shoal bottoms and portrays offshore sandbars and reefs. The beachline effects of storms and ocean tides can be plainly seen, and the best anchorages determined in advance.

Thus, in brief summary, aerial photography can be a boon to archeologists who operate in Arctic regions. If used to its full potential, it permits the exchange of field effort for most efficient laboratory effort and, therefore, it will increase productive field time, a rare commodity in the fleeting northern summers.

Dartmouth College

LITERATURE CITED

Harp, Elmer, Jr.

1968a Optimum Scales and Emulsions in Air Photo Archaeology. Proceedings VIIIth International Congress of Anthropological and Ethnological Sciences, III:163-165. Tokyo: Science Council of Japan.

1968b Anthropological Interpretation from Color. In Manual of Color Aerial Photography, J.T. Smith, ed. Falls Church Virginia: American Society of Photogrammetry.

1974 Threshold Indicators of Culture in Air Photo Archaeology: A Case Study in the Arctic. In Aerial Photography in Anthropological Field Research, E.Z. Vogt, ed. Cambridge: Harvard University Press.

Rinker, Jack N.

In Press Environmental Analysis by Air Photo Interpretation. In Photography in Archaeological Research, Elmer Harp, Jr., ed. Albuquerque: University of New Mexico Press.

Rinker, Jack N. and R.E. Frost

1968 Environmental Analysis and Remote Sensing. Technical Note. Hanover, N.H.: U.S. Army Cold Regions Research and Engineering Laboratory.

Williams, J.C.C.

1969 Simple Photogrammetry. London: Academic Press.

AERIAL ARCHEOLOGY AT THE CAHOKIA SITE

BY

MELVIN L. FOWLER

PART I: INTRODUCTION

In 1953 John Howland Rowe (1953:907-908) wrote, "The first aerial photographs of an American site were taken by Wells and McKinley in 1921-22. The pictures show little that was not equally visible from the ground, and no one was inspired to follow up the technique." If all the sources on this subject had been available to Rowe, he would have discovered that just a few months after Wells and McKinley made their aerial photographs an attempt was made to follow up the technique. In April of 1922, Lieutenant George Goddard, assisted by a Sergeant Ramey, made several photographs of the Cahokia site. These were done at the request of the Director of the Illinois State Museum who was interested in the possible geological origins and nature of the Cahokia Mounds. This was during the period of Warren King Moorehead's excavations (1922, 1928) at the site. The earlier Wells and McKinley photos were made at the behest of David I. Bushnell who was researching the area under the sponsorship of the Smithsonian Institution (Bushnell, 1922:92-105). It is apparent from the published sources that none of these investigators had any knowledge of what the others were doing. For a summary, particularly of the Goddard-Ramey flight, see Robert Hall's excellent article in the Wisconsin Archaeologist (Hall, 1968) and Goddard's own recollection of this event (Goddard, 1969:93).

It is certainly not true of the Goddard-Ramey photographs that they "show little that was not equally visible from the ground." These 1922 photographs, even 50 years later, are among our most valuable records of the Cahokia site. They are now on file in the Illinois State Museum for those who care to examine them and one is illustrated here as figure 11. To this investigator, it is the most revealing of the 1922 photographs.

Another person who was inclined to follow up the technique was

FIGURE 11 - A view of the Cahokia site taken from the east by George Goddard (Brig. Gen. USAF. Ret.). This photo was taken during the period of April 2nd-4th, 1922, from the cockpit of a DeHavailand DH4 aircraft at an altitude of 3,000 feet (letter from George Goddard to Dr. A.R. Crook dated November 22, 1922, on file at the Illinois State Museum). Monks Mound (M), the principal feature of the site, can be seen at the right center of the photo. This photo was previously published as Figure 6 by A.R. Crook (Crook 1922:12). Photo courtesy of the Illinois State Museum.
Scale: the length of the highway running eastwest in the right center of the photo up to the curve is approximately 3.4 kilometers.

Lieutenant Dache Reeves of the U.S. Army Air Service who had a great interest in American archeology (Reeves, 1936). Colonel Reeves is now retired and has been a most interesting correspondent in regard to the applications of aerial photography to archeological investigations. In the early thirties he was able to fly over several important archeological sites in North America. Included among these were Marksville, Louisiana, the earth works at Newark, Ohio, and, of course, Cahokia. His photos of Cahokia were the first vertical stereoscopic aerial photographs taken of that site. Negatives and prints of these are on file in the U.S. National Museum and are available there for further examination. Figure 12 shows the mosaic made by Colonel Reeves of the Cahokia photographs.

Both of these sets of aerial photographs show the Cahokia site when the area was primarily used for farming. Therefore many of the soil marks shown in this photography have since been diffused or obliterated by more intensive agricultural use and the building of subdivisions, factories and superhighways.

It is not surprising that this Midwestern archeological site should have required or called for pioneering efforts in aerial archeology. The Cahokia site has been known for over a hundred and sixty years and has been consistently described as the largest archeological site in the United States. It is also the location of the largest group of mounds and the largest man-made earthen structure on the North American continent. A history of this site and the various research efforts there have been outlined elsewhere (Fowler, 1969). It is surprising that more attention has not been given to aerial photography at the site.

Based upon these excellent pioneering and historic aerial photographs, the present investigator began a research project at Cahokia in 1966. One of its major objectives was the utilization of aerial photography as a basis for determining the extent of the archeological site and for locating sub-surface features in order to understand the internal complexity of the area.

This aerial reconnaissance phase of the project was composed of at least four different stages, the first of which involved the accumulation of all of the known aerial photographic records covering the site. Over the years this has been completed, and at the present time we have over 200 different aerial photographs of the site dating from 1922 to 1971.

A second portion of this program was the development of an aerial photogrammetric map of the site. It was determined that this was the most economical and efficient way to map such an area. According to our estimate, Cahokia covered an area of approximately 6.5 square miles, or more than 4,000 acres. While there are no

FIGURE 12 - A mosaic of the Cahokia site made from aerial photos taken by Colonel Dache Reeves (USAF Ret.) in 1933. Monks Mound (M) is in the lower left of the upper right hand quadrant of the photo. Photograph courtesy of Colonel Dache Reeves and the Smithsonian Institution

tremendous variations in elevation at Cahokia, the large number of mounds made the production of contour maps from land surveys prohibitively expensive. After consultation with other investigators who had experience in obtaining topographic maps of large archeological sites, we decided that a scale of 1:2000 and a contour interval of one meter would be satisfactory. It is possible after making a few minor revisions based upon detailed ground surveys, to compile a map of the Cahokia site that is extremely precise. This map can serve as a base map from which a reconstruction of the site can be made showing the site as it appeared before modern incursions.

A third step in this program was to obtain specific aerial photos to supplement the data already available for interpretive purposes. This step had two stages. The first involved obtaining stereographic coverage of the entire area. This has been done at different seasons of the year and with different types of film. At the present time, we have concluded that, for our project, standard panchromatic black-and-white aerial film is the most useful for archeological interpretation. It has been our experience that the best photos for interpretation are obtained in the middle of winter, usually in February, and that soil marks have so far been the most revealing type of data. Other emulsions were not as useful to us, possibly because of the area's high humidity and smog which may have interfered with transmissions in the infrared region of the electromagnetic spectrum.

The second step in this application of aerial archeology to the Cahokia site was the acquisition of low-level air photos of specific features and portions of the site using hand-held cameras and light planes. Some of the most interesting of these photos were used in precisely locating mounds that had been largely obliterated by cultivation. It was found that both soil marks and crop marks could be observed on standard Kodachrome or Ektachrome film which identified such features as the destroyed mounds. These films helped to record, under different growing conditions and seasons, the surface manifestations of sub-surface features such as borrow pits, drainage patterns, and ancient palisade lines.

The fourth and final stage of the aerial archeology program at Cahokia was the utilization of all of these accumulated photographs for reconstructing the archeological site (e.g., for locating the mounds that have since been destroyed), and for locating sub-surface features. The most successful application of this photography to date has been in the observation of a series of whitish lines east of Monk's Mound on early aerial photos (see figures 11, 12, and 13). On more recent aerial photographs we found that these lines still existed, although they had been almost obliterated by intensive cultivation. On the basis of the regularity of these lines and their persistence through time, as well as on the basis of discussions of their significance with various archeologists working in the region, it was decided that a major concern of our excavations would be to determine the sub-surface nature of the features.

These investigations have been previously reported (see Anderson, 1969) and can be briefly summarized here. The excavations indicated that the cause for these lines on the surface of the ground and on the aerial photographs was the construction of a series of palisade or fortification walls begun around A.D. 1100. The walls were rebuilt at least four different times. All of the rebuilding seems to have occurred in the same general locality, perhaps making the soil disturbance more intense and hence their presence on the aerial photographs all the more clear. Excavations crossing these lines at four different locations have confirmed the presence of the palisades. Thus, with a fair degree of certainty, we can map the extent of the palisades on the eastern portions of the site.

With the aid of aerial photographs, we were able to plot the exact location of our test excavations and immediately begin to work out the details of the palisade lines. Without the photographs, the uncovering and detailed studies of the palisade would have only been happenstance. Knowledge of this feature contributes greatly to our understanding of the Cahokia site. It provides us with an idea of the way the community was organized and the extent of resources and labor force that must have been available to the community.

There are less distinct lines on the map extending from the confirmed palisade area to other portions of the site. On the western half of the site is a series of lines similar to the palisade lines but which have not yet been excavated or tested (figure 12). Further aerial photographic interpretive work at Cahokia will concentrate on defining these lines and plotting out areas for excavation to determine not only the full extent of the known wall but also the location of a wall encompassing greater portions of the community. This will contribute greatly to our understanding of the site and can be tested rather quickly and with much less expenditure of resources by using the aerial photographic data already available to us.

On the basis of survey with the aid of aerial photographs, we have established many mound locations. Some of these mounds are ones that had never been mapped and are today totally destroyed. Why these mounds were missed in the very detailed mapping by Dr. A.J.R. Patrick in the 1870's and 1880's and by Moorehead in his investigations in the 1920's is not at all clear. One possibility is that they were rather densely covered with forest and brush at the time and therefore not visible. One particular group of mounds which is known only from aerial photographs and suggestions from the USGS

FIGURE 13 - A section of one of the Dache Reeves photos showing the portion of the Cahokia site from Monks Mound (M) to the east. The lines indicating the palisade (P) can be seen about 200 meters east of Monks Mound. Note also the mound locations (L) indicated in the right one-third of the photo. Photograph courtesy of Colonel Dache Reeves and the Smithsonian Institution.


500 METERS
M
P
P
P

topographic map is at the east end of the site (see figure 13). These mounds apparently were being destroyed in the 1930's when Reeves took his photographs since they appear with bright white scar marks in that photography. On U.S. Department of Agriculture photographs of the same region from the 1940's, very low-intensity white scars suggest that by that time the mounds had been leveled. Since that time, the mounds have been almost completely built over and obliterated by housing subdivisions. Some of the locations do, however, appear in the map contours and the actual topography of the land in the area today. Since these mounds are in subdivisions that will remain undisturbed for many years to come, it is probable that this photography will be our only record of them. One or two of the small mound locations may be in the present location of public school lots and testing of these mound bases could probably be carried out. Examination of 1971 black-and-white infrared aerial photos indicates disturbances in the area of at least two of the locations visible on the Reeves photographs.

Aerial photographs have also been used to relocate mounds that have been previously mapped but the locations of which are not easily found from ground reconnaissance today. One set of such mounds is in the area just north of Monk's Mound. Present contours show three mounds extant, although the Patrick map of the 1870's followed by Moorehead's map of the 1920's shows a much different arrangement. However, aerial photographic interpretation (see figure 13) indicates the presence of white soil scars in exactly the same place as those mapped by Patrick, thus confirming his mapped locations.

Another use of aerial photographs is in pointing up potential excavation problems. High and low level aerial photographic reconnaissance of the site under different soil conditions and during different seasons of the year are helpful in locating features that might be of significance in further site exploration. The most successful of these photographs have been taken with hand-held cameras from small aircraft. One of these is illustrated by figure 14. The central feature on this photograph is the Rattlesnake Mound, the large mound that more or less delimits the southern end of the site. To the left or west of this mound, Moorehead outlined two smaller mound locations. These were visible in the aerial photographs taken from a Cessna 172 with a small Crown Graphic camera in 1966. The two mound locations 81 and 82 are shown, one as a white soil mark to the left, or west of Rattlesnake Mound and the other as a crop mark to the southwest of the Rattlesnake Mound location. Other features of interest appear in this photograph. In the upper right hand quadrant of the picture and just to the north of Rattlesnake Mound is another combination crop-soil mark which may indicate a rise in that field. Another crop mark extends from the center of Rattlesnake Mound northward through this field, and may indicate some aboriginal feature such as an avenue leading from the mound to the central section of the site. Features such as these should be tested in the future for further understanding of Cahokia's organization.

Another example of low altitude photography is shown in figure 15. It too was taken from a Cessna but this time with a Rolliflex camera. Shown are the locations of large borrow pit depressions as well as mound constructions. Two of these mounds, numbers 61 and 62, had been recorded, but the lower left mound, labeled here A, had not been previously mapped. It was confirmed by ground reconnaissance.

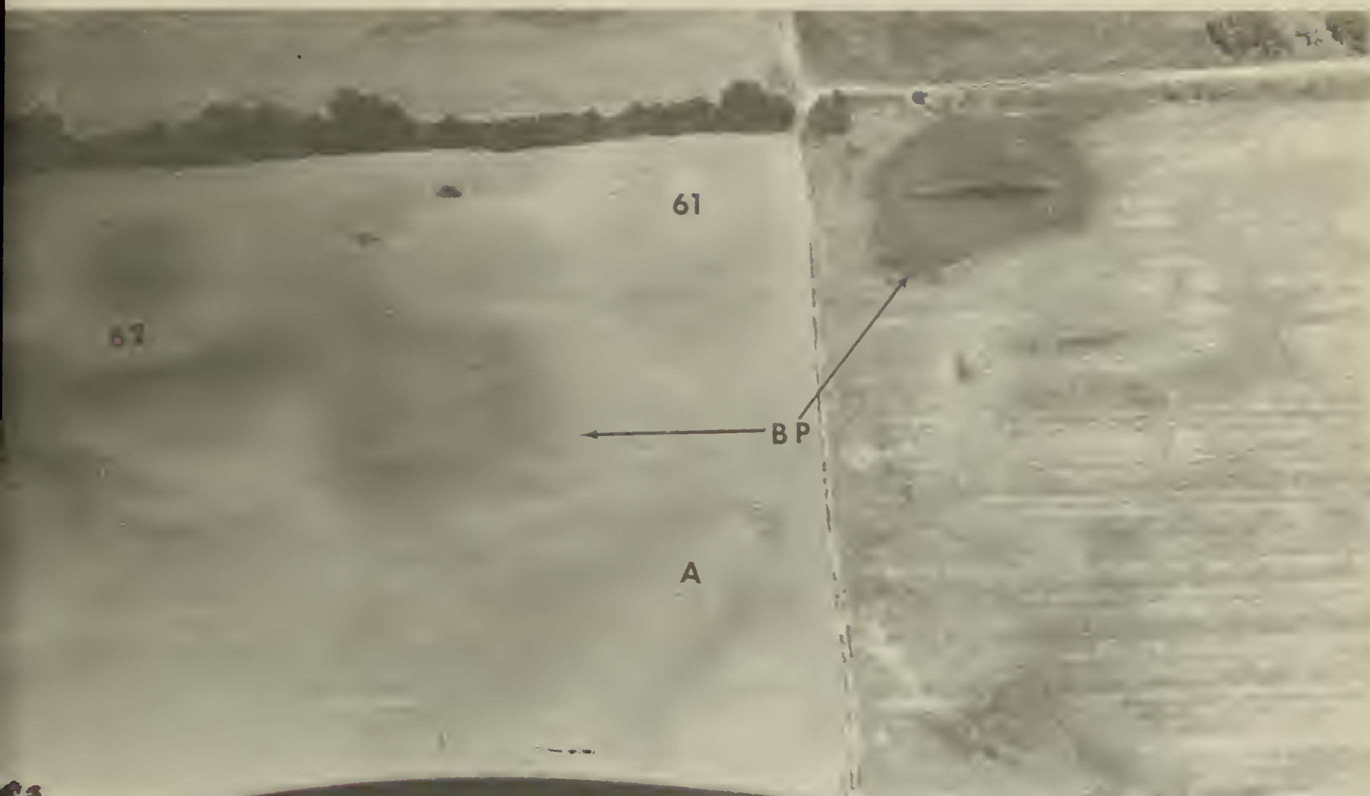
In summary, aerial photography has been used extensively at the Cahokia site. Coverage includes the earlier aerial photographs of an archeological site in North America. These early photographs have been supplemented with more recent photographs, all of which have been most useful for interpretive purposes. Each of these various sets of photographs, taken in different seasons of the year and under different crop and soil moisture situations, has revealed important information. Aerial photogrammetry was used to provide a base map for the site. Both professional high level stereographic aerial photographs and low level hand-held camera photographs have been taken of the site for various mapping and interpretive purposes. These photographs have aided in locating features that were either sub-surface or have been obliterated by modern farming activities. The location of these features has been useful in economically planning archeological excavations to confirm or define their nature. Such features include the palisade line and the locations of mounds that had either been destroyed or not previously mapped by any other method. Finally, we are convinced from this experience that aerial photography can save time and money in planning and developing strategies for more traditional archeological field work.

University of Wisconsin
Milwaukee

FIGURE 14 - This photograph was made from a Cessna 172 with a Crown Graphic 2¼ x 3¼ camera at an elevation of approximately 700 feet. In the right center of the photo is Rattlesnake Mound which is located about 1600 meters south of Monks Mound (see Figure 2). To the left, or west, of Rattlesnake Mound are white soil marks which may represent "mounds" 81 and 82 mapped by Moorehead (1928, Figure 1). A similar mark (A) can be seen to the north of Rattlesnake Mound. A crop mark (B), perhaps representing a similar phenomenon, is apparent to the southwest of Rattlesnake Mound. A dark crop-soil mark (C) is visible extending northward from the center of Rattlesnake Mound. Photograph by the author.


C
A
81
82
B

FIGURE 15 - This is a view of a section of the Cahokia site about 650 meters southeast of Monks Mound taken with a Rolliflex camera from a Cessna 172 aircraft. Borrow pit (BP) areas are indicated by the darker moist marks. Mounds 61 and 62 are indicated by soil crop marks and were known from earlier maps. Mound A is an unmapped mound whose location is indicated on this photo by soil-crop markings. Its location has been confirmed by ground survey. Photo by the author.


61
BP
A

LITERATURE CITED

Anderson, James
1969 *A Cahokia Palisade Sequence. In Melvin L. Fowler, editor, Explorations into Cahokia Archaeology. Bulletin 7, Illinois Archaeological Survey.*

Bushnell, David I., Jr.
1922 *Archaeological Reconnaissance of the Cahokia and Related Mound Groups. Explorations and Fieldwork of the Smithsonian Institution in 1921. Smithsonian Miscellaneous Collections, Vol. 72, no. 15.*

Crook, A.R.
1922 *The Origin of the Cahokia Mounds. Bulletin of the Illinois State Museum, Springfield.*

Fowler, Melvin L.
1969 *The Cahokia Site. In Melvin L. Fowler, editor, Explorations into Cahokia Archaeology. Bulletin 7, Illinois Archaeological Survey.*

Goddard, George
1969 *Overview. New York: Doubleday and Company.*

Hall, Robert L.
1968 *The Goddard-Ramey Cahokia Flight: A Pioneering Aerial Photographic Survey. The Wisconsin Archaeologist, Vol. 49, no. 2.*

Moorehead, Warren King
1922 *The Cahokia Mounds: A Preliminary Report. University of Illinois Bulletin, Vol. 19, no. 35.*

1928 *The Cahokia Mounds. University of Illinois Bulletin, Vol. 26, no. 4.*

Reeves, Dache M.
1936 *Aerial Photography and Archaeology. American Antiquity 2:102-107.*

Rowe, John Howland
1953 *Technical Aids in Anthropology: A Historical Survey. In Alfred L. Kroeber, editor, Anthropology Today. Chicago: University of Chicago Press.*

REMOTE SENSING IN ARCHEOLOGICAL EXPLORATION:

PROJECT TATTOOED SERPENT

BY

GARY W. NORTH AND HENRY T. SVEHLAK

PART I: INTRODUCTION

This is a revised version of a paper presented at the First Pan American Symposium on Remote Sensing, held in the Canal Zone, Panama, in April of 1973. We would like to acknowledge the contributions of the following:

Elbert Hilliard (Director of the Division of Historic Sites and Archaeology of the Mississippi Department of Archives and History) for bringing the problem to our attention and for serving as the state's Project Director.

Gordon Howard (Mississippi Office of Science and Technology, State Liaison Office at the Mississippi Test Facility) for serving as Assistant Director of Project Tattooed Serpent and for co-authoring the final EROS Program report on the project.

Archeologists Robert S. Neitzel and Dorothy Gibbons for their assistance in familiarizing us with the Grand Village Site.

Frank D. Beatty (General Electric Company at the Mississippi Test Facility) for figures 18-21 from his collection of World War II aerial photography over North Africa.

Mr. Joseph DiGiovanni (Raytheon Company in Rome, New York) for figures 16 and 17 from his collection of British aerial photography.

In the early 1900's, about the time of World War I, man found himself looking down on the earth from airplanes for the first time. From this remote vantage point, he discovered that he could see things he had not noticed on the ground. Such things as crop marks, soil moisture patterns, ground scars, etc., all became clues to identifying previous human activity. In addition, the aerial view presented man with a synoptic picture of the scene below him. Thus it was that the era of photo archeology began. Today this science employs special sensors operating in the ultraviolet, near and far infrared, and microwave portions of the electromagnetic spectrum. However, the most useful work is still being done in the visible and near infrared portion of the spectrum.

Figure 16 is typical of some of the aerial work done in the 1930's and 1940's in England. This black and white low altitude oblique was taken from about 800 feet over Celtic fields and a farm settlement near Great Litchfield Down in Hampshire. The ancient site is visible as a pattern of light-toned, chalk-colored soil marks which contrast dramatically with the normal colored soil in the rest of the field. The zigzag appearance of the lines is caused by the scattering of the soil due to periodic plowing. Scarcely a trace of this site would be visible to an observer on the ground.

Figure 17 is another low altitude oblique that shows the importance of soil moisture. The site is the Hutton Moor North Circle near Ripon, Yorkshire, which was photographed during a drought in 1949. The bright-toned oval is a religious monument constructed in the second millenium, B.C. The oval is approximately 200 yards across and is girded by inner and outer ditches which appear as dark rings. The two marker stones indicate the entrances to the inner circle. The precise outline of this ancient ruin is evidenced by the differences in soil moisture, undoubtedly the result of soil being scooped out of the inner and outer ditches to form the oval mound. Even though the mound has since been levelled, it has a higher percolation rate and thus has dried out sooner than the soil which has filled the ditches.

While current aerial photography of areas is desirable, a great deal of data already exists in various photo data banks around the world (see Ebert, this volume and Gumerman and Kruckman, this volume). Figures 18 through 21 are examples of photographs of archeologically significant features taken during World War II in North Africa. They illustrate how the dry desert sands aid in preserving many features.

Figure 18 is a stereo pair showing an isolated fort surrounded by hundreds of square miles of open desert. The fort was probably an old French customs station located along a desert road, which is

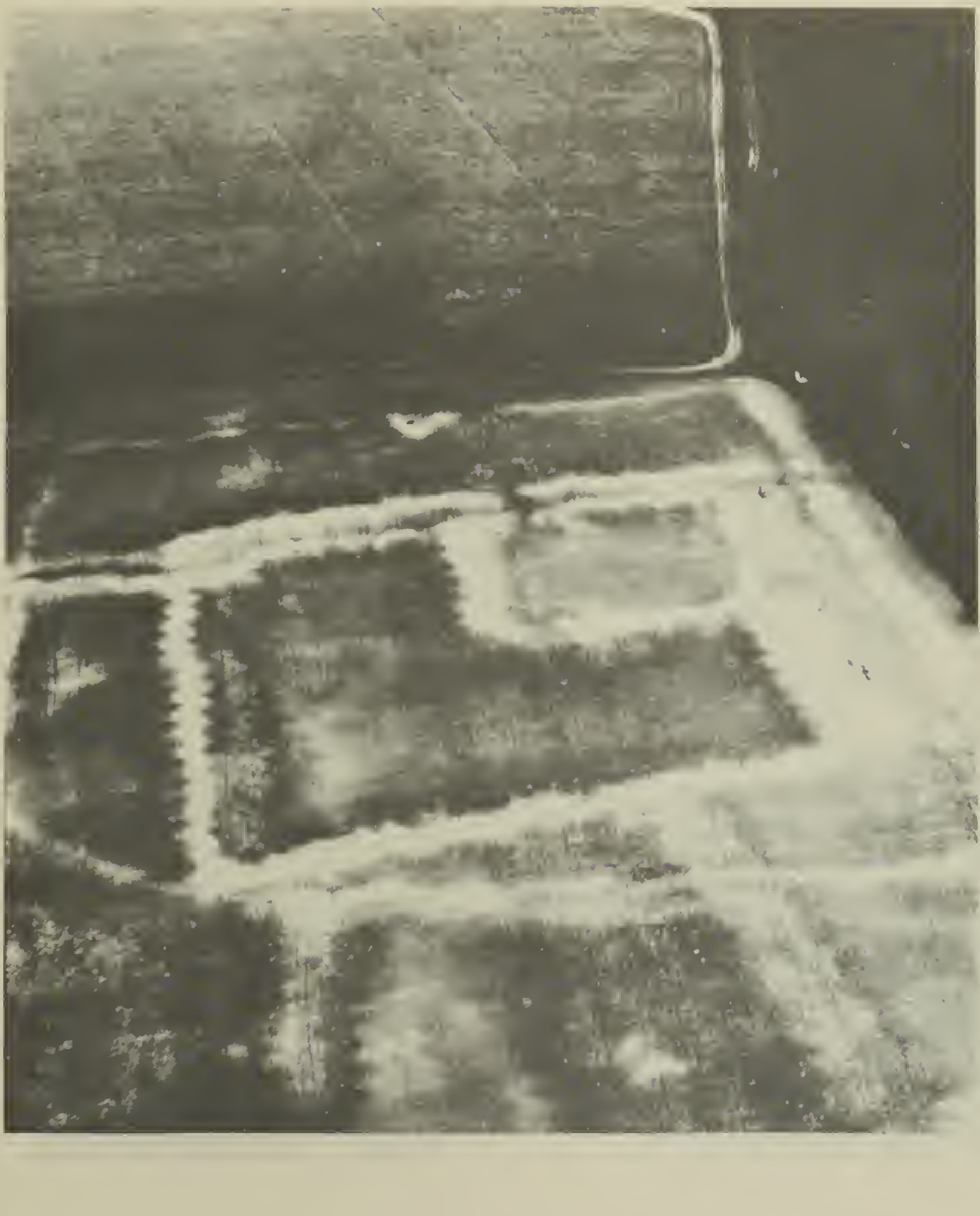


FIGURE 16 - Celtic field and farm settlement, Great Litchfield Down, Hampshire, England

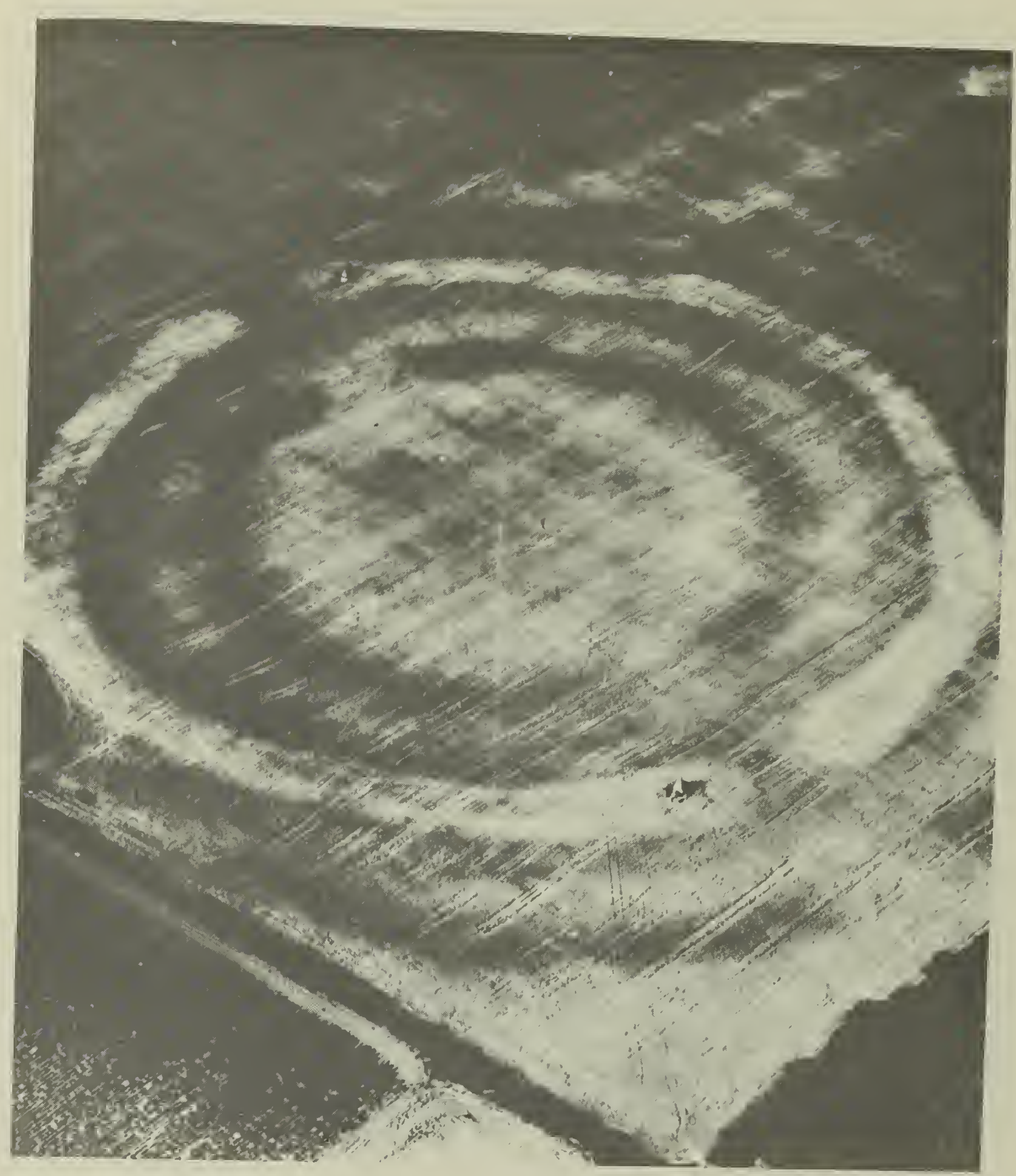


FIGURE 17 - The Hutton Moor North Circle, Ripon Yorkshire, England

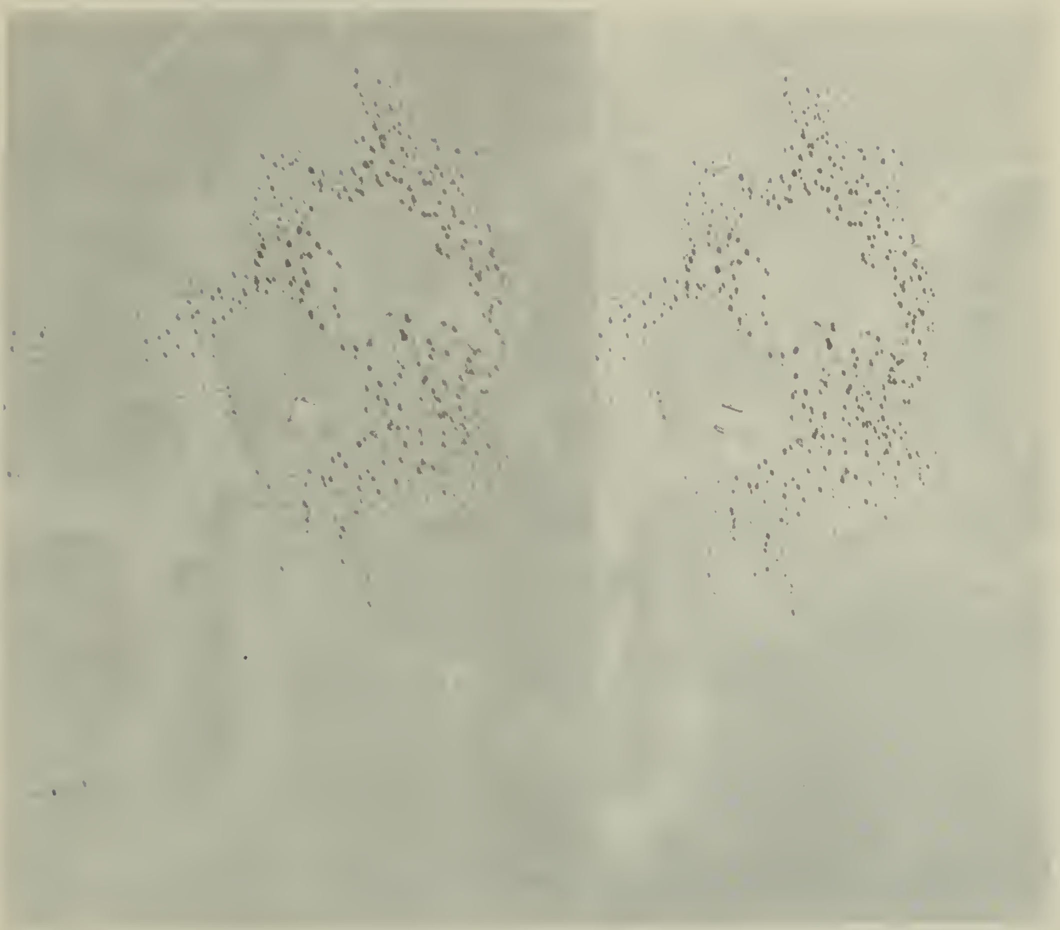


FIGURE 18 - Fort site, North Africa (Stereo Pair)

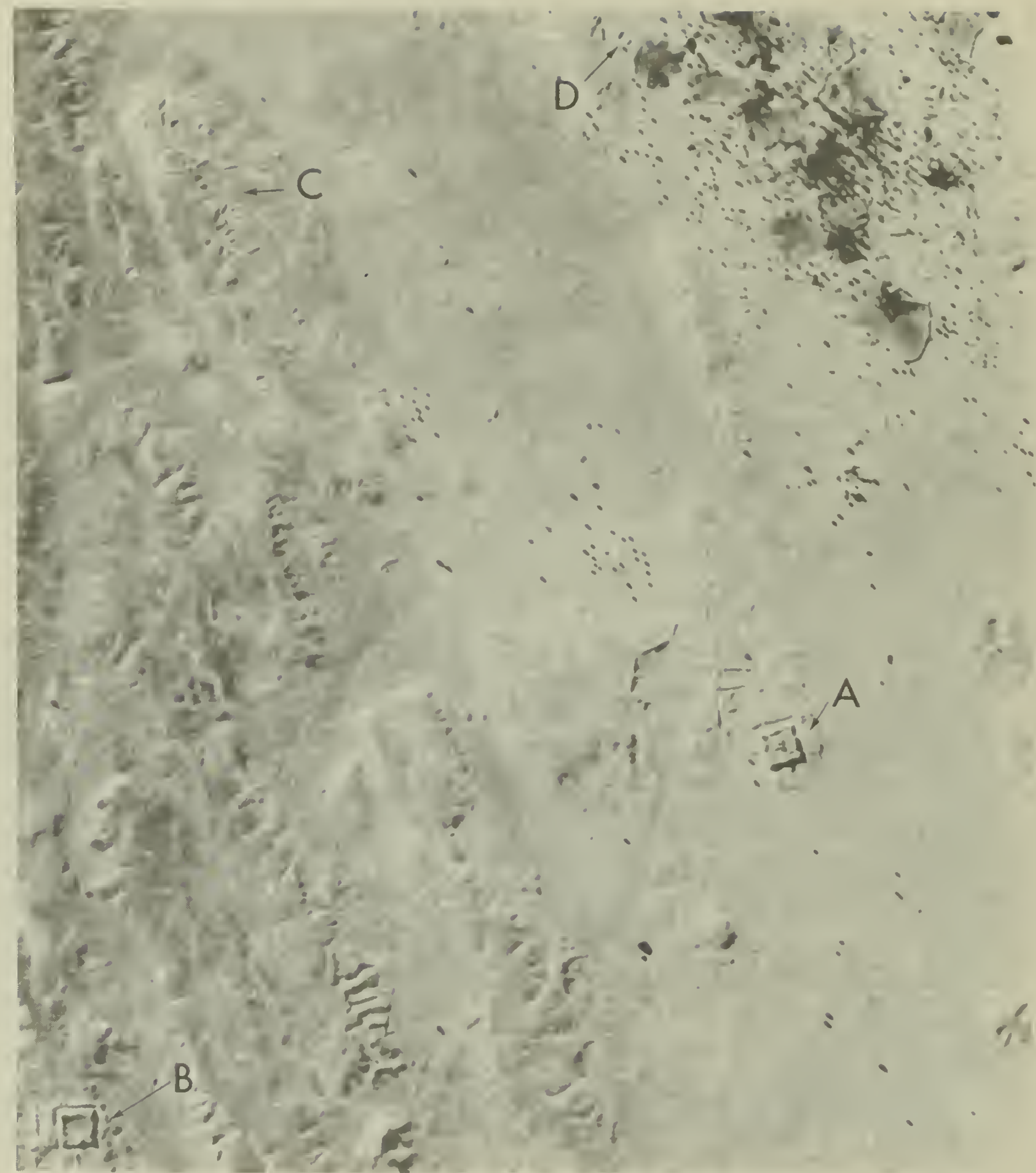


FIGURE 19 - Abandoned farm settlements in North Africa

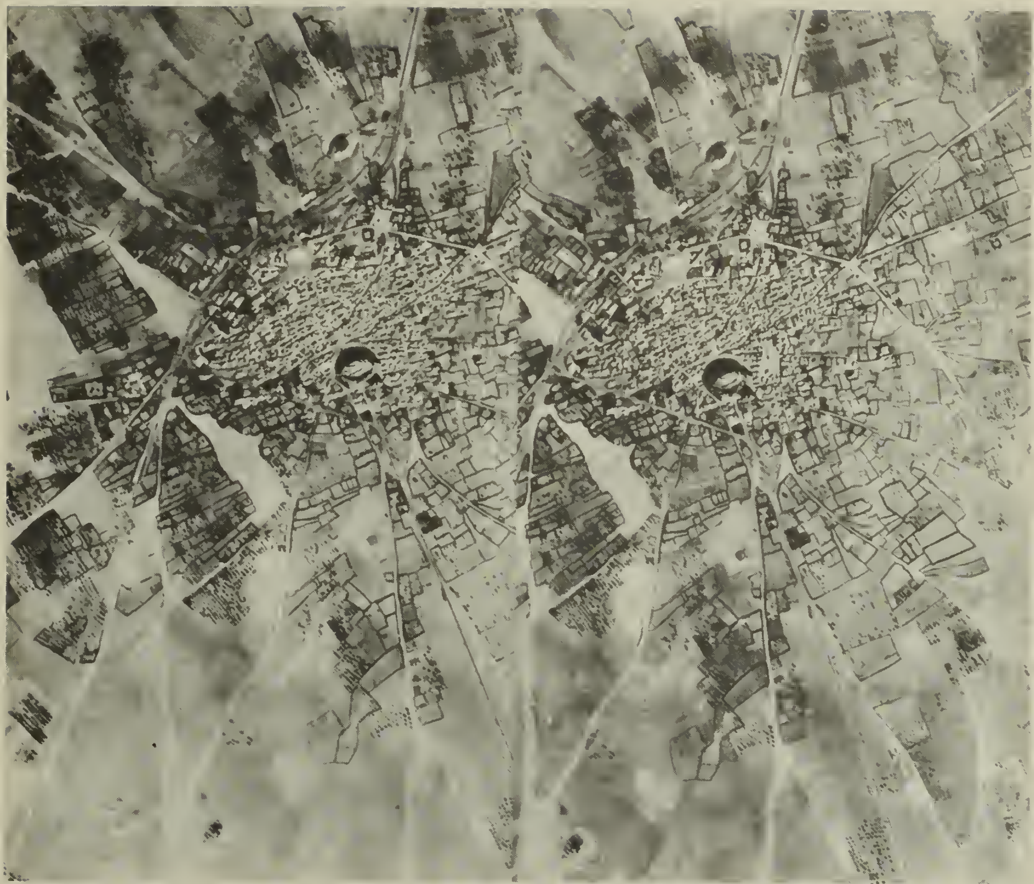


FIGURE 20 - Ancient Roman ruins in North Africa (Stereo Pair)

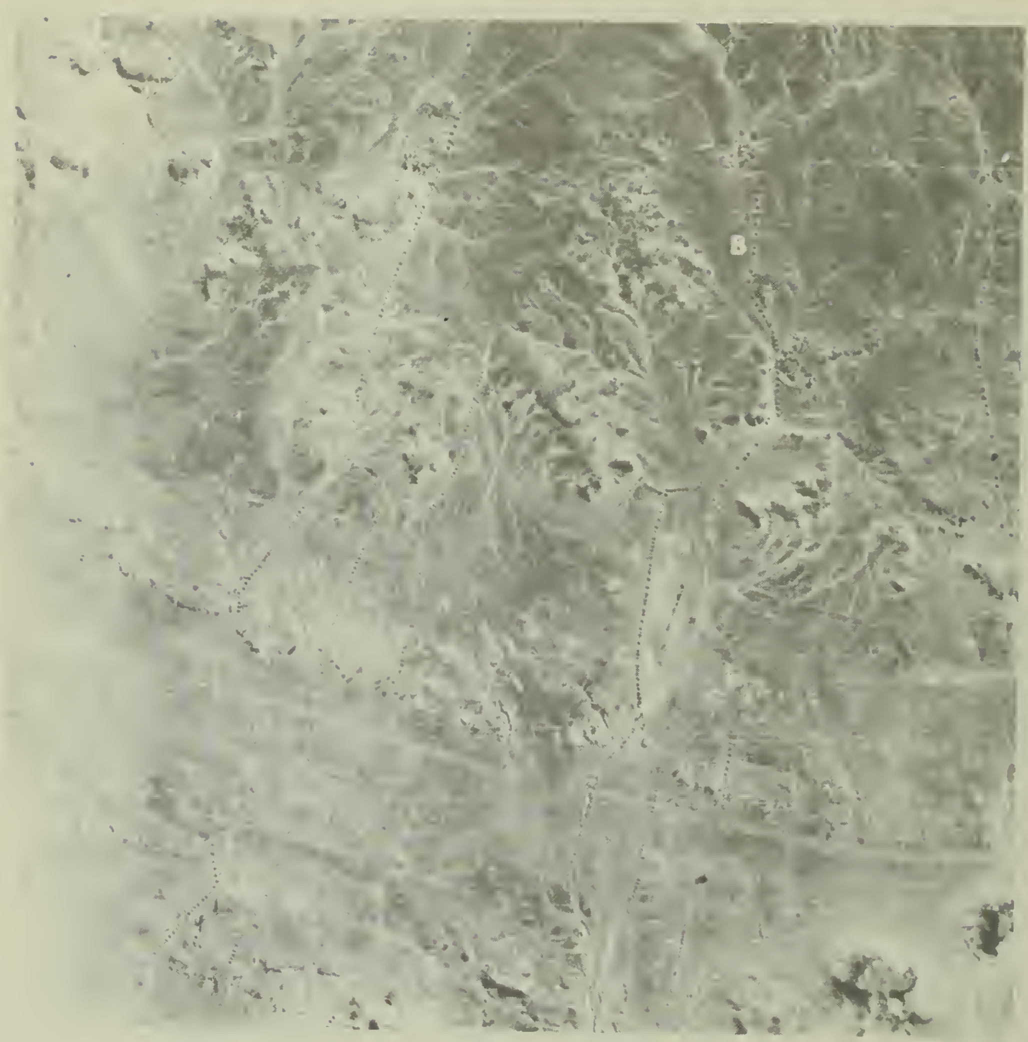


FIGURE 21 - North African qanats

seen as a white line adjacent to the site. The fort is located on a hill near a dry wash. Trees around the site indicate that the water table is still fairly high; this is probably why the facility was located at this point.

Figure 19 illustrates some prehistoric archeological sites in North Africa. Preserved over thousands of years, sites such as these often go unobserved when viewed from the ground. The synoptic aerial view not only reveals the sites' existence, but also provides clues as to their probable function. Annotations A, B, and C indicate what appear to be abandoned agricultural plots, so it is likely that these sites were farming settlements. The sites themselves are on the crests of hills, indicating either defensive considerations or a desire to locate the settlements in non-agriculturally productive areas. In addition, circular features such as those at point D indicate the presence of wells in an oasis. Even a cursory analysis of similar photographs would probably show hundreds of features such as these.

The difference between one culture and another can sometimes be deduced when studying aerial photography. Figure 20 is a stereo pair of a small North African town displaying all the classic spatial patterns of a typical Roman city. The coliseum at A is the focal point for the many roads radiating out into the desert. Directly north of the coliseum, at B, lie what may be the ruins of an old amphitheatre. These large structures, situated in what was once a community with a highly complex pattern, can be contrasted with the small mud and brick houses of the irregularly spaced and highly crowded modern Arab village.

The strong Roman influence on North Africa is further illustrated in Figure 21 by the long dotted lines which appear on the desert floor at annotations A, B, and C. These rows of dark circles are associated with underground aqueduct systems called qanats. This type of irrigation system was brought to the desert by the Romans and is still used by modern cultures. The circles are actually holes in the ground which provide access to the underground aqueducts so they can be kept clear of sand or repaired when the walls collapse. Irrigation systems, then, are another kind of cultural feature which show up as scars on the surface of the desert.

Seasonal coverage is very important in aerial archeology since crop marks, soil moisture patterns, and shadow marks show up differently at various times of the year. During winter, for example, certain cultural features may show up because they are highlighted by snow or ice. Figure 22 is a stereo pair of Fort Bull, a fort built by the French near Rome, New York, in 1756. This site lay next to a strategically important strip of land separating the Mohawk River from Wood Creek. The Iroquois referred to the area as

FIGURE 22 - 1756 French fort near Rome, New York (Stereo Pair)

"Deowansta" or "Great Carry". It was important because it was the only land gap in the Hudson-Mohawk-Oneida Lake-Lake Ontario water transportation route between the Atlantic and the Great Lakes (North 1968:1).

The outline of the old fort at A in figure 22 is accentuated by snow and ice, which accumulated in the old moat around the stockade fort. Other items of historic note on the photograph are the 1844 Erie Canal enlargement at B and the original 1817 Erie Canal at C. The canal was actually begun at a point about two miles east of this area. A drainage ditch has been cut at D, but the original canal bed is still visible at E. The straight line ground scar at F may be the last remaining trace of the old military road which connected Fort Stanwix (in Rome) with Fort Oswego on Lake Ontario.

An annotated low altitude oblique of the Fort Bull area (fig. 23) shows the fort A as it looks today. Soil marks in a cleared area near the fort at B show evidence of a prior structure which conforms in size to the description of a storehouse built a few months prior to the construction of the fort. It is anticipated that this area will be excavated in the next few years as part of a major program by the city of Rome to develop its historic attractions.

PART II: PROJECT TATTOOED SERPENT

In an effort to demonstrate the utility of aerial photography in archeology, the U.S. Geological Survey's EROS Experiments and Evaluation Office conducted a cooperative project with the Mississippi Department of Archives and History in the summer of 1972 over seven sites of known or suspected historical value. The principal study area for Project Tattooed Serpent was the Fatherland Site, or the Grand Village of the Natchez Indians. The site is located within the city of Natchez, Mississippi, along the banks of St. Catherine's Creek (fig. 24). From 1682 to 1730, it was inhabited by the families of the religious and governing elements of the Natchez tribe. It was abandoned in 1730 when French troops dispersed the Natchez throughout Mississippi and Louisiana in retaliation for a massacre at Fort Rosalie in 1729.

The Fatherland Site is thought to be one of the few two-plaza sites in this part of the United States. Besides the two plazas, there are three mounds. On top of the central and largest mound was the temple and home of "The Great Sun", the spiritual leader of the Natchez Indians. The plaza area between the central and northern mounds contained the houses of other tribal leaders including the war chieftain, "The Tattooed Serpent." Extensive excations have been carried out on these mounds by archeologists Moreau Chambers and Robert Neitzel (see Neitzel, 1965).

FIGURE 23 - Low oblique photograph of Fort Bull

FIGURE 24 - Map of Natchez, Mississippi

In the summer of 1972 the State of Mississippi sponsored a project to uncover and restore the village as a historic tourist attraction. Figure 25 is a low altitude vertical photograph of the site as it appeared in June, 1972, shortly after the digging began. The three mounds appear at A, B, and C.

The Fatherland Site, as well as six other archeological sites, were photographed during the course of Project Tattooed Serpent. The following is a description of how this work was done. Included is a breakdown of the costs involved so that archeologists not familiar with remote sensing techniques may get an idea of how much money a project of this nature requires.

Mission Planning and Flight Operations

Since budget and equipment resources were rather limited for this project, a light aircraft (a Cessna 190) and a government surplus camera (a nine-inch format, six-inch focal length K-17) were employed to collect the data. The camera was mounted in a vertical position using 2 X 4's and clothesline to hold it secure in the aircraft. The film used was black and white infrared (Kodak type 2424) with a Wratten 89B filter. Flight altitude for the aircraft was 4200 feet above terrain over all the sites with additional passes over priority areas at 1200 feet. Overlap and sidelap were specified at 60 percent and 30 percent respectively to obtain stereographic photos. A hand-held K-20, five-inch format camera with a 6 3/8 inch focal length lens was used to acquire low altitude oblique color infrared photography. Table 4 is a tabular breakdown of the films and filters used.

Table 4. Sensor Package

Camera	Film Type	Filter
K-17	Kodak Type 2424	WR 89B
K-20	Kodak Type 2443	WR 12

Ground Truth

Several weeks prior to the flight operations, the EROS investigators conducted a ground truth survey of the various sites to be flown. Briefings were conducted by the archeologists and various ground photographs were taken. During the flights, ground teams were sent to the Grand Village Site and Fort Dearborn area to lay out control targets to assist the pilot in lining up the aircraft over the sites. This was done by using two-way radios and by plac-

FIGURE 25 - Fatherland Site, Grand Village of Natchez

ing stakes with white cloth attached to identify key areas. In addition, several 45° angle trenches were dug as a key to soil tone differences on the film. Ground photographs were taken with 35 mm cameras and ground activity in the area was recorded.

Interpretation

Black and white prints of all the 9 x 9 inch frames were made from the original negatives collected during the exercise. The interpretation was done using these prints and an Old Delft Scanning Stereoscope. However, this same interpretation could have been accomplished with any good quality pocket stereoscope. Overlays were used to delineate areas for further study by the archeologists and historians. A total of five man-days was required to complete the first phase of the interpretation. At the completion of the photo interpretation, the archeologists and historians involved in the project were invited to the EROS offices to be briefed on the analysis and to study the areas of possible cultural significance delineated by the photo interpreters.

Cost Summary

Cost figures were kept pertaining to the various aspects of Project Tattooed Serpent. Many of the costs will vary from project to project, of course, but table 5 presents a rough breakdown of what might be expected from an operation such as this.

Table 5. Cost of Operation - Project Tattooed Serpent

Aircraft with pilot, 8 hours flying time	$320.00
Aerial Photographer, 8 hours	80.00
Travel expenses for field trips and planning meetings	150.00
Film costs including processing and prints	250.00
Interpretation of photos, 40 hours @10/hour	400.00
Report Preparation, 8 hours @ $10/hour	80.00
TOTAL	$1,280.00

Many of these costs may be substantially reduced by making minor changes in such things as the format of the film used or the level of expertise required to support the effort. In addition, the EROS team concluded that ground truth exercises could be very easily cut back or eliminated without affecting the validity of the interpretation. A few historic maps and primary source documents may be substituted for ground truth for this type of investigation. Ground truth is required, however, if the analysts are to gain a full working knowledge of each site they are studying.

PART III: RESULTS

Detailed analysis of the photographs collected by the EROS Program revealed several interesting features. First, a light-toned trapezoidal area shown at D in figure 25 was discovered and brought to the attention of the archeologists. This tonal anomaly had not been noticed on the ground by the archeologists who were uncovering the post holes of the house which formed the west side of the anomaly. This area may have been a fenced compound, possibly a detention area since the tribe had a penal system. The second area of interest, shown in figure 25, is a previously undetected series of straight lines perpendicular to the normal drainage in the area. The lines form a rectangle, and even though some six feet of alluvium had been stripped from this area prior to its being excavated, the ground scars are still very evident on the aerial photographs. The archeologists indicate that this area could have been the location of the sacred garden where the seed for the tribe's crops was grown and blessed. The pentagonal-shaped area at F may be a house outline, but further analysis on the ground will be necessary to confirm or refute this suggestion.

The features noted above were not detectable from surface observation, and are probably attributable to differences in soil moisture content associated with compaction, alteration, and addition of foreign substances by human activities in the area.

The team working on the project was also asked by the State to search for any evidence of Fort Dearborn, a French fort of the early 1800's thought to be located northeast of Natchez on St. Catherine's Creek (annotation A on fig. 26). Through photo analysis, the EROS team found a large tonal anomaly approximately 1¼ miles east of the area where most old maps had located the fort. This area, as shown at annotation B on figure 26 was checked by archeologists from the Mississippi Department of Archives and History. Using metal detectors, they discovered considerable evidence of the early 1800 period and definite indication of a fort or similar structure. The fort was discovered more by accident than by plan, however, since the pilot had accidentally extended one flight line beyond the suspected location.

Additional photography has also been flown over several other Mississippi sites including an area designated as Jackson Landing at the mouth of the Pearl River in the southern part of the state. This particular site has proved to be somewhat of a mystery to historians who are not sure of its age or cultural affiliations. Recent studies indicate that the area has been inhabited since at

FIGURE 26 - Map of Washington, Mississippi

least 200 B.C. Figure 27 shows a few areas which were identified from the photography as being significant, and preliminary field checks have revealed pottery sherds and other cultural evidence. The site contains the largest earthen fortification in Mississippi (annotation A), and there are indications of other prehistoric cultural features at B and C. The village layout forms a definite geometric pattern similar to other sites along the Mississippi River. A recent attempt to build a port and harbor facility, shown at D, prompted the State to designate the area as a Historic Site in order to preserve it until exploration work could be done.

Figure 28 covers another part of the Jackson Landing site. This figure shows evidence of an early pond system at A, B, and C, which had a connecting drainage ditch shown at point D. These features are probably related to an early 19th century plantation which existed on the site.

PART IV: CONCLUSIONS

As has been shown by the preceding examples, the use of aerial photography in archeology is not new, but it is still probably one of the least used tools available to archeologists and historians. When aerial photographs are used, they are often collected after initial discovery and exploration work has begun, and may comprise the base on which the archeologist plots the sites found by ground teams. While this provides a permanent record of the location of each site, the use of photography should not be limited to this one function. Trained photo interpreters have been analyzing photographs for many years for such things as vegetation, geology, hydrology, tonal definition, and spatial patterns. This same know-how is easily transferrable to archeological exploration. The cameras and films presently available can reveal a wealth of information in surprisingly fine detail. The aerial photograph will not replace ground work, but it can assist the archeologist in locating areas where it might be profitable to excavate.

Work on several of the sites discussed in this paper will continue, and more advanced sensors may be brought in to collect additional data. All of this will, it is hoped, further demonstrate the utility of remote sensing in archeology. The Department of Archives and History of the State of Mississippi has learned through Project Tattooed Serpent that this approach does work and has decided to try to photograph all sites in the state that are of historic interest - a fitting conclusion to EROS Program efforts in Mississippi.

U.S. Geological Survey
EROS Program

General Electric Company

FIGURE 27 - High altitude photograph of Jackson's landing area

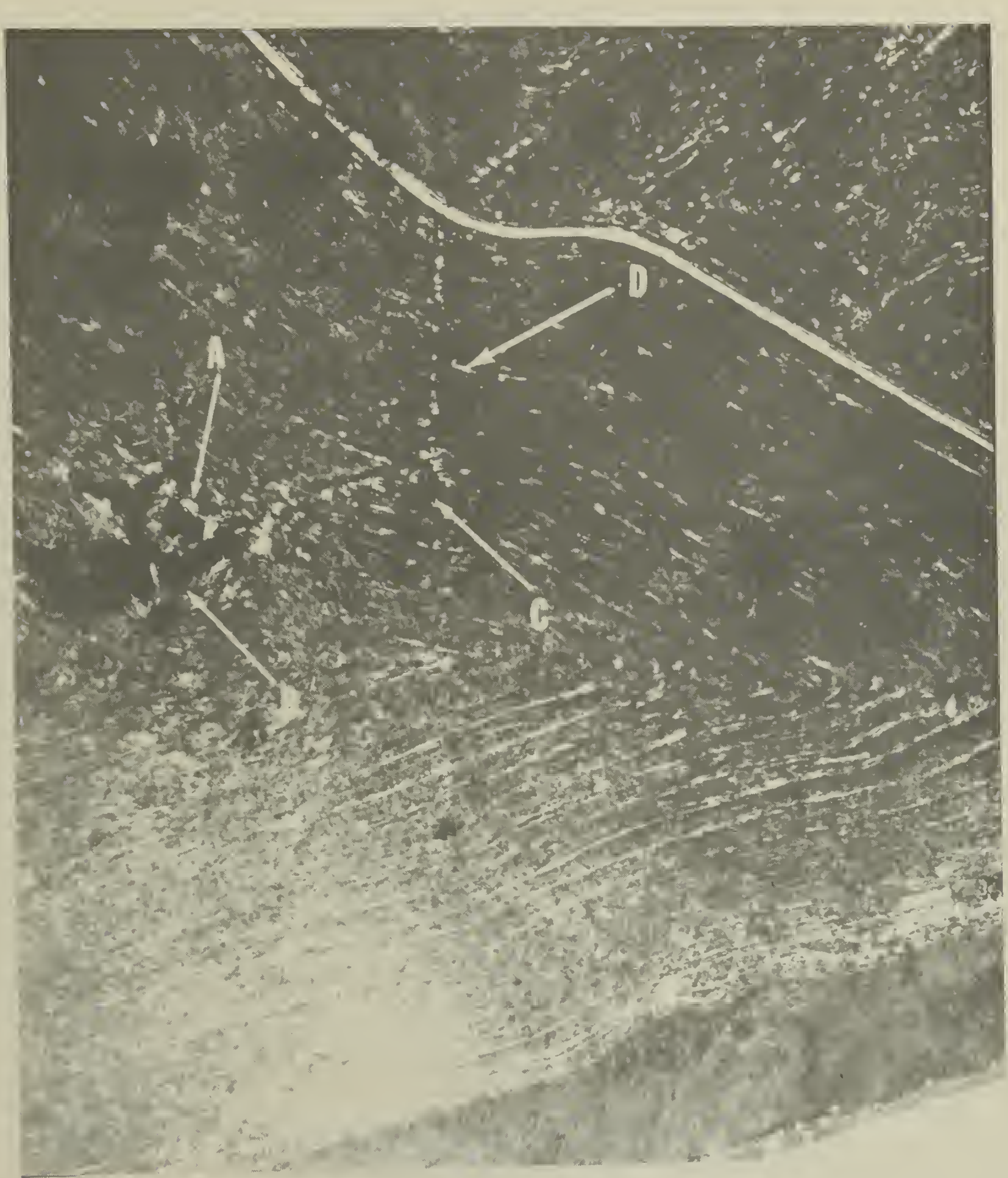


FIGURE 28 - Low altitude photograph of Jackson's landing area

LITERATURE CITED

Neitzel, Robert S.
1965 Archaeology of the Fatherland Site: The Grand Village of the Natchez. Anthropological Papers of the American Museum of Natural History, Vol. 51, part 1.

North, Gary W.
1968 Fort Wood Creek/Fort Bull: A Study of its History and a Look at its Future. Ft. Stanwix Museum, Rome, N.Y.

AERIAL REMOTE SENSING IN MARINE ARCHEOLOGY

BY

ALLAN D. MARMELSTEIN

PART I: INTRODUCTION

Remote sensor applications to marine archeological surveys are not new. SONAR, first introduced at the end of World War II, is the best example of an operational system for detecting submerged sites. SONAR broadcasts a "focused" train of sound pulses from the surface, and the reflected signal from bottom or target features is displayed or recorded. Information extraction may be simple and direct as in depth anomalies associated with a large shipwreck site, or it may be complex as in the detailed analysis of features provided by the newest imaging SONARS. SONAR and other shipborne devices such as magnetometers extend the archeologist's "vision" into otherwise inaccessible regions. However, as with oceanographic instruments used from surface vessels, they lack synopticity. This is not a serious constraint to the archeologist, but it would be useful to be able to synoptically survey large areas from aircraft or spacecraft as part of a multi-stage research plan. This paper discusses a recent application of airborne remote sensors to marine archeological survey activity.

Support for the project reported herein was provided by the Division of Archeology and Anthropology, Washington Office, National Park Service.

PART II: SENSOR SYSTEMS

Aircraft-borne remote sensing systems depend on passive or active acquisition of electromagnetic radiation, which present a unique problem when applied to the marine environment. Although sensors exist for viewing incrementally nearly all portions of the electromagnetic spectrum, seawater is essentially opaque to electromagnetic radiation. Fortunately, this is a relative, rather than absolute, property. Whereas ultraviolet, infrared, and microwave energy is absorbed in the first few centimeters of the ocean, visible energy penetrates many meters.

The light transmitting characteristics of pure seawater are the result of scattering in the blue band and absorption in the red band. Maximum light transmission occurs in the blue-green band in seawater. Turbidity due to particulate matter shifts the transmission peak into the green and reduces the absolute value of transmission. Blue light, though often predominant in the upwelling spectrum, primarily results from scattering and carries little information with respect to bottom features, a relationship which becomes exponentially acute as bottom depth increases. Thus, even in clear shoal water, greatest sensitivity to bottom features occurs in the green band.

Visual sensors integrate signal return over a depth whose magnitude is a function of wavelength and water purity. They therefore offer considerable promise as marine archeological survey tools where potential sites occupy depths within the range of reflected light of sufficient intensity to be detectable by various sensors. Candidate sensors include both photographic systems and imaging visible spectrum scanners. However, available scanners do not provide the spatial resolution obtainable with photographic systems.

PART III: DEMONSTRATION PROJECT

The problem presented to the Earth Satellite Corporation by the National Park Service was to assess the utility of aircraft remote sensors for a survey of historic shipwrecks. The area to be investigated was Fort Jefferson National Monument in the Dry Tortugas. This island group, composed of coral reef shoals and a few scattered low sand islands, lies 70 miles due west of Key West, Florida, in an area characterized by very clear water. Fine calcareous sediments, typical of such an environment, decrease visibility in the deepened channels, but during periods of low wave activity, the shoal areas are exceptionally clear.

In order to attack this problem, a multiband system using four 70mm cameras and the film/filter combinations listed in Table 6 was selected. Flight lines and flight timing were chosen to minimize glitter problems resulting from the interaction between sun angle and surface waves. Ideally, aerial photographic flights should be timed for calm seas and low sun angle.

The photographic mission was flown over Loggerhead Reef, an area previously surveyed by conventional techniques. Results of the prior survey were available as ground documentation but were not consulted until after the aerial photography was interpreted.

Table 6: Film/Filter Combinations

Film/Filter	Rationale

False Color Infrared/Wratten 12 - This film is typically filtered to exclude blue light, a feature advantageous for marine applications. It is sensitive to the green band, but exposure indices are based on solar infrared sensitivity. For marine applications the film must be overexposed relative to standard exposure, the magnitude of overexposure empirically determined by conditions on the site. Features are rendered in false color.

Blue Insensitive Color/No Filter - This film is experimental and specifically designed to take advantage of increased penetration afforded by lack of blue response. To prevent exposure by residual blue sensitivity in the red and green sensitive emulsions, it may be exposed through a Wratten 12 or 15 filter. Features tend to appear in false color due to lack of a blue sensitive reversal layer.

Conventional Color Film/No Filter - This film was selected for control purposes. The majority of the area to be surveyed was so shallow that the broad latitude of this film would provide adequate rendition of bottom features. Further, features are reproduced in near natural color.

Panchromatic/Wratten 12 - This black and white negative film was chosen for reproduction purposes. It was filtered to be blue insensitive, so that while lacking color rendition, it approximates the penetrating and imaging characteristics of the two preceding films.

Several problems complicated the analysis. Expectation of deteriorating weather prevented adequate mounting of the camera system, and scattered cloud cover on the site resulted in a variable flight altitude. Thus the scale of the original photography only approximates 1:7600, and all photography was degraded to some extent by image vibration. This degradation was most noticeable on the slowest film (conventional color).

Each frame was analyzed to assess portrayal of the submerged reefs as well as to determine if targets of archeological significance were present. Examination of the films indicated that water clarity in the Dry Tortugas was of such high quality that all film/filter combinations adequately portrayed bottom features, especially in the shoal areas of prime importance to this study. However, as water depth increased, the bottom remained more clearly visible on the blue-insensitive film in areas where it began to fade on the color photography. Indications are that color infrared film also offered considerable utility for water penetration. It must be pointed out, however, that exposure indices must be carefully adjusted to properly expose the green sensitive emulsion.

Intensive interpretation of the photography was limited to two areas, one inside the target area, the other outside. Both areas yielded information of considerable importance.

Figure 29 is a frame from the target area on Loggerhead Reef. Although identified features are indicated, they are not as sharply defined here as on the companion color transparencies due to the absence of subtle color tonal differences in black and white reproduction. The outlined features are believed to be pieces of ships' rigging, materials, and armament strewn across several thousand square meters of reef by the breakup of several vessels. This area corresponds to a previously identified site, the "Nine Cannon Wreck" site. Identifications were made before the interpreter knew the exact nature of this site.

This frame, like many others over the target site, contains evidence suggestive of tracks cut into the coral by ships of various sizes that were swept onto the reefs. The narrow white line projecting nearly parallel to the margin at the bottom center is a track cut recently by a small sailboat running onto the reef. Larger tracks in other areas may have been caused by larger or older wrecks. The slow growth of coral polyps as well as the scouring effect of sand serve to preserve these tracks, perhaps for centuries in extreme cases. In any event, the tracks are secondary evidence pointing to areas for prime consideration as wreck sites.

Figure 30 is a frame taken outside the prime target area.

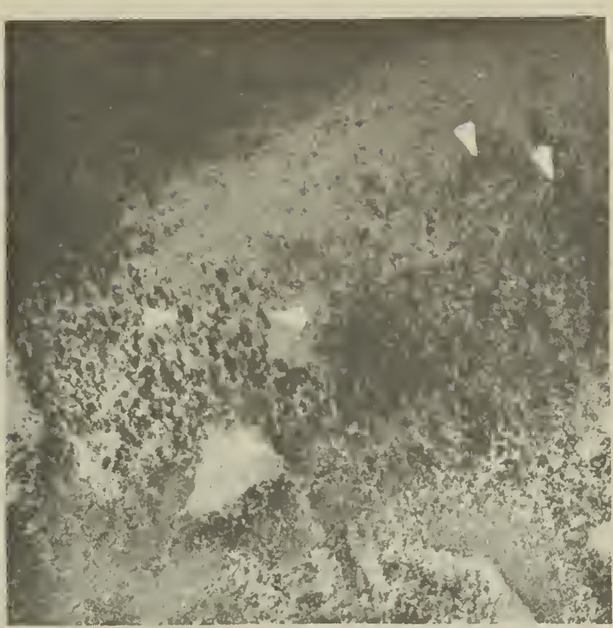


FIGURE 29 - "Nine Cannon Wreck" site.
Original scale 1:7,600,
enlarged 1.5 times

FIGURE 30 - "Nuestra Senora del Rosario"
site. Original scale 1:7,600,
enlarged 3 times.

During cursory examination of the frames in this area, an anomalous feature was detected. As outlined on the figure, a curvilinear feature whose shape contrasts sharply with the predominantly linear features of the surrounding area lies on the main reef face. Although this area is outside the main ground survey area, convergent evidence suggests that it may well be the single most important wreck site in the National Monument.

One of the instruments employed in this shipwreck survey was a proton magnetometer, an instrument that detects anomalies based on the disturbance of the background magnetic field due to the presence of base metals. During the period when the proton magnetometer was not engaged in the main target area, it was towed northeast and recorded a large anomaly near the site referenced above. Swimmer inspection produced positive identification of ballast stones and other artifacts over a broad area. The aerial photographic, magnetic anomaly, artifactual, and archival evidence indicate that this site may contain the remains of the 17th century Spanish galleon "Nuestra Senora del Rosario", known to have been lost in the Dry Tortugas. As in the previous example, discovery of this site was made prior to access to the supportive evidence. Using available small scale photography, each of the above sites was precisely positioned so that future surface survey parties might easily relocate them.

PART IV: CONCLUSIONS

For application in clear shoal waters, use of unfiltered, conventional color film would be fully acceptable for survey purposes. In areas where more turbid conditions prevail, careful application of the blue insensitive/blue filtered color films is indicated.

Flight timing is extremely critical in marine archeological surveying. Flights should be timed to minimize reflected light; in other words, low sun angle is preferred. Also, they should be timed for periods of low wave activity.

The utility of multiscale photography as a base map substitute in areas such as Fort Jefferson, where accurate base maps are lacking, should preclude the often impossible task of relocating a submerged site in areas with few emergent features.

Aerial photography and other marine imaging systems exhibit unique advantages for marine archeology. Such sensors do not in themselves offer a panacea for marine surveys, but merely provide a better vantage point for viewing what should be, except for perspective, otherwise visible to the surface observer. A completely buried site would likely be invisible both to surface observers and aerial photography. However, when used in concert with, and as a directive for, conventional survey procedures, aerial photography offers an unmatched dimension for rapid surveillance, synoptic perspective, and precise positioning.

U.S. Fish and Wildlife Service

REMOTE SENSING INTERPRETATION OF AN ANASAZI LAND ROUTE SYSTEM

BY

THOMAS R. LYONS AND ROBERT K. HITCHCOCK

PART I: INTRODUCTION

The use of aerial photography in archeological research has received increasing attention in recent years (cf. Gumerman and Lyons, 1971). New instruments are constantly being developed and new techniques are being formulated and applied in remote sensing investigations. Archeologists of the National Park Service's Chaco Center, recognizing the potential utility of remote sensing, applied it to researches in the Chaco Canyon region of northwestern New Mexico (fig. 31).

Chaco Canyon was a major area of prehistoric human occupation in the Southwest. Numerous archeological surveys and excavations have shown that the Chaco Canyon National Monument region underwent a lengthy period of cultural development. It has been occupied at various times by Paleo-Indians, by bearers of the Desert Culture, by Basketmakers and Pueblo Indians, by early and modern Navajo farmers and herders, and by Anglo-American and Hispano ranchers.

Until quite recently, remote sensing has been considered as an exploratory tool to be used as a supplement to archeological field surveys. However, remote sensing is far more than this. It can be used not only as an aid to ground surveys but as a tool of analysis and interpretation. It is currently being employed to study a number of different problems in the Chaco Canyon region, but this report emphasizes one specific problem: the analysis of lineaments leading to or from a number of Chacoan sites of various kinds.

PART II: THE ENVIRONMENTAL SETTING

Chaco Canyon is an erosionally incised feature 20 miles long and no more than a mile wide. It lies in the upper reaches of the Chaco River drainage basin in San Juan County, New Mexico, a semi-

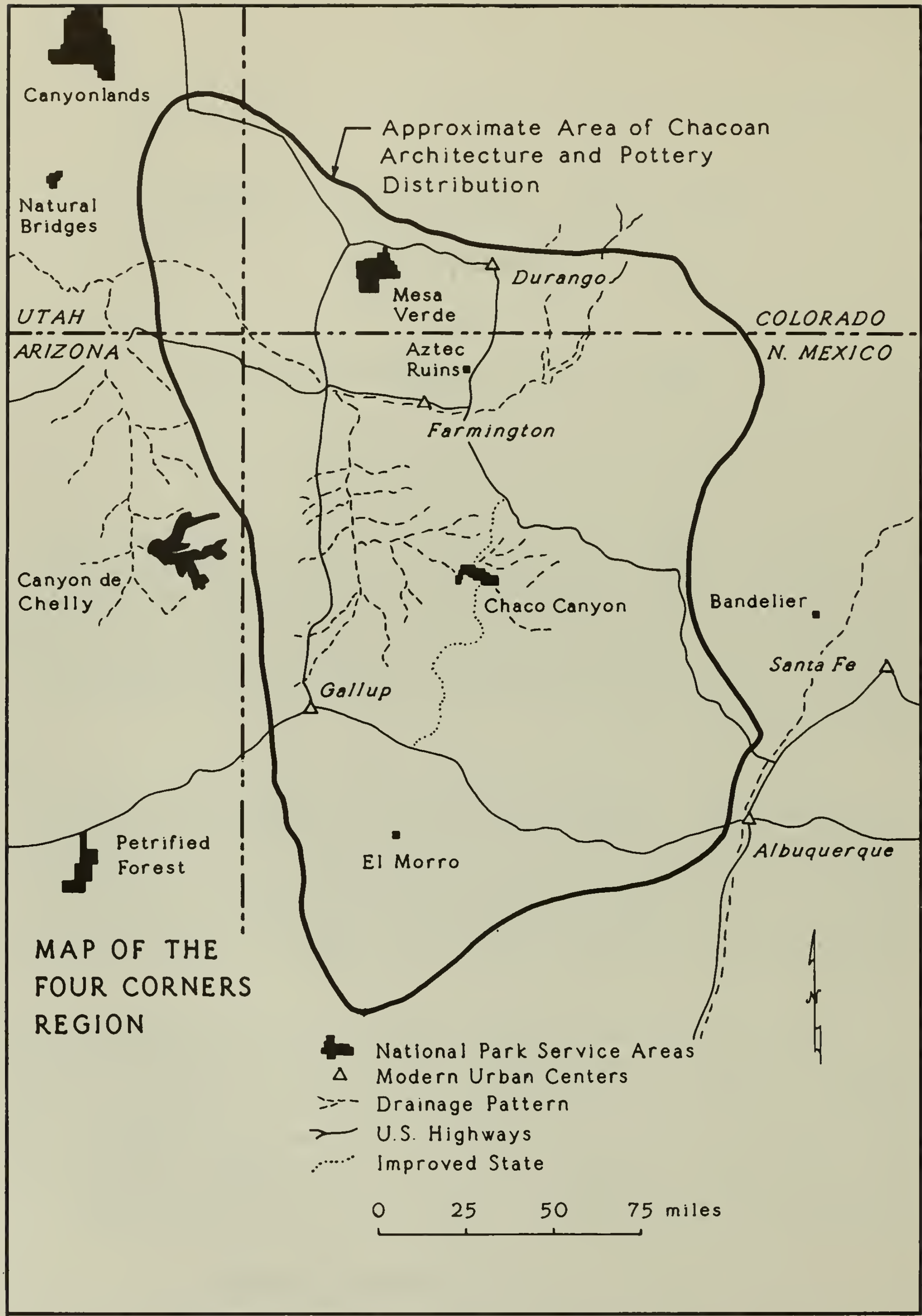


FIGURE 31 - Map of Chaco Canyon - Four Corners Region

arid environment. The surrounding area, consisting of mesas, steppes, and badlands, is essentially canyonless. Consequently, Chaco Canyon is physiographically unique (fig. 32). Chaco Wash, which drains an extensive area of approximately 4500 square miles, is dry most of the year, flowing only after heavy rains. Rainfall is meager, ranging from 6 to 15 inches a year and averaging 10 inches. Vegetation is correspondingly sparse. The climate of the region has been classified as varying between cold desert and steppe (Brand, et al., 1937:45).

Vivian and Mathews (1965) pointed out that Chaco Canyon is the only large confined area in the region in which there was enough alluvial soil available for large-scale farming purposes. The combination of fertile land and flood-water irrigation using run-off waters from the walls of the canyon enabled the prehistoric inhabitants to grow a variety of crops (Gwinn Vivian, 1970a, 1970b). Sandstone from the cliffs was available for building, and there was abundant timber in the area at one time that could be utilized for both building and fuel (Vivian and Mathews, 1965:7; Hawley, 1934: 65-75). It appears that floral and faunal sources were extensive enough to support an early hunting and gathering population and later to serve as a substantial supplement to agriculture.

PART III: THE PROBLEM AND THE APPROACH

The study and possible resolution of specific archeological problems were required to develop interpretive techniques and to determine applications and limitations of various sensors and sensor combinations. One such problem involved the further identification, mapping and explanation of lineaments first noticed by Navajo Indians living in the area and reported by Neil Judd (1954). Gordon Vivian in the late 1940's observed these alignments on Soil Conservation Service photography which was flown in the 1930's.

To begin the study of these alignments (now known to be prehistoric roadways) and their associated archeological features, black and white aerial photography of the region was purchased from the U.S. Geological Survey (USGS) and the Soil Conservation Service (SCS). The scale of this photography is approximately 1:32,000. In addition, the Chaco Canyon National Monument proper was flown on contract with the USGS at a scale of 1:3,000, again using black and white film. No color, color IR, multiband photography, or thermal scanner imagery was available for this study. The camera type and other photo identification information for the existing USGS photography and that flown for the Center on contract were as follows:

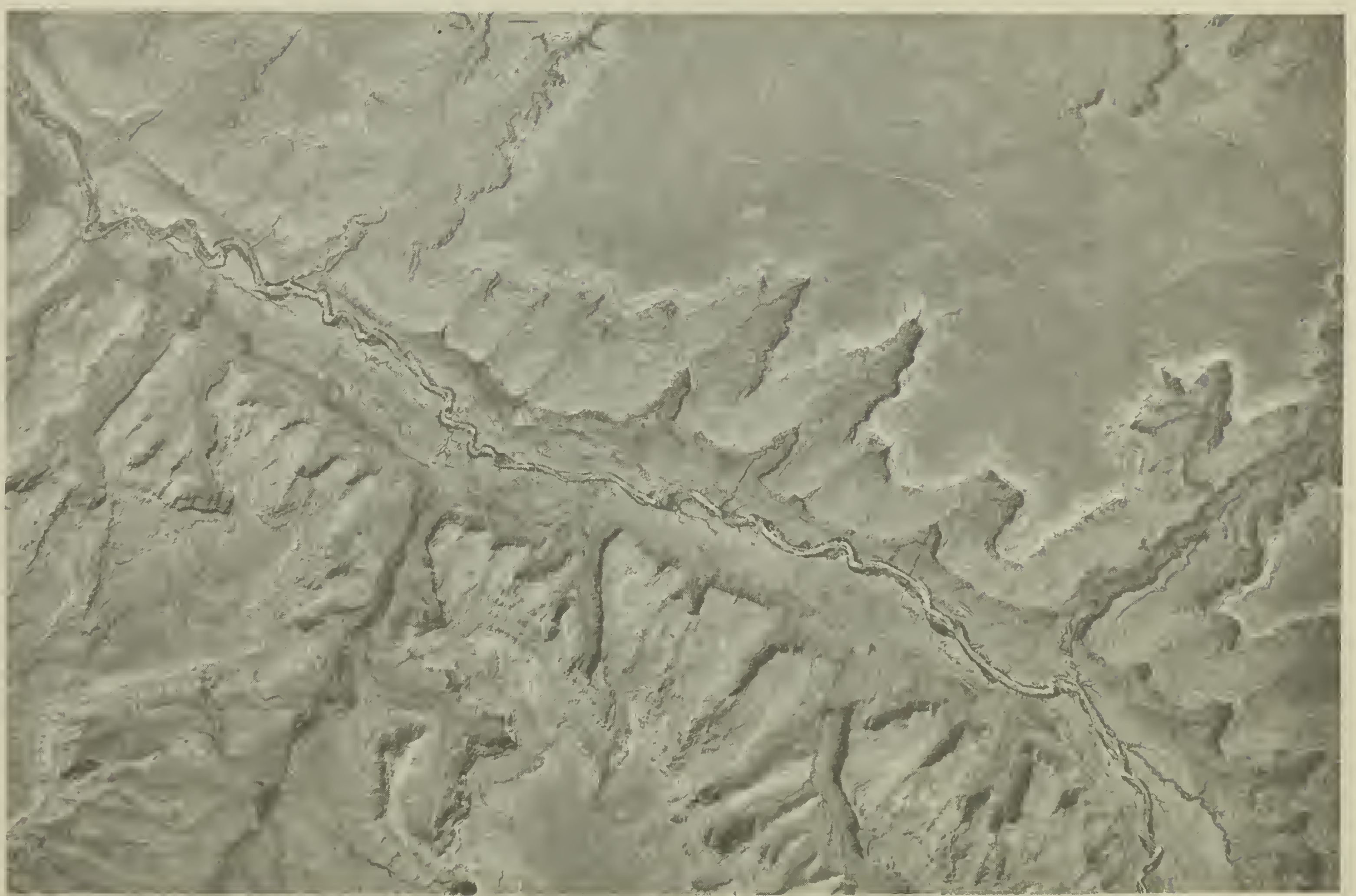


FIGURE 32 - Aerial photographic view of the central portion of Chaco Canyon

AERIAL PHOTOGRAPHY IDENTIFICATION

USGS Regional Photography GS-VBEH

Camera	54-017
Lens	Planigon # XF6751
Filter	-
Focal length	152.80 mm
Film type	B & W
Film format	9-1/2 x 9-1/2"
Angle	vertical
Scale	1:32000
Date	1/15/65

USGS Contract Photography

Camera	T-11
Lens	-
Filter	#12
Focal length	6"
Film type	Super XX
Film format	9 x 9"
Angle	vertical
Scale	1:3000
Dates	5/20/71 - 8/24/71 - 10/6/71

The existing USGS and SCS imagery of the areas, flown for topographic mapping and other purposes, proved to be of considerable utility for reconnaissance and for historical information. Large areas of coverage were acquired at modest costs (see Ebert, this volume, for further information on existing sources of imagery). In addition, it served as a base for developing specifications for the acquisition of aerial data designed for the specific research problem.

In order to determine the general applicability of the available and acquired imaged data to the study objectives, a "first scan" review was made of the photography. Results were sufficiently encouraging that detailed visual inspection and interpretation with the aid of a mirror stereoscope were undertaken. After inspection of the vertical stereo photography, field checks were made to verify identification and interpretation of various recognized features and anomalies.

PART IV: HISTORY OF REMOTE SENSING IN THE CHACO CANYON REGION

The use of aerial photos for the study of past human occupations of the Chaco Canyon region is not new. The first flights over Chaco with archeological application in mind were made by the famous aviator Charles Lindbergh and his wife Anne in 1929 (Deuel, 1969:190-194; Kidder, 1930). As a result of this work, archeologists such as Alfred Kidder realized the potential value of aerial reconnaissance for locating sites and for studying relationships between sites and nearby physiographic features.

Gordon Vivian was the first archeologist to successfully apply remote sensing interpretive techniques to Chaco Canyon archeology (Gwinn Vivian, personal communication, 1972). The imagery he used was SCS aerial photographs taken in the 1930's. In this photography Vivian noticed faint lines or lineaments north of the Penasco Blanco ruins which he at first thought were part of a water control system. Excavations by Gwinn Vivian in 1971, however, established that similar features lying between Pueblo Alto and Pueblo Bonito were not water control structures but were instead broad roadways.

Gwinn Vivian (1972: fig. 8) with the aid of aerial photography and ground checks, has mapped several roads running north of Old Alto, between Old Alto and Chetro Ketl, Pueblo Bonito, and possibly Pueblo del Arroyo. He also lists five other areas where he identified similar features. As pointed out by Judd (1964:141-142), these and other roads are frequently in direct association with rock-cut or masonry steps in the sandstone cliffs of the canyon. Vivian has measured the breadth of the linear features and found the "primary roads" to average 9 meters in width and the "spur roads" to average 4 1/2 meters in width, both having edges defined by banked earth or low masonry walls (fig. 33).

PART V: IMAGERY ANALYSIS

One of the first steps to be taken in the application of remote sensing techniques to archeological data is the development of a "recognition pattern" keyed to the area of study. A "recognition pattern" is the interpretive tool which enables the investigators to relate an imaged pattern to its true identity. Reliability of the recognition patterns is established and new recognition patterns are developed by means of periodic field checks of known and anomalous features in the landscape.

For example, in the Chaco Canyon area, it is necessary to be able to identify and recognize such linear features as fence lines, telephone lines, modern two-track vehicular roads and other environmental modifications in order to differentiate between prehistoric and contemporary cultural features. Fence lines surrounding the national monument appear clearly on aerial photographs because of the differential use of the range land outside and inside the monument, and because of the collection of tumbleweeds and other debris along the wires. A characteristic pattern of fence lines is the

FIGURE 33 - Roadway over slick rock showing masonry border (curb)

frequent right angle turns made at section corners. Lineaments which we now know to be ancient roadways do indeed often change direction but do so usually at a much more acute or obtuse angle (fig. 34).

Virtually all of the vehicular dirt roads in the Chaco area were developed as wagon trails or pickup truck trails and have a characteristically curvilinear pattern. The vehicles were subject to topographic influences and to vegetation concentrations and did not follow a planned surveyed route as the prehistoric roadways apparently did.

Therefore, when the characteristics of the local environment have been field checked, the historic or modern cultural alterations of the landscape can be eliminated. Using this approach with black and white vertical aerial photography, many human modifications of the natural landscape which cannot be recognized from a ground station vantage point can be recognized on a stereoscopic model (figs. 35 and 36).

There are several environmental factors responsible for the photographic expression of the old roadways in this semi-arid region. The absence of some ambient, floral species or the decrease in their density in the linear features has been observed on the ground. In a few places, the reverse is true in that floral density has increased. These phenomena alone, however, are not the only controlling factors. Topographically, the roadways are often slightly depressed or incised in the surrounding sandy soil. This permits a somewhat greater accumulation and retention of soil moisture which results in a subtly increased vegetation density not visible to the unaided eye but which accounts for differential reflection of incident sunlight. The possibility exists that shadow marks are also responsible for the discernment of certain portions of the lines. Most of these ancient roadways are invisible or scarcely discernible from the ground except in a few localized areas where alignments of stone or dirt mark their lateral boundaries (fig. 33), or where the road has been cut deeply into soil or through a knoll or hillock.

The investigators have now recognized numerous hitherto unrecorded segments of the ancient roadways and associated features plus an expanded system or network of roads which extend northward from Pueblo Alto (figs. 34 and 37). One of these roadways leading out of Pueblo Alto has been traced nearly 30 miles in a northerly direction and apparently connected Chaco Canyon with communities in the San Juan River valley. At a point about 3 1/2 miles north of Pueblo Alto, the roadway passes immediately to the east of a mound which was interpreted on photographic examination as an unexcavated pueblo ruin. This association of ruin and roadway observed on the aerial photography was field checked, thus providing

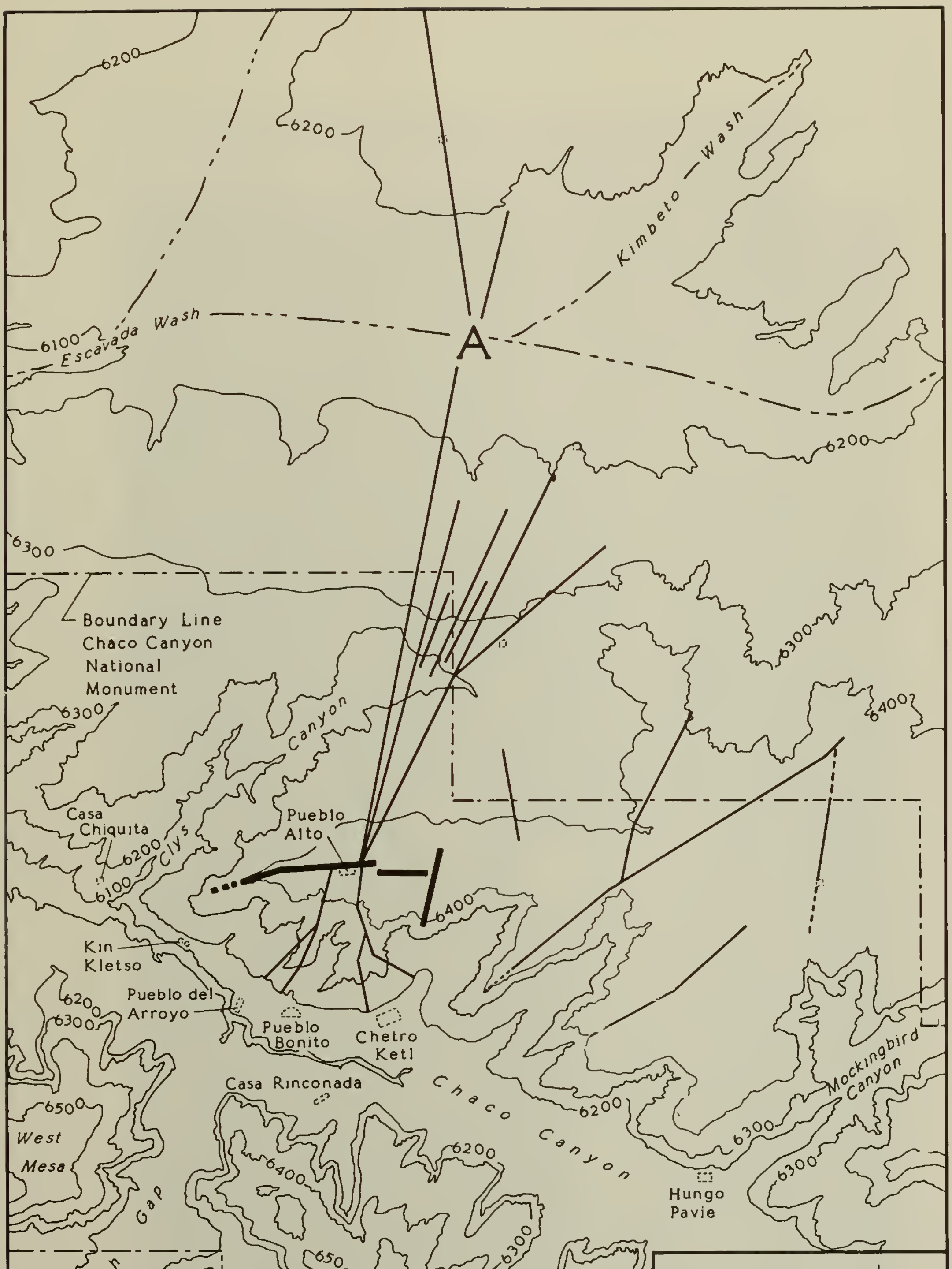


FIGURE 34 - Roads plotted on modified USGS map

FIGURE 35 - Surface expression of roadway across stabilized dunes above Chetro Ketl ruin

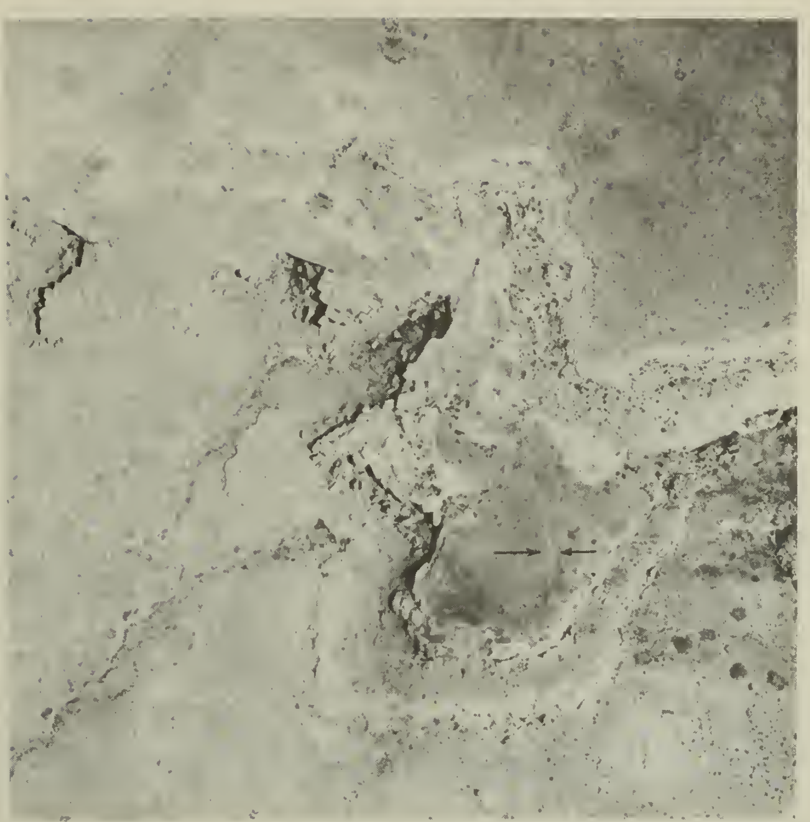


FIGURE 36 - Aerial view of same roadway as shown in figure 35 across stabilized dunes above Chetro Ketl ruin

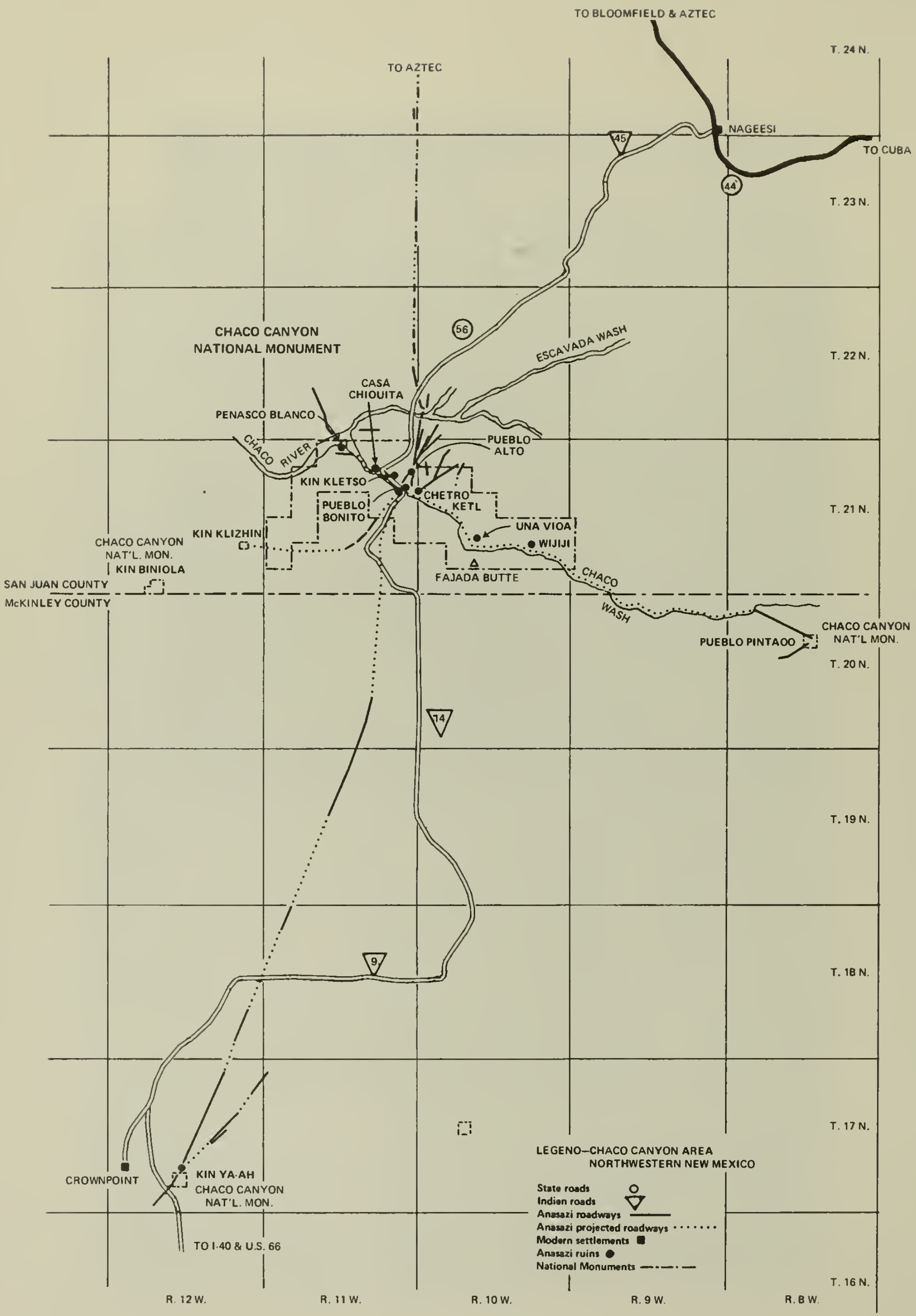


FIGURE 37 - Map of Chaco Canyon with road segments and network

a site which may serve to test hypotheses designed to explain the functions of these enigmatic features (fig. 38).

The Pueblo Alto network of roadways converges upon a point in a masonry wall approximately 90 feet east of the pueblo's exterior wall. This convergence was not detected prior to the use of aerial imagery. One road was laid out in a direct line to the Escavada Wash at Point A (fig. 34). Photo interpretation revealed that this was an area of low banks and probably served as a fording spot. Beyond Point A, the road changes direction from northeast by north to a heading due north and maintains this azimuth for many miles.

The Chaco Canyon roadways have been plotted on USGS 7 1/2 minute topographic sheets by visual transfer of alignments from the aerial photography. Well defined topographic features recognized on both media were used for control.

Gwinn Vivian (1970a:73) originally interpreted the extensive masonry walls associated with Pueblo Alto as elements of a water diversion system. Through test excavations he determined that these walls are resting on bedrock. They average a little over two feet in height and two feet in width.

Aerial photo interpretation suggests an alternative function for the walls. On a stereo model it is clear that the wall segments extend to or close to a point on the sandstone cliffs and that they lie along a topographic crest or divide (fig. 34). Such a position would not serve to control or direct meteoric waters since normal drainage would carry runoff away from rather than to or along these features. The configuration of the walls with flagstone paved surfaces in places and their direct alignment with road segments and stairways suggest that they were part of the roadway system and served as causeways not unlike the Mayan sacbeob.

The number and extent of the roads which have Pueblo Alto as their focal point suggest that this settlement served as a communication center of some importance. The communication links running between Pueblo Alto, Pueblo del Arroyo, Pueblo Bonito and Chetro Ketl point up several important factors. One is the obvious means for rapid and continuous communication between these centers; another is the extensive interaction implied by this system. Further, the roadways leading to this cluster of settlements from distant points (fig. 34) also indicate the importance of these settlements in the pattern of life of the ancient inhabitants of the region. The identification and recognition of the nature and extent of the road system provide a basis for the construction of hypotheses concerning the function and purpose of the extensive linear features of these ancient communities and the level of their engineering technology.

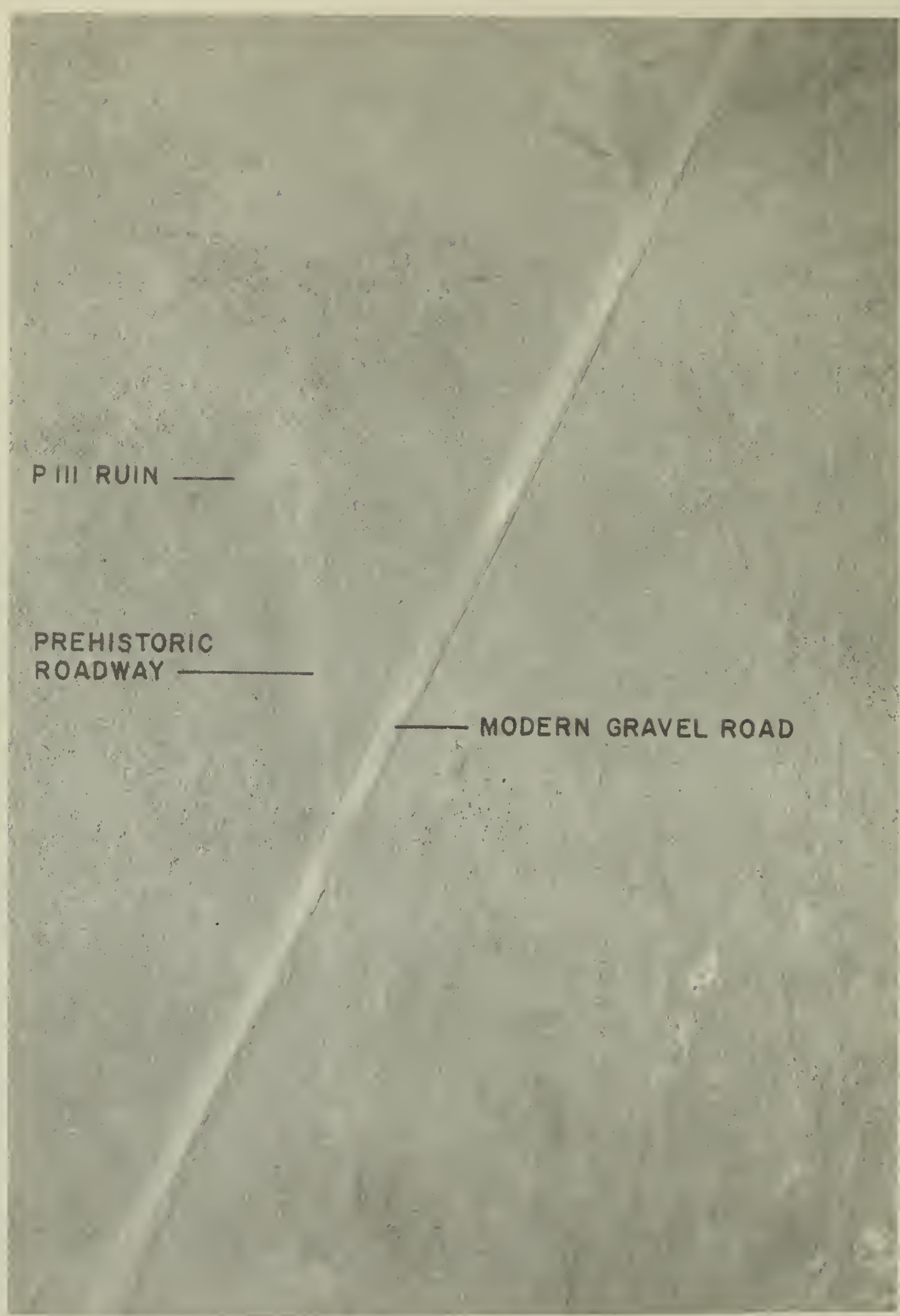


FIGURE 38 - Old Alto north road and Pueblo III ruin

PART VI: FIELD CHECK OF INTERPRETIVE CONCLUSIONS

Aerial photographs and topographic maps with plotted roadways were taken to the field for ground truth checks. A number of features and associations were verified, and as a consequence, confidence in the subsequent photo interpretation rose to a near 100 percent level.

The first verification of a road-ruin association was made at the previously mentioned pueblo site three and a half miles north of Pueblo Alto. The roadways leading from Pueblo Alto to Pueblo Bonito and Chetro Ketl were investigated, and the associations found between roadways and rock-cut and masonry steps are abundant. The cutting of roads through low knolls mentioned by Judd was seen at two locations: at a point about two miles south-southwest of Pueblo Bonito on a road that leads out of South Gap and on toward Kin Klizhin and possibly Kin Bineola, and at a point between two small village sites about a mile from the head of Chaco Canyon on a road that leads to Pueblo Pintado. Numerous small sites were found next to or near the roadways.

Roadway features observed in numerous localities on the ground and on photographs indicate their extensively engineered characteristics and the builders' frequent and somewhat puzzling disregard of topographic obstacles. Untold numbers of cubic yards of top soil were scraped from the surface and mounded along the roadways. Some stretches of the roads had borders of rock or masonry. An excellent example of a roadway with a number of associated features was observed at Penasco Blanco. There, a road twenty feet wide was cut an estimated five feet into aeolian soil, with most of the spoil dirt being piled on the upslope side (fig. 39). Masonry borders lined parts of the road, and there was rock and soil fill where it crossed a small draw east of the pueblo. In addition to the fill, a causeway at the bottom of a steep ravine was 12 feet long, 6 feet wide, with masonry borders 2 feet high (fig. 40).

Aerial photo interpretation and subsequent field checks have confirmed the existence of the following roadways along with a number of associated features. Seven roads lead north from Pueblo Alto. Two roadways occur near Penasco Blanco, one of these leading toward the northwest and the other running in an east-west direction immediately south of the ruin. Within Chaco Canyon proper, a few segments have been found leading upstream to the head of the canyon and on to Pueblo Pintado. From Pueblo Pintado, a short segment extends eastward and another southwestward. Several roadways pass through South Gap, one heading toward Kin Klizhin and another

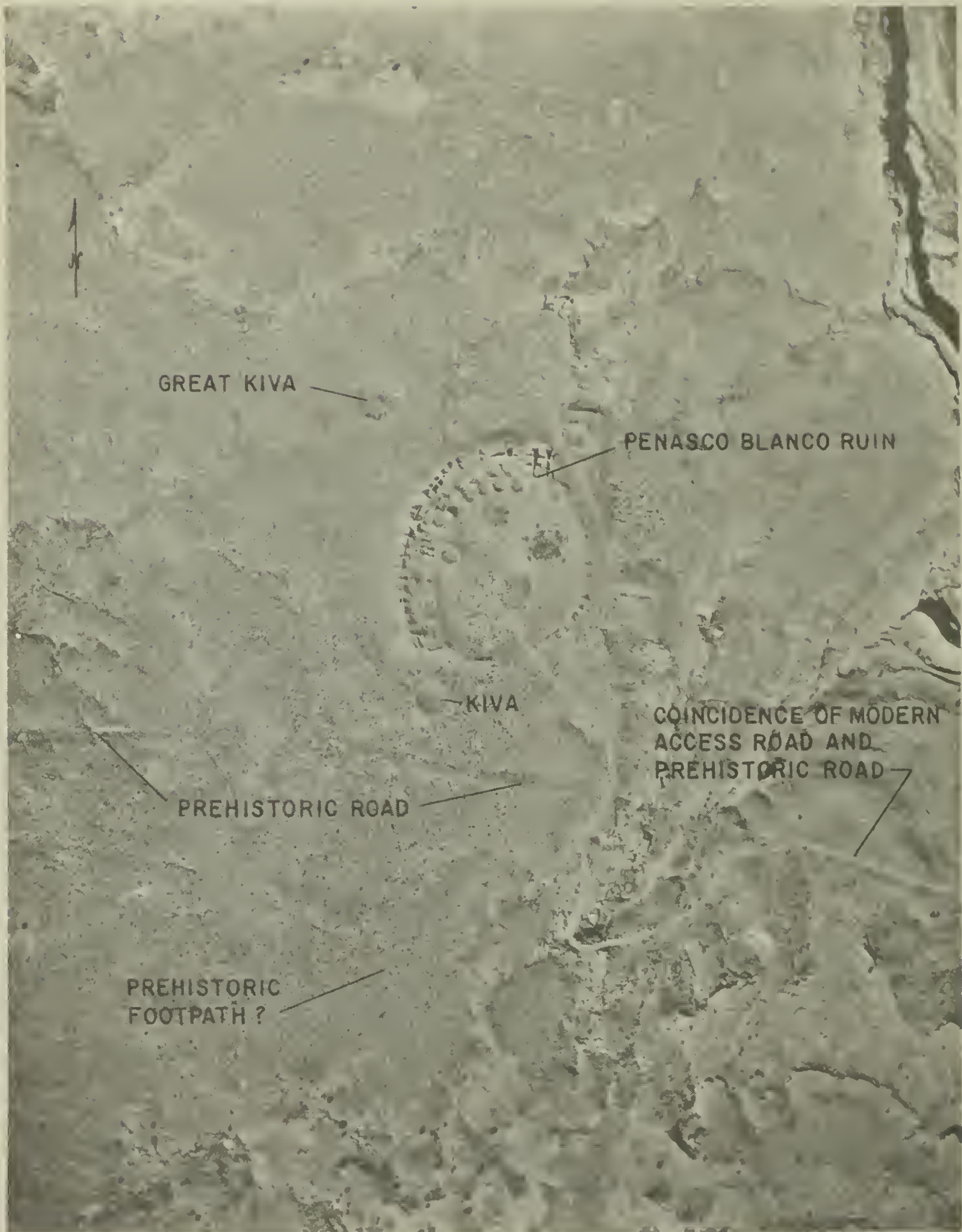


FIGURE 39 - Aerial view of Penasco Blanco area. Road deeply cut into dune soil.

FIGURE 40 - Penasco Blanco "causeway"

traceable to Kin Ya-a some thirty miles to the south. At Kin Ya-a the roadway from the north passes through the site and continues toward the southwest. Another branch ran northeast, apparently toward Pueblo Pintado. From the vicinity of the large ruin of Chetro Ketl, an interesting route runs to the north for 3 1/2 miles past several sites to a group of ruins on the Escavada Wash. Thus, our study substantiated the road segments reported by earlier investigators and added a substantial number of new ones not previously known.

PART VII: PREHISTORIC AND HISTORIC ROADS IN THE SOUTHWEST

In an effort to determine whether early European visitors in the Southwest were able to distinguish roadways or road-like features prior to recent alterations of the landscape, an examination of some of the pertinent literature was undertaken. It was found that historical references to Indian "roads" were made by a number of early explorers, both Spanish and American. Fray Marcos de Niza, for example, described a trip from the Tonto Creek-Salt River area in Arizona toward Zuni which lies 88 straight line miles to the southwest of Chaco Canyon, saying, "On the first day we travelled over a <u>wide and much used road</u>. We arrived for dinner at a spring which the Indians had indicated to me, and then at another one, where we slept. Here I found a shelter, which they had just built for me, and another one, in which Esteban had slept when he passed here. There were also old shacks and many signs of dead fires of the people who had traveled this road on their way to Cibola. In this manner I travelled twelve days . . ." (Hammond and Rey, 1940: 75). Further he states, "In the regions where there were no settlements, they (the Indians), informed me where I would find food and lodging . . ." (ibid., p. 74). There is the suggestion of way stations for the use and comfort of the traveler. Additional references to roads by Spanish explorers can be found in Hammond and Rey (1929:99; 1940:182, 222; 1966:220).

U.S. Army explorers have also made contributions to our knowledge of ancient roadways in the Southwest. One explorer, Lieutenant Joseph C. Ives, made a visit in 1850 to the Hopi country 150 miles to the west of Chaco Canyon and stated that from the village of Mishongnovi "several trails radiated from the foot of the bluff in perfectly straight lines, and could be traced a long way over the level surface. One conducted to the canyon of Flax (Little Colorado) river and doubtless to the Yampais (Havasupais as he used the term) village; another, the chief told us, was the trail of the Apaches; another, that of the Coyoteros; a fourth came from Zuni, and still further east was the Navajo trail leading to Fort Defiance" (Ives, 1861:122). No actual designation of "roads" is made in this reference, but the engineered nature of the pathway is suggested by the description "in perfectly straight lines." Another soldier, General James H. Carleton, took time out from chasing Mescalero Apaches in southern New Mexico to make drawings of the ruins at Gran Quivira and to comment on the existence of a canal that ran from Gran Quivira 15 miles eastward to the Gallinas Mountains (Carleton, 1854). In all probability this feature was a road rather than a canal, since it does not follow a gradient, but proceeds across the terrain without regard to differences in elevation.

There are not only historical references to roadways in the Greater Southwest, but archeological observations as well. At Gran Quivira, Richard Howard (1959) reports that he sectioned what was thought by General Carleton to be a canal, but that it turned out to be a trail instead. Another roadway was found not far from Mesa Verde in Colorado. This roadway, up to 1 1/2 feet deep and 15 to 20 feet wide in places, runs from a large Pueblo III ruin at the head of Sand Gulch to another large Pueblo III ruin near Yellow Jacket Canyon, a distance of 5 to 6 miles (Alden Hayes, personal communication, 1973). A whole series of roads was mapped in 1833 by C. De Berghes, a German mining engineer, in the La Quemada area of northern Mexico (Hendrick, Kelley, and Riley, 1971: xv-xvi). Finally, Earl Morris, reporting on the excavation of Aztec Ruin in northwestern New Mexico, mentions that there was a road leading from the pueblo to sandstone quarries three miles to the northwest (Morris 1915:666).

The existence of roads in the Chaco Canyon region specifically has been known for some time. Hosteen Beyal, an elderly Navajo who lived in the area for many years, told Neil Judd about some of his early recollections of his life there as a boy (Judd, 1954:343-350). As Judd puts it, "When asked about the so-called 'roads" on both the north and south cliffs, Beyal remarked that they were not really roads, although they looked like them. He says they were built by the Chaco people. One road led from Pueblo Pintado to Pueblo Bonito and on to Penasco Blanco. Another led from Pueblo Bonito to Kin-yai; a third, from Kinbiniyol to Kin-yai; still another, from Kin-biniyol to, or through, Coyote Canyon and on to a point near Fort Defiance. On each of these 'roads' one could see, until recently, cuts where the road passed through small hills". Another elderly informant, Padilla, was queried by Judd as well. Judd states, "When asked concerning the 'roads' mentioned by Hosteen Beyal as having been made and used by the ancient Chacoans, Padilla said he has seen very few of them because they have been washed out or covered over by sand and silt. Their locations are indicated, however, by cuts through low knolls. As one rides across country, one notices a succession of these cuts" (Judd, 1954:347). Judd's final remark about roads reads "Beyond Tomacito's place, at the south end of The Gap, is a cut that some Navajo call a canal but it looks more like a wagon road to our informant. (It is, in fact, a part of a 'ceremonial highway', a type of construction to be described in a future publication)" (Judd, 1954:350). Unfortunately, this publication has never appeared.

Gordon Vivian also noticed the roadways in and around Chaco Canyon. In a memorandum to Superintendent McNeil of Chaco Canyon National Monument dated October 29, 1948, he gives an account of an interview with Richard Wetherill's widow, in which she told him that "north of Alto in certain lights you can still see what appears to be a wide roadway running down to the Escavada. In the old days this was very clearly defined in the spring or early summer because the vegetation on it was different from any other and it could be traced clear to the San Juan." This is apparently a reference to the road which has been traced 30 miles north of the canyon.

There can be do doubt that a highly complex roadway system existed in the Chaco Canyon region. The above mentioned references to these roadways lend support to our conclusion that these features are part of a major roadway system connecting not only population centers in Chaco Canyon with each other but also with centers in outlying areas.

PART VIII: IMPLICATIONS OF AN INTEGRATED LAND ROUTE SYSTEM

In summary, important observations about the roads in and around Chaco Canyon have been made on both aerial and ground surveys:

1. roadways connected the major Chaco towns with one another as well as with outlying towns;

2. the roadways converge on the town cluster of Pueblo Alto, Chetro Ketl, Pueblo Bonito, and Pueblo del Arroyo;

3. the roadways are associated with a fairly large number of the smaller village sites;

4. the roadways are associated with a number of features, including cuts, fill, stairways, curbings, and a causeway;

5. the roadways are well-engineered features, which required extensive construction and maintenance;

6. as of this report, the extent of the roadways has been measured and mapped in excess of 250 miles.

Many of the functions of the roadways have yet to be determined, but the authors would like to suggest one possibility. These roadways may have served to greatly facilitate redistribution of goods and/or services. This suggestion is little more than speculation, but its validity can be tested. A number of test implications would have to be generated, such as the presence of non-local goods in Chaco towns and villages, or the presence of a disproportionately large number of storage facilities designed to handle incoming goods.

PART IX: CONCLUSIONS

It is apparent from aerial photographic interpretation that the extensive, engineered roadway network in the Chaco Canyon area is of greater magnitude than originally anticipated and will ultimately have a geographic extent considerably in excess of the known 250 linear miles. The network ties together:

1. the major sites within Chaco Canyon,

2. lesser sites in the area and

3. outlying population centers such as Kin Ya-a, Pueblo Pintado, and probably the Salmon and Aztec Ruins, and other large but lesser known Chacoan communities.

The overall roadway pattern suggests that the town cluster of Pueblo Bonito, Pueblo Alto, Chetro Ketl and possibly Pueblo del Arroyo was the demographic center of the Chacoan world. Further, it is apparent that these features required a considerable expenditure of time and energy for both their construction and maintenance, and consequent complex group organization and controls.

All of the roadways so far identified in the Chaco area appear to be Pueblo III in age. Evidence for this is the direct association of most of the networks with ruins such as Pueblo Alto, Pueblo Bonito, Chetro Ketl, Penasco Blanco, Kin Ya-a and Pueblo Pintado. It has also been noted that several of the roadways are in direct physical association with several small Pueblo II village occupation areas. This is not to suggest, as yet, that the roadways were originally constructed in Pueblo II times. It may indicate, however, the routes themselves--the traffic patterns, so to speak--were established in Pueblo II times and were later "modernized" during the Pueblo III period.

Construction of the system is tentatively placed in the 11th to 12th centuries A.D.

Given the extent and complexity of the roadways as we know them to date, several functions can be inferred:

1. the roads provided guidance and passage for the travel of groups and individuals;

2. the routes were used for transport of goods and materials;

3. the roadways served to facilitate communication between widely separated population centers;

4. finally, the road system served as an integrative mechanism, the effectiveness of which remains to be demonstrated.

A new dimension was added to archeological investigations in Chaco Canyon by virtue of the recognition of the magnitude and functions of the land route system. The roadways are a factor to be taken into account in the overall planning of further research in the area. No other such road system is known to exist in the United States, or for that matter in the area north of Mexico.

It is concluded finally that remote sensing, specifically aerial photographic interpretation, is a technique of value and expanding potential for archeological exploration and interpretation as exemplified by the analysis of the Anasazi land route system.

Chaco Center
National Park Service
University of New Mexico

LITERATURE CITED

Brand, Donald D., Florence M. Hawley, and Frank C. Hibben
1937 Tseh So, A Small House Ruin, Chaco Canyon, New Mexico, University of New Mexico Bulletin, Anthropological Series, Vol. 2, No. 2. Albuquerque.

Carleton, James H.
1854 Diary of an Excursion to the Ruins of Abo, Quarai, and Gran Quivira in New Mexico. 9th Annual Report of the Smithsonian Institution. Washington, D.C.

Deuel, Leo
1969 Flights into Yesterday: The Story of Aerial Archeology. St. Martin's Press. New York.

Gumerman, George J. and Thomas R. Lyons
1971 Archaeological Methodology and Remote Sensing. Science Vol. 172: 126-132. Washington.

Hammond, George P. and Agapito Rey
1929 Expedition into New Mexico made by Antonio de Espejo, 1582 - 1583. University of New Mexico Press. Albuquerque.

1940 Narratives of the Coronado Expedition. University of New Mexico Press. Albuquerque.

1966 The Rediscovery of New Mexico. University of New Mexico Press. Albuquerque.

Hawley, Florence M.
1934 The Significance of the Dated Prehistory of Chetro Ketl, Chaco Canyon, New Mexico. The University of New Mexico Bulletin, Vol. 1, No. 1. Albuquerque.

Hedrick, Basil C., J. Charles Kelley, Carroll L. Riley
1971 The North Mexican Frontier. Southern Illinois Press. Carbondale and Edwardsville.

Howard, Richard M.
1959 Comments of the Indians' Water Supply at Gran Quivira National Monument. El Palacio 66:85-91. Santa Fe.

Ives, Lieutenant Joseph C.
1861 Report upon the Colorado River of the West. Government Printing Office. Washington, D.C.

Judd, Neil M.
1954 The Material Culture of Pueblo Bonito. Smithsonian Miscellaneous Collections, Vol. 124. Washington.

Kidder, Alfred V.
1930 Colonel and Mrs. Lindbergh Aid Archeologists. Masterkey. Vol. 3, No. 6:5-17. Southwest Museum. Los Angeles.

Morris, Earl H.
1915 The Excavation of a Ruin Near Aztec, San Juan County, New Mexico. American Anthropologist 17:666-681.

Vivian, Gordon and Tom W. Mathews
1965 Kin Kletso: A Pueblo III Community in Chaco Canyon, New Mexico. Southwestern Monuments Association, Technical Series. Vol. 6, Part 1. Globe.

Vivian, R. Gwinn
1970a Aspects of Prehistoric Society in Chaco Canyon, New Mexico. Ph.D. Dissertation. University of Arizona.

1970b An Inquiry into Prehistoric Social Organization in Chaco Canyon, New Mexico. In Reconstructing Prehistoric Pueblo Societies. William A. Longacre, ed. University of New Mexico Press. Albuquerque.

1972 Prehistoric Water Conservation in Chaco Canyon. Final Technical Letter Report for NSF Grant No. GS-3100. Tucson.

REMOTE SENSING METHODOLOGY AND THE CHACO CANYON PREHISTORIC ROAD SYSTEM

BY

John A. Ware and George J. Gumerman

PART I: INTRODUCTION

The purpose of this remote sensing project focusing on Chaco Canyon National Monument in northwestern New Mexico, was two-fold. The first objective was to determine the capabilities of various types of remotely sensed data and interpretive instruments in delineating cultural features such as prehistoric roads. The second objective was to explore the extent and character of the prehistoric land routes or roads converging on the ruin of Pueblo Alto, one of the major ruins in the monument. In addition, we offer suggestions for future research on the road system of Chaco Canyon and the ruin of Pueblo Alto.

The imagery evaluated was panchromatic and true color photography in varying scales, as well as multispectral photography. Also, color-additive multispectral viewers and an isodensitometer or color density slicer were evaluated for their potential in isolating prehistoric land routes.

The most exciting aspect of the Chaco Canyon road network is, of course, the socio-cultural implications of this system for the understanding of Anasazi society. Nevertheless, a first step is an understanding of the physical characteristics of the road network, and this is one of the purposes of this project. Although we do not consider the function or social consequences of the prehistoric land route system in this paper, a short statement on the Chaco roads is essential here for historical perspective. Recent work by Vivian and Buettner in Chaco Canyon has led to the "rediscovery" of prehistoric land routes that connect a number of sites (Vivian, 1972). Segments of these roads had been noted by a number of earlier observers, but their comments sparked no large scale research efforts in northwestern New Mexico.

The roads are characterized by "well-defined roadbeds frequently bordered by masonry walls or mounded earth, masonry and rock-cut stairways at cliff edges, and probable ramps in other scarp locations. There is some indication that these roads were laid out on a preconceived route that avoided major topographic obstacles but that could accommodate minor obstructions such as low hills, which were cut through" (Vivian, 1972, personal communication).

As Lyons and Hitchcock (this volume) have demonstrated, long linear cultural features traversing various types of sub-environments are ideal for testing the applicability of remote sensing to archeology. The Pueblo Alto road system was selected because more roads, and roads of different types, terminate at this community than at any other ruin in Chaco Canyon.

Work was accomplished under contract No. 14-10-3-930-246 from the U.S. National Park Service. We thank R.G. Vivian, R. Buettner, T.R. Lyons, R. Lister, J. Thrift and A. Hayes for assistance and advice. We also wish to thank the University Museum, University of Pennsylvania for helping to obtain imagery.

Prescott College students who assisted in the field and laboratory were: L. Barker, L. Capper, C. Chang, D. Hanson, K. Jones, M. Reed, S. Sessions, and S. Wilson.

PART II: METHODOLOGY

The investigations of the Pueblo Alto prehistoric road system were accomplished in three phases: 1) an aerial reconnaissance utilizing black and white and true color aerial imagery, multispectral photography, and data derived from an isodensitometer study of the Pueblo Alto area; 2) a ground survey conducted on foot to determine morphological characteristics of apparent land route sections; and 3) a series of test excavations designed to obtain profiles of road segments in order to determine the nature, consistency and range of variability in the archeological remains and their relationship to the imagery.

The first phase of the investigation entailed an aerial photographic reconnaissance of the study area for the purpose of locating various road segments described by Vivian (1972), and delineating additional linear features which had previously been overlooked on imagery and on the ground.

The vertical aerial photographic coverage of the Pueblo Alto study area consisted of the imagery shown in table 7.

All of the imagery except the multispectral and color photography was flown with approximately sixty percent overlap of the photographs, ensuring stereo coverage. A stereoscopic viewer was used in the field and in the laboratory for all of the interpretive work of the aerial reconnaissance.

Table 7. Aerial imagery of the Pueblo Alto area.

Film Format	Film Type	Scale	Date	Photographic Agent
9" x 9"	B & W	1:32,000	1935	U.S. Soil Conservation Service
9" x 9"	B & W	1:32,000	1959	Contract
9" x 9" 4 frame	Multi-spectral	1:3,000	1971	U.S. Geological Survey
2¼" x 2¼"	B & W	1:3,000	1971	U.S. Geological Survey
2¼" x 2¼"	Color	1:3,000	1971	University of Pennsylvania Museum

The existence of multiscale imagery allowed us to assess the archeological value of photographs of different scale. One of our principal tasks at Pueblo Alto, then, was to determine the relative capabilities of multilevel aerial imagery and ground-based survey in terms of rendering data relevant to the discrimination of prehistoric land routes and to determine the quality of data which could be extracted from each of these observation platforms. Multilevel aerial imagery coupled with ground-based reconnaissance essentially provides a stratified series of observation platforms from ground level to several miles above the surface of the earth.

Existing aerial imagery of the Pueblo Alto study area provides two distinct levels or aerial platforms from which to view the Pueblo Alto road system. A high altitude observation platform was provided by two sets of 1:32,000 black and white photographs, and a low altitude platform was provided by sets of black and white and true color photographs at scales of 1:3,000 (see table 7). The ground truth survey provided the vantage point for the third observation platform which was, of course, at ground level. Most of the interpretive work relating to the high altitude aerial images was accomplished using the earlier set of 1935 photographs. The clarity and resolution obtained from these images was far superior to the resolution of the 1959 photographs. The reason for this difference in clarity has not been determined; however, a number of variables may have been operative during the latter flight to reduce the overall resolution of the photographs. Local meteorological conditions such as dust-laden winds, for example, can significantly influence the resolution of aerial photography. The possibility also exists that erosion in the valley north of Pueblo Alto has subsequently obscured a number of surface features which were visually distinct in 1935. In addition, it is not known at what time of day the photographs were taken and this is, of course, an important variable.

The imagery was studied prior to the ground truth study in Chaco Canyon and all linear features which could not be identified as modern artifacts of human landscape alteration, such as modern roads, fence lines, plow marks, and so on, were marked on the photographs for investigation.

The second phase of the investigation involved a ground truth survey of the study area. As expected, the time of day, specifically the angle of sunlight, was an important factor in distinguishing the shallow linear depressions characteristic of most of the road sections. The best time of day to discriminate road depressions on the ground was in the early morning. The low-angle sunlight of early morning produces long shadows which help to accentuate extremely subtle topographic features such as road segments and low masonry walls. Shortly after sunrise (ca. 1 to 1½ hours) many road segments which were clearly visible at dawn virtually dissolved into the landscape and became indistinguishable from such natural topographic features as drainage channels and surface depressions created by structural basins in the underlying bedrock.

Low angle, late afternoon sunlight did not produce comparable results. This is probably due to late afternoon meteorological conditions, characterized by dust-laden winds of high velocity which tend to obscure the more subtle ground features. In addition, the direction of sunlight may be important in distinguishing a particular road.

These factors affecting feature recognition significantly restricted the amount of time that could be effectively devoted to ground reconnaissance. As a result, the optimal daylight hours were spent in locating and marking the road segments with stakes and flagging tape, and the intervening period (late morning and early afternoon) was spent in mapping road alignments and recording more prominent large scale phenomena, such as masonry walls and distinct road depressions.

The third phase of the investigation, involving test excavation of various road segments, was conducted simultaneously with the ground reconnaissance. The field work was carried out during a two-week period in September, 1972. Trenches were excavated at right angles to apparent road depressions in order to obtain lateral profiles of road beds. The primary excavation unit employed in these tests was a one-meter wide test trench. The length of the trenches varied with the apparent width of the road depressions; most trenches were 15 to 20 meters in length. Excavation was performed by hand.

A total of eight test trenches were put through seven apparent land route segments at Pueblo Alto (fig. 41). The selection of road segments to be tested was initially done on the basis of road depression prominence; the most distinct road depressions were tested first in order to establish reliable criteria for evaluating the less distinct and therefore more questionable surface depressions.

In several instances, portions of the test trenches were expanded in order to delineate various features encountered within the trench, such as stone rubble curbings, masonry walls, etc. Testing outside the basic one-meter test trenches was limited, however, due to lack of time.

In addition to testing various road depressions, a small section of the long north wall of Pueblo Alto was exposed by trenching (see fig. 42). The north wall extends from the northeast corner of Pueblo Alto to a point approximately 100 meters east of the pueblo. At the terminus of the wall is a masonry room block and a large kiva depression.

The excavation revealed an opening or "gate" in the masonry wall, at a point approximately 40 meters east of the main room block of Pueblo Alto. This opening is one meter in width, and is situated at a point where several road sections appear to converge (fig. 42).

PART III: DATA AND RESULTS

Road Attributes

In order to determine the resolution capabilities of different types of imagery and of various observation platforms on and above the Pueblo Alto study area, a list of 18 road attributes was compiled for eight apparent segments in the Pueblo Alto road system. These attributes served as indices for determining the relative resolution capabilities of each of the observation platforms. Each attribute was examined from the vantage point provided by each of the observation platforms, and the relative visibility of the attribute was noted. In this way, it was hoped that a list of attributes constituting a recognition pattern could be developed for each of the three observation platforms. The 18 attributes (figs. 43, 44, and 45) were compiled using all available sources of data, including

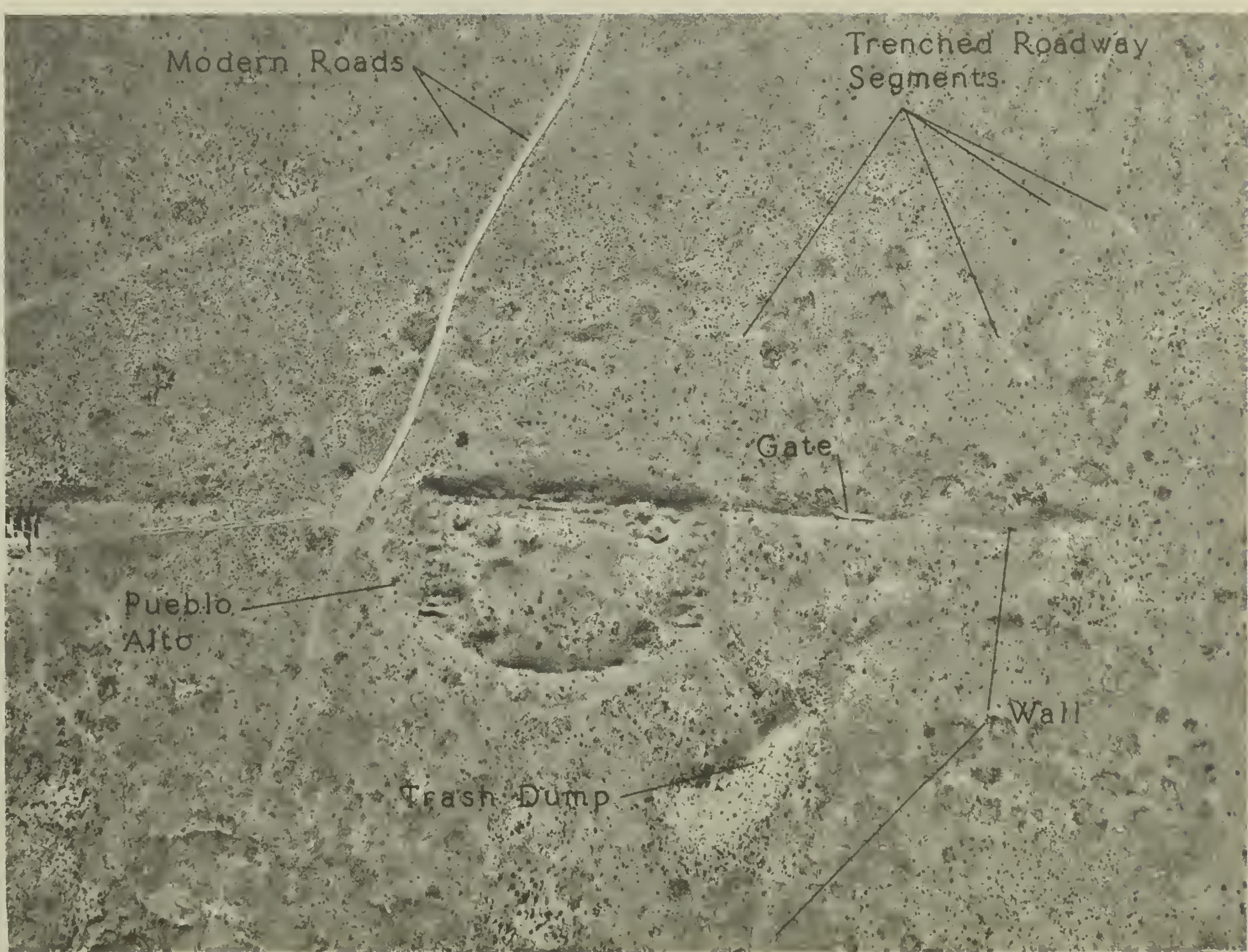


FIGURE 41 - Pueblo Alto area showing excavated test trenches

FIGURE 42 - Gate in north wall of Old Pueblo Alto

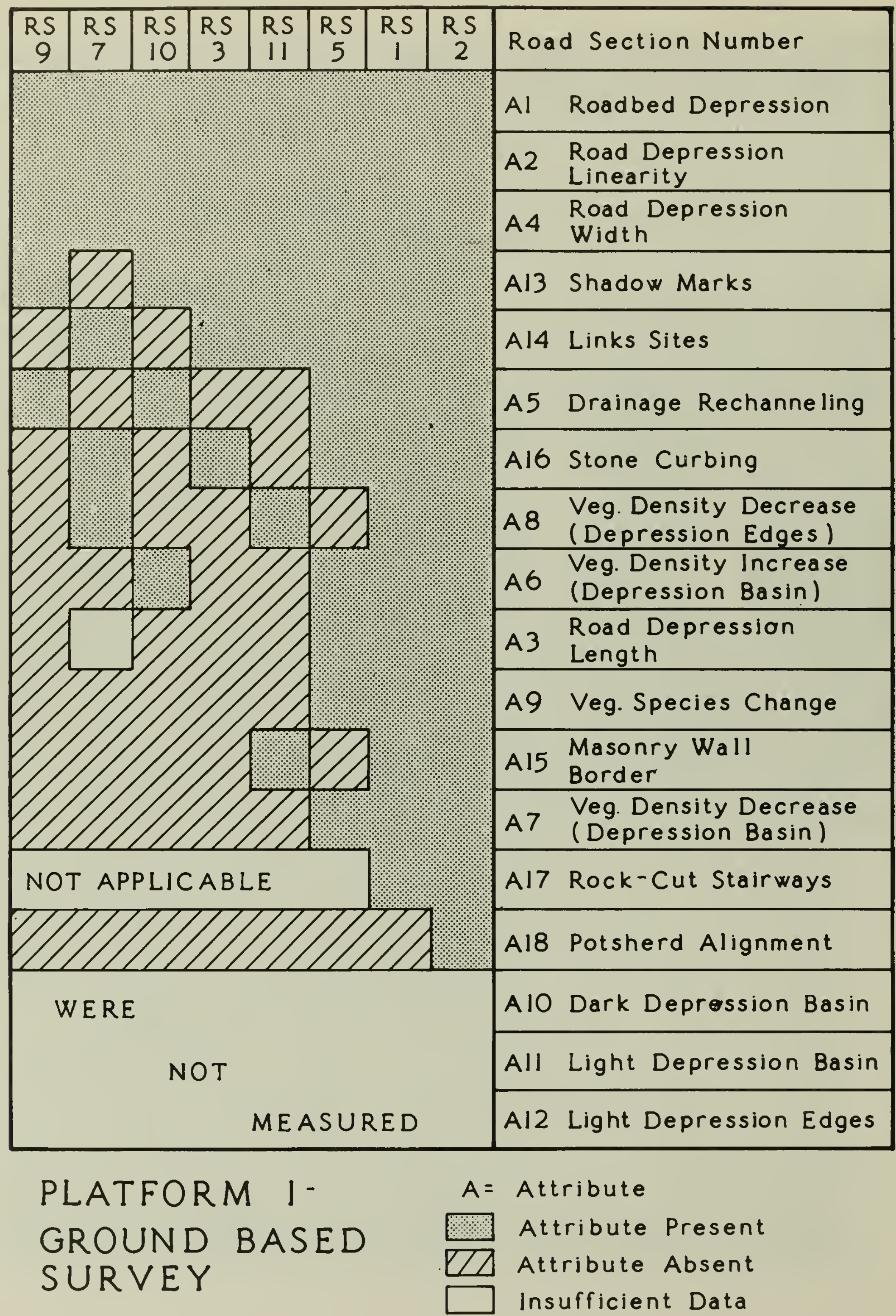

RS 9
RS 7
RS 10
RS 3
RS 11
RS 5
RS 1
RS 2
Road Section Number
A1 Roadbed Depression
A2 Road Depression Linearity
A4 Road Depression Width
A13 Shadow Marks
A14 Links Sites
A5 Drainage Rechanneling
A16 Stone Curbing
A8 Veg. Density Decrease (Depression Edges)
A6 Veg. Density Increase (Depression Basin)
A3 Road Depression Length
A9 Veg. Species Change
A15 Masonry Wall Border
A7 Veg. Density Decrease (Depression Basin)
A17 Rock-Cut Stairways
A18 Potsherd Alignment
A10 Dark Depression Basin
A11 Light Depression Basin
A12 Light Depression Edges
NOT APPLICABLE
WERE NOT MEASURED
PLATFORM I - GROUND BASED SURVEY
A= Attribute
Attribute Present
Attribute Absent
Insufficient Data

FIGURE 43

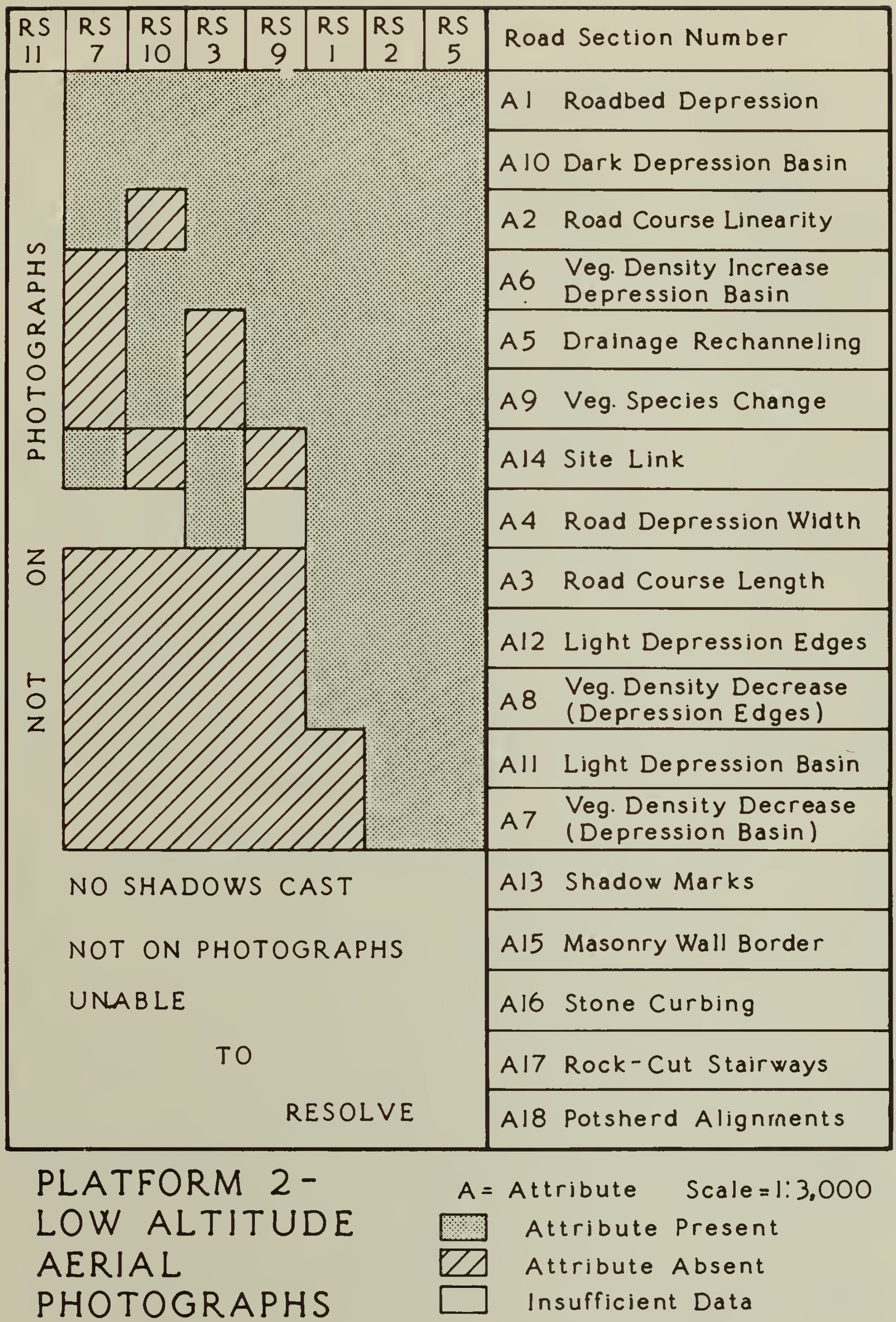

RS 11
RS 7
RS 10
RS 3
RS 9
RS 1
RS 2
RS 5
Road Section Number
A1 Roadbed Depression
A10 Dark Depression Basin
A2 Road Course Linearity
A6 Veg. Density Increase Depression Basin
A5 Drainage Rechanneling
A9 Veg. Species Change
A14 Site Link
A4 Road Depression Width
A3 Road Course Length
A12 Light Depression Edges
A8 Veg. Density Decrease (Depression Edges)
A11 Light Depression Basin
A7 Veg. Density Decrease (Depression Basin)
A13 Shadow Marks
A15 Masonry Wall Border
A16 Stone Curbing
A17 Rock-Cut Stairways
A18 Potsherd Alignments
NOT ON PHOTOGRAPHS
NO SHADOWS CAST
NOT ON PHOTOGRAPHS
UNABLE
TO
RESOLVE
PLATFORM 2 -
LOW ALTITUDE
AERIAL
PHOTOGRAPHS
A = Attribute
Scale = 1:3,000
Attribute Present
Attribute Absent
Insufficient Data

FIGURE 44

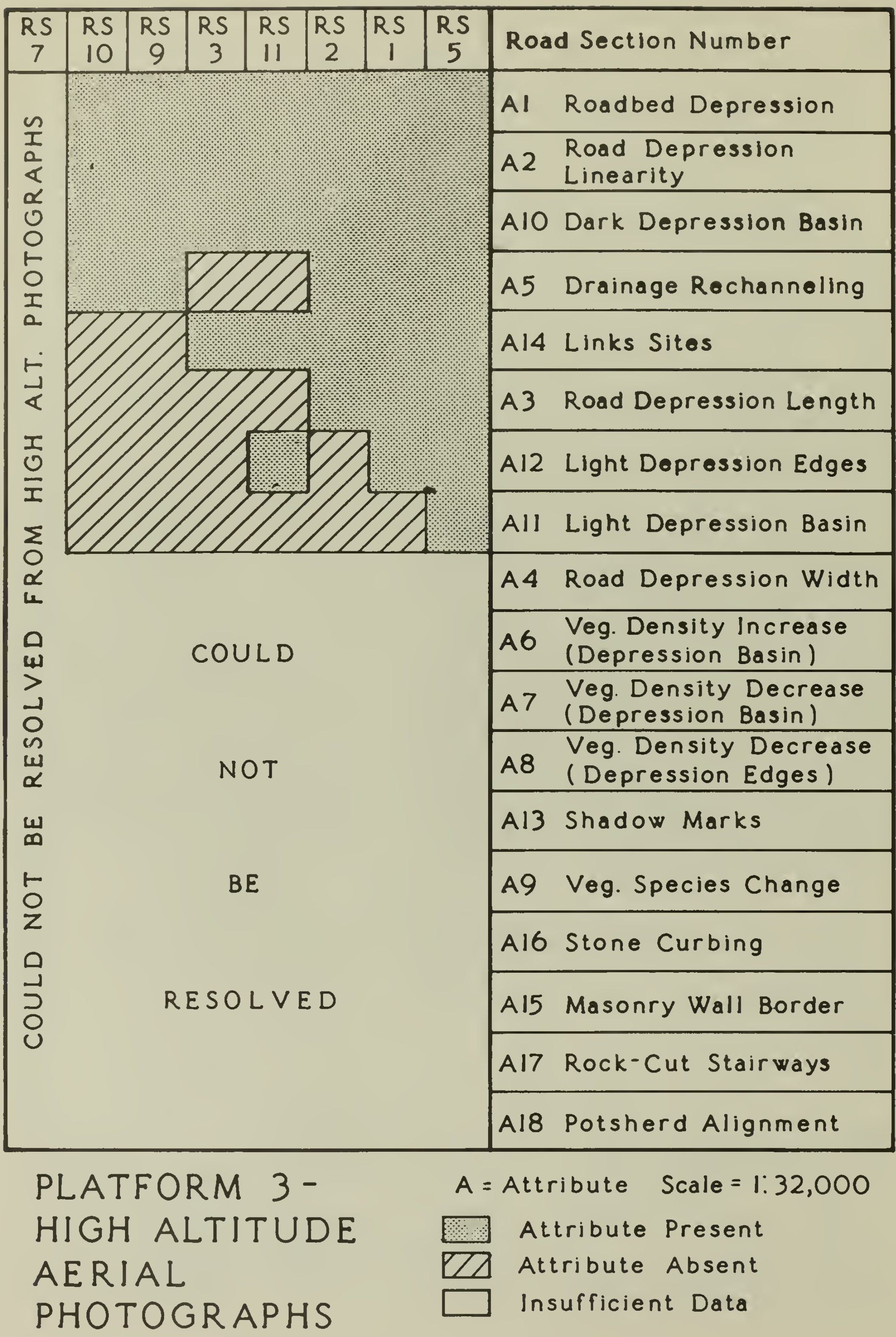

RS 7
RS 10
RS 9
RS 3
RS 11
RS 2
RS 1
RS 5
Road Section Number
A1 Roadbed Depression
A2 Road Depression Linearity
A10 Dark Depression Basin
A5 Drainage Rechanneling
A14 Links Sites
A3 Road Depression Length
A12 Light Depression Edges
A11 Light Depression Basin
A4 Road Depression Width
A6 Veg. Density Increase (Depression Basin)
A7 Veg. Density Decrease (Depression Basin)
A8 Veg. Density Decrease (Depression Edges)
A13 Shadow Marks
A9 Veg. Species Change
A16 Stone Curbing
A15 Masonry Wall Border
A17 Rock-Cut Stairways
A18 Potsherd Alignment
COULD NOT BE RESOLVED FROM HIGH ALT. PHOTOGRAPHS
COULD NOT BE RESOLVED
PLATFORM 3 - HIGH ALTITUDE AERIAL PHOTOGRAPHS
A = Attribute
Scale = 1:32,000
Attribute Present
Attribute Absent
Insufficient Data

FIGURE 45

aerial imagery, ground reconnaissance, and previously unpublished sources on the Chaco Canyon road systems.

These attributes can be grouped into three broad classes of related attributes including: 1) those which pertain to the gross morphological configurations of the road courses; 2) those which are a direct or indirect consequence of alterations in natural drainage patterns; and 3) those which directly relate to cultural features, such as masonry walls, stone curbing, etc. Although this list is by no means comprehensive, we believe it comprises an important first step in defining those features which contribute to the identification of prehistoric land routes. In particular, a number of potentially important attributes which relate to seasonal variations in vegetation patterns were not included in this list due to the difficulty of maintaining adequate controls over these variables.

As indicated in figures 43 through 45, all of the road segments in the Pueblo Alto area are characterized topographically by shallow surface depressions (Attribute 1), averaging 15 meters in width and approximately 0.5 meters in depth. These depressions are characterized by relatively straight, linear courses (Attribute 2). In some instances, roads have been cut through low hills to maintain their linear configuration (Judd, 1954:346). Road depression linearity proved to be particularly valuable in land route recognition since it effectively distinguishes between road depressions and such non-linear topographic features as meandering drainage channels.

A third characteristic attribute of the road segments in the Pueblo Alto area and in the greater Chaco Canyon area is total observable length of each road segment (Attribute 3). For example, two of the more prominent road segments in the Pueblo Alto area (fig. 41, Roads 1 and 2) are of considerable length, originating near the canyon bottom and terminating at points on or beyond the Escavada Wash, several miles north of Pueblo Alto. The very length of the segment indicates its cultural nature. This attribute may be of particular value in distinguishing between "primary" roads and smaller "spur" or branch roads, described by Vivian (1972:10). It can probably be assumed that the primary routes will be of considerably greater length than the spur roads, and thus be distinguished on the basis of total length as well as road base width. Vivian's excavations of prehistoric road sections recorded two types of road base: primary roads averaging 9 meters in width; and secondary roads averaging 4.5 meters in width.

Another consistent characteristic of road segments in the Pueblo Alto road system is the uniform width of their surface depressions (Attribute 4) which generally averages between 8 and 12 meters. The value of this attribute is its use in differentiating between prehistoric road depressions and remnants of historic wagon or auto roads which generally leave a much narrower surface impression.

Many characteristic land route attributes are associated with the rechanneling of surface runoff (Attribute 5). It is immediately apparent from surface and aerial investigations of the Pueblo Alto area that many of the prehistoric road segments north of the pueblo have caused significant alterations in the natural runoff pattern in the local watershed. This situation proved to be a significant factor in road recognition, both from the air and on the ground.

The topography north of Pueblo Alto slopes gently to the north and is drained by a deeply entrenched arroyo which forms the head of Clys Canyon (USGS Topographic Sheet, Pueblo Bonito Quadrangle, New Mexico). Many of the prehistoric roads in the Pueblo Alto system cross this watershed, intercepting and rechanneling many small arroyos and water channels which drain the slopes immediately north of Pueblo Alto. A frequent consequence of this interference with the natural drainage pattern is a rechanneling of water courses down the interior of the road depressions. In several instances following a heavy rain, water was observed in puddles in the interior of the road depressions where natural basins in the roads act as catchments for runoff. In six of the eight road segments investigated, active headward-cutting arroyos were observed following the courses of the prehistoric roads.

Numerous phenomena are associated with this altered drainage situation, but the most important of these from the standpoint of road recognition are the effects on local vegetation patterns. Since the advent of aerial archeology, the effects of subsurface cultural features on surface vegetation patterns have been studied and well-documented. As Deuel (1969:44) so aptly states, "vegetation acts in somewhat the same manner of a chemical developer of exposed photographic plates: it throws up the latent pictures."

There is often a noticeable increase in plant density in the bottoms of prehistoric road depressions (Attribute 6) in instances where runoff has been channeled into the depression basins and allowed to settle into the underlying soil. The inverse of this situation often prevails in instances where active headward-cutting arroyos cut through portions of road segments. Arroyo cutting is often accompanied by a general decrease in the vegetation density in the interior of the road depression (Attribute 7), resulting from the continual downward cutting of the arroyo channel. Another phenomenon closely associated with arroyo formation in road depressions is an increase in the density of certain shrubs, particularly four-wing saltbush (Atriplex canescens), relative to a general decrease in the number of other plant species (Attribute 9). Saltbush tends to favor disturbed or eroding soil, and as such, acts as an effective indicator species for eroding road courses. All of the road segments in the study area which exhibited this type of selective vegetation increase are presently being eroded by headward-cutting arroyos.

From the high altitude aerial platform these diagnostic alterations in vegetation patterns usually are resolved as either dark or light lines. In some instances, a dark line (Attribute 10) on the high altitude platform corresponds to an increase in vegetation density in the road depression basins, and a light line (Attribute 11) corresponds to an eroding section of road in which vegetation density has decreased in response to rapid arroyo cutting.

It is important to note, however, that a one-to-one correspondence for these phenomena cannot always be inferred, since there are a number of other factors which are capable of producing dark and light linear impressions on high altitude imagery. For example, a dark line may result from an increase in plant vigor, rather than a measurable increase in plant density. In fact, we would expect that there would be a heightening of plant vigor in the bottoms of road depression basins as a result of increased absorption of rechanneled rainwater. Dark lines can also be attributed to shadow marks (Attribute 13), and conversely, light linear impressions are often the result of topographic highlights which have no relationship to vegetation patterns, but are instead a function of the angle of incident sunlight and the orientation and surface characteristics of objects on the ground.

Several road segments in the Pueblo Alto system are characterized by a general decrease in vegetation density along the edge of the road depression (Attribute 8). In at least three instances (Road Sections 1, 2, and 11) this attribute appears to be related to various artifacts of road construction, principally stone curbing and masonry wall borders. The large quantity of rock which usually comprises these features tends to inhibit the growth of plants at the margins of the road depressions.

A third class of related ground attributes can best be described as cultural phenomena. These include such road features as stone curbings, masonry walls, various modifications of the bedrock over which the road passes and the propensity for roads to link sites and other prehistoric features.

Perhaps the most consistent of these cultural attributes is a tendency displayed by prehistoric land routes to originate or terminate at other cultural features (Attribute 14). Six of the eight linear depressions investigated during the course of the survey converged at or near the ruin of Pueblo Alto. This characteristic has been attributed to other road systems in Chaco Canyon. According to

Neil Judd's Navajo informants, all of the large ruins in Chaco Canyon were once linked by roads (Judd, 1954). Virtually all traces of these features have subsequently been destroyed by erosion or alluviation in the canyon bottom (Vivian, 1972: 15). Recently, photo-interpretation of early Soil Conservation Service imagery has indicated that a few vestiges of these canyon bottom roads can still be identified (Lyons, 1972, personal communication).

Stone curbing is another common feature present in half of the excavated road depressions (Attribute 16). Curbing varies from several courses of crude masonry to simple mounds of sandstone rubble which appear to have been randomly cast to the side of the road when cleaning the roadbed surface. It became evident during the course of the survey that the more sophisticated form of sandstone masonry curbing was limited to places where roads cross large sandstone bedrock exposures. Most of these features are concentrated to the south of Pueblo Alto on benches overlooking Pueblo Bonito. Here, where large expanses of sandstone slickrock are exposed, the principal function of the masonry curbing appears to have been to delineate the borders of the prehistoric roadway.

To the north of Pueblo Alto where roads are excavated into the valley alluvium, no such formal attributes were recorded. Here, curbing generally take the form of stone rubble mounds along one or both sides of the roadway (figs. 46 and 47). These features appear to be a product of the initial roadbed excavation and perhaps partially the result of roadway maintenance in which loose rocks and other debris were periodically removed from the center of the roadbed and thrown to the side of the road. When rubble borders the road, it is usually on the downslope side, as if the sandstone were placed there to retard erosion.

Rock-cut stairways (Attribute 17) are another common attribute of Chaco roads in instances where land routes encounter topographic obstacles such as canyon scarps or rock ledges. At least two roads (Road Sections 1 and 2) in the Pueblo Alto system descend the steep northern escarpment of Chaco Canyon and incorporate rock-cut stairways at various points along their routes. Vivian (1972:13) has indicated that these features also occur in isolated circumstances and not as part of any definite road system.

The low masonry walls (Attribute 15) which radiate out from the ruin of Pueblo Alto and crisscross much of the study area have been known for years; however, their function has always been obscure. For example, they have been postulated to be water control devices (Vivian, 1970:73-74) and as causeways within the system (Lyons and Hitchcock, this volume). Of a total of five exterior masonry walls observed in the study area (the north wall of Pueblo Alto is considered here as one continuous wall), at least three appear to border

FIGURE 46 - Road section 5, closeup of west curb

FIGURE 47 - Road section 3, closeup of east curb

a prehistoric roadway (fig. 41). One of these apparent road segments was trenched (Road Section 11), but the results were inconclusive. It appears that before any definite statements can be made concerning the relationship between these exterior masonry walls and the Pueblo Alto road system, a more comprehensive series of test excavations will have to be undertaken.

During his 1971 survey of the Chaco Canyon road systems, Buettner (personal communication, 1972) found that prehistoric road courses were often distinguished on the surface by a relatively high concentration of potsherds (Attribute 18). In fact, when all other road features became too vague to follow on the ground, the line of potsherds associated with the road course was often the only indicative feature which could be traced. In the Pueblo Alto system, however, cultural debris in association with the road sections was notably absent. Even upon excavation, few road sections yielded more than a handful of potsherds. A more extensive survey of the Chaco Canyon road network is therefore necessary in order to establish whether or not this is an exception to the rule.

Black and White Imagery

Once the list of road attributes was compiled, we isolated those attributes which were best resolved from each of the three observation platforms, *i.e.*, high altitude, low altitude, and ground-based survey. We expected to find that each platform would be best suited for the resolution of certain kinds of attributes, and this, in fact, proved to be the case. Figures 43 through 45 illustrate these varying capabilities in chart form.

We suggest that the relative value of each of these observation platforms (and, for that matter, any additional platforms which may be available in the future) in terms of data sources for future land route studies depends on the kinds of questions asked and the types of data needed to provide answers to those questions. It is, therefore, essential that future investigations of Chaco land routes be prefaced by thoughtful and systematic research designs which are capable of anticipating the kinds and quality of data required before ground or aerial surveys are initiated.

1) Platform 1 (Ground Survey)

The resolution and overall interpretive capabilities of ground reconnaissance are summarized in figure 43. As is apparent from the table, nearly all of the road attributes selected for use in this study could be effectively resolved from a ground station vantage point. It would be misleading, however, to mistake this capability as particularly advantageous in locating and defining prehistoric road alignments, since the discrimination of most of these attributes at ground level would have been virtually impossible without the aid of aerial imagery.

Data derived from the study of the aerial imagery were used throughout the ground truth survey to locate various road segments on the ground. Once these segments were located and adequately defined on the ground, most attributes were usually distinguishable. Without the aid of remote imagery, however, many of the road segments might never have been found. This is an important consideration when judging the overall value of ground-based survey to land route recognition and interpretation. The primary point to keep in mind is that, even though ground-based survey is capable of resolving most land route attributes, many if not most of these features are much easier to distinguish from an aerial observation platform.

Most land route depressions in the Pueblo Alto study area are of such low profile that surface recognition is extremely difficult except in instances where vegetation or drainage anomalies highlight the road depression. We found one of the best vantage points from which to observe subleties of road profiles was from a position lateral to the road course, and preferably from a vantage point several feet higher than the road. From this position, lateral oblique view of the road course is obtained, and extremely subtle changes in topographic relief are usually discernible. In contrast, by taking a position in the center of the road and looking down the length of the road course, it is often difficult to discern any evidence of a topographic change. As a result, many extremely subtle road depressions were more easily tracked by walking outside and parallel to the road course instead of down the center of the road (see fig. 48).

Other attributes relating to land route morphology, such as road course linearity, depression width, and length can be resolved, but with considerable difficulty from a ground-based survey. If a road depression can be resolved and points near the borders marked, it is not a difficult task to measure the distance between the points and derive an approximate value for the depression width; accurate determination requires excavation. In many instances, however, road depressions do not exhibit distinct borders and, therefore, estimates of road widths may vary considerably.

The determination of road linearity and road length presents altogether different problems for the ground-based investigator. The recognition of these attributes from a ground station vantage point requires rather extensive reconnaissance of each road segment, noting any alterations in land route orientation and recording these on a base map from which the total length of the road course can also eventually be calculated once the points of origin and termination of the feature have been determined. Fortunately, the use of aerial imagery eliminates the necessity for this time-consuming task.

FIGURE 48 - Road section 5 surface depression, before excavation

Recognition of road linearity, width, and length is also, of course, dependent on optimal lighting conditions, especially when there are no other distinguishing attributes present such as vegetation lines and rechanneled arroyo cuts marking the prehistoric road course.

Several important attributes associated with land route alterations of natural drainage patterns are distinguishable from the ground platform. A total of five of the sampled road sections in the Pueblo Alto study area are responsible for various drainage alterations, from the rechanneling of arroyo cuts to the catchment and retainment of local runoff. Many of the local effects of this drainage interference are distinguishable at ground level.

Arroyo channels which have been "captured" by road depressions tend to conform to the linear configuration of the land route within whose boundaries they dissect. These abnormally straight drainage cuts and the dark bands of vegetation which usually line their course are distinguishable on a surface reconnaissance. In other instances, the gradient of the lineal depression is such that runoff is channeled into the roadbed and allowed to settle into the underlying soil. This increased water absorption in road depressions can be visually manifested in several ways: 1) soil comprising the interior of the depression is generally darker than outlying soils due to its increased moisture content; 2) vegetation density would be expected to increase in depression basins in response to this increased moisture content; and 3) a heightening of plant vigor would be anticipated for plants benefiting from the soil moisture content of lineal depressions. It would also be expected, of course, that all of these conditions would be seasonally variable and would be more readily apparent during or immediately following the moist months of late July, August, and early September.

The subtle changes in vegetation patterns and soil coloration characteristic of most road segments, however, are often difficult to distinguish from a ground station vantage point. The ground investigator is often too close to the subject to immediately distinguish these subtleties of vegetation and soil coloration. Often, when slight variation in vegetation patterns or soil coloration are observed on a ground-based survey, the actual extent or degree of the variation is difficult to objectively evaluate. The result is often simply a subjective impression which contributes little to the establishment of reliable ground-based land route recognition patterns.

On the other hand, ground survey is often vital to aerial imagery interpretation when resolution factors do not permit the discrimination of small scale phenomena from an aerial observation platform. It would perhaps be beneficial, in this respect, to establish some quantitative means of measuring relative vegetation densities and subtle changes in soil coloration and moisture content, but such techniques would undoubtedly involve a considerable expenditure of time where comparable results could probably be obtained from examination of low altitude aerial photographs.

The greatest advantage of a ground station vantage point lies in its ability to resolve small scale or extremely low profile road attributes which cannot always be identified from an aerial platform. Potsherd alignment and rock-cut stairways or "hand and toe holds" are examples of small scale features which are usually beyond the resolution capabilities of aerial platforms.

In reviewing the data in fig. 43, some correlations between various road attributes are immediately apparent. In two instances, for example (Road Sections 2 and 7), the presence of stone rubble curbing corresponds with a decrease in vegetation density on the borders of the road depression. This situation would, of course, be anticipated since concentrations of rock or gravel tend to inhibit plant growth and hence should decrease vegetation density. In two instances where stone rubble curbing did not effect a corresponding decrease in vegetation density (Road Sections 3 and 5), stone rubble was not present in sufficient quantities to act as effective growth inhibitors. In both of these cases, stone curbing was distinguishable only after excavation of the road depression.

Masonry walls bordering road courses (Road Sections 1, 2, and 11) have a similar inhibitory effect on plant growth, and these features are often resolved as distinct light lines on aerial imagery. Other land route attribute correlations can easily be inferred from the table.

A second class of road attributes which we found could not be adequately resolved from aerial observation platforms includes certain low-profile features such as exterior masonry wall and various forms of roadside curbing. Although these features can often be distinguished as light linear impressions on aerial imagery, positive identification and adequate interpretation usually requires a ground truth check.

Surface reconnaissance is, therefore, the only means of gathering data on land route attributes which cannot be adequately resolved from an aerial observation platform. Certain road attributes are simply too small to be registered on standard aerial photographs. Other relatively large road features are of such low surface relief that their aerial resolution often depends on extremely favorable lighting conditions.

The principal disadvantage of ground-based survey for recording data relevant to so large a subject as prehistoric roadways is that it places the investigator too close to the subject. It is somewhat analogous to viewing a painting two inches away from the canvas; the investigator becomes trapped by the particulars. We do not mean to imply, however, that ground reconnaissance will not be an important aspect of future land route studies. Ground truth surveys will continue to be necessary until adequate land route aerial recognition patterns have been established in order to monitor the validity of aerial interpretations. Ground studies will also continue to be important in providing data on small land route features which cannot be resolved from an aerial platform.

2) Platform 2 (Low Altitude)

A summary of low altitude resolution capabilities based on available panchromatic aerial imagery is presented in figure 44. Unfortunately, low altitude data was compiled for only seven road sections in the Pueblo Alto system. Road Section 11 is not covered by the low altitude black and white photographs (1971) and resolution obtained from the true color imagery was considered inadequate for comparative analysis.

The interpretation of the low altitude imagery was, at times, severely hampered by the poor quality of the photographs. The black and white photographs lacked sufficient overall contrast to highlight a number of important ground features. The resulting "flat" images exhibit little or no shadow and highlight illumination of topographic anomalies and, therefore, optimal resolution conditions were not obtained and low altitude interpretive capabilities were restricted.

In spite of these interpretive limitations, however, the low altitude observation platform proved to be well suited for general land route investigations. This is due to the vertical position of the platform; it is low enough to resolve small scale ground phenomena, yet high enough to detect the general patterns of land route configuration.

Low altitude imagery which proved to be especially amenable to stereoscopic viewing was extremely valuable in distinguishing low profile ground phenomena. For example, road depressions, visually indistinguishable from a ground vantage point, were generally easy to discern from the low altitude imagery with the aid of a stereo viewer because of its vertical exaggeration. In addition to distinguishing road depressions, the stereo viewer facilitates the resolution of other attributes, including road depression width, masonry walls, and various alterations in drainage patterns. In each of these cases, a slight to moderate alteration in surface relief is associated with the attribute. These subtle changes in topographic relief are registered under the stereo viewer as abrupt changes in vertical relief. Thus, distinct road depression edges are generally discernible under the stereo viewer, and relative road widths can therefore be resolved. Exterior masonry walls generally appear as light lines of positive relief; arroyo channels are registered in exaggerated negative relief. Other attributes, such as linearity and length, are not enhanced by the stereo effect.

Low altitude imagery, with or without stereoscopic perspective, provides the most suitable platform for the discrimination of attributes related to drainage alterations, including changes in vegetation density, selective species change, and so on. In this respect, low altitude imagery is a potentially important investigative tool for studies relating to sub-environmental problems, especially changes in the desert ecosystem as a result of various types of prehistoric and modern landscape modifications.

Individual plants are easily distinguished on the low altitude imagery, and their distribution can be plotted in order to determine relative plant density patterns. We were able to distinguish from low altitude platform imagery six road segments which exhibited increased floral density patterns, two more than could be distinguished on the ground-based survey.

Variations in the distribution of various plant species can also be resolved from the low altitude observation platform. For example, fourwing saltbush, an important indicator species of eroding road courses, is easily distinguished by its dark foliage. Five of the excavated road sections exhibited increases in saltbush concentration, and all five of these road courses are presently being cut by arroyo channels.

A total of five attributes (13, 15, 16, 17, and 18) could not be distinguished from the low altitude platform. Of these, three (stone curbing, rock-cut stairways, and potsherd alignments) are too small to be adequately resolved from an aerial platform. No masonry wall borders were present in the area encompassed by the low altitude black and white aerial coverage; therefore, these features were not recorded. Similarly, shadow marks were notably absent on the low altitude imagery.

Imagery derived from the low altitude observation platform is capable of resolving many small scale ground phenomena which contribute to land route recognition patterns and, at the same time, discern large scale patterns in land route configuration. In this respect, Platform 2 essentially combines the best interpretive capabilities of both ground and high altitude observation platforms. Low altitude imagery discerns small scale ground phenomena which are perhaps best resolved from a ground station vantage point, yet it is not plagued with the degree of recognition interference which makes ground survey at times so impractical. Low altitude imagery, then, retains the ability to distinguish those attributes which contribute to the overall recognition pattern of each road segment.

It will be necessary for future low altitude investigations to take into account meteorological variables which affect image resolution. With imagery of better resolution at the low altitude platform, we may expect to considerably refine the recognition pattern represented in figure 44.

3) Platform 3 (High Altitude)

Data derived from the high altitude 1:32,000 scale aerial imagery is presented in figure 45. Attributes were compiled for seven road sections in the Pueblo Alto area; Road Section 7 could not be adequately resolved on the available high altitude imagery.

Three attributes, including roadbed depression, road course linearity, and dark depression basin, were recorded for all of the excavated road segments from the high altitude platform. Fairly distinct road depressions could be discerned on the high altitude imagery with the aid of a stereo viewer. The clarity of these depressions varied, however, depending on variables which are still undefined. Under the stereo viewer, various sections of road courses exhibited well-defined surface depressions, while for other equally visible sections, no evidence of a depression or other topographic anomaly could be discerned. The reason for these inconsistencies in high altitude stereo resolution remains unclear, but they are probably related to image scale and the decrease in photo resolution at high altitude.

All of the road segments displayed dark depressions, indicating the presence of various attributes or attribute combinations operating beyond the resolution capabilities of the high altitude platform. Several attributes, including differential vegetation patterns (increased floral densities) and shadow marks, can account for these dark linear depressions.

Attributes relating to land route configuration patterns, such as road course linearity and length, were particularly easy to discern from the high altitude platform. The recognition of these large scale attributes benefits from the broad aerial coverage of the high altitude photographs. This aerial coverage also assists in discerning relationships between individual roads, road systems, and large Chacoan town sites.

Other attributes within the resolution capability of high altitude imagery include various drainage alterations associated with the prehistoric road cuts (arroyo channels are easily resolved on high altitude imagery with the aid of the stereo viewer), and light depression basins and edges generally associated with recent erosional activity in the interior of the road depressions.

As indicated in figure 45, the majority of road attributes could not be distinguished at high altitude. Most of these features are simply too small to be adequately resolved on high altitude imagery, although in many cases their presence may be inferred by discrete tonal shifts on the black and white image. For example, a dark lineament on high altitude imagery could be attributed either to an increase in vegetation density in the depression or to a shadow. These attributes do, in fact, correlate on the high and low altitude imagery.

High altitude platforms afford the best vantage point from which to record large scale attributes of prehistoric land routes, such as road depression linearity, road length, and relationships between various road segments. A general reconnaissance of road systems and their relationships to each other and to the large Chacoan town sites would undoubtedly derive most of the initial data from a high altitude reconnaissance.

On the other hand, high altitude imagery is not capable of resolving small scale ground phenomena, but rather, records the cumulative effects of these small scale attributes as various shades of gray on the photographic print. The visual perspective afforded by high altitude photographs is somewhat analogous to viewing a painting from across a long hall: the artist's plan and artistic design are readily discerned from a distance, but the type of paint or the sizes of brushes he used to create the image are much more difficult to discern from the distance necessary for the resolution of the central image. Similarly, high altitude imagery resolves large scale patterns of road configuration but does not yield data concerning the particulars of road construction.

True Color Imagery

In an attempt to determine the differences in resolution capabilities between color and black and white imagery, a systematic comparison of the two film types was made. True color film depicts images as the human eye perceives them and not simply as a series of gray tones, thus adding several perceptive dimensions to panchromatic film. Unfortunately, in order to distinguish those variations in aerial resolution which are attributable to the color as opposed to the panchromatic image, it is necessary to isolate and control a number of variables of aerial resolution which are not directly related to differences in photographic emulsion types.

The lack of control of some non-photographic variables, such as time of day and seasonality, which affect aerial resolution make a comparison of the relative resolution capabilities of panchromatic as opposed to color imagery invalid at this point. Nevertheless, certain statements concerning color film may be made.

According to Gumerman and Lyons (1971:128), "the advantage of color photography in the Southwest test area seems to lie more in the recording of natural rather than the cultural landscape." The value of color imagery in detecting variations in soil types is obvious on the color photographs of the Pueblo Alto study area. For example, areas of recent aeolian dune deposition are readily apparent owing to a sharp shift in color from the pinkish windblown sand to brown sand alluvium which comprises most of the valley floor. In several cases portions of road segments are covered by small sand dunes which obliterate all surface evidence of the road depression. This is the case immediately north of the gate in the north wall of Pueblo Alto where at least three prehistoric roads converge.

There is the obvious fact, of course, that photo interpreters are accustomed to identifying features by color as well as by shape and form. An archeologist trained to recognize features by morphological characteristics also associates color with a feature. As a result, color gives him one additional parameter on which to base his judgement. Whether this additional factor is worth the expense on prehistoric road studies is doubtful.

Multispectral Imagery

A multiband camera takes photographs of a single target simultaneously in several bands of the spectrum. It provides a variety of lenses, filter and film combinations, each designed to obtain a maximum amount of information from a particular portion of the spectrum. The resulting negative can be viewed in a single composite color additive presentation. The basic concept is that a color composite image can be produced when one projects positive photographic transparencies which are: 1) taken in different parts of the spectrum; 2) projected through different types of filters; and 3) superimposed on one another. For purposes of our experiment, we hoped to be able to determine what parts of the spectrum and what added color combinations delineated the roads most accurately.

The multispectral photographs of the Pueblo Alto study area were taken by a cluster of four Hasselblad 500 EL cameras, each photographing different parts of the spectrum. The photographs were viewed through an I^2S color additive viewer.

The results were that no roads were visible with any combination of colors we used. Even at the highest illumination of the projector, the transparencies appeared too dense. Recent experiments with multispectral photography indicate that the photographs should be slightly overexposed and developed with as great a contrast as possible in order to be used in a color additive viewer (Lepley, 1972, personal communication). Our multispectral imagery did not have these characteristics.

Although this experiment was not a success, we suggest that multispectral photography may still be one of the best types of imagery for delineating prehistoric roadways because different spectral bands have been demonstrated to be capable of isolating different cultural and natural phenomena.

Isodensitometer Studies

An Isodensitometer will produce colored contours from gray tones in a transparency, i.e., it produces colored isolines of density so that the product is a quantitative measurement of density variations in a photograph. Different gray tones are converted into digitized color contours.

The purpose of this experiment was to determine if tonal variations could be detected which would isolate the roads as different colors from the surrounding areas. If successful, the roads could be isolated with little difficulty with an isodensitometer.

Again, this experiment proved unsuccessful in isolating roads. Several sections of the major roads were visible using the isodensitometer; however, they were easier to distinguish on the black and white transparency itself.

We feel that our lack of success does not mean the use of the isodensitometer has little value in studies of prehistoric road systems. The isodensitometer available to us was a Data Color 704, a relatively inexpensive and unsophisticated device. Newer machines with a much greater resolution capability are now becoming available and we suggest that these machines be applied to the road system problem in the future. It is a simple procedure which might produce startling results.

Excavation

As stated above, the purpose of the test excavations was two-fold: to determine the nature of the prehistoric road remains; and to isolate those variables which most directly influence aerial and surface resolution of the road system.

Unfortunately, the results of the excavations were inconclusive. This is due in part to a paucity of diagnostic features exhibited by the road segments tested. Actual roadbeds were extremely difficult to define in almost every case. Road Section 2, which is partially chipped out of shallow bedrock, was the only road segment north of Pueblo Alto which displayed a well-defined road base. The remaining roadbeds displayed little if any evidence of intentional preparation.

In all but two of the road sections tested (Road Sections 2 and 5), excavations revealed a hard, irregular surface of tan "calichified" sand at an average depth of 30 to 50 cm. below present ground surface. A comparable caliche surface was encountered in a test pit 1-meter square which was excavated several meters west of Road Section 2, outside any distinguishable prehistoric road depression. Below this caliche layer, the soil is extremely well-consolidated and almost impenetratable with hand tools.

The indication here is that formal preparation of the road surface was the exception rather than the rule in the land route segments which converge on Pueblo Alto. The absence of prepared road surfaces suggests that most of the roadbeds were excavated to a hard, well-consolidated natural surface, beyond which excavation was extremely difficult. This natural surface served as the road base with little if any formal preparation. If formal attributes are present, they usually take the form of some variety of stone or rubble curbing at the edges of the road excavation. Four, or just over half, of the road segments tested exhibited some form of stone curbing, either coursed masonry (Road Sections 1, 2, and 6) or sandstone rubble (Road Sections 2, 3, and 5).

Rubble curbing, however, is not a formal attribute in the strict sense of the word since the presence or absence of this feature seems to be entirely dependent on the type of terrain over which the road passes. All the road segments which exhibit stone rubble curbing have been excavated through a thin crust of surface alluvium down to a crumbly sandstone bedrock surface. Where roads are footed in deeper soil, the road excavation usually terminates at the natural caliche layer, and unless loose rock was removed from the center of the roadway during excavation, no attempt at maintaining a formal road curbing was made.

The best example of sandstone rubble curbing was observed in Road Section 2, at a point approximately 30 meters north of the northwest corner of Pueblo Alto (fig. 49). Low mounds of sandstone pebbles and spalls line both sides of the roadbed, approximately 8 meters apart. Near the center of the road is a shallow depression, 4.5 m. in width and averaging 5 to 10 cm. in depth, which terminates at sandstone bedrock. The bedrock exposed in the bottom of the roadbed is extremely crumbly and small fragments were continually dislodged as a result of vigorous sweeping with a broom. The sandstone rubble lining the road section is probably the product of frequent roadway maintenance designed to remove the loose rock and other debris which was continuously churned up from the bedrock base as a result of foot travel. Sandstone rubble curbing was also recorded for Road Sections 5 and 3 (figs. 46 and 47).

Several sandstone rubble mounds were found peripheral to Road

FIGURE 49 - Test trench through road section 3, note rubble at edges of road bed

Section 7. These differ from other forms of rubble curbing in that they are discontinuous, isolated mounds of rubble and soil rather than linear concentrations of sandstone rubble. A trench through Road Section 7 cut portions of two of these rubble mounds; their interior matrix consisted of small sandstone chunks mixed with sand. A few potsherds and flecks of charcoal were also noted.

Unfortunately, no positive roadbed was found in the trench through Road Section 7. The precise relationship between these rubble mounds and the prehistoric roadbed was, therefore, not determined, although these may have been products of roadway maintenance or construction.

Excavation at the north wall of Pueblo Alto exposed a section of masonry at a point where at least three prehistoric land routes appear to converge from the north (fig. 41). Prior to excavation, a slight dip or depression was noted in the wall approximately 40 meters east of the northeast corner of Pueblo Alto. Aerial photographs were consulted and the low point in the wall was found to correspond with the point of the road convergence. As mentioned earlier, a test trench was excavated along the north face of the wall, exposing 18 meters of masonry facing; 3.5 meters were exposed on the south face of the wall. Excavation revealed an opening or gate in the north wall, measuring one meter in width (fig. 42).

The wall is composed of various sizes and shapes of unmodified yellowish sandstone blocks set in copious amounts of brown clay mortar; the interior of the wall is filled with large amounts of soil and sandstone rubble. Its average thickness at the gate is 1.4 meters. The original height of the wall at the gate is difficult to estimate since a number of masonry courses have collapsed at the opening. The maximum height of masonry in better preserved sections of the wall, however, is just over one meter. The large quantity of fallen wall debris removed during excavation suggests an original height of at least 0.5 meters above that which is presently preserved.

The gate is surprisingly narrow considering the width and number of roads which apparently meet at this section of the wall. The opening at the north face of the wall is slightly narrower (0.95 m.) than at the south face (1.05 m.). This difference is assumed to be accidental and a result of the relatively poor quality of construction of the masonry wall.

Following the excavation of the gate, the trench along the north face of the wall was expanded an additional two meters from the gate in order to expose any evidence of a roadbed leading to it. The excavation revealed a hard-packed caliche surface which slopes sharply down to the north, away from the gate. No evidence of a prepared road surface was found.

In order to establish the relationship between the opening in the north wall and the various road sections which converge on this point, it will be necessary in the future to trench the area immediately north of the gate. We feel that several long trenches constructed parallel to the wall several meters north of the gate would enable the archeologist to determine the relationships among a number of converging roads. This would also be an ideal location for establishing whether or not there is any super-positioning of roadbeds as a means of determining relative road building sequences.

PART IV: CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

The remote sensing investigation of the Pueblo Alto land route system can be judged successful if viewed as a means of determining how to proceed with the overall mapping and study of this immense and yet difficult to discern network of prehistoric land routes.

There is no doubt that the best way to find and map the road network is with aerial imagery. When this project is undertaken, it will be necessary to consider seasonal and meteorological variables as well as photographic variables.

It will be necessary to have optimum lighting conditions. The early morning or perhaps late afternoon sun is best when the sun is 5 to 15 degrees above the horizon. There should be a clear sky with no clouds or haze to interfere with shadow marks. The air should be calm as high winds tend to suspend dust which affects resolution capabilities.

Three specific times of year appear to be optimum for obtaining imagery in this arid region. In late summer, the vegetation patterns would be strengthened a few days after the first summer rains. In spring, if there is any precipitation, the results of photography should be comparable to late summer. In winter when light snow covers the ground, road segments might be very distinct. The best snow would be a light flurry in which snow is blown and remains to one side in the road depression, highlighting the road course.

Control of the photographic variables will be essential at this stage of the study. If imagery is to be obtained in the future, we strongly suggest panchromatic film as the standard. If the object is to follow and define the road system rather than individual attributes, the best scale would be between 1:12,000 and 1:32,000. This scale permits easy identification, but reduces the number of photographs that must be handled in the field - an important factor.

We suggest there be strict controls in exposure, development and printing operations to ensure the sharpest possible image and greatest possible resolution. High contrast film and paper should be used to bring out subtle differences in the imagery.

Oblique as well as vertical imagery should be taken and analyzed. Oblique photographs of the study area may reveal road sections which show up only very indistinctly or not at all from a vertical position.

If funding permits, imagery of different types should be collected. Color infrared film might detect differences in plant vigor, thereby delineating the roads. More sophisticated isodensitometer studies should be carried out and better quality multispectral photographs taken and analyzed.

A most valuable experiment could perhaps be undertaken with a helicopter. Road segments could be followed and crews set down to mark them. Several thousand dollars spent in helicopter time could save a crew several months field checking photographs on the ground. The helicopter has often been glamorized or its potential worth to the archeologist overstressed, yet in attempting to locate road systems, it might prove to be an invaluable aid.

To understand the road system, more emphasis will have to be placed on excavation. We suggest that some road section be excavated with test trenches considerably wider than one meter so that the true character of the roadbed and curbings can be seen.

Finally, if the character and function of the Chaco road system is to be understood <u>as a system</u> within a cultural matrix, the roads have to be mapped in as great detail as possible and in relationship to one another and to sites. Hopefully this report will serve as a suggestion for carrying out such a systematic study and will encourage archeologists to proceed with systematic and holistic studies of prehistoric land route systems.

We hope this paper can provide the archeologist with a better understanding of how to utilize aerial photographs of different scales for understanding large prehistoric features. Aerial photography is unique in the potential it offers in understanding the relationships of sites or regions that are part of a network by virtue of connecting road systems. canals, or walls. Aerial photography has many functions, but its aid in understanding the relationship of site to site, or area to area, might be one of the most valuable, because networks of this type are the most difficult to delineate from a surface survey.

Southern Illinois University

LITERATURE CITED

Deuel, Leo
1969 Flights into Yesterday: The Story of Aerial Archaeology. New York: St. Martin's Press.

Gumerman, George J. and Thomas R. Lyons
1971 Archaeological Methodology and Remote Sensing. Science 172:126-132.

Judd, Neil M.
1954 The Material Culture of Pueblo Bonito. Smithsonian Miscellaneous Collections, Vol. 124. Washington, D.C.: Smithsonian Institution.

Vivian, R. Gwinn
1970 An Inquiry Into Prehistoric Social Organization in Chaco Canyon, New Mexico. In Reconstructing Prehistoric Pueblo Societies, William A. Longacre, ed. Albuquerque: University of New Mexico Press.

1972 Prehistoric Water Conservation in Chaco Canyon. Final Technical Letter Report for NSF Grant No. GS-3100.

REMOTE SENSING WITHIN AN ARCHEOLOGICAL RESEARCH FRAMEWORK: METHODS, ECONOMICS, AND THEORY

BY

JAMES I. EBERT

PART I: INTRODUCTION

The utility of remote sensing in the preliminary and observational phases of anthropological and archeological research has long been acknowledged (Deuel, 1969; St. Joseph, 1951; Gumerman and Lyons 1971; Gumerman, 1971). Nonetheless, practicing researchers in these fields often discount its value to their personal projects. Some feel that such data are inapplicable to their work, or at least of insufficient use to warrant the trouble. Others express the vague feeling that remote sensor data, in particular aerial photography, are difficult and expensive to obtain. Still others, while convinced of aerial data's applicability and aware of its existence, fear the seemingly complex techniques and instrumentation necessary for its analysis. Most of the papers in this volume attack the former objection - that of application. It will hopefully be shown that aerial remote sensing can also be a valuable analytical tool in problem-oriented social research involving assessments of the relationships between people and the space they occupy. The purpose of this paper is to confront the latter objection, the economic and physical intricacies of remote sensor data acquisition and use.

PART II: THE PLACE OF REMOTE SENSOR DATA IN ARCHEOLOGY

Remote sensing is a unique method of simultaneous collection of many categories of data, the nature of which are not automatically apparent at first inspection. Observations from the archeological record are the consequence of unseen and probably unseeable processes and causal forces which are in turn the real object of study. Such data, then, must be tied into the total research design through arguments of relevance to both higher theory and to conceptually "lower" test implications.

There are two major junctures in the process of doing science at which remote sensor data have a potentially important role. One of these is simple inductive observation, the "bouncing" of simple observations against the researcher's broad expectations or belief in the nature of the world. If, during such a process, expectations about what should be found in the real world are met, little has been gained - but more often than not inconsistencies between paradigmatic beliefs and reality appear. Such inconsistencies require explanations, and form the core of scientific problem formation. It is primarily in this context that remote sensing has been utilized in past social research.

Science is only partly concerned with discovery, however. Once inconsistencies between the way things are expected to work and how they do operate are pointed out, the existence of processes additional to or divergent from those originally assumed to govern the phenomena observed must be proposed. The interpretation of remote sensor imagery can provide a linkage between theory on one hand and data on the other.

The Electromagnetic Spectrum

Remote sensing refers to the monitoring of any of the properties of an object or situation from a remote vantage. The class of data which lends itself most obviously to remote sensing is electromagnetic radiation. All materials at temperatures above absolute zero produce electromagnetic radiation in the form of waves or particles. The electromagnetic spectrum is a continuum of natural (passive) and induced (active) radiation in wavelengths varying from fractions of a millimeter to several kilometers. The methods of remote data collection useful to the archeologist are primarily those which produce a visual or graphic representation of electromagnetic radiation reflected or emitted from the earth's surface.

The methods of remote monitoring of electromagnetic radiation are limited by the technology which permits its conversion into the narrow band of radiation visible to the unaided human eye. There is at present no single sensing device which can span more than a small part of the electromagnetic spectrum, nor is such a device likely to appear in the near future.

Commonly used or promising techniques for the remote collection of electromagnetic data include microwave, radar, and a wide range of photographic techniques. Mechanical scanning, a technique which continuously samples radiation through the use of a bank of electric sensors upon which sections of the total image are successively focused, also holds promise for geographically-oriented research.

Radar and microwave remote sensing, still relatively unrefined since their conception as a defensive technique during World War II, utilize a portion of the electromagnetic spectrum approximately one centimeter to three meters in wavelength. Both of these sensing methods employ the transmission of radiation from an aerially mounted source and the subsequent reception of reflected signals. Electrical impulses are then "translated" into a visible image on either a cathode-ray tube (in the case of plan-positive radar) or onto photographic paper for a more permanent record (side-looking airborne radar). Stereoscopic configuration is not possible given the configuration of contemporary radar apparatus.

Radar and microwave, although unwieldy and not commonly available to archeologists, exhibit unique capabilities which may be of future value. Their lower-than-light frequencies are unaffected by haze, clouds, snow cover and vegetative growth; hence, information on terrain obscured or below the Earth's surface can be recorded. Radar is sensitive to variations in the temperature, moisture content and chemical composition of the surface from which signals are reflected, and these properties may aid in the generation of additional and possibly pertinent data. It has also been suggested that radar can be useful in distinguishing variations in texture of surface material down to the size of one-half the wavelength used, or approximately one-quarter inch (Avery, 1962).

Sequential scanning devices which detect radiation of natural origin are currently being practically exploited by some remote sensing projects, primarily in agriculture and pollution control. The data yielded by such instruments is of a coarse-grained nature compared to regular photographs; it is, however, valuable in the recognition of patterns of land use and geomorphology. Utilizing a small number of delicate sensors, scanning devices can detect slight differences in the "spectral signatures" of objects or features on the ground. By comparing such signatures determined experimentally on the ground with aerially-obtained data, discrimination can be made between different vegetative covers, water temperature, and other gross environmental variables. Scanner output is coded in the form of a sequence of scalar image intensity values, and as such is directly suitable to computer analyses, mapping and manipulation. These techniques have been used to great advantage in the interpretation of modern agricultural patterns and the spread of plant diseases (LARS, 1970).

Photography

Although photography is an old and relatively simple technique, it provides the most easily available, economical, and probably the most widely useful remote sensing data source for the archeologist. The basic instrument of photography is the camera, which focuses reflected or emitted light on a sensitive emulsion which is chemically altered to produce a negative. Positive prints, either on a transparent or paper base, can be produced from a negative. Both negative and positive images have utility in remote sensing.

Films are one of the most variable and confusing components of the photographic process. Film is usually composed of a thin acetate or polyester strip which has been coated with light-sensitive emulsion; the properties of the emulsion vary in several dimensions. "Speed" or sensitivity to intensity of light is one of these, and is usually measured in relative units rated by the American Standards Association (ASA index). Films with a higher ASA number are more sensitive to light, and are useful in situations of low illumination. Emulsions also vary in sensitivity to different wavelengths of the electromagnetic spectrum. Such variation affects the intensity of the image created in black-and-white films and both image density and color in color films. The spectral sensitivity registered by emulsions can be further manipulated through the use of filters, which attenuate certain portions of the electromagnetic spectrum that would have otherwise reached the camera lens.

Aerial Photography

Aerial photographs are taken with sophisticated and precise cameras designed specifically for the production of undistorted, high resolution negatives in large format. Photos taken both at an angle perpendicular to the ground (vertical) and those taken at an acute angle (oblique) are useful in remote sensing, although certain properties of vertical photos make them easier to use. Vertical photos are usually exposed along a straight flight path; the camera's shutter is triggered by a mechanism coupled to an airspeed indicator to assure that each exposure overlaps the next by about 60 percent for reasons discussed below.

Most aerial cameras in use today produce negatives measuring nine by nine inches, although a 9" x 14" format is employed by some government agencies and color transparencies are often taken on 70 mm film. Multispectral cameras, usually a gang of unit-mounted cameras differing in the filters affixed to their lenses, commonly expose either four or nine small frames on a standard 9" x 9" film.

Aerial cameras are constructed to provide necessary data pertaining to the conditions under which each negative is exposed, called ephemeris data, directly on the negative itself. Aerial photographs from modern cameras usually contain some or all of the following data:

FIDUCIAL MARKS	indicate the center of each side of the negative; useful in finding image center.

FRAME NUMBER

FLIGHT LINE DESIGNATION

PHOTOGRAPHIC DATA	f-stop, exposure time, film type

SCALE OF IMAGE

DATE and TIME

LENS DATA

Although the placement and form of these data are variable, they must either exist on the negative or be recorded elsewhere before photogrammetric methods can be applied to imagery. Many suppliers of aerial imagery, for example the United State Geological Survey, maintain a collection of ephemeris data separately from the image itself. Requests for full ephemeris data should always accompany orders for imagery.

The vantage from which remote sensor imagery is exposed is referred to as a platform. The earliest aerial photographic platform was a balloon in France in 1856. Since that time, cameras have been carried aloft in many different ways. Although a wide variety of lighter-than-air platforms were pioneered for military reconnaissance, it was not until the advent of the airplane that aerial platforms were put to anthropological use (Rowe, 1953). Most present-day aerial archeology relies on aircraft-borne sensing devices, although low-altitude balloons and elaborate tripods and bipods have been designed and recommended for photography and subsequent mapping of detail on archeological sites.

Satellites have, in the last several years, provided a space platform for the gathering of remote sensor for the earth sciences recently. At present, the resolution provided by radio-transmitted imagery from unmanned space platforms allows the identification of only those cultural features larger than about 300 x 300 meters, ruling out all but the largest structures or features. Recent Skylab imagery, taken under the supervision of orbiting astronauts with high-resolution film and cameras, reveals modern cultural features more clearly. Imagery taken from satellite platforms is of obvious value in delimiting independent variables such as vegetation and water resources, however.

Determination of the ideal platform, like all other aspects of any research strategy, must be geared to the problem at hand. While geologists efficiently employ extremely high altitude and consequently small-scale imagery, most conventional archeological research requires photos of a scale below 1:40,000. Experiments in the identification of prehistoric roadways and other cultural features in the Chaco Canyon region of northwestern New Mexico suggest that imagery of varied scales can serve as data sources at different stages of problem-oriented research. These experiments, carried out by the Remote Sensing Project at the Chaco Center, a National Park Service office in Albuquerque, will be discussed at length later in this paper.

Film Processing

Most firms that fly aerial imagery also maintain their own film processing facilities or contracts with a lab that does such work. The researcher should realize that each photographic transformation (negative to positive, positive to negative) results in a degradation in image quality due to cumulative optical and chemical aberrations. "First generation" imagery, usually original negatives in photo print processes, are sharper than "second generation" prints made from them. It follows, of course, that succeeding generations of imagery will be progressively less sharp and less useful in terms of image discrimination.

In many cases, the risk of destroying original negatives prevents their use in practical research, especially in the field. Government agencies, including the U.S. Geological Survey (USGS) and NASA, produce duplicate negatives (from which prints ordered by individuals are reproduced) and store the originals permanently, safe from scratches and mishap.

Many imagery types which are suitable for some uses are not useful for others; in this case successive generations of imagery may be reproduced on various types of film. For example, color transparency imagery - far more useful in the laboratory for image discrimination of many types than black-and-white print imagery - may be reproduced using wide-latitude b/w film and printed in black and white for use in the field. Choice of reproductive films is as important as choice of primary films in such situations, and the multi-generational product may bear little resemblance to a first-generation image in terms of quality resolving power and edge definition, even in the same photographic medium.

Imagery Handling and Storage

Whether remote sensor data is simply employed as an observational aid or functions as a link in a longer chain of analytical reasoning, proper data handling and technical facilities can multiply its value many times. Although an exhaustive discussion of remote sensor data handling is outside the scope of this paper, many of the references listed here contain information useful to the archeologist.

Most modern films and papers employed in the rendering of of aerial imagery are non-flammable and stable over time, unlike some older photo negatives and prints. Archival-quality fixing of prints should be specified when available for personally-contracted aerial photography. In the laboratory, film and prints should be carefully handled. Rolled film can be stored in the airtight plastic or metal tubes in which it is packed, while flat negatives or transparencies should lie flat in celluloid folders or between sheets of high quality bond paper.

PART III: VIEWING AND INTERPRETIVE TOOLS AND PROCESSES

There comes a time when the archeologist will finally want to "get down to earth" via the agency of aerial remote sensor imagery. By far the most common use of aerial photography in archeology in the past has been the technically unaided viewing of oblique shots. This requires no equipment and can be useful as a first observational step in the pursuance of any archeological question. A hand magnifier may be useful in bringing out detail.

The technique of stereoscopy adds another dimension to the interpretation of aerial imagery. Operating on the same principle as human vision, the stereoscope provides a means for the superimposition of a stereo pair of photos taken sequentially along a flight line. The resultant illusion of vertical depth facilitates the differentiation of features having such a dimension on the ground.

Stereoscopic viewing, while a valuable aid in the inductive stages of archeological inquiry, is not an analytical tool in the strict theoretical sense of the word. The burden of observational confidence rests solely with the interpreter, who must make the selection of which aspects of archeological or any other class of evidence visible on the image are significant. "Significance", of course, varies directly with the immediate context, or problem, in which interpretation is undertaken.

Photogrammetry

Fortunately for the deductive enterprise of science, methods have been developed for the derivation of analytical data (in many cases scalar in nature) from photographic imagery over and above that extracted by the interpreter. Perhaps the most significant of these methods is photogrammetry, which embodies the practice of making quantitative measurements from photographs.

Photogrammetry has developed as a precise and useful mathematical tool in the areas of topographic survey, medical radiometry, and microscopy. The application of photogrammetric principles to archeology, as well, holds demonstrable promise.

Some of the basic properties of photography make it especially useful as a basis of measurement. A photograph is a scaled-down (or up) representation of a reflected scene; if the camera is properly constructed, all parts of the image are proportional to those in the actual scene. What is more, the photographic scale can be accurately determined - that is, distances in the real scene can be derived from measurement of distances on a controlled photographic representation. The relationship between distances on the photographic emulsion and those on the ground can be expressed as:

$$\frac{\text{focal length of lens}}{\text{Altitude}} = \frac{\text{size of image}}{\text{size of object}}$$

The above relationship pertains to distances measured on a single plane perpendicular to the axis of the camera lens. It should be apparent, however, that not all objects recorded in a photograph will be on such a plane. In all probability, several planes lying at different distances from the camera lens will be involved. The apparent distance between points on these planes will vary inversely with the distance of each plane from the lens. While this at first seems to pose considerable problems for the photogrammetrist, this principle is actually of great aid. With the aid of simple trigonometric principles, the height or projection toward or away from the camera of an object can be determined. Height determinations can be made by various methods from both single and stereo photographs (Avery, 1962).

The stereoscopic principle of height or altitude determination is the technique whereby most topographic maps are produced today. With the aid of stereo plotting devices, altitude contours can be determined to within an accuracy of 0.10 feet from a camera altitude of 20,000 feet. The Kelsh plotter, used by the USGS, is one such device.

The utility of photogrammetric mapping in archeology should be obvious. Lyons et al. (1972) and Pouls et al. (1976) illustrate the productivity of such mapping in the examination of a large-scale irrigation system. Structures and elevations on sites or in parts of sites can also be accurately mapped by this method. Stereo pairs taken from low-flying aircraft or ground-anchored platforms such as balloons or tripods can serve as the basis for the plotting of artifacts and features within excavation units, thus making the recording of such data by hand unnecessary.

In addition to these "traditional" methods of extracting data from aerial imagery, modern technology is at an increasing rate providing electronic and mechanical devices which facilitate interpretation. Such methods include microdensitometry, multispectral viewing, and electronic image enhancement. Some of these will be discussed later in this paper within the framework of the Chaco Center Remote Sensing Project.

Ground-Truth Checking

An integral part of the utilization of aerial imagery in the context of any research design is ground-truth checking. Remote sensor imagery collects a wide range of information, but in many cases it is not at first possible to state confidently just what the tonal and intensity gradations visible on a photographic image actually correspond to on the ground. Nonetheless, this logical link is just as important as any other linkage made in the course of the scientific process.

The process of linking actual pertinent data with the photographic configurations of a remote sensor image proceeds much as does any other inductive-deductive evaluation process. The interpreter, hopefully familiar with both actual ground conditions and with aerial views of the same, studies a specific area remotely recorded. Some specification of what the interpreter believes he is seeing on the imagery is made, and these conclusions are then independently checked in the field. Although the results of many interpretive efforts are cataloged in terms of nominal categories, it is plain that numeric data is more suited for such testing.

Ultimately, every skilled interpreter reaches the conclusion that there is a subjective, "artistic" element to viewing aerial photography in a useful way. While this may or may not be true, it is apparent that recognition patterns are built through practice and experience. There is no way to become proficient in such a skill except by looking practice.

PART IV: TO FLY OR NOT TO FLY: ECONOMY IS A RELATIVE THING

For many archeologists, doubts concerning the use of aerial remote sensor imagery in their particular research hinge upon considerations of economy. This is not an unrealistic concern. As an incidental tool for the visualization of a site already examined in other archeological ways, even the acquisition of preflown imagery of the site area may seem expensive.

Economy, however, is only important in relative terms. The question, "Expensive in relation to what else?" must be asked. It seems obvious that, when employed as an adjunct to an integrated and well-planned research design, aerial imagery can result in considerable savings of both time and money. For example, if ecological variables are taken as independent and to some extent causal within an archeological research framework, vegetative mapping of the surrounding area through the use of aerial photography - even if this imagery costs several thousands of dollars - may be less costly than dispatching a field crew of several men to do the job. Examples of the use of aerial imagery in the mapping of complex sites, which is far quicker and more accurate than the same job done on the ground by a 3-man crew, will be discussed later.

In some cases, too, data readily apparent from inspection of aerial imagery is totally unobtainable on the ground, regardless of time and cost. The Chaco Canyon prehistoric roadway survey, to be discussed in detail later in this paper, offers an example of such a situation.

Although the exact costs of any imagery acquisition project may vary with the contingencies of the project, including area, scale, and field checking, there are some generalizations that can be made on this subject that may prove useful to archeologists planning research. No surveys of remote sensing economics have been made to date, to the knowledge of the author, which deal specifically with archeological applications. However, estimates of cost parameters have been made with regard to remote sensing projects in general (Aguilar, 1967). Initial unit costs, which account for a large part of the costs of projects covering a relatively small area, are primarily involved with getting a properly equipped plane into the air, and with setting ground control. These costs remain fairly constant up to a certain point, and an estimation of such costs may give the archeologist an idea of the sorts of expenses he may be likely to encounter in acquiring his own imagery. Other costs encountered by aerial archeologists are in mapping, drafting, and image rectification. The material in tables 8 through 10 was compiled by Jorde and Bertram (1976).

These tables present actual comparative cost estimates for two archeological mapping projects carried out at the same site, Kin Bineola Pueblo in Chaco Canyon National Monument. The first of these projects was accomplished with alidade and plane table, and all work was done on the ground and only half the site was mapped, (see fig. 50). In the second effort, remote sensing techniques were brought into play. Ground control was professionally set, imagery flown to an appropriate scale, the imagery was set up on a stereo plotter, and the site photogrammetrically mapped (see fig. 51). Since the ground mapping of Kin Bineola only encompassed half of the total site, aerial mapping costs were initially estimated on this basis (table 8). Table 9 presents ground mapping costs adjusted to the full-site proportions, along with commensurate aerial costs.

A comparison of the figures presented in tables 8 and 9 shows small projects to be less expensive when mapped on the ground, while as the size of the area mapped increases, ground and aerial costs become increasingly similar. It can be seen from a compilation of Chaco Center costs for flying, mapping and digitizing (storage of x, y and z coordinates in a computer-compatible medium) seven major pueblo ruins that the economy of employing aerial imagery in such

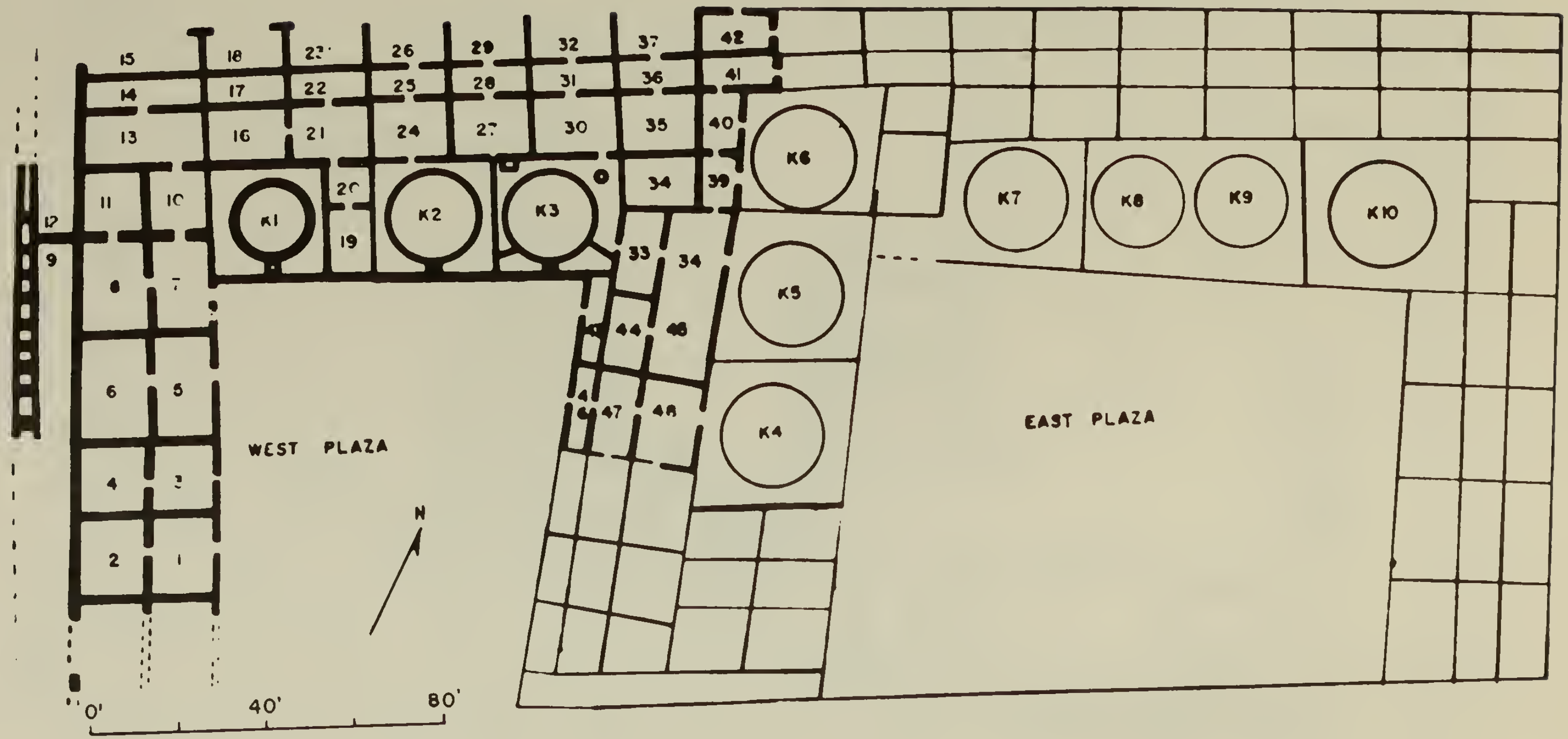


FIGURE 50 - Kin Bineola map made with plane table and alidade

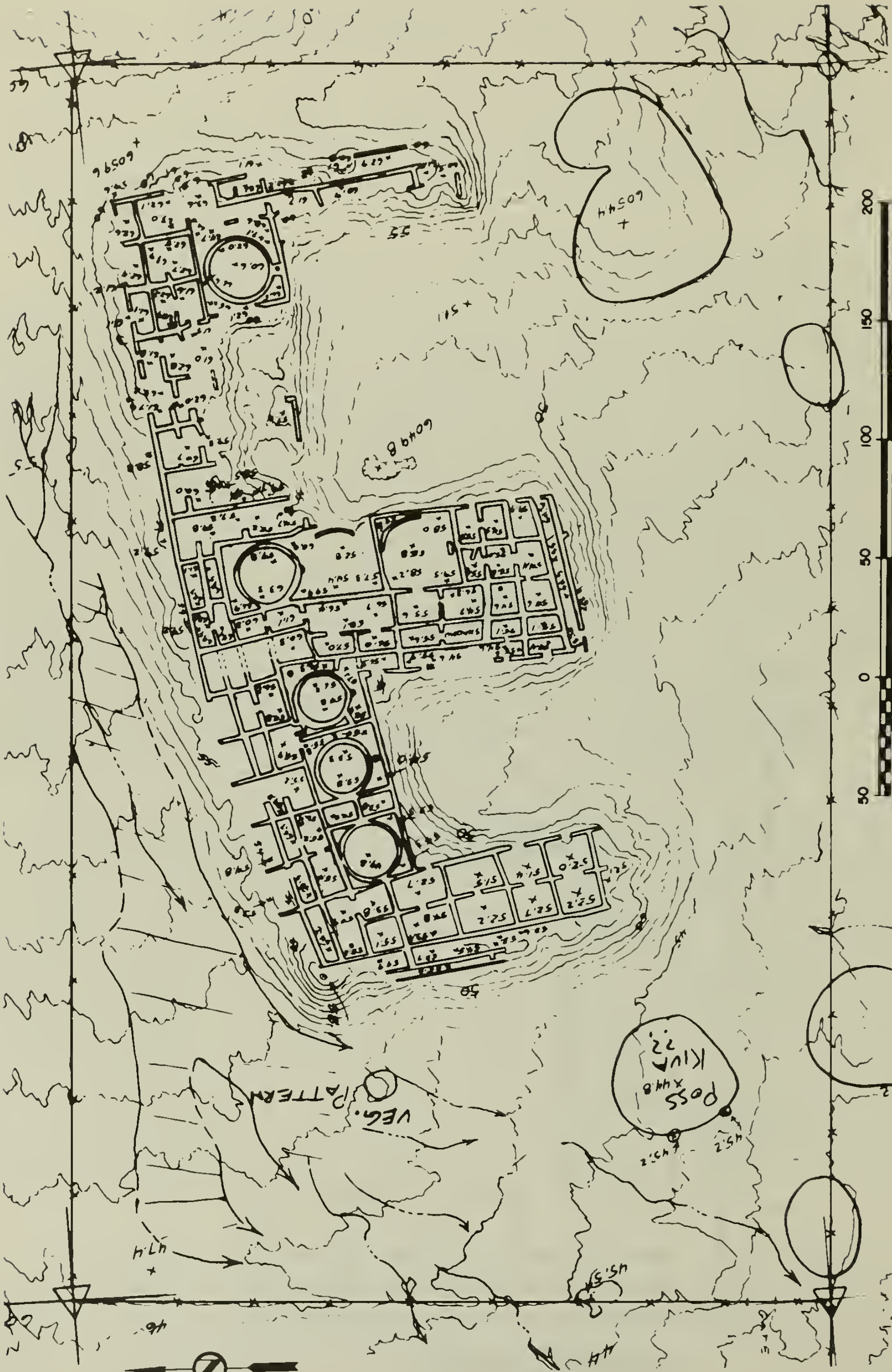


FIGURE 51 - Photogrammetric map of Kin Bineola prepared by Koogle & Pouls Engineering, Inc.

Table 8. Comparative Costs: Ground vs. Aerial Mapping of Kin Bineola - Partial (½ site) Mapping: Actual Cost.

Ground Mapping Costs			
A.	Salaries and Wages		
	1. Crew Chief (40 hours)	$ 200	
	2. Crew Member (40 hours)	120	
	Subtotal		$ 320
B.	Travel and Per Diem		
	1. Travel (650 miles + rental)	155	
	2. Per Diem (5 days)	200	
	Subtotal		355
C.	Materials and Services		
	1. Instrument Rental	25	
	2. Drafting Services (10 hours)	75	
	Subtotal		100
	TOTAL		$ 775
Aerial Mapping Costs			
A.	Flight Fees		
	1. Base Cost	$ 300	
	2. Per Site Photography Fee	50	
	Subtotal		$ 350
B.	Laboratory Fees		
	1. Lab Set-up		400
C.	Mapping Fees		
	1. Planimetry and Digitization		225
D.	Ground Control		
	1. Setting ground control		150
	TOTAL		$1,125

Table 9. Comparative Costs: Ground vs. Aerial Mapping of Kin Bineola - Complete (full site) Mapping: Estimated Cost.

Ground Mapping Costs		
A. Salaries and Wages		
1. Crew Chief (80 hours)	$ 400	
2. Crew Member (80 hours)	240	
Subtotal		$ 640
B. Travel and Per Diem		
1. Travel (900 miles + rental)	260	
2. Per Diem (10 days)	400	
Subtotal		660
C. Materials and Services		
1. Instrument Rental	50	
2. Drafting Services (20 hours)	150	
Subtotal		200
TOTAL		$1,500
Aerial Mapping Costs		
A. Flight Fees		
1. Base Cost	$ 300	
2. Per Site Photography Fee	50	
Subtotal		$ 350
B. Laboratory Fees		
1. Lab Set-up		400
C. Mapping Fees		
1. Planimetry and Digitization		525
D. Ground Control		
1. Setting Ground Control		150
TOTAL		$1,425

Table 10. Actual Costs for Flying, Mapping and Digitizing Seven Chaco Sites.

Site	Digitizing & Planimetry	Topographic Contours
Pueblo Bonito	$ 550	$ 125
Chetro Ketl	525	110
Penasco Blanco	425	100
Pueblo Pintado	425	100
Poco		325*
Kin Bineola	525	125
Kin Ya-a	375	100
TOTALS	$2,825	$ 735
Flying Fee	$ 300	
8 Sites @ $50	400	
Lab Set-up	400	
TOTAL	$1,100	
		$2,825
		735
		1,100
	GRAND TOTAL	$4,660

*Includes planimetry.

projects soon overtakes the projected costs of ground-based mapping (table 10).

The products of ground vs. aerial mapping are far less comparable than the costs involved. The ground-based regime used in this comparison provides no vertical control. It is apparent, too, that the ground-based map represents only a more or less "stylized" picture of reality when compared with the product of aerial mapping (fig. 51).

In the Chaco Center mapping case, then, aerial photogrammetric mapping has proved less expensive than the same job done with conventional survey methods. Kin Bineola, or any other pueblo mapped in the course of Chaco Center projects, is of course not directly comparable to most other archeological sites in North America. Costs incurred in the course of pursuing other research designs, it should be emphasized, will fluctuate with data requirements and the physical characteristics of the site.

Using Existing Imagery

Aerial imagery has been used for many purposes for many years; hence, over any given area of the Earth's surface, there is a high probability that at some time aerial imagery has been exposed. The United States and certain Western European countries such as Great Britain are especially well-covered in this respect, and aerial photos of varying scales and qualities are usually available for any area of these nations. 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 limited areas at what are often more useful scales for archeological investigation. Some likely U.S. Government sources of such imagery are listed in Appendix A.

An obvious advantage in the use of pre-existing imagery during the course of archeological research is the low cost to the user. Standard government agency prices for such imagery begin at $1.75 for a 10 in. by 10 in. black-and-white print, with quantity discounts after 25 prints. At some scales and in some situations a single stereo pair might be all that is required. At such rates, it would be unfortunate if small-scale aerial imagery were not employed in the initial planning stage of all archeological fieldwork today.

Very often, however, pre-existing aerial imagery does not meet ideal criteria for utility at all stages of archeological fieldwork. For example, standard and easily obtainable black-and-white imagery used by the United States Geological Survey in topographic mapping, taken at scales between about 1:20,000 and 1:60,000, is not useful in delineating or examining features smaller than about 50 feet in their largest dimension. Thus smaller site details are difficult to extract from such photography. In most cases, it is preferable to tailor the seasonal, weather and sunlight conditions as well as the scale of aerial imagery to the specific questions asked and information desired in the course of research design. An example of the integration of several types of pre-existing imagery as well as imagery contracted with specific questions in mind into such a design is presented later in this paper in reference to the Chaco Center Remote Sensing Project's prehistoric roadways survey.

A point arises in discussions of archeological fieldwork that may well have a bearing here, too. The archeological record is in a constant state of flux and destruction, not only because of natural agencies but in many cases as a result of the manipulation of the archeologist himself. Because of this, he has an obligation to the future and must record and preserve all possible data, even data which may not within the farthest reaches of his imagination be useful to him at the time of his investigations. Aerial imagery is an ideal tool with which to meet this obligation, primarily because it records many classes of data and because it can be preserved and duplicated until the analysis of such data is desired or rendered possible. Many archeologists have recognized this and make an effort to photographically record all aspects of their investigations from excavation units to entire sites (Whittlesey, 1973). There are indications that, because of such obligatory considerations, aerial photography and interpretation will soon be a funding consideration in all federally-supported salvage archeological projects, at least in the American Southwest. It goes without saying that the ideal imagery with which to fulfill data-recording obligations is that which allows maximum recovery of many classes of archeological data - probably implying high-resolution imagery, preferably color transparency base, at scales from about 1:5,000 to 1:10,000 or smaller.

PART V: AERIAL REMOTE SENSING IN ARCHEOLOGY: A CASE STUDY

An example of the use of aerial remote imagery in the formulation and investigation of an actual archeological problem should illustrate more clearly the analytic use of such data and bring other possibilities more applicable to different problems to mind. The case discussed here will be the prehistoric roadway survey conducted by the Remote Sensing Project of the Chaco Center, National Park Service. Since the appearance and "history" of the Chaco Canyon roads is the subject of two other papers in this volume, this discussion will be restricted primarily to the methods employed, both in the laboratory and in the field, in past and current Chaco Center investigations.

A research problem often presupposes a "surprise", a set of observations not in keeping with the scientist's model of reality. In the case of the Chaco roads, the surprise is present and compound. In the first place, the existence of the features themselves is contrary to prior experience; nowhere north of Mexico is any other similar network known to exist.

More surprising than the simple presence of the Chaco roads, however, is their appearance and location on the ground. In the early, pre-problem stages of this research, little was known of appearance and location. Only a few miles of the system had been recorded and described, and these few miles seem in many ways atypical of the entire system as now recorded (see Lyons and Hitchcock, this volume; Ware and Gumerman, this volume). In 1969, a number of flights over selected areas believed to contain roadway features were made, resulting in black-and-white imagery varying in scale from 1:3,000 to 1:12,000. More roads appeared on this imagery, some in definite association with Pueblo III communities built between A.D. 950 and 1100. Many of the lineations detected on this early imagery were as wide as 10 meters, and inspection of these areas on the ground revealed a concave cross-section. It was determined, also, that this "narrow view" was too restricted to afford an overall impression of the system. An examination of 1:32,000 scale imagery flown in the early 1960's by the U.S. Geological Survey proved smaller scales to be useful in delineating the extent and form of the entire network. The roadways detected in the early stages of interpretation of the smaller scale imagery produced yet more surprises. These segments were almost uniformly straight, varying not more than a few compass degrees off course over several miles, and almost every major pueblo site in the Chaco area was associated with at least one of the segments.

By the time it was determined conclusively that indeed <u>something</u> existed on the ground, and that what was there was a unitary phenomenon, about half of the currently mapped Chaco roadway system had been "discovered". In addition, a variety of questions demanding explanation danced in the minds of the researchers. Are these in fact "roads"--communication and transport routes? Were they constructed consciously? If so, when and by the Anasazi? What social and economic regime could be responsible for such facilitative or justificational technology? Satisfactory answers to these and other relevant questions obviously require a great variety of supportive data. The exact extent of the network must first be known. The road study, in final analysis, must integrate archeology with physical geography, geology, and irrigation studies (to mention a few). Between 1969 and 1975, the Chaco Center conducted a blanket archeological ground survey of the Monument. Interplay between this and the roadway survey may also prove valuable.

Remote sensing technology has aided in the collection of some of the required data. Intensive interpretation of the 1:32,000 scale USGS imagery was coupled with the use of 1:20,000 Soil Conservation Service (USDA) photos taken in the 1930's in the initial mapping of the network. It was reasoned, and correctly so, that the older imagery would reveal features now destroyed by natural weathering and modern construction. Later stages of mapping were facilitated by blanket large-scale coverage (1:6,000 ektachrome transparency) of the canyon. Whereas black-and-white photography of similar scale was of little use in gathering locational data, the ektachrome emulsion registers minute changes in soil and vegetational cover color, which in turn to co-vary with the loci of the roadway features.

Two additional techniques that went beyond simple visual interpretation of aerial imagery formed an integral part of initial problem-oriented survey. Ground-truth checking, the technique by which an interpreter assures himself of the veracity of his inferences made on the basis of visual inspection, was intensively conducted during the summer of 1973. Due to profuse vegetation and a too-close perspective, the Chaco roads are often indiscernible on the ground. Points can be located on the imagery, however, where the features should be visible. Such areas, which included cuts made in hillsides and places where retaining walls might have been necessary, were located on the ground with the aid of photos and topographic maps. In many cases, confirmatory evidence was found. It should be noted that 100 percent confirmation of results of interpretation through ground-truth checking is not necessary. Ground-truth checking is largely a device to build the interpreter's confidence in his learned recognition patterns. It has nothing whatever to do with the testing of the validity of causal propositions.

Also during the summer of 1973, back in the laboratory in Albuquerque, electronic image manipulation and enhancement techniques were applied to imagery which had already been examined. Electronic image manipulation was pioneered for amplifying data not readily apparent to the human eye contained in industrial and medical X-ray film emulsions. Several firms now market what are essentially closed-circuit television systems which both represent varying density levels with artificial color contours and emphasize contrast differences in a photographic emulsion. An 8-band International Imaging Systems (I^2S) Digicol housed at the Chaco Center was instrumental in the discovery of approximately 35 percent of the currently mapped Chaco roadway system.

Much of the data that will eventually be brought to bear on the Chaco roads problem will derive from conventional excavation of ruins and features associated with the roadway system itself. Current work at the Chaco Center is being geared toward the specific examination, preparatory to excavation, of many Chaco pueblos. Since an accurate and comprehensive pre-excavation site map is useful to operational sampling, the major Chaco ruins are currently being micro-topographically mapped. Both black-and-white and color transparency imagery varying in scale from 1:1,200 to 1:6,000 is utilized for this purpose. The digitization and computer storage of coordinates within a pueblo, easily accomplished by most modern engineering firms, allows the computer plotting of cross-sections, profiles, and areas contained by walls. One of the responsibilities of the National Park Service is the preservation and in some cases reconstruction of prehistoric resources for park visitors. It is expected that computer digitization of the Chaco ruins will aid in these tasks as well.

An additional technique inadequately experimented with during the summer of 1973 was that of spot photography taken with hand-held cameras from an aerial platform. Several flights were made in a light airplane over Chaco Canyon, and oblique imagery was exposed with a 35 mm, large-magazine motorized camera. Color transparency, color infrared transparency, and black-and-white infrared films were all exposed. However, color infrared proved the most promising. Although few totally new roadway segments were located through the use of color IR film, one of its interesting properties may be of future use to archeologists: matured vegetation appears light-colored on an IR emulsion, while vigorous vegetation shows in bright red. When flights are timed to coincide with the beginnings of vegetative maturation in a specific area, cultural or organic concentrations - where vegetation matures earliest - stand out strikingly. Initial indications following the summer 1973 experiments at Chaco Canyon are that such selectively-flown infrared imagery may be very helpful in finding otherwise hard-to-locate features such as Basketmaker pithouses.

PART VI: CONCLUSIONS

It is interesting to contemplate the combination of aerial and on-the-ground archeology that should further the goals of Chaco Canyon research in the future. On a simple and intuitive level, aerial imagery should be of use in the pre-determination of the value of on-the-ground investigation of certain areas and sites to the overall problem. Once such selection is made, large-scale imagery will aid substantially in the design of site-specific sampling procedures. Finally, pre-excavation recording of the physical nature of specific sites, easily accomplished through the use of aerial imagery and stereo plotting methods, can be of value in subsequent efforts at reconstruction or preservation of those sites - a responsibility which must be met in the course of archeological work under the aegis of the National Park Service.

Remote sensor data should once again be employed during the course of excavation. One of the most time consuming and exacting tasks that falls to the archeologist during traditional excavation is the hand recording of the appearance and location of artifacts, site features, stratigraphic evidence, and soil anomalies as they appear. Phased, level-by-level vertical stereo photography of on-going excavations can be photogrammetrically interpreted to provide much data more accurately than hand recording; an additional value of photographic recording is that all available locational information can be quickly collected prior to a determination of just which parts of these data are germane to the research goals at hand and must be plotted or further manipulated. Aerial imagery always provides more information than is sought, and can be stored for the use of future scientists on their own problems. Photographic coverage can be obtained during the course of excavation from airplane platforms, or perhaps more economically by the use of balloons and bipod platforms such as those pioneered recently by Julian and Eunice Whittlesey (1972, 1973).

It is also likely that classes of data not hitherto employed or available archeologically will be revealed through the agency of aerial or subaerial photography as well. The ability of infrared or narrow-spectrum response films to detect and make apparent otherwise undetectable soil discolorations and differences has been discussed (Gumerman and Lyons, 1971; Garofalo and Wobber, 1973; Tartaglia, this volume). Experimental films, designed specifically to accentuate and record certain on-the-ground phenomena such as phosphorus content, are currently in the planning stage. Only recently, Kodak announced the limited production of an experimental film which renders water "transparent" and which should be of much use in underwater archeological detection from the air (Specht, Needler, and Fritz, 1973).

The full gamut of possible technical and methodological practices, including improved films, the use of sophisticated equipment, and just plain "interpretive practice" that can benefit archeological remote sensing can obviously only be hinted at here. Specific practices arise in the context of specific problems being attacked with the aid of aerial remote sensing. Beginners may find consultation with more experienced scientists employing these methods useful. An admittedly incomplete list of such persons in the United States and Europe has been compiled and added to this paper as Appendix B.

The role of space-platform photography and mechanical sensing has also been the subject of speculation in the past (Lyons, Inglis, and Hitchcock, 1972). While the relatively low resolution of the video signals which constitutes ERTS imagery renders it unsuitable for exploration of archeological features on the ground, the periodic 18-day coverage provided by these satellites gives the archeologist a grasp of environmental variability on a large scale at any point on earth, information which should be incorporated into any ecologically-oriented systematic archeological investigation. Skylab imagery, selectively exposed by astronauts aboard the orbiting laboratory, is of sufficiently higher resolution than unmanned satellite photographs to permit the identification of actual cultural features on the ground. Initial inspection of imagery centered on Phoenix, Arizona, has revealed vestiges of prehistoric irrigation facilities even within the present city limits (Ebert and Lyons, n.d.).

Finally, aerial remote sensing fulfills only part of the requirements for any research design. The use that most archeologists make of remote sensing techniques usually falls under exploration or immediate induction; an inspection of most of the papers in this book (including this paper) will show this to be true. Such use can be a first step toward integrating data and theory, or it can be - as it unfortunately often is - taken to be an end in itself. In either case, remote sensing is fully compatible with the researcher's goals, although the results in the latter case will always be inconclusive, uninformative, and possibly uninteresting.

In a more specific way, however, remote sensing and the data derived from such techniques may be a path toward better science. The data "revealed" by remote sensing is rarely if ever self-evident; it is the task of the interpreter to consider the pattern apparent on the imagery in the light of his beliefs about the nature of the world, and to extract variables which he feels are relevant to his problem orientation. This is often done in a very informal, even "artistic" way by photo interpreters. But, it is in the context of just such statements of relevance that science becomes the unique, fascinating, and in many ways counter-cultural phenomenon that it is.

University of New Mexico

LITERATURE CITED

Aguilar, A.M.
1967 Cost Analysis for Aerial Surveying. Photogrammetric Engineering 33:81-91.

Avery, T. Eugene
1962 Interpretation of Aerial Photographs. Minneapolis, Minnesota: Burgess Publishing Company.

Deuel, Leo
1969 Flights into Yesterday: The Story of Aerial Archaeology. New York: St. Martin's Press.

Ebert, James I., Robert K. Hitchcock, and Richard L. Taylor
1974 Middle Range Theory in Archaeology. Paper presented at the 39th annual meeting of the Society for American Archaeology, Washington, D.C.

Ebert, James I., and Robert K. Hitchcock
1973 Spatial Inference and the Archaeology of Complex Societies. Paper presented at the Mathematics in the Social Sciences Board Conference on Formal Methods for the Analysis of Regional Social Structure, Santa Fe, New Mexico.

Ebert, James I., and Thomas R. Lyons
n.d. Prehistoric Irrigation Canals in Downtown Phoenix: The Past Moulds the Present. In Preparation.

Garofalo, Donald and Frank J. Wobber
1973 Remote Sensing for Environmental Studies in Mined Areas. Photographic Applications in Science, Technology, and Medicine 8:32049.

Gumerman, George J.
1971 Archaeology and Aerial Photography. Proceedings of the Second ARETS Symposium. Tucson. Arizona: University of Arizona.

Gumerman, George J. and Thomas R. Lyons
1971 Archaeological Methodology and Remote Sensing. Science 172:126-132.

Jorde, Lynn B. and Jack B. Bertram
1976 Current and Future Applications of Aerospace Remote Sensing in Archeology: A Feasibility Study. Chaco Center, National Park Service and University of New Mexico, Albuquerque.

Laboratory for Applications of Remote Sensing (LARS)
1970 Remote Multispectral Sensing in Agriculture. Laboratory for Agricultural Remote Sensing Annual Report, Volume 4.

Lyons, Thomas R., Michael Inglis, and Robert K. Hitchcock
1972 The Application of Space Imagery to Anthropology. Proceedings: Third Annual Conference on Remote Sensing in Arid Lands, pp. 244-264. Tucson, Arizona: Office of Arid Lands Studies, University of Arizona.

Lyons, Thomas R., Basil G. Pouls, and Robert K. Hitchcock
1972 The Kin Bineola Irrigation Study: An Experiment in the Use of Aerial Remote Sensing Techniques in Archaeology. Proceedings: Third Annual Conference on Remote Sensing in Arid Lands, pp. 266-283. Tucson, Arizona: Office of Arid Lands Studies, University of Arizona.

Pouls, Basil G., Thomas R. Lyons and James I. Ebert
1976 Photogrammetric Mapping and Digitization of Prehistoric Architecture; Techniques and Applications in Chaco Canyon National Monument. in Thomas R. Lyons, ed., Remote Sensing Experiments in Cultural Resource Studies: Non-destructive Methods of Archeological Exploration, Survey, and Analysis. Reports of the Chaco Center, No. 1. Albuquerque, New Mexico: Chaco Center, National Park Service.

Rowe, John H.
1953 Technical Aids in Anthropology: A Historical Survey. In Anthropology Today, Alfred L. Kroeber, ed. Chicago: University of Chicago Press.

Specht, M.R., D. Needler, and N.L. Fritz
1973 New Color Films for Water-Photography Penetration. Photogrammetric Engineering 39:359-369.

St. Joseph, J.D.S., ed.
1951 A Survey of Pioneering in Air-Photography. Aspects of Archaeology in Britain and Beyond. London: H.W. Edwards.

Whittlesey, Julian
1972 A Multi-band Camera for Archaeology. Photogrammetric Engineering 38:817-819.

__________ Whittlesey Foundation Newsletter. New York: Whittlesey Foundation, Inc.

APPENDIX A

The following represents a list of government repository and "clearing-house" agencies which either maintain a file of reproducible aerial remote sensor imagery or records of imagery available and its source. Researchers wishing to begin their fieldwork with inexpensive, pre-flown imagery should contact some or all of these agencies; a specification of the exact location of interest should bring a quick affirmative or negative response.

UNITED STATES DEPARTMENT OF AGRICULTURE
Soil Conservation Service
Cartographic Division
Federal Center Building
Hyattsville, Maryland 20782

1) Mosaic of ERTS-1 imagery of coterminous U.S. and Alaska, scales ranging from 1:1,000,000 to 1:5,000,000.
2) Vertical imagery of the United States at varying scales. Publication: Aerial Photography Mosaic Status Maps, Soil Conservation Service, USDA, March 1, 1972.

UNITED STATES DEPARTMENT OF AGRICULTURE
U.S. Forest Service
Washington, D.C. 20250

1) Vertical aerial imagery, primarily in Forest Service lands or related areas.
2) Publications and lists:
   Aerial Photography Status Maps as of May 1, 1970. Technical Report ETR-7100-4A. Lists imagery held by the Forest Service and gives scale and index information.
   Map: Aerial Photography, CY 1970, 1971, 1972. Graphic illustration of 1970-1972 Forest Service imagery acquisitions.

UNITED STATES DEPARTMENT OF AGRICULTURE
Agricultural Stabilization and Conservation Service
Administrative Services Division
2505 Parley's Way
Salt Lake City, Utah 84109

1) Handles ERTS-1 imagery.
2) Processes color composites of ERTS-1.

DIRECTORATE FOR DEFENSE INFORMATION
Audio-Visual Division
Office of the Assistant Secretary of Defense
Washington, D.C. 20301

Handles paperwork for acquisition of imagery from outside the United States. User must first obtain approval for public release of imagery from the embassy of the country in question. When such information is held by the U.S. Government, a copy of the embassy release approval must accompany inquiry to the above office.

EROS DATA CENTER
10th and Dakota Avenue
Sioux Falls, South Dakota 57198

1) ERTS imagery.
2) NASA aircraft imagery and photography.
3) USGS aerial photography, scales from 1:12,000 to 1:66,000.
4) Services:
   Training. Discipline-oriented courses in remote sensing in agriculture, forestry, geography, geology, hydrology, and oceanography.
   Emphasizes ERTS data.
   Assistance on interpretation techniques.
   Instruction in use of interpretive instruments for visitors to the center.
   Searches for imagery designated by geographical areas.
5) Ordering information:

   EROS Data Center
   Data Management Center
   Sioux Falls, South Dakota 57198

   (605) 339-2270 (commercial)
   (605) 336-2381 (FTS users)

6) Numerous publications describing services offered by the center, catalogues of imagery held, etc., are available.

   The Eros Data Center, USGS INF-72-24 (R-11)
   Studying the Earth from Space, USGS INF-71-17 (R-2).

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Ames Research Center
Moffett Field, California 94305

1) High-altitude (usually U-2 platform) coverage in support of ERTS-1 and Skylab.

2) Earth-Science applications - e.g. Arizona Land Use Experiment, interagency mapping and land classification.
3) 4-band 70mm multispectral camera package, Wild RC-10 cameras with color IR film.
4) All Ames Research Center imagery is available to the public through the EROS Data Center.

NATIONAL ARCHIVES AND RECORDS SERVICE
General Services Administration
Washington, D.C. 20408

1) Holding data from the mid-1930's to 1942.
2) List of Holdings: Aerial Photographs in the National Archives, Special List Number 25.
3) Index sheets of all holdings, $3.00/sheet. Contact prints and enlargements at regular government prices (9 x 9, $1.75).

UNITED STATES DEPARTMENT OF THE INTERIOR
U.S. Geological Survey
Map Information Office
Reston, Virginia 22092

1) Soil Conservation Service imagery, scales of 1:10,000 to 1:44,000.
2) USGS imagery.
3) EROS - regular imagery, plus color composite files and capabilities.
4) Status of Aerial Photography in the United States, map. Information on who has what (private).
5) Services: Autographic Theme Extraction - graphic simplification of photo imagery through photographic manipulative processes.
   Publications: Autographic Theme Extraction, U.S. Government Printing Office 1972-0-473-697, and Astrogeology: Geologic Research in Space, U.S. Government Printing Office 1972-0-461-763.

UNITED STATES DEPARTMENT OF THE INTERIOR
U.S. Geological Survey
Reston, Virginia 22092

Regional Headquarters:

Atlantic Region Engineer
USGS
1109 North Highland Street
Arlington, Virginia 22210

Central Region Engineer
USGS
Box 133
Rolla, Missouri 65401

Rocky Mountain Engineer
USGS
Building 25, Federal Center
Denver, Colorado 80225

Pacific Region Engineer
USGS
345 Middlefield Road
Menlo Park, California 94025

1) USGS vertical imagery, scales of 1:12,000 to 1:72,000.
2) Twin low-oblique mapping photography, booklet available on request.
3) Soil Conservation Service imagery taken since 1940.
4) Regional Forest Service coverage, scales of 1:10,000 to 1:32,000.
5) Map: Status of Aerial Photography, describing availability of privately-acquired aerial imagery in the United States. USGS holds records of who contracted, stores imagery.

APPENDIX B

The following list of archeologists concerned in some way with remote sensing is not meant to be either exhaustive or even particularly representative; it consists of those with whom we at the Chaco Center have had conversations or who are widely published. The primary criterion for inclusion on this list was the demonstration of some measure of methodological expertise in remote sensing technology in addition to the use of aerial imagery in doing archeology - hence, not everyone who has simply used aerial photos in their research is included. In addition, some of those included here are non-archeologists, grounded in remote sensing technique, who have shown an interest in the problems of prehistory. Although direct permission for inclusion on this list was not obtained from any of these individuals, they are able and in most cases willing to discuss remote sensing problems encountered by those new to such techniques, or to suggest where beginners should go for help.

ADAMS, ROBERT McC.
Dean, Division of Social Sciences
University of Chicago
Chicago, Illinois

AGACHE, ROGER
Ministere d'Etat Affaires Culturelles
Direction des Antiquites Prehistoriques
de Nord et de la Picardie
6 Bis, Rue de Capucins
80-Abbeville, France

ARMILLAS, PEDRO
Department of Anthropology
University of Chicago
Chicago, Illinois

BINFORD, LEWIS R.
Department of Anthropology
University of New Mexico
Albuquerque, New Mexico

BROWN, MARGARET
Department of Anthropology
Northwestern University
Evanston, Illinois

BEVAN, BRUCE
Museum Applied Science Center for Archaeology
33rd and Spruce Streets
Philadelphia, Pennsylvania

CHEVALLIER, RAYMOND
3 Square Debussy, 92
Antony, France

CLELAND, CHARLES E.
Curator of Anthropology
The Museum
Michigan State University
East Lansing, Michigan

DEUEL, LEO
350 East 54th Street
New York, New York

EBERT, JAMES I.
Department of Anthropology
University of New Mexico
Albuquerque, New Mexico

EMRICK, Lt. Col. HARRY W. (USAF)
Department of the Air Force
Department of Geography
USAF Academy
Colorado

FORAMITTI, Dr. HANS
Jacquinasse 2
Wien III, Austria

FOWLER, MELVIN L.
Department of Anthropology
University of Wisconsin
Milwaukee, Wisconsin

GOGUEY, RENE
Recherches d'Archeologie Aerienne
4, Rue Dolonel-Marcaire, 4
21 Talant-des-Dijon, France

GUMERMAN, GEORGE J.
Department of Anthropology
Southern Illinois University
Carbondale, Illinois

HAMPTON, JOHN N.
Royal Commission on Historical Monuments (Britain)
National Monuments Record
Air Photographs Unit
Fortress House, 23 Saville Row
London, WIX LAB, England

HARP, ELMER, Jr.
Department of Anthropology
Dartmouth College
Hanover, New Hampshire

HITCHCOCK, ROBERT K.
Department of Anthropology
University of New Mexico
Albuquerque, New Mexico

INGLIS, MICHAEL H.
Technical Applications Center
National Aeronautics and Space Administration
Stanford and Central Street, S.E.
Albuquerque, New Mexico

KRUCKMAN, LAURENCE D.
Department of Anthropology
Southern Illinois University
Carbondale, Illinois

KEDAR, YEHUDA
Department of Geography
State University of New York
Binghamton, New York

LYONS, THOMAS R.
Chaco Center
National Park Service
Box 26176
Albuquerque, New Mexico

MARMELSTEIN, ALLAN D.
Earthsat, Inc.
1771 "N" Street, N.W.
Washington, D.C.

MILLON, RENE
Department of Anthropology
333 Harkness Hall
University of Rochester
Rochester, New York

MEYER, WILLIAM
United States Geological Survey
1819 North Meridan
Indianapolis, Indiana

MOSELEY, MICHAEL E.
Department of Anthropology
Harvard University
Cambridge, Massachusetts

PAQUET, JEAN-PIERRE
2, Rue de Tourville
Paris, 7e, France

RAINEY, FROELICH
Applied Science Center for Technology
University Museum
33rd and Spruce Streets
Philadelphia, Pennsylvania

ST. JOSEPH, J.K.S.
Director in Aerial Photography
University of Cambridge
Cambridge, England

SANDERS, WILLIAM T.
Department of Anthropology
Pennsylvania State University
University Park, Pennsylvania

SCHMIEDT, (Generale) GIULIO
Piassa Fardella di Torrearsa
Florence, Italy

SCHORR, THOMAS S.
Department of Anthropology
Faculty of Arts and Sciences
University of Pittsburgh
Pittsburgh, Pennsylvania

SIEGE, PETER
Deutsche Forschungs- und Versuchsanstalt fur
Luft- und Raumfahrt e. V. (DFVLR)
Institut fur Satellitenelektronik
8031 Oberpfaffenhofen
Post Wessling/Obb.
Germany

SOLECKI, RALPH
Department of Anthropology
Columbia University
New York, New York

STRANDBERG, (Capt.) CARL H.
2114 Olive Avenue
Fremont, California

TANDARICH, JOHN
Office of the State Archaeologist
Department of Anthropology
University of Iowa
Iowa City, Iowa

TARANIK, JAMES V.
Iowa Geological Survey
16 West Jefferson Street
Iowa City, Iowa

TARTAGLIA, LOUIS JAMES
Department of Anthropology
University of California at Los Angeles
Los Angeles, California

TROUSDALE, WILLIAM
Department of Anthropology
Smithsonian Institution
Washington, D.C.

VOGT, EVON S.
Department of Anthropology
Harvard University
Cambridge, Massachusetts

WHITTLESEY, JULIAN H.
Whittlesey Foundation
31 Union Square
New York, New York

WRIGHT, HENRY T.
Department of Anthropology
University of Michigan
Ann Arbor, Michigan

YACOUMELOS, NICK G.
Department of Civil Engineering
University of Illinois
Champaign-Urbana, Illinois

☆ U.S. Government Printing Office: 1977—730-848