REPORTS
of the
CHACO CENTER

NUMBER ONE

REMOTE SENSING EXPERIMENTS IN CULTURAL RESOURCE STUDIES

Non-destructive Methods of Archeological Exploration, Survey, and Analysis

[redacted]

CHACO CENTER

National Park Service
U. S. Department of the Interior

and

University of New Mexico

Albuquerque

Cultural Resources Management Division
Washington

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REMOTE SENSING EXPERIMENTS IN CULTURAL RESOURCE STUDIES

Non-destructive Methods of Archeological Exploration, Survey, and Analysis

Assembled by Thomas R. Lyons

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CHACO | CENTER

National Park Service
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1977

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REPORTS OF THE CHACO CENTER

The Chaco Center, a joint National Park Service - University of New Mexico facility, was established in 1971 to conduct multidisciplinary research in and about Chaco Canyon National Monument, New Mexico. One of the Center's missions is to disseminate information resulting from its various programs to those individuals and institutions involved in similar or related types of research. Most monographs concerning major projects of the Center will be issued as numbers of the National Park Service *Publications in Archeology*.

Other reports, prepared by staff members of the Chaco Center or by individuals collaborating with the Center, may be relatively short, may deal with narrowly defined specific problems, and do not warrant the widespread distribution of our major monographs. Nevertheless, they are significant contributions to knowledge and need to be made available to those concerned. With this goal in mind we have established a mechanism to provide limited distribution of copies of these papers, *Reports of the Chaco Center*, of which this is number one. The format of these reports, which obviously is not a masterpiece of the printer's art, has been chosen because it lends itself to prompt presentation of data and because it is economical, both important factors at this time when long delays in printing and accelerating publication costs are the rule. We trust these reports will present our findings in a concise and professional manner even though we have eliminated some of the desirable features of more traditional methods of publication.

Reports of the Chaco Center will include papers upon all facets of our comprehensive research which broadly encompasses an examination through time of man and nature in the Chaco Canyon area. Most archeological reports and papers dealing with remote sensing will be prepared by staff members of the Chaco Center, while studies in other fields of Anthropology and in Biology, Geography, Geology, and other disciplines will be written predominately by collaborating scholars many of whom are associated with the University of New Mexico.

Editing of the *Reports* will strive to provide a degree of uniformity in certain aspects of format and in specialized terminology but will not place restrictions upon or attempt to influence authors' opinions or interpretations of materials and data. Reports will present the author's point of view which may not always be shared in completely by other staff members or associates of the Chaco Center.

Certain manuscripts prepared for the Chaco Center have been or will be published in the National Park Service *Publications in Archeology*, in journals of scientific societies, in assembled works resulting from symposia, or in compendiums of invited papers. In order to maintain an up-to-date record of all Chaco Center research, each number of the *Publications in Archeology* and the *Reports of the Chaco Center* will contain a complete chronological listing of all published papers and reproduced reports of the Chaco Center.

Robert H. Lister
Chief, Chaco Center

CONTRIBUTIONS

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

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 Archeological Survey. Sampling in Archaeology. James W. Mueller, ed., University of Arizona, 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, Sr., 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.*

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INTRODUCTION

The literature of archeology has, in the last decade, been the scene of perhaps the greatest turmoil in the social sciences since the advent of behaviorism in psychology. The professed issue of much of this debate centers upon the question of whether archeology is properly a science, whether science proceeds automatically and unconsciously from skillful description of observations -- or whether "doing science" requires the sort of conscious, always self-critical extra effort suggested by philosophers of science. And while academic discussion is not always in harmony with the practical aspects of a profession, none can deny that changes are taking place in archeology today.

A great deal of what has been written in archeology since the late 1960's reinforces a distinction commonly made in the field today concerning the existence of two rival schools: the "new archeology" and the more traditional "old school". As with all things designated new, the new archeology has been the target of a number of outright attacks on what are supposed to be its underlying principles. Other archeologists have noted their belief in the distinction between new and old, perceiving a paradigm change, or a shift in goals.

An examination of the historical basis for the distinction between new and old archeology may shed light upon difficulties encountered in the contemporary literature. New archeology has been identified by some with a demand for explanation over description, following the order of one of several deductive logical paradigms. Such authors, in an honest attempt to accomplish something, miss the point of earlier objections to traditional archeological methods. Logical paradigms are not the formula route to knowledge of the past, but are simply tools by which the archeologist may judge whether or not he has reached simplistic and false "explanations". The new archeology is not a new framework or a new body of theory; it might be best viewed as a movement toward a new perceptiveness in archeological science, a methodology.

Another aspect of archeology that has changed in recent years is research priorities, a change actually much more closely related to changes in basic paradigm than the issue of "explanation". Most notably, archeologists have begun to realize that a too-close perspective must give way to a more realistic regional view before statements of a general nature can be made concerning human behavior as a whole. This is not to say that there is nothing to be gained by studying a single site or a specific type of artifact. A regional framework, however, may be the only way that some classes of archeological information can be reached. And finally, one of the greatest advantages of a regional data-collection scheme is that it produces great amounts of redundant information. While some might view this as resulting in a "data glut", such is not the case; information theorists have long acknowledged that it is in redundancy that the greatest volume of testable data lies.

In several ways, various pieces of federal legislation have encouraged archeological survey and salvage operations that are becoming the basis of archeology in the United States. Archeology is no longer a summer game to be lightly regarded; it is big business, and accounts are carefully planned, watched, and audited. Archeology must become increasingly efficient, accurate, and product-oriented. While in many ways this could be viewed as unfortunate, tending to force a "piecework" attitude on the part of both archeologists and clients, it can also be argued that such a regime compels just what archeologists have needed in recent decades, explicitness in the postulation of beliefs and the consequent testing of these against reality. Increasing public funding of archeology may be the impetus to a marriage between the "academic" emphasis of university archeology and the pragmatic archeology of cultural resource management.

Given the increasing responsibilities and possibilities of his profession, how is the archeologist to confront the necessity of speed and economy that faces him today. New requirements demand new techniques; and one of the most promising tools available to the field today is remote sensing. This volume contains a series of reports on experiments conducted with varying degrees of success in archeological remote sensing. The concern here is with method and application.

We wish to thank the following National Park Service employees who had the foresight to recognize that remote sensing in cultural resource management had a promising future: Douglas H. Scovill, Chief Archeologist; Robert H. Lister, Chief, Chaco Center; Walter P. Herriman, Superintendent, Chaco Canyon National Monument. The Committee for Research and Exploration, National Geographic Society, provided funds which supported a number of experiments reported upon in this volume. The Earth Resources Observation System program of the United States Department of the Interior has, over a number of years, generously provided funds and consultation. Endorsement and support of programs in remote sensing have been received from the University of New Mexico from the inception of the Chaco Center. The efforts of Joe C. McKinney, Campus Planner, Edmund B. Kasner, Director, Research and Fellowship Services, and

Paul H. Silverman, Vice President for Research and Graduate Affairs have been particularly helpful. To list all individuals who have assisted the various authors in their tasks is obviously not feasible, but to them all we wish to express our appreciation.

TRL
JIE

October 1976

THE ROLE OF REMOTE SENSING IN A REGIONAL ARCHEOLOGICAL RESEARCH DESIGN: A CASE STUDY

BY

JAMES I. EBERT AND THOMAS R. LYONS

There is, we think, an ever-increasing realization in archeology today that a regional framework is appropriate for many sorts of research problems. Certainly, a regional scope is requisite to the application of geographical macro-locational theory, a necessary adjunct to archeology if more than a single site is assumed to have participated in the prehistoric system. A regional frame is also unavoidable when problems involve the interaction of components of a complex social system. And finally, a regional view is automatically implied when ecological variables are taken as being important determinants or constraints to behavior -- and they always <u>must</u> be if culture (and hence our subject matter) is defined as an adaptive system.

There is another more pressing reason, however, that archeology must gear itself to working within a regional framework in considering the relationships between loci of residence and activity; and that is salvage archeology. Many of the projects for which surveys are required under federal regulations cover large areas; even if what constitutes archeology is not prescribed by regulation or law, it seems reasonable to expect the relationships between the locations and the functions of sites to be sought and analyzed. Archeologists have an obligation to record not only specific or unique sites but also to document the range of variation among sites, and locational and other minimal data from all sites within an area to be destroyed.

Doing archeology within large areas presents certain problems, however. One of the most frightening of these is the sheer bulk of archeological data that must be collected, analyzed, and in many cases stored. No discussion of this problem will be presented here other than to point out that the information available at an archeological site is not only artifactual, but may consist of relationships and facts not physically collectable and storable on shelves. Corroborative data required in the testing of beliefs generated about the nature of archeological variability in the area must also be collected, within the framework of a problem or series of problems, and it can be argued that this must involve an assessment of the total external environment, or "ecology", of the area.

We would like to argue that remote sensing, the monitoring of data from a remote vantage through the use of aerial photographs and other sensing devices, provides one of the best and most economical means by which archeological and corroborative data can be collected and stored in the course of regional survey. We would also like to emphasize that, although remote sensing has been peripherally considered by archeologists for many years, an acceleration in the development of techniques and methods will be necessary before the full potential of aerial data-gathering can be realized by the discipline.

To illustrate the role of remote sensing in archeological discovery, data collection, and constructive inference, we would like to summarize some of the work being done by the Remote Sensing Project at the Chaco Center, a National Park Service office in Albuquerque. This work centers primarily on a specific regional area, Chaco Canyon and the Four Corners region.

Chaco Canyon is an erosional feature in northwestern New Mexico which has long been noted for its spectacular multi-roomed pueblo ruins. Chaco Canyon became a National Monument in 1907 and has been the target of much archeological speculation, some very astute and some totally unwarranted. The occupational period that produced the most impressive archeological record at Chaco Canyon occurred from about AD 950 to 1150; these people are referred to as the "Anasazi" by the Navajo that inhabit the area today.

Archeologists and ethnologists in the Southwest, searching for an understanding of Anasazi culture, have relied primarily upon ethnographic analogy drawn from present-day pueblo peoples for ideas, often implying an assessment of "truth" in the process. Anasazi were, according to their reasoning, a democratic, egalitarian people subdivided into single-locus political units, their lives ruled by the symbolism and ceremony which also produced their solidarity. Whether such a Benedictine characterization bears reference even to modern pueblo society is doubtful; the argument that it characterizes the Anasazi occupation at Chaco Canyon simply cannot be made. We would like to make the point that the concept of prehistoric/historic similarities between the native cultures of the Southwest has colored the thinking of archeologists, resulting in what may well be a glaring misuse of data observed today. Some of the observations made by the Chaco Center Remote Sensing Project cast doubt upon the equational use of modern ethnographic data in understanding Anasazi prehistory.

A basic tenet of the "new archeology", one that we feel would be accepted and acknowledged by almost all archeologists, is that a conceptual framework represents a set of integrated arguments ranging from high-level, universal or near-universal beliefs about human behavior, through a chain of ever-more-specific arguments relevant on one hand to higher theory and on the other to measuring devices -- taxonomies and classifications -- directly useful in the apprehension of physical data. Many sorts of observations made on the archeological record are pertinent to a single area of higher-level theory; in fact, the crucial test of the usefulness of higher-level beliefs may well be a measure of the sheer variety of data-specific arguments they subsume. We would like to discuss one area of data-specific argument revealed by remote sensing at Chaco Canyon, that relevant to prehistoric roadway features there.

Short segments of linear and bounded prehistoric "roadways" have been known to exist in Chaco Canyon for over 100 years. The three to four miles of these features recorded in 1960 fit well with ethnographically-derived projection to the specifics of Anasazi culture: the roads must have been ceremonial facilities, perhaps racetracks which in today's pueblos function as a redistributive and integrative facility.

Early in the 1960's, however, it was noted by R. Gwinn Vivian and others that examination of aerial photography revealed other, fainter markings similar in appearance to the known roadway features. In 1969, the Chaco Center at the University of New Mexico began an intensive program of interpretation of these features. It was reasoned that if more of the system could be discovered, the implications of the roadway features in terms of the more general cultural dynamics of the Chaco area might be substantially altered.

This reasoning proved correct, and in this case, the "surprise experience", basic to the formulation of all problems of an archeological nature, was evident and compound. Many miles of such features could be detected, not only within the canyon, but also connecting all of the major Chaco Canyon ruins with other large pueblos of a similar time period outside the canyon.

Preliminary mapping of the roadway system proceeded with the use of U.S. Geological Survey 1:32,000-scale black-and-white aerial photographs. It was found that the roads showed up best on imagery taken when the sun angle was low, and when a stereoscope was employed in their interpretation. A recognition pattern was slowly being built, that is, we were defining the criteria, often implicit, by which an interpreter recognizes and classifies the information seen on the imagery. It became apparent that the prehistoric roadways differed from modern roads in that they were in many cases almost perfectly straight, and seemingly ignored topography. In some cases the roadways were modified with terraces, rock alignments, curbs, and stairways. Finally, it also became apparent that many of the features were very faint, difficult to detect even from aerial imagery, and were being constantly made fainter by natural erosion and wind-drifting. It was thus reasoned that the roadways might be more easily detected from Soil Conservation Service 1:20,000 scale aerial photos taken in the 1930's -- another supposition that proved correct.

Other types of aerial imagery, flown under contract, were also employed in the discovery phase of the prehistoric roadway survey. Scales between 1:12,000 and 1:2400 black-and-white imagery, because of the magnitude of the features being apprehended in this case, proved of little use in the actual detection of roadway phenomena. This does not, of course, rule out the use of similar imagery for other purposes. One practical lesson we learned is that differences in sensitivity of various photographic emulsions is important in discerning on-the-ground features by remote sensing. A series of Ektachrome transparency film flown at a scale of 1:12,000 proved especially useful, primarily due to the unusually high rainfall received at Chaco Canyon during 1973-74, resulting in great vegetational growth and diversity.

Electronic image enhancement and manipulation techniques were also employed in the course of the prehistoric roadway survey; their use resulted in the discovery of 20 to 30 percent more roads from the imagery. And of course, we spent time in ground-truth checking, an integral part of all remote sensing.

At the end of the 1974 field season, the picture of the Chaco Canyon roadway system was greatly changed from that of a few years earlier. Over 200 miles of verified roadway features connected pueblos within the Monument with each other, with points as far distant as a verified 65 miles and perhaps as far as Mesa Verde, and with numerous "non pueblo" sites as well. A new interpretation of the importance of the roadways to the total Anasazi system is warranted, based to some extent upon a network analysis of the results. Perhaps this is evidence of an economic system, inter-connecting pueblos that were integral units in a single, regional system.

Discovery is not the endpoint of archeology; it is rather only the first step. In research planned for the future by the Chaco Center Remote Sensing Project, data gathered through remote sensing will be used to test ideas consequent to the above "gross model" of the Anasazi system. The questions asked will be formulated to determine whether other aspects of the archeological record at Chaco Canyon are in accord with our prior estimations. A few of these other aspects are listed below:

1) If the roadways facilitated the transport of economic goods such as food, natural resources, or manufactured

items, we would expect an ecological diversity measure to vary between nodes of the Chaco system. Such independent variables as ecological diversity are easily accessible through the use of remote sensing.

2) Another implication of our economically-deterministic view of Anasazi culture is that labor organization could be expected to vary between nodes, as well. Photogrammetric data could lead to an assessment of variation of room sizes (and thus perhaps family sizes) and labor-justificational devices (kivas, the distribution of which might be relevant to task-group composition) between nodes. Again, such data is easily derived through remote sensing.

3) Variability in economic "power", or wealth, could also be expected between pueblos in a ranked society such as the economic interpretation of the Chaco roads implies. Perhaps the volume of discarded trash relative to estimated population at each node could be taken as relevant to such variation -- a sort of measure of "affluence" that could be derived from remote sensor data by the use of photogrammetric principles.

In conclusion, we emphasize that the record at Chaco Canyon is obviously of a very different nature and scale than sherd scatters in Missouri or fortified villages along the Atlantic seaboard. It is apparent that certain combinations of scale and emulsion in aerial imagery is appropriate for discovery and certainly the accumulation of data relevant to independent variables in any regional archeological case. Remote sensing can and will be a valuable and much-used tool in the archeological survey of the future.

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CURRENT AND FUTURE APPLICATIONS OF AEROSPACE REMOTE SENSING IN ARCHEOLOGY: A FEASIBILITY STUDY

BY

LYNN B. JORDE AND JACK B. BERTRAM

PART I: INTRODUCTION

The author would like to acknowledge the assistance of a number of persons whose comments and suggestions aided immeasurably in the preparation of this report. Dr. Thomas R. Lyons, James I. Ebert and Robert K. Hitchcock of the Chaco Center were instrumental in providing access to data and information and for explaining and describing the work of the Remote Sensing Project there. Helpful advice was also provided by Dr. W. James Judge, and Jack B. Bertram of the University of New Mexico Department of Anthropology. Finally, a debt of gratitude goes to the Chaco Center itself, headed by Dr. Robert H. Lister.

This report, which is a summary of research carried out under National Park Service Contract No. CX 700030206 and funded primarily by the U.S. Geological Survey EROS Program, is dedicated to the necessity of rapidly and economically analyzing, protecting and managing archeological and historical resources. Insight gained at the Chaco Center of the National Park Service, and University of New Mexico during the application of remote sensing to the discovery and mapping of prehistoric sites and features within a problem specific framework has suggested other applications of such techniques to the efforts of the National Park Service and those of archeologists in general. The efficiency and wide area coverage afforded by aerial remote survey and mapping point to the possible utility of these techniques in historical inventories. Public Law 89-665 and Executive Order 11593 emphasize the responsibilities of the Department of the Interior in preserving prehistoric and historic resources; aerospace remote sensing methodology should prove very helpful in such an endeavor.

The Royal Commission on Historical Monuments of Great Britain is currently utilizing aerial photography as an aid in the inventory and reconnaissance of prehistoric and historic sites across the entire country. Although such blanket coverage is unfeasible in the United States at present, localized coverage could be of use in governmental administrative offices such as those dealing with National Parks and Monuments and Natural, Historical and Recreational Areas. Circumscribed areas could be inventoried using the techniques discussed here in a fast and efficient manner, providing information for resource administration and management.

Just as importantly, remote sensing holds promise as a data collection and measurement device for the archeological scientist. As will be demonstrated in the study which follows, there are many ways in which the variables that affected the behavior of past people, as well as the products of this behavior itself, can be observed and measured using remote sensing methods. In many cases, it can be argued that such observation and measurement are more efficient, faster and ultimately more useful than data gathered by traditional archeological methods.

This report is presented in three parts, the first of which is a general statement concerning the utility of remote sensing methods and techniques to a number of present and future archeological necessities. This discussion is couched in terms which will hopefully render it informative to the archeologist and the planner interested in costs and products in a more utilitarian sense.

The second section of the present report deals more specifically with the evaluation of research, methodological experimentation and fieldwork carried out at the Chaco Center in Albuquerque and at Chaco Canyon. The role of remote sensing techniques and the data derived thereby in these Chaco Center efforts is examined and the comparative value of different approaches discussed.

One of the most promising remote sensing "tools" for the archeologist today is photogrammetric mapping. In the third section of this report, special attention is paid to differences in product, speed, accuracy and cost between traditional on-the-ground mapping efforts and aerial techniques oriented toward the same end.

Although the following report is phrased in terms of the utility of remote sensing in archeological science and cultural resource management, we would like to stress our belief that such methods are valuable in many of the same ways in anthropology, biology, geology, and many other social and natural sciences. In an age when academicians, scientists, conservation interests and government seem to be cooperating with increasing success in bringing together knowledge and concrete action, remote sensing may provide one of our broadest and most useful technical aids.

LBJ
JBB

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PART II: APPLICATIONS OF REMOTE SENSING TO ARCHEOLOGY: JUSTIFICATION, IMPLEMENTATION AND FEASIBILITY

BY

LYNN B. JORDE

The first section of this report will examine potential applications of remote sensing to archeological fieldwork, management and data collection in general. Some of the applications discussed have already been used with varying degrees of success; others have yet to be implemented. For each suggested application, three factors will be considered: the justification for use of the application (i.e., how it will benefit the archeologist), the implementation of the application (the actual techniques required), and the feasibility of the application. Feasibility will be evaluated in terms of costs and returns, citing actual costs and time requirements when possible. Obviously, it is not yet possible to give precise cost-time analyses for the untested applications.

Detection of Cultural Features

For many archeologists, detection of cultural features is the goal of remote sensing in archeology. Any work devoted to the history of archeological remote sensing (e.g. Reeves, 1936; Crawford, 1954; Deuel, 1969) is replete with examples of cases in which archeologists were able to locate sites and other man-made features by using aerial photography. The justification for the use of remote sensing for this purpose is hardly necessary: one of the first things the archeologist must know is where sites are located. This information in itself can be valuable for studies in locational analysis and settlement pattern. Given the current emphasis on viewing archeological sites in a broad regional context (e.g., Plog and Hill, 1971; Gumerman and Kruckman, 1974), the "synoptic overview" offered by aerial photography is of great value.

Traditional methods of feature detection

Three types of indicators have been used traditionally to locate cultural features on the landscape: shadow marks, soil marks, and crop marks. Shadow marks are simply the shadows produced on the landscape by the slight differences in the height of the ground surface which result from the presence of cultural features. According to Solecki (1957), these are best photographed just after sunrise or just before sunset to accentuate shadows. "Low oblique" photographs, those in which the apparent horizon is not shown, should be taken with the camera oriented so that shadows are facing it.

The second traditional method of detection, the delineation of soil marks, relies on the fact that human activity almost invariably disturbs the soil to some extent. In some cases, particularly when large architectural sites defined here as sites which have some visible remaining architectural structure, such as pueblos are involved, this disturbance of soils is preserved for centuries, but is often visible only from the air. Solecki (1960) notes that soil marks are most helpful for site detection in arid climates, and Martin (1971) points out that soil marks are much more visible on some types of soils, such as chalk and gravel soils, than on others (e.g., loess and loam).

Crop marks, the third traditional form of detection, were noted to occur over prehistoric sites by observers as early as the sixteenth century (Fagan, 1959). These marks consist of noticeable differences in vegetation patterns resulting from past human activity. They can be either "positive" (when disturbance has caused a higher amount of nutrition and/or moisture to exist -- a prehistoric canal, for example) or "negative" (a lower amount of nutrition and/or moisture occurs -- above a masonry wall, for example). Riley (1946) presents a more detailed description of these principles. Generally, crop marks tend to be more prominent in dry weather, since lack of moisture causes the roots of plants to strike deeper into the soil, increasing the chances of their coming into contact with subsurface prehistoric features. Cereal grasses appear to be the best types of plants for discerning crop marks (Solecki, 1960), while porous soils, due to their low water retention capacity, are the most promising types of surface for emphasis of crop differences (St. Joseph, 1961).

Crop marks and soil marks can often be distinguished quite adequately with black-and-white photographs of a scale of 1: 20,000 (Harp, 1968). The cost of purchasing existing stereo-paired photographs at this scale (such coverage has been made over 95 percent of the United States) is only 12 cents per square kilometer (Colwell, 1972), while the cost of having this type of coverage flown by a contractor runs generally from $2 to $12 per square kilometer, depending on the scale of the imagery (Colwell, 1972). It seems clear that, in terms of amount of information and cost, these are both extremely valuable and feasible methods of obtaining a great deal of important information economically.

<u>Site detection using infrared photography and thermal infrared scanning</u>

Both "near" infrared (IR) radiation (detectable photographically) and "thermal" infrared radiation (detectable only with special scanners or radiometers) are invisible to the naked eye. Near infrared radiation is contained in the 700 to 1000 nm. wavelength range while thermal infrared radiation extends from 1000 nm. to 1,000,000 nm. A lucid and more detailed discussion of these aspects can be found in Holter (1970) and Holz (1973).

Generally, near infrared photography is taken with color infrared film (Ektachrome Infrared Aero Film) and black-and-white infrared film (camouflage detection film). Usually, a Wratten 12 or 15 filter is used to block out radiation in the blue range, resulting in photographs portrarying the green, red, and near infrared parts of the color spectrum. Since the short blue wave lengths are screened out, and the longer infrared rays recorded, near IR photography is valuable for penetrating atmospheric haze.

Color infrared offers an advantage in feature detection in that it emphasizes differences in plant growth. Vigorous plant growth above a site (see "crop marks", above) is thus emphasized due to the higher water content of the leaves of the more vigorous vegetation. Also, differential retention of water by various types of soils (e.g., water-absorptive adobe walls, etc.) can sometimes be shown on near IR photos, particularly after a hard rain (Cameron, 1958; Hoffer and Johanneson, 1969).

Color IR photography has been used by a number of archeologists, with varying degrees of success reported. Tartaglia (1974) found color IR to be the best type of emulsion available for site detection, and Strandberg (1967b) notes its value in distinguishing cultural from natural features. Harp (1968), however, feels that color IR is no better than panchromatic photography for site detection, a result which agrees with a major evaluation undertaken by the Itek Corporation (1965).

Thermal infrared scanners can detect slight differences in the thermal radiation emitted from objects on the ground. While the resolution of thermal IR imagery is not as good as that of photographic imagery, Holter (1970, p. 80) reports that recent developments have improved the quality of thermal IR to such an extent that it now "approaches photographic quality."

For archeologists, the potential value of thermal IR stems from the fact that "thermal imagery of soils has the unique characteristic of being influenced by subsurface characteristics" (Myers, 1970, p. 291). Such things as underground masonry walls, due to higher heat emission, will register on an IR scanner (Gumerman and Neely, 1972). Since the most important single factor in determining soil temperature is water content (Myers and Heilman, 1969), thermal infrared scanners are also able to sense the lower temperatures of water-retentive underground structures. Schaber and Gumerman (1969) used an IR scanner to locate prehistoric agricultural fields near Sunset Crater in Arizona. These fields showed up better on thermal IR imagery than on conventional photographs due to their location in an area high in volcanic ash content. Matheny (1971) has suggested that thermal IR scanners be used to find underground charcoal lenses associated with archeological sites.

In spite of these applications and the enthusiasm expressed in other papers (e.g., Gumerman and Kruckman, 1974), it should be pointed out that the utility of thermal infrared imagery in finding cultural features is not yet firmly established. Schaber and Gumerman's work was done in a rare type of setting (below a recently active volcano), and Matheny's suggestion is probably impractical in view of the many possible sources of distortion (recent forest fires, recent campfires, etc.). The cost of a simple thermal scanner, while it has decreased from $50,000 for a basic Bendix scanner in 1969 (McCullouth, et al., 1969) to $25,000 in 1973 (Legault, 1972), is still prohibitive enough to substantiate Hammond's (1971) opinion that it is too expensive for the archeologist. The possibility of renting or borrowing one of these machines exists, however, since many Forest Service agencies use them to detect forest fires. Military air bases also employ very sophisticated (and often classified) thermal IR equipment. The archeologist who feels that thermal IR imagery could be of benefit in feature detection should probably consider these sources before requesting funds to buy his own scanner.

Feature detection by presence of nonindigenous plant species

Several archeologists (Matheny, 1962; Linton, 1961) have made use of the fact that prehistoric cultural disturbance of an area sometimes leaves its traces in the form of specific plant species growing in the vicinity. Examples of such types of plants are the "squaw bush" in the Southwest (Lyons, personal communication, 1974) and the "Gumbo Limbo" tree in the Southeast (Anonymous, 1969). The Gumbo Limbo tree was used for posts in prehistoric stockades; the posts often developed roots to become trees.

Occasionally the presence of such plants can be detected with panchromatic (black-and-white) photographs; however, detection from the air of the slight tonal differences caused by these plants are often enhanced through the use of color or color infrared film, which, according to most authorities is superior to panchromatic film for discerning differences in vegetation types (Gumerman and Lyons, 1971). Taking into consideration the small number of sites on which these plants occur in numbers great enough to be visible from aerial platforms, the conclusion reached here is similar to that of the Itek Corporation study (1965); for most projects involving feature detection, the added expense of using these films is not warranted by the small amount of additional information they produce.

Site pattern recognition

While the above methods of site detection are valuable mainly for locating architectural sites, many sites have no architectural manifestations and modify the environment so slightly that their existence cannot be discerned directly from an aerial platform. The presence of such features often can be inferred indirectly, however, since as more than one archeologist has noted, "...knowing the physiography of a region can help the archeologist to predict where cultural features might be" (Lyons, Pouls, and Hitchcock, 1972).

One aspect of physiography which can be very helpful in predicting site location is the distribution of water sources. A number of workers have been able to detect ancient beach lines with aerial photographs (Lyons, 1969; Agache, 1964; Linton, 1961). Another type of water resource which can be found with aerial photographs is fossil springs, since these often cause increases in plant vigor (Gumerman, 1971a).

In addition to studying water resources, archeologists have incorporated aerial analysis of landforms into their methods for locating sites (Judge, 1973; Dawson and Judge, 1969), thereby further increasing predictive abilities. By including the factors cited by Butzer (1964) (presence of caves, alluvial deposits), accuracy of prediction could be improved even further.

A mathematical method which could be used to predict economically the probability of finding cultural features in a given location would be multiple regression. As independent (predictor) variables one would use the above factors. In addition to these, one could use proximity to lithic resources, amount of arable land within a given radius, amount of topographic relief, and total available water within a given radius. The dependent (predicted) variable would be the probability of having a site located in the area studied, or, if the researcher desires, the density of sites in a given area. This method has yet to be implemented. The advantage of employing it as a research tool would be that all of the above variables can be calculated using remote sensing data acquired in the form of inexpensive panchromatic photographs.

Site pattern recognition as a means of site prediction appears to have great (and as yet unrealized) potential for archeology. In addition to being useful both for architectural and non-architectural sites, most physiographic photo interpretation can be carried out using relatively small-scale panchromatic photos, making it highly feasible from an economic standpoint.

Ecological Studies

"Most archeologists who use air photos today are still mainly concerned with the simple recognition of architectural plans on the ground surface and the location of relatively complex occupation sites. We have not yet attained that degree of sophistication which can exploit the holistic relationship of the cultural landscape and the natural landscape" (Harp, 1966, p. 727).

This quotation summarizes elegantly a major obstacle: most archeologists simply do not realize the full potential of remote sensing. While site detection is indeed a worthwhile application, it is far from being the only archeological purpose which is served by remote sensing. The remainder of this paper is devoted to a discussion of the many facets of archeology beyond site detection which are being studied using remote sensing techniques.

The importance of the "ecological perspective" in understanding culture has been recognized for some time by archeologists (e.g., Clark, 1952) and is now taken for granted by most (Watson, LeBlanc, and Redman, 1971). Since culture is best defined as man's nonbiological means of adaptation to his environment (White, 1959), the archeologist must, in order to understand culture, understand the environment to which culture allows man to adapt. As will be shown here, remote sensing techniques can be valuable tools in aiding the researcher to understand the environment and the relationship between it and man.

Mapping of vegetative zones

For the reasons given above, it is becoming increasingly common for the archeologist to study not only the immediate sites of past human activity, but also the surrounding vegetation (e.g., Flannery, 1965, 1968; Gorman, 1972). While this traditionally has been done by means of ground surveys, a great deal of evidence is available to support the position that this can be done more quickly, accurately, and economically using remote sensing techniques. Ecologists have been using aerial photography for some time in the mapping of environmental zones and plant communities (Poulton, Schrumpf, and Garcia-Maya, 1971; Benson, 1971; Colwell, 1971). The consensus is that the best single type of film for this purpose is color infrared film, although vegetative mapping of Chaco Canyon has shown that color Ektachrome film also yields encouraging results.

A few archeologists have also come to realize the value of remote sensing for vegetation mapping (Gumerman and Lyons, 1971; Gumerman and Kruckman, 1974). Gumerman and Neely (1972) used aerial photos to map microenvironmental zones in the Tehuacan Valley which had been previously surveyed on the ground by Flannery (1967). They achieved "100 percent accuracy" in identifying the zones and were able to map all of them in only a few hours.

These archeologists, and others who have worked with vegetation mapping, also recommend color IR as the best single film. However they agree that panchromatic photos should also be taken, since occasionally these reveal features (especially cultural ones) which are not observable on the color IR photos.

In terms of cost, it would appear that the added expense of obtaining color infrared coverage of an area would in many or most cases be justified, since this procedure is much faster and requires fewer personnel than traditional on the ground ecological surveys.

While in the above examples single photo images were employed to map vegetation zones, increasing attention is being given to the use of multispectral "color composites", particularly by students of ecology, forestry, and agriculture (Peterson, et al., 1969). Basically, multispectral imagery involves taking several pictures of the same object simultaneously, each of the shots being exposed to a different portion of the color spectrum (e.g., one each to blue, green, red, and infrared). Either a system of multiple cameras is used (Whittlesey, 1972) or else a more sophisticated, and usually more accurate, multiple-aperture camera is used. Some of the multiple-aperture systems currently in use contain up to thirty apertures, thus separating the region from 400 to 1000 nm. into thirty separate sections (Polcyn, et al., 1969). Colwell notes that "...although four bands are sometimes better than three and occasionally five bands are better than four, a still further increase in the number of bands yields little additional information" 1970, p. 185). Ross (1973) agrees with this position.

Once the images have been taken, they are viewed with an "additive color viewer", an instrument which overlays the several images, resulting in a composite image which includes the entire photographic portion of the spectrum, if desired. The principal advantage of this technique is its flexibility: certain portions of the spectrum can be omitted from the composite, and the hue, saturation, and brightness of each exposure in the composite can be adjusted by using lamps and filters in the viewer. This allows the worker to emphasize features which show up best at certain wavelengths and with certain types of illumination (such as certain plant species or certain types of cultural features). Also, sources of distortion (haze, etc.), which show up only at certain wavelengths, can be easily deleted. Using this technique, the researcher can, through different combinations, view natural color, color infrared, or panchromatic photographs of the same area. More detailed discussions of the mechanics and applications of multispectral imagery can be found in Yost and Wenderoth (1967, 1968, 1969).

Experiments with multispectral photography and viewing at the

Chaco Center have been largely inconclusive to date. This difficulty stems primarily from the fact that multispectral cameras must be carefully aligned and filter factors determined in accordance with specific conditions of light and target at the time the imagery is flown; in the future, more attention will be paid to such preliminaries. Multispectral ERTS imagery has, however, been employed in the course of Chaco Canyon research and appears to be promising in delineating gross vegetational zones and other biophysiographic data important to the understanding of prehistoric settlement and subsistence.

The study of available natural resources

Increasingly, archeologists are concerning themselves with the prehistoric availability and utilization of various types of resources. The nature and distribution of available resources has exerted much effect on the behavior of past cultures, vis-a-vis technology, economy, demography, settlement pattern, social organization, and various other components of the cultural system. It is becoming quite common now to study the relationships between prehistoric man and the resources available to him. (Zubrow, 1971, 1973; Thomas, 1972, 1973). In many cases, the resource studies carried out laboriously by workers on the ground could have been done more quickly and easily from the air, using techniques already developed in other disciplines. This section examines some of these techniques.

Floral Resources. The importance of a knowledge of the approximate density of floral resources has been recognized by a number of archeologists (Butzer, 1964; Munson, Parmalee, and Yarnell, 1971; Lyons, Inglis, and Hitchcock, 1972). When studies by archeologists of present-day floral resources have been carried out in order to give some indication of past resource distribution, cumbersome ground surveys have been employed. Workers involved in forestry and wildlife management have obtained good results in calculating such quantities using aerial photographs. Colwell (1968, 1970) has calculated total vegetation volumes using multispectral imagery, while Carneggie, Pettinger, and Hay (1971) discuss the use of Apollo 9 color and color IR imagery to determine the carrying capacity of range lands in Arizona. Joy and Harris (1960) have calculated density and weight of individual plant species used for forage with color photos at a scale of 1:2000.

Another type of floral distribution which is often of interest to the archeologist is that of timber, since nearly all prehistoric cultures used timber for firewood and/or for building shelters. Foresters have long been involved in determining volume of timber from the air (Avery, 1958). Measurements such as crown area and crown height are taken from aerial stereo pairs. These dimensions are then used with tables which compute timber volume (Langley, 1971) or with multiple regression equations (Sayn-Wittgenstein and Aldred, 1972) to determine total volume of timber in an area. Colwell (1970) notes that, by using panchromatic stereo pairs, these measurements can be determined more accurately from the air than from the ground.

It can be seen that the methodology and technical skills exist for the evaluation of floral resources. The imagery required is usually fairly simple and economic and would probably be obtained by the archeologist for vegetation mapping anyway. The methods and studies presented here represent an opportunity to gather very valuable information quickly and economically.

Faunal Resources. For many reasons, the archeologist is often interested in the distribution of faunal resources. Particularly interesting is the study of available faunal resources versus utilized faunal resources (Munson, Parmalee, and Yarnell, 1971), and why differential selection of resources occurs. Several studies have been done on bison population distribution (Reher, 1970, n.d.; Frison and Reher, 1973) as well as an antelope distribution (Nimmo, 1971). These types of studies could be greatly facilitated by some of the techniques utilized in wildlife management. Leedy (1960, 1968) has used panchromatic and color aerial photographs to study the migratory patterns and population sizes of musk ox, caribou, and some types of birds. As an indication of the accuracy that can be achieved even with small-scale photos, Colwell (1970) reports being able to distinguish cows from sheep on panchromatic photographs of a scale of 1:20,000. Even fish populations can be counted and mapped using aerial photography, as reported by Eicher (1953). For nocturnal animals, Thackrey (1973) recommends the use of thermal IR scanning.

The archeologist interested in studying modern faunal distributions as a guide to patterns in the past can use remote sensing, then, with at least some degree of success assured. Since only medium-scale panchromatic photographs are really necessary for most such studies, the study of faunal census and migratory patterns would not be prohibitively expensive. In fact, much of the information needed for such a study would be contained on photographs already taken for other purposes (e.g., vegetation mapping, site detection). The use of thermal IR carries the same restrictions mentioned above - the resolution does not necessarily permit the discrimination of species (McCullough, et al., 1969), and the necessary equipment is expensive.

Water Resources. The distribution and availability of water is probably the single most important factor in determing past human behavior. Much valuable information about cultural adaptation can be obtained by studying the relationships between water distribution and site distribution, density, and type.

For mapping present-day drainage systems, aerial photography is considerably faster and requires fewer personnel than ground study methods. It is also much more accurate than standard topographic maps (Sternberg, 1961). Color infrared photography is usually recommended for hydrological studies, due to its ability to discriminate moisture patterns (Parry and Turner, 1971; Strandberg, 1967b). In addition to studying modern drainage systems, aerial photography can be used to study fossil springs and prehistoric lakes and seas, as mentioned above.

Remote sensing is quite feasible for archeological studies of drainage patterns, since fairly simple imagery (panchromatic and perhaps color IR) is sufficient. Most hydrological studies can in fact be carried out adequately using the 1:20,000 scale photographs which are usually readily available at low cost.

Lithic Resources. Since prehistoric men used lithic materials both for tools and for building shelter, knowing the location and extent of these resources is of great potential value for the archeologist. Agache (1964) reports success in identifying the jagged outlines of French Paleolithic quarries, while Kedar (1958) maintains that aerial photographs were the only means that enabled him to distinguish natural escarpments from man-made quarries. While panchromatic photos can be used for discriminating rock types, geologists agree that natural color exposures are superior for this purpose (Tator, 1960). Ballew (1969) has added a bit more sophistication to rock-type discrimination, using multispectral imagery combined with multiple discriminant analysis to delineate different kinds of rocks. This is probably the most accurate method thus far employed.

Pedological Resources. Knowing the types of available soils can be of great aid, particularly to the archeologist studying prehistoric agriculture. An analysis of what types of activities tend to occur on various soil types could yield valuable information in terms of environmental adaptation.

Generally, either color exposures (Tator, 1960; Ware and Gumerman, 1974) or multispectral imagery are recommended for optimal delineation of soil types (Yost and Wenderoth, 1969; Polcyn, et al., 1969). Frost (1960) feels that a scale of 1:10,000 to 1:20,000 is usually adequate for this purpose.

While the study of the distribution of soil and rock types would almost certainly involve some of the more expensive imagery (color or multispectral), there are archeological situations in which such information would be quite useful. In such situations, remote sensing is a viable technique, although its superiority over ground surveys in this area has yet to be unquestionably proven.

Agricultural Fields. While most of the above discussion deals with the effect of environment on man, this section will deal with one very important facet of man's effect on the environment - agricultural fields. While a few archeologists have expressed interest in the distribution and area of prehistoric fields (e.g., Adams, 1962; Parsons, 1968), such interest has not been widespread, due perhaps to an inability to delineate fields from a terrestrial perspective. Several archeologists working with aerial photos have reported considerable success in finding and measuring fields. Parsons (1969) used aerial photography to find ridged fields in Eduador. While he was able to find these fields quite easily from the air, "from the ground they are not easy to detect...." (Parsons, 1969, p. 79). Kedar (1958), working in southern Israel, was able to map "all" of the 2000 year-old agricultural fields in his study area, using panchromatic stereo pairs. In addition, he was able to show an interesting positive correlation between field size and the size of catchment basins (also measured using aerial photographs). Schaber and Gumerman (1969) used thermal IR imagery to find agricultural fields in Northern Arizona which had been previously unobservable.

While it is interesting to know the location and size of agricultural fields, one must be able to link them to a certain period in time in order to make meaningful interpretations in terms of the fields and the people who farmed them. Indeed, the lack of ability to discriminate between abandoned fields less than one hundred years old and those used centuries ago is the cause for a great deal of pessimism regarding the study of agricultural fields. Gumerman (1971a), however, has devised a relative dating method for fields in the Tehuacan Valley, using differential densities of vegetation as an age indicator. Also, Pouquet (1968) used thermal IR scanning to date alluvial deposits in the Nile River Valley, making use of the fact that older deposits accumulate a higher humic content, raising their water absorption capacity and thus causing them to emit less thermal radiation. With these dating methods, and others yet to be developed, the problem of temporally pinpointing fields may be solved using remote sensing methods.

Knowing the location and extent of agricultural fields, the archeologist can begin to explore many interesting relationships. By comparing the total amount of arable land (measurable on air photos) with the total area of agricultural fields, a measure of utilization intensity can be derived. By measuring distances from fields to the nearest human settlement, one can determine how far people were willing to travel to farm, a measure of the importance of an agricultural way of life. Adams (1962), working on the Khuzestan Plain in Iran, was able to show that the prehistoric population there was undergoing considerable economic stress, since they were utilizing even small, very marginal areas for agriculture.

By measuring soil fertility with multispectral imagery (Carneggie, Pettinger, and Hay, 1971; Polcyn, et al., 1969), the archeologist could determine how efficient an agricultural system was with respect to land use, ie., whether the most fertile areas were being most heavily exploited and whether settlements tended to locate more closely to fertile areas.

An interesting instance of the utility of remote sensing data in the inspection and analysis of prehistoric irrigation systems is provided by work carried on since 1970. For many years it was acknowledged that grid-shaped irregularities in vegetative vigor probably due to prehistoric agricultural fields and canals could be noted on the alluvial floor of Chaco Canyon by observers atop the high cliff walls. R. Gordon Vivian (1965) noted that such outlines were even more apparent from the air. Since these features were delineated primarily by vegetative differences, and since rainfall and plant vigor are highly variable in arid regions, a search was made at the Chaco Center remote sensing laboratory of imagery exposed in the past on which the outlines of prehistoric agricultural facilities could be discerned. Through the use of several different imagery types - including black-and-white, black-and-white IR, and color Ektachrome films - at least two areas of extensive irrigation features were delineated and mapped. The excavation of one of these features during the summer of 1974 revealed that the Chaco inhabitants built bordered field plots which were probably irrigated with impounded water and tilled intensively (see Loose and Lyons, this volume).

Human population size and distribution

In order to fully understand and appreciate the relationship between prehistoric man and his environment, as much information as possible must be gathered on the distribution of prehistoric populations. So much work has been done on the study of prehistoric population size and distribution (Gumerman, 1971b) that a justification of this type of study hardly seems necessary.

The estimation of population size by aerial photography will probably have to be confined to populations inhabiting architectural sites. Working with such sites, Longacre (1970) estimated population from the ground by counting the number of sites in the area he studied and the number of rooms per site. This could probably be done almost as accurately and much more easily with inexpensive panchromatic photos of an area, using common site-detection methods. In some instances, the researcher can measure room sizes from the photographs, enabling the estimate of population sizes using any of the available formulas based on floor areas (Naroll, 1962; LeBlanc, 1971; Wiessner, 1974).

Since implementation of this technique would require little expense and effort, and since it appears to have fairly high potential accuracy and validity, it is quite feasible for archeological use (see Drager, this volume).

If the archeologist could obtain information on all of the variables discussed in this "environment" section, he would have an extremely good grasp of the relationship between culture and ecology in his study area. Possibly, one set of aerial photographs could provide all of this information. While multispectral imagery, due to its flexibility and completeness, would be the ideal form of coverage for the environmental studies, other combinations (especially color IR and panchromatic stereo pairs) would certainly be sufficient. In fact, most of the pertinent information could probably be obtained with standard medium-scale (1:10,000 to 1:20,000) panchromatic photographs.

Pre-excavation Sampling and Volumetrics Studies

Sampling

It is quite common now for the archeological survey to employ a sampling design stratified on the basis of vegetation zones (Ragir, 1967). It is also quite common to use aerial photographs for the initial demarcation of the zones. Often, the easily accessible panchromatic photographs of 1:20,000 scale are used. While some of the more sophisticated vegetative mapping techniques discussed above might produce more information, it would seem that, for most survey purposes, inexpensive existing panchromatic photographs should be used. Given the low cost and high potential returns shown by previous work, this technique is indeed well worth the small expense it entails.

Considerably less work has been done on sampling only certain areas of individual sites ("intrasite" sampling), and most of this work has been done either on middens (Cook and Heizer, 1951) or on architectural sites (Hill, 1970). While sampling units in middens can simply be designated as arbitrary grids, architectural sites often are excavated using rooms as the sampling unit. Since room outlines are not always visible from the ground, the archeologist frequently must spend a week or two excavating to find the outlines of rooms before he can impose a sampling design. This is costly in terms of both time and money.

Aerial photographs, particularly stereo pairs, can often reveal very very faint outlines of walls not visible from the ground. In this case, two panchromatic aerial photographs could save the investigator much time and money. However, it often happens that room outlines are completely obscured. In this circumstance, the results of Cameron's (1958) work would be beneficial. He was able to map walls of Nova Scotian historic sites which had no surface expression by using aerial color infrared photographs. The color IR film was able to detect moisture differences between the soil above the water-retaining walls and the surrounding area.

Another possible tool for mapping walls would be thermal IR scanning, since it would sense either the decreased heat emission of moisture-laden walls or the increased radiation of heat-retentive walls.

Considering the amount of money, labor, and time which could be saved by one or two color IR photographs in mapping room outlines, this technique would be an economical way of going about the delineation of sampling units. The thermal IR is of dubious utility, however. First, the lower resolution of thermal IR images might make it altogether useless for wall mapping; second, it is quite expensive.

Volumetrics

The archeologist preparing to excavate a large site with limited time and funds will probably want a fast, accurate method of determining how much dirt he will have to move. Such a figure would tell him what percentage of the site he could excavate, as well as what kinds of excavation techniques might be necessary. Since photogrammetric mapping of sites is gaining some popularity (see below), it is possible to derive a volume estimate from a topographic map of the site. Young (1954), working with wood pulp piles, describes a measurement technique whereby the total area of the pile within each contour interval is measured with a planimeter. This area is then multiplied by the difference between the height of the contour and the height of the ground beside the pile to yield the cubic volume estimate. This is repeated for each contour interval; the sum for all intervals gives the volume of the pile. Young reports that for less than five piles, it is more economical to do the job with a ground survey crew. If five or more piles are estimated, the cost per pile of the aerial method becomes lower than that of the ground survey method. Pierson (1959) reports less than four percent error using this technique for wood pulp, ore, and coal piles.

Considering the cost of photogrammetry (discussed in the accompanying paper on photogrammetric mapping), the archeologist with a single site an acre or so in size would be better off to measure volume from the ground, unless the site had already been mapped photogrammetrically. For larger sites, however, this method could serve as a comparatively inexpensive and very time-saving means of determining volume.

Another possible use of this technique would be the measurement of trash mound volume in relation to population size, since this, according to Ebert, Hitchcock and Lyons (1974), may be an indication of "social affluence". Again, if only a few small trash mounds are to be measured, this technique would be impractical. Only if the sites had already been mapped, or if many large trash mounds were being studied would this technique be feasible.

The most immediate use of volumetrics determination at Chaco Canyon will be made in conjunction with planning the excavation of Pueblo Alto, which is scheduled to start in 1976. Excavating a large architectural ruin poses problems not only in regard to sampling and analytical strategy, but in the area of simple physical contingencies as well; thousands of cubic yards of dirt must be dug, sifted, and moved to a location where they will not interfere with subsequent work. In the case of the Pueblo Alto excavation, it is expected that accurate volumetric estimates will provide a means of determining how much work must be done, how labor and time should be budgeted, and how many seasonal "phases" a coherent research project there will require.

General mapping of sites and surrounding area

Since a separate paper dealing with the costs of aerial mapping is included in this report, this section will cover only those aspects of mapping not previously discussed.

While photogrammetric mapping of sites is undoubtedly the most accurate available mapping method, various other procedures have been used successfully to make maps from air photos. Willey (1959), for example, obtained maps of site plans by projecting transparencies of panchromatic aerial photos on a screen and simply tracing the site outlines on paper placed on the screen. He found these maps to be more accurate than compass-chain maps and somewhat less accurate than plane-table maps. For his purposes, the approximate two percent error he cites for this technique was tolerable.

Matheny (1971) was able to prepare a planimetric map (no contours) of a Mexican jungle area in two hours; mapping this same area had taken a ground crew two months. Solecki cites a similar example from the Near East: aerial photography produced accurate maps quickly, while ground survey proved to be "too slow, expensive, and inadequate" (1960, p. 729). Collier and Vogt, involved in ethnographic fieldwork in Mexico, report that "the (aerial) photographs allow us to construct maps as accurately and completely as we might by surveying and sketching at a site itself with much greater expenditure of time and effort" (1965, p. 2). Aerial photographic maps are not always optimal, however. Harp (1974), working with small, widely dispersed hunter-gatherer sites in the Arctic, finds ground mapping to yield more information with less output of time and cost than aerial mapping. The above evaluations would seem to indicate that aerial mapping is best suited to larger sites which are spaced closely together.

Photogrammetric mapping may be one of the future archeologist's most valuable tools for the planning of excavations and analysis of large architectural sites. Experiments now in progress at the Chaco Center, which will be discussed in greater detail in the second part of this report have shown that Chaco Canyon pueblos can be mapped far more accurately and economically by such methods than was possible from the ground.

Phase mapping

This type of mapping involves taking stereo photographs of a site while excavation is in progress. Since the photographs are taken at designated intervals in the excavation (every six inches in depth, for example), the need for time-consuming extensive manual recording of the vertical and horizontal positions of artifacts is all but eliminated. This technique offers the advantages of permanent, easily accessible, and very accurate recording of information and the virtual elimination of laborious paper work on the site. Very few archeologists have experimented with this method of data recording. At the Jones-Miller site, a bison kill site in northeastern Colorado, workers are reporting success using photos taken from a tripod (Stanford, personal communication, 1974). In a situation such as a bone bed, where spatial relationships are of great importance, phase mapping can be of great value.

There is currently some question as to which type of aerial platform would best serve the purpose of phase mapping. Each platform will be evaluated here.

Airplanes. In certain instances, the use of airplane platforms in archeological phase mapping may be useful. Since the cost of individual flights in an airplane is considerably more than the repeated use of a more permanent platform (see below), such photography would probably not be attempted after the clearing of individual excavation units within a site. It could, however, be employed reasonably several times during the excavation of a large architectural site to provide a basis for whole-site mapping of overlapping structures.

Helicopters. Helicopter platforms are even more costly to use than airplanes in the acquisition of imagery; other drawbacks include extreme vibration and the fact that at low altitudes, the blades stir up large quantities of dust (Colwell, 1956). In some cases, however, the use of helicopter platforms can certainly be justified; experimentation currently in progress at the Chaco

Center should help to determine the feasibility of using a helicopter to obtain low-angle oblique stereo photographs for use in architectural photogrammetric mapping.

Kites. Bascom (1941) used a camera attached to a box kite to map archeological sites. While this may work under perfect conditions, control is difficult.

Balloons. The use of tethered balloons to photograph archeological sites is not new. Guy (1932), working in Palestine, was probably the first archeologist to successfully use a tethered balloon. More recently, Whittlesey (1967, 1970) has patented a 600-cubic-foot hydrogen-filled balloon and camera apparatus. This appears to be one of the more promising tools for phase mapping, and also for large-scale site maps. Certain problems are encountered with tethered balloons, however. Wind fluctuations make it somewhat difficult to obtain stereo pairs (Lyons, personal communication, 1974), and the 150 to 1000-foot camera altitude usually used for balloon photography make it more suitable for more general photographs of entire sites than for photos of individual rooms or grids. Whittlesey's balloon and camera mount was flown over a number of archeological sites and features at Chaco Canyon in May, 1974; a remotely controlled Hasselblad EL 500 suspended by a gimbal mount provided black-and-white and color imagery of excellent quality in a 70 mm. format. The balloon proved a versatile and steady platform for photography between heights of about 5 meters and as much as 1000 meters, although there was some difficulty in obtaining parallel-format stereo pairs as indicated above.

Bipods. Also developed by Whittlesey (1966a, 1966b), the "bipod" consists of two aluminum poles assembled as an A-frame, with a platform near the top of the structure to support the camera. Two guylines support the frame. The poles of a bipod recently made available by Whittlesey can be extended so that the camera can be positioned up to 5 meters above the ground. By moving it a predetermined distance (two or three persons are required to manage it), controlled stereo pairs can be taken. The weight of the instrument is 10 pounds, and it sells for about $80. With Whittlesey's cooperation, the Chaco Center is currently testing the feasibility of this bipod for archeological use; results are so far encouraging.

Tripods. These can be used in much the same manner as the bipod. Silva (personal communication, 1974) recommends them over bipods, since measurement of the triangle formed by the three legs allows precise determination of the vertical and horizontal location of the camera and hence greater photogrammetric accuracy. With the bipod, a plumbob, which is rather unstable in windy conditions, is used to do this.

Other Platforms. Cherry pickers have also been suggested as a suitable camera platform (Colwell, 1963); their considerable weight, however, makes them impractical for most archeological use. Colwell (1963) also suggests the use of overhanging cliffs and ledges. Where these exist (above cave sites, for example), they could be quite practical as aerial platforms.

It seems apparent that, for detailed phase mapping, either a bipod or tripod platform would be most feasible. For a more general view of the site plan, a tethered balloon would be of greater value. Results of the ongoing research by Whittlesey and the Chaco Center should shed additional light on this equipment vis-a-vis its potential saving of time and labor over traditional recording methods.

Preservation of Cultural Resources

The Federal Government is developing an increasing realization of its responsibility to protect and preserve the nation's historical and archeological resources (Scovill, Gordon, and Anderson, 1972). Some of the ways in which remote sensing can aid in exercising this responsibility are discussed in this section.

Environmental impact studies

The environmental impact study, from an archeological viewpoint, determines the nature and extent of damage that will be done to the archeological resources in an area about to be modified by human activities (power plant and dam construction, strip mining, road building, etc.). Aerial photographic surveys could be especially useful in the "preliminary survey" phase of these studies. By aiding in the detection of sites, it could be of value in indicating those areas in which additional "intensive survey" by a ground crew might be required. If "mitigation of impact" is to be carried out by the archeologist (i.e., excavation of sites), remote sensing could aid in both intra- and intersite sampling and in the calculation of volumetrics to allow the archeologist to make an accurate estimate of the amount of time, money, and labor needed to carry out mitigation of impact. The chief advantage of remote sensing techniques in this area is its appreciable saving in time, which is often of the essence in these types of situations.

Mention should be made of the possibility of doing "mitigation of impact" work after an area has been flooded. Jewell (1961) used aerial photographs to map the locations of sites in California flooded by a dam. While this can be done in a few cases, it obviously is not recommended as the usual course of action.

The value of complete aerial photographic documentation of an area before it is modified or destroyed has been recognized by both archeologists (Ebert, 1974) and historians (Harrell, Crawford, and Peplies, 1966). Fowler (1974) has already made use of aerial photographs taken years ago of a part of Cahokia now covered by a housing subdivision. As the destruction of the natural landscape increases, such photographic coverage will become invaluable. Indeed, one should strive for the best possible photographic coverage of these areas, (multispectral imagery, when possible), in order to preserve a maximum amount of information for future researchers.

Management of archeological resources

Aerial photographs can be of definite value in making rapid surveys of the general condition of archeological resources. The Bureau of Land Management recognizes their value in detecting sites that have been "potted" (Flynn, personal communication, 1975). If photographs are available in sequence over a period of years, the effects of destructive agents, both natural and human, can be assessed, allowing officials to determine what kinds of protection and stabilization are necessary.

Determining optimum locations for building, facilities, etc.

Many areas which contain archeological resources (e.g., National Monuments) must also contain various types of public buildings and facilities. Aerial photographs, since they provide an excellent overall view of the area, can aid in planning the location of these buildings so that archeological resources are not disturbed, and so that visitors to the area can derive maximum appreciation of these resources, while the site incurs minimal disturbance and destruction. A number of workers have used aerial photos in planning various types of outdoor recreation areas (Colwell, 1950; Wilson, 1960; Dill, 1963). In all cases, they found a few simple black-and-white photographs to be of great utility in providing the synoptic view of the area necessary for efficient planning.

For most of the purposes outlined in this section, panchromatic photographs would easily be sufficient. Since acquisition of these photographs is quite inexpensive, they would represent a good investment in most cases. When an area is threatened by a construction or mining project, officials should consider it imperative to obtain the very best and most complete photographic coverage possible. Maps and drawings portray only the information thought to be relevant by the persons responsible for them; researchers of the future may find some other type of information to be pertinent. Only high-quality photographs can secure the complete and precise record needed to insure that as much information as possible is preserved for future analysis.

Ethnographic Research

While this study is concerned with archeological applications of remote sensing, the very important role of ethnographic analogy in archeology is receiving increasing recognition by archeologists (Chang, 1967), especially as a means of deriving hypotheses to be tested by independent archeological data (Binford, 1967). This section will briefly discuss some of the archeologically relevant work being done with remote sensing in ethnography.

Many of the cultural-environmental relationships discussed above could be studied ethnographically (e.g., floral and faunal biomass, water availability) using aerial photography. A few ethnologists have recognized this potential (Collier, 1967), but most are as yet unaware of the many possible benefits of remote sensing for cultural-ecological research.

One area of study in which ethnographers have taken advantage of remote sensing is that of land use patterns. Such things as field sizes, distances from villages to fields, and the intensity of utilization of various areas for agriculture have been profitably studied (Denevan, 1963; Stokes, 1950; Vogt, 1969). Archeologists, too, have evinced an interest in the ethnographic study of land use patterns using remote sensing techniques. Lyons, Inglis, and Hitchcock (1972) have proposed that photographs taken from space platforms could be used to monitor the locations of smoke plumes resulting from "slash and burn" (swidden) agriculture, and to see how the locations change through time.

The estimation of population size has also been carried out by ethnographers using aerial photographs (Schorr, 1969; Hackenburg, 1967). It would be most interesting to compare population estimates derived in this manner with estimates derived using the floor-area population estimation techniques cited above. This could be done quite easily, for example, by using Stubbs' (1950) aerial photographs of most Southwest pueblos and comparing known populations for 1950 with populations computed using floor-area formulas.

Finally, it should be noted that Vogt (1968) has made use of remote sensing for ethnographic analogy in archeological interpretations. By studying the land-use patterns of the present-day Zinacantecos of Chiapas, Mexico, he was able to propose models for land use among the prehistoric Maya.

Great potential exists for deriving models of cultural behavior through the application of remote sensing techniques to ethnographic field research. Both the archeologist and the ethnologist could benefit immeasurably from information obtained this way.

"Miscellaneous" Applications

This section will discuss a few additional applications of remote sensing which, while of potential value, could not be suitably treated in previous sections. The first of these is the use of radar imagery. The radar system is an "active" sensor (i.e., it receives signals which it generates itself, as opposed to "passive" systems, which are designed only to receive naturally emitted or reflected radiation). Since radar uses relatively long wavelengths (.90 cm. to several meters), most forms of atmospheric disturbance, such as clouds, fog, and rain, do not affect radar sensors. In fact, radar can sometimes be used to penetrate forest canopies. Sidelooking airborne radar (SLAR) has been used to map parts of Panama previously unmapped due to constant cloud cover (Viksne, Liston, and Sapp, 1973). Stereo radar images are now available (Dellwig, MacDonald, and Kirk, 1970), allowing topographic contours to be plotted from radar images. Since over four million square miles of the earth's surface is covered by clouds almost continuously (Crandall, 1969), and since "most archeologists will agree that it is important to obtain a good topographic base map from which to work" (Lyons, Pouls, and Hitchcock, 1972), radar may have some utility for the archeologist in some cases.

Two major problems are encountered in using radar: (1) the resolution, as yet, is rather poor, so only small-scale maps (e.g., 1:100,000) can be prepared; (2) radar is still extremely costly. The only way the archeologist could make use of it economically would be to borrow images previously acquired for other purposes.

"Terrestrial photogrammetry" is a technique used by some architects which has possible uses for the archeologist. This technique involves taking stereo pairs of archeological ruins at a horizontal angle while on the ground and using these images to make three-dimensional maps of the site. It has been proposed that such a permanent and accurate record of the site (wall dimensions, etc.) would be valuable and that persons interested in ruin stabilization could make use of the precise measurements obtained this way in determining which parts of the site are in greatest need of repair.

While the concept is interesting, digitization and stereo plotting are quite expensive for relatively small sites (see Section III). From a horizontal perspective, a set of simple photographs is often a sufficient record of the site; most stabilization workers can detect bulges and other types of weaknesses in walls without the use of terrestrial photogrammetric techniques.

Buettner-Janusch (1954) has made use of black-and-white infrared photographs to map stratigraphic profiles in the excavation of a rock shelter in Illinois. He reports that stratigraphy visible on the infrared photos could not be discerned on panchromatic photographs. The high contrast properties of infrared film and its sensitivity to moisture content should make it valuable in much stratigraphic work. Since photographs of profiles are usually taken, the archeologist would probably do well to take infrared photos as well, especially if the stratigraphy is complex and difficult to interpret.

Several researchers have noted the value of aerial photographs in planning surveys: (Miller, 1957; Kedar, 1957). Travel routes, rendevous locations, water sources, and campsites can often be seen more easily from aerial platforms. Since panchromatic photographs of medium scale are sufficient for such purposes, this application is very practical for the survey archeologist.

Considering the increasing amount of attention being devoted to underwater archeology (Bass, 1966), mention of the role of remote sensing in this area is pertinent. As noted above, Jewell (1961) has mapped site locations in an area inundated by a dam. Baiae, an ancient Roman city submerged under thirty feet of water, was mapped in its entirety using aerial photographs (Solecki, 1960). Mapping of archeological features is not necessarily confined to bodies of still water: Strandberg and Tomlinson (1970) mapped prehistoric fish traps in the Potomac River using panchromatic 1:10,000-scale photographs.

Underwater archeological work has thus far been confined to bodies of comparatively shallow water. Natural color film (Smith, 1963) or multispectral imagery (Colwell, 1961) can penetrate up to 70 feet in still-standing water, while a new two-layer emulsion developed by Specht, Needler, and Fritz (1973) can penetrate still bodies up to 100 feet and turbid water up to 30 feet. For the underwater archeologist interested in stereo photogrammetry, it should be noted that Harris and Umbach (1972) have developed a method to plot stereo maps of underwater objects.

It can be seen, then, that the underwater archeologist has a sizeable arsenal of tools, which, compared to the traditional employment of scuba divers to laboriously and awkwardly map underwater features, is accurate, fast, and economical.

Summary

Traditional methods of site detection were discussed, and it was concluded that inexpensive panchromatic photographs of medium scale would suffice to detect sites using these methods. The use of color infrared imagery to detect the presence of nonindigenous plants and the use of thermal infrared scanning for site detection were discussed; the conclusion was reached that, for simple site detection, the added cost of these types of imagery is not justified by the slight increase in detection capability they might offer. The use of site pattern recognition for predicting the location of both architectural and nonarchitectural sites was discussed. This technique, particularly if used quantitatively, offers great potential for archeological studies and can in most cases be implemented satisfactorily with panchromatic photographs. For site detection, then, the archeologist should usually use nothing more expensive than panchromatic photographs.

One of the great and as yet unrealized potentials of remote sensing is the study of the relationship between prehistoric man and his environment. By using remote sensing to study the present ecological setting of a site, the archeologist can make certain inferences about ecological settings in the past. Obviously, the inferences are much stronger if it can be established that the climatic regime at that time was similar to that of the present. As has been demonstrated by workers in other disciplines, remote sensing techniques can successfully be applied to the study of the quantity and distribution of floral, faunal, hydrological, lithic, and pedological resources. The location and extent of prehistoric fields can also be studied, although such study may be confined primarily to semiarid environments which have not undergone modification by modern populations. The distribution and size of prehistoric human populations may also be amenable to study using remote sensors.

Much of the information discussed in the "environment" section could be acquired using panchromatic exposures. However, in a number of situations, color, color infrared, or even multispectral imagery would be preferable due to their higher capacity for information retrieval. Due to the expensive instrumentation required for multispectral work, it is recommended here that, unless the archeologist already has access to multispectral cameras and viewers, he should attempt to obtain coverage of his study area by both panchromatic and color infrared photographs. This combination would procure maximum amounts of information about the environment at a reasonable cost.

The value of remote sensing in both intrasite and intersite sampling was next considered. Since panchromatic photographs would suffice for most types of intersite sampling designs, remote sensing is recommended as an economical tool. For intrasite sampling, color IR or thermal IR imagery would often be necessary, but considering the amount of time and labor often expended in defining room outlines by traditional methods, the cost may well be justified.

The phase mapping of archeological sites using various types of platforms was evaluated, and it was concluded that, for stereo mapping of artifacts in rooms, grids, etc., bipods or tripods offer the greatest potential. For a wider perspective of the site, tethered balloon photography is perhaps the most promising technique. Current experimentation by the Chaco Center will provide valuable information on cost and quality of these types of mapping.

Remote sensing was shown to have applicability in the preservation of cultural resources. First of all, it should be stressed again that photographic coverage of an area about to be destroyed is invaluable. For environmental impact studies aerial photographs can be used in the preliminary survey phase and also in sampling and volumetrics necessary in the mitigation of impact phase. Aerial photographs can be of value also in the planning of official buildings and facilities to be constructed in the vicinity of archeological sites. The expense of remote sensing for most of these applications would be well within reasonable limits, since panchromatic photographs would usually be the preferred type of imagery.

Since the archeologist can derive many valuable hypotheses and models from the results of ethnographic research, some of the current uses of remote sensing in ethnography were discussed briefly. It is hoped that ethnographers will make more extensive use of aerial photography in their research.

Radar imagery, due to its low resolution and high expense, must be considered impractical in all cases except those in which weather conditions leave it as the only alternative. The proven value of panchromatic aerial photographs in the planning of archeological surveys was noted, as was the positive value of infrared photography for the delineation of stratigraphic profiles. Terrestrial photogrammetry is both expensive and of dubious utility for small sites and projects. It was shown finally that remote sensing can be applied profitably to the growing study of underwater archeology.

The ideal aerial photographic coverage would be multispectral imagery. Virtually all of the types of information discussed above could be acquired using this technique. The considerable expense involved in using multispectral sensing cannot be ignored, however. A combination of panchromatic and color infrared coverage is nearly as valuable and costs much less. It would be possible to obtain information on site location, ecology, sampling, and mapping all in one or two flights. Considering the tremendous amount of information that could be derived this way, such complete coverage would certainly be practical both economically and methodologically.

It should be emphasized finally that inexpensive panchromatic photographs of a medium scale will secure most of the kinds of information discussed here. The use of more sophisticated imagery, while providing more information, generally costs more per "unit" of information. Ultimately, the archeologist himself must decide what kinds of information are critical, given his research objectives. Having made this decision, he will hopefully find this study useful in determining which techniques are most feasible for acquiring the information.

PART III: AN EVALUATION OF SOME RECENT REMOTE SENSING PROJECTS OF THE CHACO CENTER

BY

LYNN B. JORDE

The second section of this report is essentially a series of "case studies" based on actual laboratory and field experimentation carried out by the Remote Sensing Project at the Chaco Center. Much of the research discussed under this heading is specifically oriented toward the problems of archeology and management as necessitated by the responsibilities of the National Park Service; it should be noted too, that the Chaco Center remote sensing program is experimentally as well as applications-oriented. With these caveats in mind, we hope to apply experience gained in the context of actual research to the analysis of the feasibility of a number of different remote sensing techniques in archeology.

The Chaco Center: Background

The Chaco Center (then the New Mexico Archeological Center), upon its inception in 1969 as a joint research center of the National Park Service and the University of New Mexico, initiated studies in remote sensing to be used in conjunction with archeological and environmental research in Chaco Canyon, an archeologically significant area in northwestern New Mexico. The results of ongoing remote sensing studies in Chaco Canyon have been encouraging to the extent that these efforts have been expanded to include remote sensing analysis applicable to other areas that come under the jurisdiction of the National Park Service.

Situated in the Four Corners region of the southwestern United States, Chaco Canyon provides a physiographically and culturally unique situation. The semi-arid San Juan basin, in which the region is located, is characterized by steppes, mesas, and sharply eroded canyons. One of the largest of these is Chaco Canyon wherein extensive amounts of alluvium accumulated, making the area favorable for agricultural usage by prehistoric peoples.

Chaco Canyon was occupied for thousands of years, with the peak occupation period occurring between AD 1000 and 1200. The population density of the canyon was impressive, with several thousand people occupying an area twenty miles long and one-half to three-quarters of a mile wide. Chaco has always been noted for the extensiveness of its ruins. One ruin, Pueblo Bonito, had 800 rooms and may have housed as many as 1200 people, making it the largest single dwelling unit in the United States until the 19th century.

Archeological investigations have been carried out in Chaco Canyon since the middle of the 19th century, supported by such institutions as the American Museum of Natural History, the School of American Research, the University of New Mexico, the Museum of New Mexico, the National Geographic Society, and, currently, by the National Park Service. Excavations have revealed the presence of great masonry pueblos which housed large numbers of people, small habitation sites in which single families lived, elaborate ceremonial structures (kivas), and numerous kinds of water control features. Recent remote sensing work in Chaco has resulted in the location and mapping of a large number of roadways which connect not only the pueblos in the canyon with one another but also with sites as distant as fifty miles. The great population density, the extent of the ruins, the large ceremonial structures, and the complex water control and road systems have led archeologists to believe that Chaco Canyon culture was probably highly complex socially, politically, and economically.

Detection of Features

The Chaco Center has used aerial photography to determine the location and extent of a number of important archeological features in the Chaco Canyon area. Among these features are the "Chaco roadways". While the existence of prehistoric roadways in Chaco Canyon has been known for over a hundred years, the nature of the complete system is now just beginning to be elucidated by researchers at the Chaco Center. In 1969, black-and-white photographs ranging in scale from 1:3000 to 1:12,000 were taken of areas where roads were known to exist. By studying the roads shown on these photographs, workers were able to develop an explicit set of criteria for recognizing the roads on aerial photos ("pattern recognition"). These criteria were then applied to the finding of roads on inexpensive and readily available panchromatic photographs flown by the U.S. Geological Survey at a scale of 1:32,000. Also helpful were photographs taken in the 1930's by the USDA Soil Conservation Service. Use of the pattern recognition technique allowed mapping of about seventy-five percent of the 200 miles of roads thus far known to exist.

In the course of mapping the roadways, a number of additional features were mapped, including ramps, stairs, footholds, and one "causeway" associated with the roadways. Also mapped were ruins and prehistoric fields located near the roadways.

To aid in detecting the roads, the Chaco Center has made use of an eight-band International Imaging Systems (I^2S) Digicol. This machine, basically a closed-circuit television system, measures the "gray scales" or density levels on a photograph. It then assigns one of thirty-two colors to a density level. This allows maximum contrast, since the human brain can distinguish much more readily among different colors than among different shades of gray. To detect the roads, another Digicol capability known as "edge enhancement" was employed. Two images of a photograph, one positive and one negative, are electronically superimposed and then slightly offset. This offsetting enhances the contrast of linear trends on the photograph, thereby emphasizing features such as roads, fields, canals, and room blocks. This machine was responsible for the discovery of about twenty-five percent of the Chaco roads which have been mapped to date. Also, it was used to map one of the prehistoric fields, facilitating interpretation of the gray scales on the original photograph.

In evaluating the costs and benefits of this particular project, it must be kept in mind that the Chaco roadway system is one of the few transportation networks known to exist north of Mexico. Study of the roadway system will yield appreciable benefits in terms of increasing present knowledge of social, political, and economic organization in the prehistoric Southwest.

Vegetative types tend to be expressed in varying shades of gray in a photograph, and this machine can also aid in vegetative mapping of areas around sites. Since the Digicol automatically calculates the percentage of area occupied by each shade of gray, the investigator would no longer need to use cumbersome planimeters to determine percentage distributions of vegetation types. It should also be pointed out that members of other professions have found electronic densitometry useful: X-ray technicians use them to detect faint bone fractures, while geologists use it to discern the fracture patterns in sediments and mineralogical specimens. Considering its potential, the archeologist can consider such instrumentation within the realm of his financial limits.

Comparison of Various Types of Emulsions and Scales

In conjunction with the work done on location and mapping of features in Chaco Canyon, the Chaco Center has evaluated the utility of various types of photographic emulsions and scales for archeological use in the Southwest. Their results show that photographs of scales from 1:20,000 to 1:32,000 are best suited to locating and mapping the roadways, while other features, such as irrigation systems and ruins, are more optimally studied with photos in the 1:3000 to 1:12,000 range. Color and color infrared transparencies were found to be the most useful all-around photographic medium, which is interesting in that it conflicts with the results of studies done by Harp (1968) and by the Itek Corporation (1965). These studies both recommend panchromatic photography as the best general medium for archeological remote sensing; however, Harp's study was carried out in the Arctic, while that of the Itek Corporation was done in Nebraska. The difference in conclusion may be due to differences in the environments in which the studies were done. This disagreement in results emphasizes the fact that such studies <u>must</u> be carried out in <u>all</u> types of environments, since environmental factors can significantly affect the utility of various films and scales.

Multispectral Imagery

Limited work has been done with multispectral photography to date. Since the Chaco Center has invested in an I^2S mini-addcol additive color viewer (described in the first part of this report), and since multispectral imagery has been shown to be very valuable for ecological studies, it is hoped here that use of this technique will be developed and expanded further.

Calculation of "Ecological Diversity"

The Chaco Center is currently developing a technique to measure the ecological diversity of an area, based on the amount of variation in the shades of gray on aerial photographs and ERTS imagery. Using the Digicol, a standard "average" gray tone is established; ecological diversity is calculated by running lines across the photograph and counting the numbers of times the shade of gray diverges significantly from the "average" gray tone. Ecological diversity, then, is measured by diversity of gray shades. While this technique is rather crude and presupposes some rather tenuous assumptions, it has been shown empirically to have value: the sites of cultures which are known to settle in diverse ecotonal areas (e.g., Desert Archaic) tend to occur with greater frequency in areas calculated as being more "diverse" using the gray-scale technique. This method of site prediction is another type of "site pattern recognition", as discussed in the "applications" paper. While it needs further refinement, it should be of value to the archeologist.

Management and Planning in Chaco Canyon National Monument

The Chaco Center has made use of panchromatic aerial photos to aid in the planning of the construction of new buildings in Chaco Canyon. As noted in the "applications" paper, the synoptic overview afforded by aerial photographs allows the planner to provide for maximization of use and enjoyment of the area's resources, while insuring minimum destruction of the resources. There can be no doubt that use of aerial photographs for this purpose is economically feasible and should be considered by all engaged in the management of archeological resources.

Interdisciplinary Benefits

A valuable byproduct of research done by the Chaco Center is that some of its data and results have been used profitably by researchers from other disciplines. The University of New Mexico biology department, for example, has found some of the aerial photographs to be of aid in their ecological studies of Chaco Canyon. The Chaco Center is now participating in a move to pool their remote sensing equipment with that of other departments at the University of New Mexico in order to establish a "remote sensing laboratory". This should allow wider use of the expensive and sophisticated equipment.

Dissemination of Information

Any organization engaged in experimental research should consider it an obligation to disseminate the results of their research. Below is listed the material published or delivered at professional meetings by the Chaco Center.

Ebert, J.I.
1974 Remote Sensing within an Archaeological Research Framework: Methods, Economics, and Theory. In Aerial Remote Sensing Techniques in Archaeology, T.R. Lyons and R.K. Hitchcock, eds. In press.

Ebert, J.I., R.K. Hitchcock, and T.R. Lyons
1974 The Role of Remote Sensing in a Regional Archaeological Research Design: A Case Study. Paper presented at the 39th annual meeting of the Society for American Archaeology, Washington, D.C.

Gumerman, G.J., and T.R. Lyons
1971 Archaeological Methodology and Remote Sensing. Science, Vol. 172, pp. 126-132.

Lyons, T.R.
1970 Space Imagery, a Multi-discipline Teaching Aid. Paper presented at the Earth Science Teacher's Conference, New Mexico Institute of Technology, Socorro, New Mexico.

1971 Remote Sensing and Archaeology. Paper presented at the School of American Research Symposium on Photography in Archaeology, Santa Fe, New Mexico.

1972 Some Applications of Space and Aerial Remote Sensing Technology to Anthropological Disciplines. Paper presented at the Albuquerque chapter of the New Mexico Geological Society.

Lyons, T.R., and R.K. Hitchcock
1972 Remote Sensing Interpretation of an Anasazi Land Route System. Paper presented at the 37th annual meeting of the Society for American Archaeology, Miami Beach, Florida.

Lyons, T.R., and R.K. Hitchcock, eds.
1974 Aerial Remote Sensing Techniques in Archaeology. In press.

Lyons, T.R., R.K. Hitchcock, and J.I. Ebert
1973 The Use of Remote Sensing in the Mapping and Analysis of a Prehistoric Irrigation System. Paper presented at the 38th annual meeting of the Society for American Archaeology, San Francisco, California.

Lyons, T.R., M. Inglis, and R.K. Hitchcock
1972 The Application of Space Imagery to Anthropology. In Proceedings of the Third Annual Conference on Remote Sensing in Arid Lands. Tucson: University of Arizona Press.

Lyons, T.R., and W. Oates
1970 Space Imagery: An Investigative Tool in the Earth Sciences. Paper presented at the New Mexico Institute of Technology, Socorro, New Mexico.

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

Conclusions

Parts II and III of this paper have evaluated the feasibility of the major remote sensing projects conducted by the Chaco Center Remote Sensing Project. Most of the projects have high potential benefit for the archeologist, particularly the balloon and bipod experiments, the comparison of photographic emulsions and scales, and the mapping of large sites by aerial photogrammetry. The water control and perspective drawing projects, considering their specialized nature and high total costs, are probably the least practical of the projects, in terms of overall possible archeological utility. In certain cases, however, they may be of some use.

PART IV: PHOTOGRAMMETRIC MAPPING FOR THE ARCHEOLOGIST

BY

JACK B. BERTRAM AND LYNN B. JORDE

The subject of photogrammetric mapping, perhaps one of the single most important areas of innovation in archeological remote sensing today, has been mentioned in a general way in the first part of this report. The purpose of this final section is to examine the specifics of applying photogrammetric methods to the recording, mapping and eventual utilization of archeological and historical data. To this end, a cost analysis of photogrammetric projects carried on at the Chaco Center and elsewhere will be followed by a discussion of some of the possible products and applications of data so acquired.

Introduction

In recent years, aerial photography has come to play an increasingly important role as a tool in the surveying and mapping of archeological sites. This can be attributed at least in part to three advantages offered by photogrammetric techniques:

(1) The high potential accuracy of maps produced from air photographs.
(2) The flexibility offered by both maps and air photographs (i.e., the wealth of detail recorded on an air photograph can have numerous applications beyond that of site map production).
(3) The complete preservation of virtually all observable detail, which then will be available for analysis by archeologists of the future, who will possess superior interpretive techniques.

Given these advantages, the archeologist is still confronted by the very important question: what is the cost of air photogrammetry, and will the benefits and advantages of these techniques justify the cost? This study will provide some guidelines which will aid in answering these questions.

The data used in the comparative cost analysis were taken from ground surveys and aerial surveys of two sites: Tijeras Pueblo, a Pueblo IV habitation located 15 miles east of Albuquerque, New Mexico, and Kin Bineola, a Pueblo III town located 50 miles south of Farmington, New Mexico, in Chaco Canyon National Monument.

Before proceeding to the cost analysis itself, it might be useful to outline briefly the essentials of air photogrammetry. Acquisition of the photographs usually involves taking stereo pairs. The precise spatial coordinates of each photograph are determined by setting up "ground control stations". These are usually large sheets of plastic ("panels") which are anchored on the ground and located precisely in three dimensions by standard ground survey techniques. The location of other points included in the photographs can be calculated from their spatial relationship to the panels, as seen in the photographs. Rectification of the photographs, a laboratory procedure, involves any corrections of photographic distortions (e.g., camera tilt caused by uneven air currents). Mapping is accomplished by transferring the images to special photographic plates (diapositives) and then plotting the images as points in three dimensions using special plotting stereoscopes. The resulting maps, which can be either topographic or planimetric, or both can be plotted to virtually any desired degree of accuracy. Also, many engineering firms have facilities which enable "digitization" of the plotted points, an automatic process which involves the recording of the three dimensional location of each point on computer punch cards or magnetic tape.

Generalized Analysis of Aerial Survey Costs

Cost Estimation

An independent analysis of aerial survey costs was not undertaken in this study, since it would duplicate to a great extent the work of Dr. Antonio Aquilar of Kansas State University. Aquilar's (1967) study is based on the results of 237 aerial survey projects, ranging in cost from $500 to $250,000. His work will be summarized in this section as a background for the comparison of the costs of ground and aerial survey.

Aquilar notes some 100 factors which contribute to the cost of photogrammetric mapping. A few of these might be mentioned here. Ground control costs are determined by travel time for survey crews, the number of and distance between ground control points to be located and marked, the character of terrain and vegetation in the area, the efficiency of the survey crew, and other factors familiar to most archeologists. Flight costs depend on flight time to and from the area to be photographed, and the scale at which it is to be photographed. Photographic costs are dependent on the type of emulsion, cameras, and filters used, the scale of imagery acquired, the form of the final prints, etc. Mapping costs are determined by the number of photographs to be rectified, relief of the area to be mapped, amount of vegetational cover present, scale of final map, amount of detail required, and a large number of additional factors. Added costs appear in the form of final drafting, equipment depreciation, salaries, administration and planning, etc.

It is important to note that preparatory steps, such as establishing ground control stations and flying to and from the site, contribute far more to the cost of most small-scale (200 acres, or less) mapping projects than do such variables as photoprinting, total number of photos taken, detail of maps, etc. For example, maps of two similar but physically separated sites (where two individual "setups" are required) with contour intervals of two feet are far more expensive than one map of one site at the same scale with one-foot contour intervals.

What follows is a summary of Aquilar's findings in his industry directed cost analysis. Figures 1 through 4 illustrate the approximate maximum and minimum costs of the production of various scales of photogrammetric "manuscript maps" (maps printed on paper in such a manner as to be suitable for inclusion in manuscript copies). Seventy-four percent of the projects studied by Aquilar yielded overall costs which fell within the specified maximum-minimum boundaries. Another 15 percent deviated less than 25 percent in actual cost from the predicted cost. The remaining 11 percent of the projects deviated not more than 50 percent from the estimates. The costs cited by Aquilar have been multiplied by 1.4 to compensate for the inflation that has taken place during the 10 years since his data were collected.

To include final drafting costs in the estimate, the minimum and maximum cost values in figures 1 through 4 should be multiplied by 11.7. Maximum and minimum costs for ground control can be computed by multiplying the cost per acre figures by 0.8.

An estimate of the additional cost of digitization of the plotted points on topographic maps is given by:

$$D = \$150.00 + \$0.03(P)$$

where D is the digitization cost and P is the number of points to be digitized. Planimetric digitization will cost somewhat more per point than topographic digitization, since the labels included on planimetric maps must be manually punched on the computer cards.

As figures 1 through 4 show, cost per acre is decreased considerably when large tracts of land are mapped. Costs are also decreased if contractors can execute projects for several different clients in one flight. Since one flight made for several clients would require some advance planning by the contractor, the archeologist with a "rush job" would not be able to take advantage of this means of cost reduction.

It should be emphasized that the cost per acre figures shown here are not fixed quotations and can be considered only as guidelines.

Actual Examples of Estimated Costs

1. Tijeras Pueblo (topographic map)

An estimate of the cost of aerial mapping of a site comparable to Tijeras Pueblo was provided independently by Basil G. Pouls (personal communication, 1974) of Koogle & Pouls Engineering, Inc. The estimate was made for an area of 500 ft. x 500 ft. (5.74 acres) mapped at a scale of 1 in. = 30 ft. and at a contour interval of one foot. The cost of digitization of one point per 100 square feet was also estimated. As can be seen, when digitization is excluded, the total cost of $585 (about $110/acre) falls well within the range of per acre costs predicted by Aquilar's curves.

Base Costs	
Ground control	$110
Laboratory fees	100
Flight costs	200
Photography	50
Base cost subtotal	$460
Mapping costs	
Topographic contours	$125
Digitization	175
Mapping cost subtotal	$300
TOTAL COST	$760

Tijeras Aerial Mapping Costs

2. Kin Bineola (planimetric map)

An estimate of the cost of aerial planimetric mapping of the ruin of Kin Bineola and the surrounding area was also provided by Basil G. Pouls (personal communication, 1974). The estimate was made for planimetric mapping of a two-acre site area at a scale of 1 in. = 30 ft. This estimate included the digitization of a large number of room wall elevations. Again, it can be seen that the basic cost estimate (4230/acre) falls within the range predicted by Aquilar's cost curves.

Base Costs	
Ground Control	$110
Laboratory fees	400
Flight costs	300
Photography	50
Base cost subtotal	$860
Mapping costs	
Planimetry and digitization	$525
TOTAL COST	$1385

Kin Bineola Aerial Mapping Costs

Methods of Ground Map Production

1. Alidade (plane table) mapping:

This method has the advantages of reduction of final drafting time and the potential for interpretive sketching. Disadvantages include limited accuracy, weather limitations, and lack of automatic digitization of points.

2. Transit mapping:

Advantages with this type of mapping are greater portability, all-weather utility, and the option of automatic digitization of field data. The main disadvantage encountered is the need for extensive drafting time. This can be obviated, however, if the digitized data are used to make computer maps, since computer mapping allows significant reduction of drafting time.

The Costs of Ground Survey

1. Cost estimation techniques:

A number of factors must be taken into consideration when estimating costs for ground survey. Some of these would include the number of ground points to be mapped, the amount of time required to establish the location of each point, and the number of persons composing the survey crew. Other cost factors are salaries, per diem compensation, vehicle rental rates, and instrument rental rates. The methods and assumptions used in evaluating these factors are given in appendix I. Figures 5 and 6, which illustrate cost estimates derived using these methods and assumptions, show cost per acre plotted against total number of acres surveyed.

2. Examples of the application of cost-estimation techniques:

a. Tijeras Pueblo, topographic map.

Using the methods given in appendix I, it is estimated that 882 points would be mapped for this 250,000-square-foot site. For alidade mapping, which requires 4.5 minutes per point (appendix I), 66 crew hours would be required. Adding the four hours required for "setups", a total mapping time of 70 crew hours, or 8.8 crew days, is derived. For transit mapping, at 3.5 minutes per point, mapping of this same area would require 56 hours, or seven crew days. The following table summarizes the estimated ground-mapping costs for Tijeras Pueblo, as derived using the methods given in appendix I.

	ALIDADE	TRANSIT
Time:	9 days	7 days
Costs:		
Salaries	$770	$616
Vehicle rental	210	156
Instrument rental	37	28
Drafting	30	60
TOTAL	$1047	$860

Tijeras Pueblo Ground Mapping Costs

b. Kin Bineola ruin (with surrounding area), planimetric map.

This two-acre site area requires the mapping of 1250 ground points. Alidade mapping time is estimated at 100 crew hours (including six setup hours), or 12.5 crew days. Transit time is estimated at 78 crew hours, or 10 crew days. Estimated costs for the planimetric mapping of Kin Bineola ruin and the surrounding area are summarized below:

	ALIDADE	TRANSIT
Time:	13 days	10 days
Costs:		
Salaries	$1100	$858
Per diem	780	600
Vehicle rental	264	188
Instrument rental	67	54
Drafting	70	100
TOTAL	$2281	$1800

Kin Bineola Ground Mapping Costs

Comparison of Ground and Aerial Mapping Techniques

Comparison Using Estimated Costs

1. Tijeras Pueblo:

Table I summarizes and combines the cost estimate data given above for aerial and ground mapping costs of Tijeras Pueblo.

	Alidade	Transit	Aerial
Data acquisition	$1017	$800	$460
Data processing	30	60	300
TOTAL	$1047	$860	$760
Accuracy	low	fair	high
Detail	medium	fair	high

TABLE I

"Data acquisition" is defined here as all activities involved with procuring the data: the actual survey for the alidade and transit methods, and the flight, photography, and laboratory activities for aerial mapping. "Data processing" is the actual making of the maps: drafting for the ground methods, and digitization and plotting for the aerial method. "Accuracy" of the map is simply how closely it approximates actual landforms. "Detail" is the amount of actual data that can be observed on the map.

2. Kin Bineola:

Table II makes the same comparisons for Kin Bineola and surrounding areas as above for Tijeras Pueblo.

TABLE II

	Alidade	Transit	Aerial
Data acquisition	$2211	$1700	$860
Data processing	70	100	525
TOTAL	$2281	$1800	$1385
Accuracy	fair	medium	high
Detail	high	medium	high

From these tables it can be seen that, for the estimated ground and aerial costs, aerial mapping is less expensive than either ground method and affords a greater degree of accuracy and detail than do the ground methods. It should also be pointed out that, while ground mapping techniques will give <u>only one</u> map of a site, aerial photographs can yield many types of maps, as well as perfectly preserving an accurate record of the site for future analysis.

Comparison Using Actual Costs

Actual cost figures were available for the planimetric mapping of Kin Bineola ruin. Figures were available for the ground mapping (by transit) of one half of the room block (not including surrounding area) and the aerial mapping of the room block with surrounding area included. The costs for ground mapping of the entire room block were estimated from these actual figures. As can be seen from the figures in appendix II, aerial mapping of half of the room block is considerably more expensive than ground mapping. However, when the entire room block is mapped, ground mapping costs double, while only the planimetry-digitization costs increase for aerial mapping (i.e., "data acquisition" costs remain the same, while only "data processing" costs increase; for ground mapping, both "acquisition" and "processing" increase). This is a good illustration of the principle that air mapping becomes more economical with larger or multiple sites.

The Feasibility and Utility of Photogrammetric Structural Mapping

Methods of estimating aerial mapping costs have been discussed, and cost estimates for mapping Tijeras Pueblo and the Kin Bineola area were made. A detailed method for estimating ground survey costs was developed and this method was applied to Tijeras Pueblo and Kin Bineola to derive cost estimates for the ground mapping of these sites. Finally, the ground mapping costs were compared to the aerial mapping costs. Using cost estimates for Tijeras Pueblo and the Kin Bineola area, aerial photography was shown to be less expensive than ground mapping, while providing greater accuracy and detail. Comparing actual costs for Kin Bineola ruin, aerial mapping was found to be more expensive than ground mapping when only half of the ruin was mapped. When the entire ruin was mapped, however, the air mapping costs were slightly lower than ground mapping costs.

The single most important conclusion reached as a result of this study is that, for sites of an area greater than approximately two acres, aerial mapping is cheaper than ground mapping; it also provides the advantages of greater accuracy, flexibility, and the preservation of a great amount of detail for future analysis. For sites less than two acres in size, ground mapping techniques may well give the investigator more for his money.

For the cost-conscious archeologist, it should be pointed out that various means of reducing the expense of data acquisition in aerial mapping have been suggested elsewhere (e.g., photographing of sites from tethered balloons rather than airplanes).

In the data processing phase, considerable time and money can be saved through the use of computer mapping of digitized points. This technique involves plotting the locations of points on an architectural site which have been measured in three dimensions as a two-dimensional map plot or perspective drawing. Plotting of these points requires that the data be computed with a FORTRAN IV graphics program and then plotted using an off-line plotter. With minor changes in the FORTRAN program, the ruins can be plotted from a different viewing angle (see Pouls, Lyons and Ebert).

The actual costs of making such "computer maps" are not exorbitant. For a site such as that shown in fig. 2, in which 2000 digitized points were used to make the plot, about 45 seconds of "CPU" (central processing unit) time are required, the cost of which is about $4.00. A standard 8 x 10 in. plot requires about 10 minutes of time on the off-line plotter, which costs about $3.00. Adding the cost of the computer consultant ($5.00 an hour) and the original cost of writing and subsequently modifying the FORTRAN program, such a map could be produced for about fifteen to twenty dollars.

Since this type of map is based on precisely measured points, it is probably more accurate than an artist's drawing could be. With some modification, plots of just some of the walls have been made, thus allowing the archeologist to view the structure as it would have looked at a given point in time, before certain building additions were made. It would also be possible to plot the location of artifacts in the ruin, permitting a visual study of spatial configuration and clustering of artifacts. Perhaps the most salient advantage of this technique is that the data and programs necessary to make such plots can be transmitted by computer teletype terminals in any location, and, if desired, plotted on the teletype terminal. Data transmitted this way would reach its destination in seconds with no chance of being "lost in the mail". Archeologists in other parts of the country (or archeologists in the field) could thus have immediate access to accurate site plans.

The cost of the actual plotting of these maps in negligible; the great bulk of the cost of the plots lies in securing the digitized data through aerial photogrammetric techniques. Unless such data had been previously collected for other purposes (e.g., topographic mapping, as discussed above), the cost of securing data for these plots would cause them to be unreasonably expensive, considering the final output. Employing a good artist to make the sketches would probably be more economical in this situation. In any case, the archeologist must decide for himself whether the product and its potential uses as outlined here warrant expenditure of the cited amount of money.

Photogrammetric Mapping of Water Control Systems

Photogrammetric mapping has been employed to map the prehistoric irrigation system in the vicinity of Kin Bineola, a Pueblo III town located in the Chaco Canyon National Monument. Black-and-white stereo pairs were taken at a scale of 1:6000 in order to microtopographically map the irrigation system and other cultural features, as well as Kin Bineola itself. The resulting contour maps allowed more accurate delineation of the water control system, which had previously been difficult or impossible to observe.

While the cost of preparing topographic maps for large areas from aerial photographs appears to be lower than that of preparing maps using ground survey techniques, the cost of such maps is still considerable. For the archeologist interested in simply determining the location and extent of a feature such as a water control system, panchromatic stereo pairs viewed with a conventional stereoscope would probably be sufficient. If doubt exists whether a feature could have been used to transport water, accurate data measurement of horizontal and vertical distances would be necessary. For this purpose, aerial photogrammetric mapping is probably the most economical method available.

Balloon and Bipod Platforms for Photogrammetric Mapping

As has been previously mentioned, the Chaco Center, in cooperation with Julian Whittlesey, is currently conducting experiments on the costs and benefits of using tethered balloon and bipod platforms for archeological mapping (these platforms are discussed in Part II). Research in this area is extremely important, since it involves a potential revolution in many of the phases of the collection of data during excavation. Considering the time and money that could be saved if these methods are shown to be practical, the small amount of time and capital devoted by the Chaco Center to experimentation is easily justified.

APPENDIX I

A METHOD FOR ESTIMATING THE COST OF GROUND SURVEY AS OF 1974-1975

In estimating costs, the following assumptions were made:

1. Travel costs are measurable by means of commercial rental rates on 4-wheel-drive vehicles, assuming that, on the average, one day of rental time corresponds to eight hours of field time and 100 miles of vehicle travel.

2. Instrument rental costs were determined on the basis of local commercial rates. One day of instrument time corresponds to eight hours of field time.

3. Instruments to be compared are a theodolite, transit, and alidade.

4. All ground-control points are chained; all other points are located by stadia and range pole.

5. For all three instruments, each setup requires one half hour.

6. For topographic mapping, the number of points to be mapped is computed as : $N_t = \frac{(A - 100)\ \text{tangent}\ (S)}{I\ V}$

where N_t = number of points to be mapped

A = area mapped, in square feet

S = mean site slope in degrees from the horizontal

V = vertical accuracy desired, in feet

I = contour interval, in feet

This formula provides only a rule of thumb, although it is based on actual mapping experiments.

7. For planimetric mapping of site features, the number of points required is computed as:

$$N_p = D\ R$$

where R = number of rooms and/or features to be mapped

D = number of points per room or feature

8. Crew time per point is estimated as follows:

Alidade:	4½ minutes
Transit:	3½ minutes
Theodolite:	2½ minutes

These estimates include rest periods, rod movement time, sketch time, and, for the transit, vertical reading time. All are somewhat high for optimal conditions and skilled crews.

9. A standard crew of three persons is assumed for all instruments.

10. Ground control crew time is estimated as:

$$T = 2(F - 100) + \tfrac{1}{2}B)$$

where T = time in crew hours

F = distance to be chained in feet

B = number of setups required

This formula assumes that a typical crew can double-chain 300 feet per hour and that establishment of vertical control requires, on the average, as much time as establishment of horizontal control. (See also assumption 5.)

11. Per diem costs are estimated as $20.00 per day per person.

12. Salaries are calculated as $88.00 per crew-day (8-hour day, $5.00/hour for the crew chief, $3.00/hour for each of the two crew persons).

13. Vehicle rental rates are those quoted by firms in Albuquerque, New Mexico for a four-wheel-drive Ford Bronco:

$15/day	15¢/mile, no minimum
$72/wk.	12¢/mile, 1 week minimum
$215/mo.	12¢/mile, 1 month minimum
$275/mo.	1000 free miles, 12¢/mile thereafter, 2 month minimum

14. Instrument rental rates are also based on Albuquerque rates:

	per day	per week	per month
Alidade + plane table	$7.50	$22.00	$55.00
Transit	7.50	25.00	60.00
Theodolite	x	x	x
Stadia rod	1.00	3.00	8.00
Range pole	x	x	x

(Range pole cost is negligible. Theodolite rates, where available, would probably be somewhat higher than transit rates.)

It should be pointed out that such considerations as brush cover and complicated topography have been neglected. Allowances for such considerations should be made where they pertain.

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USE OF AERIAL PHOTOS IN ARCHEOLOGICAL SURVEY ALONG THE LOWER CHACO RIVER DRAINAGE

BY

RICHARD W. LOOSE AND THOMAS R. LYONS

PART I: INTRODUCTION

During the winter of 1973 and spring of 1974, approximately 68.5 square miles of federal coal lease land along the lower Chaco River drainage were surveyed to supply a complete inventory of archeological sites prior to the initiation of mining operations. The survey was carried out by the Office of Contract Archeology in cooperation with the University of New Mexico, Albuquerque. A total of 703 archeological sites were recorded by two separate field crews in a period of 90 field days. The accurate and consistent location of site positions on U.S. Geological Survey (USGS) topographic maps became one of several technical problems encountered by the survey crews. A location technique combining information from both USGS topographic maps and aerial photographs solved the problems that arose.

PART II: THE PROBLEM OF GROUND CONTROL

Any map is an abstract two dimensional representation of a three dimensional surface. Thus, maps are open to subjective interpretation both while being initially compiled and when subsequently used in the field. During an archeological survey, ground control must be established so that when all of the area concerned has been examined, the location of sites is accurately recorded. Contour lines, section boundaries, or arbitrary transects may be used for ground control; but it must be kept in mind that such control exists only on the map and must be subjectively transferred to the landscape by the map user. This sort of problem was encountered during the early stages of the Coal Gasification Survey.

The mining lease was divided in 67 east-west transects which were 1/5th of a mile wide and averaged 4.68 miles in length. These transects were used for ground control and as a basis for taking a 10 percent initial sample of the total area to be surveyed. This 10 percent sample was then used to predict the site types and density of the remaining 90 percent. Master maps used in recording site locations were compiled using 7½ minute USGS quadrangles with a 1:24,000 map scale. Transects were drafted directly on the maps using a light table and T-square. It was soon discovered that errors of up to 200 meters were generated in placement of transect boundaries on the maps to be used by two separate field crews. Thus, the possibility of "holidays" existing on the ground to be examined became apparent. It was decided that air photos would be the ideal way to locate and record site locations. A vertical aerial photo was found to be less liable to subjective interpretations of topographic features than was the smaller scale USGS maps.

PART III: METHODOLOGY

The original imagery used to generate black-and-white prints for field use was 9 in. x 9 in. aerial color transparencies taken in the summer of 1973. This imagery type was acquired for use in soil and vegetation studies and for analysis in an International Imaging Systems' (I^2S) Digicol. Intermediate negatives and 9 in. x 9 in. black-and-white contact prints were made at a scale of 1: 12,000. A photo index mosaic was also constructed and half-tone printed on a mylar sheet for an overall image of the area. Osalid copies could be easily made from the mylar master. Among other advantages, the mosaic provided an excellent up-to-date road map of the survey area.

Three copies of the 9 in. x 9 in. black-and-white contact prints were made, two for the field and one for the home office. When used in the field, the 1:12,000 scale was found to be very workable. Only a few photos had to be carried for one day's work, yet the scale allowed identification of objects as small as ant hills and individual salt bushes. A small pin hole was punched next to a discovered site and an identification number was written next to the hole on the back side of the photo. With a pocket stereoscope, a site could be precisely located in even the most confusing badlands or in extensive flat areas. This system permitted the transfer of a site location to a 7½ minute quadrangle map either in the office or in the field with desired accuracy and thus provided a double recording of site locations.

Other advantages were soon discovered. It was found that the use of the aerial photos in the field enabled the crews to survey transects precisely and thus eliminated "holidays".

One major function of an archeological site survey is to provide for site relocation on the ground. It was determined that spotting site locations on aerial photos was far more accurate than the traditional method of triangulating site locations from prominent landmarks on 7½ minute quadrangle maps with a Brunton pocket transit. Consequently, other field crews using such marked imagery have no problem in revisiting a site previously surveyed.

PART IV: CONCLUSIONS

1) Air photos provide a wealth of up-to-date topographic and environmental data which are not as readily available or as accurate if taken from standard maps.

2) Photos are easy to carry and easier to interpret in stereo than are two-dimensional maps.

3) Site locations can be very accurately spotted (many times the actual site can be seen with a pocket stereoscope) and relocated easily at a later date.

4) Since the location of significant sites and a permanent record are of paramount importance in archeological investigation, air photos are a necessary tool of the archeological survey.

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SITE LOCATION TECHNIQUES IN THE CANYON DEL MUERTO SURVEY

BY

DON P. MORRIS AND LARRY MANIRE

Cultural resource management in Canyon de Chelly National Monument involves 700 known archeological sites of an estimated 2000 within the Monument boundaries. Obviously accurate description of these numerous sites is fundamental to any research or management program. Of the fundamental descriptive attributes, location is the most crucial for several reasons. Many sites are characterized by such attributes as sherd scatters, sweat lodges and hogan clusters, which can be easily confused with one another without extremely specific locational information. In an archeological district where management goals entail long-term preservation, accurate location will facilitate collection of additional data and monitoring of site conditions.

The Canyon del Muerto survey has developed an accurate and inexpensive technique which may be of interest to others facing a similar problem. Our system uses off-the-shelf components--conventional aerial photography, orthophotoquads, and routine computer programs--to achieve our goals.

Although Canyon de Chelly is known for its spectacular cliff dwellings, the largest number of sites occur on the surrounding plateau, much of which is obscured by thick pinyon juniper forests. These sites range in age from Basketmaker to modern Navajo. With the exception of recent Navajo sites, architectural features are nil. Preliminary ground reconnaissance at the beginning of the project indicated that site density increased toward areas of thick pinyon juniper, rather than more open areas of vegetation. Discussions with archeologists with aerial photogrammetry experience indicated that conventional aerial interpretation would yield relatively little information under these circumstances.

Nonetheless, conventional black and white aerial stereopairs were obtained at a scale of 1:1500 of the area; every other negative was enlarged to a scale of 1:500 and printed on mylar. These nearly indestructible prints were carried in the field, and with conventional topographic maps, served as the principal navigational and site location aids. At this scale, individual trees were distinguishable and site positions could be easily determined. For large sites, boundaries could be located on the photograph. The mylar prints held all types of markings well, with colored felt tip pens being the most suitable.

On return to camp, locations were transferred from the aerials to 7½ minute orthophotoquads. Coverage of the state of Arizona, except for the Grand Canyon, at this scale is universal and is available from Arizona Resources Information System, 1812 West Monroe Avenue, Phoenix, Arizona. Orthophotos provide the pictorial qualities of a photograph with the corrected scale and distance measurements possible from a standard topographic map. The photographic qualities of these quads allowed transfer of site locations accurately, although orthophotos are not as clear as conventional aerials because of their production process. This is the principal reason for the use of uncorrected aerials in the field.

Universal Transverse Mercator (UTM) coordinates were taken from the plotted site locations on the quads and entered into the computer file with other site data. At monthly intervals, preliminary plots of recorded sites at a scale of 1:62500 were generated by the program CDMSPLT 11 in Tucson and sent to the field crew so they could check for obvious errors. At the end of the field season, maps scaled at 1:24000 (the original scale of the orthophotoquads) were produced by CDMSPLT 30 and overlaid on the field copies of these quads to determine accuracy of plotting. Eleven and thirty inch Calcomp Plotters were used to produce these two scales. A two percent error rate, almost entirely due to human error in determing UTM coordinates, was noted and easily corrected. This is a very fast and inexpensive check of the computerized data.

At this point, the data and maps can be printed with any combination of attributes desired by area managers or researchers--all sites by time periods, all sites with unstable walls by time periods, all sites with perishable materials, and so forth. Using standard SELGEM routines, maps can be of any complexity desired. In our efforts to reduce plotting costs, we have restricted our output to simple site plots with tick marks which allow alignment of the plot over a base map of suitable scale. In the future, additional digitization will be used to produce more elaborate maps.

The basic procedure is inexpensive, simple and records data permanently, both as original field records and as a retrievable computer format. The system can be elaborated upon in various ways, such as direct computer plotting of UTM coordinates. These more complex procedures must be evaluated carefully in terms of individual project needs relative to costs.

Western Archeological Center
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AIR-BORNE TV AS AN ARCHEOLOGICAL REMOTE SENSING TOOL

BY

RICHARD W. LOOSE

PART I: INTRODUCTION

Archeologists have utilized aerial photography since the early days of balloon flight to locate and identify prehistoric cultural phenomena. As techniques of remote sensing become more sophisticated, archeologists continue to capitalize on new developments which facilitate interpretation of aerial imagery. One technique which has been overlooked for some time, however, is the use of air-borne video-tape recording system.

During the spring of 1974, a video-tape of Chaco Canyon National Monument was made in conjunction with a 70 mm. motion picture film. The original purpose of the project was to obtain color imagery of a suspected prehistoric agricultural field near Chetro Ketl ruin. The video-tape system was used simultaneously with the 70 mm. camera as a guidance device for a 200 in. focal length Schmidt lens attached to the motion picture camera. The video (TV) camera was optically collimated with the motion picture camera and gave a "real time" view of what was being seen through the Schmidt camera system. The quality of the video image was excellent and offered a new perspective to the archeological remote sensing program of the National Park Service - University of New Mexico Chaco Center. Many features which were obscure on conventional imagery were readily apparent on the video-tape, especially features of a linear nature.

PART II: PREVIOUS INVESTIGATIONS

It has been assumed that a relatively large population inhabited Chaco Canyon during the 11th century A.D. When the great "Towns" were being built and occupied. The complex social organization necessary to build the Puebloan "Towns" could have been utilized in constructing an intensive agricultural system. Such a system would have been a necessary part of the subsistence pattern in the Chaco

Canyon area during the 1000's.

Evidence of prehistoric agricultural systems within the Canyon has been fragmentary to date, but suggests the existence of large scale irrigation canals, terracing, and bordered garden plots (Vivian, 1972; Vivian and Mathews, 1965). Many early investigators have mentioned water control and agricultural features in the Chaco (Holsinger, 1901; Judd, 1954) but no comprehensive work on the total amount of land under cultivation by the ancient Puebloans has been published. Our goal was to use remote sensing techniques to generate a usable "recognition pattern" which would allow us to quantify the area of land under cultivation and the extent of canal systems. This, in turn, might lead to an estimate of man hours needed for construction and maintenance of such an intensive agricultural complex. Finally, we might be able to estimate the amount of organization that would be necessary to produce such a system in Chaco Canyon.

PART III: VIDEO-TAPE ANALYSIS

Extensive ground checks of the Chetro Ketl field area were made prior to obtaining the video and 70 mm. color imagery. No linear features could be discerned on the ground visually. Both neutron densiometer and sub-surface radar profiles failed to show any linearities. Magnetic anomalies did show up using a spin magnetometer, but no patterns as obvious as those on black and-white aerial photos were found.

Examination of the 70 mm. color film showed the linear features about as well as the original black-and-white prints. However, when viewed on a 17 in. black-and-white TV monitor, the video-tape revealed a grid pattern which was quite well defined. Another faint grid pattern near Casa Rinconada was also revealed and an abandoned historic road used in the early 1900's was clearly visible. This road had been recorded photographically but the video-tape gave the clearest rendition of any imagery obtained. This road was checked on the ground and literally could not be seen while standing in the middle of it in many areas.

At the large ruin of Pueblo Alto, some prehistoric road segments not previously mapped (Ware and Gumerman, 1974) from conventional imagery or by ground crews were evident on the video-tape. Other linear features near Pueblo Alto, such as low walls, were also quite apparent on the video-tape imagery. Renditions of the plaza walls at Old Alto and at Tsin Kletzin were excellent.

After viewing the video-tape on a TV monitor, the video was fed through an International Imaging Systems (I^2S) digital image processor and edge enhancement system and then viewed on a monitor screen. Usually, an air photo is first scanned with a videcon, then enhanced (a phase delay technique) and finally displayed on a monitor. Using a video-tape image, the scanning step is eliminated and the resultant enhanced image is one generation younger. After manipulating the video-tape and enhancement machinery, a previously unrecorded wall across the west end of the great ruin of Pueblo Bonito was discovered. Judd (1964) had recorded such a wall on the east side of the ruin but not on the west side. This feature appears to be similar to an extension of the north wall at Pueblo Alto. Further investigation may reveal that such walls were common at the major Chacoan "Towns" and have been buried by alluvium. A subsurface radar profiling technique is presently being tested at Chaco Canyon and if practical, could be used in conjunction with the video-scan to map buried walls without any excavation, except for occasional control information.

PART IV: CONCLUSIONS

Video-tape and recording systems can provide a unique new dimension to remote sensing programs in archeological applications. Imagery stored on tape is not bulky and is easily labeled and filed in small cannisters. This type of imagery seems to be especially useful in locating faint linear features if coupled with electronic enhancement devices such as the I^2S processing system. The video imagery also gives the viewer a "real time-continuous strip" sense which cannot be duplicated on anything other than motion picture film. As the viewing angle of the video camera changes slightly in a moving aerial platform, faint features are more easily seen than on one static frame from a conventional air photo flight line. Resolution, though not as good as that of aerial photography, is quite adequate for identification of cultural disturbances at scales between 1:3000 and 1:6000 when viewed on a 17 in. monitor.

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ARCHEOLOGICAL INVESTIGATIONS AT CHACO CANYON USING A SUBSURFACE RADAR

BY

ROGER VICKERS, LAMBERT DOLPHIN, AND DAVID JOHNSON

PART I: INTRODUCTION

It is a pleasure to acknowledge the continual encouragement and assistance in the field of Dr. Tom Lyons of the Chaco Center, and Dr. Jim Judge, also of the Center, for his assistance in the 1976 survey. We would also like to thank the National Park Service at the Chaco National Monument for their cooperation during our repeated visits. Our thanks also go to Dr. Elizabeth Ralph and Bruce Bevan of the University of Pennsylvania Museum for their participation in the experiments. Partial financial support from the University of Pennsylvania and the Chaco Center is gratefully acknowledged. Finally, belated thanks go to our many colleagues at SRI, particularly John Tanzi, Philip Bentley, and Bruce Craig, who donated much of their evening time to developing and testing our equipment.

Over the past three years, several experiments have been conducted in the use of subsurface probing radar for archeological exploration. A number of these experiments, reported here, were conducted at various sites within Chaco Canyon National Monument, New Mexico, for the purpose of evaluating the performance of subsurface radar when applied to archeology. The original system used in these experiments was a ground-penetrating radar that was developed for use in locating underground utilities and shallow geologically related phenomena such as solution cavities, fractures, and voids. A natural outgrowth of this work was the use of the radar system to investigate other man-made objects such as archeological structures that may have suffered partial or total burial. This paper describes subsurface-radar principles of operation, use in the field, and data reduction.

PART II: PRINCIPLES OF SUBSURFACE RADAR

In their operating principles, the radar systems that are used for subsurface work have a strong resemblance to shallow-reflection seismic systems ie., a short burst of energy at a selected frequency is transmitted into the ground and reflected energy is received from any interface or discontinuities within the range of the transmitter. The radar antennas are usually placed close to the ground and moved along in a continuous fashion, while the echoes are viewed on an oscilloscope face and simultaneously displayed on a facsimile recorder.

The major factors that affect the performance of the radar are:

(1) conductivity of the soil,

(2) dielectric constrast between the target and the soil,

(3) the shape of the target and its orientation with respect to the radar antennae, and

(4) density of scattering bodies within the soil that produce echoes similar to those from the targets.

Of these, the one that places the greatest limitations on the use of radar in archeology is the soil conductivity. This parameter is itself a strong function of water content and clay content of the soil. In general, soils with more than a few percent of moisture will attenuate radar signals too strongly for the technique to be useful. In contrast, however, we have found one example in Oregon where the soil moisture was high due to year-round heavy rainfall, and all the compounds causing ionic conductivity had been leached from the soil. Because of the importance of conductivity, it is recommended that soil samples be taken at depths of one to three feet in the area to be surveyed, and wrapped in moisture-tight containers before shipping for laboratory analysis of their electrical properties. In the case of Chaco Canyon, the results of laboratory analysis are shown in figure 1. The losses shown in this figure are given in decibels per meter (dB/m) as a function of frequency. Since decibels are logarithmic units, the losses correspond to 10 times the logarithm (base 10) of the ratio: (power into the soil/power after propagating through 1 m of soil).

RADIO FREQUENCY LOSSES IN FOUR SAMPLES
FROM CHACO CANYON, NEW MEXICO

Frequency (MHz)	Attentuation Coefficient (dB/m)			
	Sample			
	1	2	3	4
10	0.24	0.20	--	0.33
20	0.45	0.45	--	0.64
30	0.60	0.66	--	0.90
40	0.83	0.82	--	1.2
50	1.0	1.0	--	1.4
60	1.3	1.2	11.7	1.4
70	1.4	1.4	14.2	1.7
80	1.5	1.5	16.2	1.9
90	1.8	1.7	19.6	2.0
100	2.0	1.8	22.0	2.1
120	2.6	2.2	24.3	2.5
140	3.2	2.8	30.1	2.9
160	4.1	3.2	36.1	3.4
180	4.4	3.4	43.0	3.8
200	5.8	3.5	55.0	4.2
220	7.4	3.8	69.0	5.2
240	--	5.1	86.0	6.2
250	--	5.7	--	7.5

Sample 1 Construction sandstone, Pueblo Alto, average dielectric constant, ϵ_r = 4.9 to 6
Sample 2 Alluvial sand, Pithouse E, ϵ_r = 1.7 to 2.1
Sample 3 Alluvial clay Chaco Wash, ϵ_r = 7.0 to 12
Sample 4 Alluvial loam below trash dump, ϵ_r = 1.6 to 2.4

Figure 1

A good estimate to use for a subsurface radar is that it can detect return signals about 80 to 100 dB below the level of the transmitted signal. If typical values are used for reflection coefficients and antenna coupling efficiencies, a typical system could tolerate only 40 to 60 dB of loss in the ground. Thus, from figure 1, a soil with high clay content (sample 3) from Chaco Canyon would cause a radar loss of about 22 cBm/m at 100 MHz and would therefore limit the useful two-way radar range to 2 to 2.5 m.

It is easily seen from figure 1 that the losses increase with frequency, and that greater penetration would therefore be possible with lower frequencies. Unfortunately, other constraints make it unprofitable to operate at frequencies much below 100 MHz. The most important of these is resolution, which itself is directly proportional to frequency. At 100 MHz, the resolution that one might expect in typical dry soils would be about 0.75 m. Other constraints that make the low-frequency option unattractive are the increased antenna size required and the increased transmission time during which echoes cannot be detected. As a result of many experiments at a large variety of sites, we have concluded that the usable frequency range for archeological radars when searching for near-surface structures is from 100 MHz to 400 MHz.

PART III: RADAR EQUIPMENT

A number of major features are common to all subsurface radars. First, all such radars use resistively loaded antennae operating very close to, or directly on, the ground. Secondly, they all use a sampling oscilloscope to display the echo waveform and reduce the bandwidth of the data stream. Finally, all such radars applied to surveying work use a recorder of the facsimile type for displaying the radar data. A simplified diagram of a subsurface radar operating at 400 MHz is given in figure 2. In our earlier systems, all the indicated equipment except the oscilloscope and the pulse generator, was mounted on a movable cart connected with two low-loss cables to the remaining instruments and data-recording devices. In some radars, the source was replaced by an avalanche transistor that was then used to shock-excite the antenna. This resulted in a much smaller system, and a resultant signal with different spectral characteristics from the design shown. In general, we have had more success with the modulated signal scheme shown in figure 2, although this was not used until 1975 at Chaco Canyon.

In most cases of subsurface radar sensing, data processing subsequent to the survey can enhance the desired echoes from buried features, and can reduce the ambiguities in interpretation. For this reason, the profiling data are usually recorded on magnetic

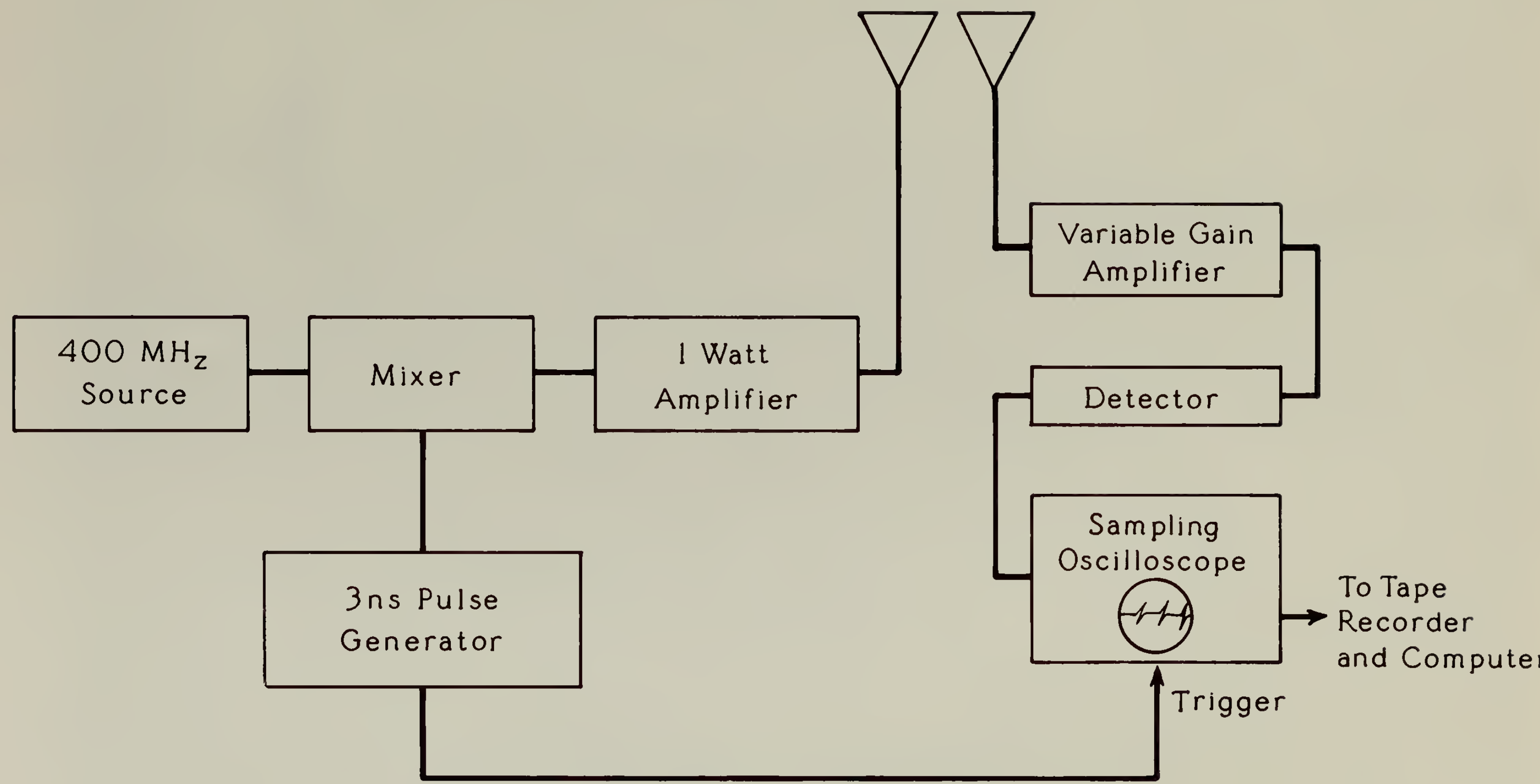

FIGURE 2 - Subsurface Radar System

tape as well as on the real-time chart display. One further item of equipment that is very helpful in radar surveys is a resistivity meter. This instrument, which is a standard geophysical tool (Tagg, 1944), is used to measure the low-frequency resistivity of the soils at different effective depths. These data can be used to predict the performance of a given radar system in terms of its penetration, and can indicate any changes in operating frequency that would be advantageous. Resistivity profiles can also be taken in which the resistivity of the near surface is mapped as a function of horizontal position. When such a profile is taken over a known structure, the resistivity of the structural material can also be calculated. Figure 3 shows the resistivity instrument being deployed at Pueblo Alto. The total equipment is composed of four electrodes and a measuring system.

PART IV: OPERATING PROCEDURES

As mentioned, the first step in radar surveys is to obtain data on the electrical properties of the materials to be surveyed, and this is usually accomplished by use of sample analysis in the laboratory. Knowledge of the electrical properties allows the operator to calculate the optimum radar frequency for that site, or indeed to determine whether a radar survey would be totally unsuccessful at any frequency. The second step is to obtain resistivity profiles over the area to verify that the in-situ bulk properties are the same as those predicted by laboratory measurement. An example of the data from such a profile is given in figure 4, which was taken over a known masonry structure outside Pueblo Alto in Chaco Canyon. The anomalous resistivity of the wall can be clearly seen. Radar tests and traverses are then made. In past years these traverses have followed a rectilinear grid pattern at a spacing dictated by the local geography and the amount of ground cover that had to be removed. As will be described later, this limitation has now been eliminated. The last step in subsurface surveys is to reduce and interpret the data. Every effort must be made to perform some interpretation in the field at the time of the survey, since the correlation of surface expression, radar data, and unwanted surface targets (rocks, tree roots, or metallic refuse) is very important and cannot be duplicated after leaving the site.

PART V: RESULTS OF SURVEYS AT CHACO CANYON

1974 Survey

The first surveys at Chaco Canyon with radar equipment were conducted in 1974 (Vickers and Dolphin, 1975), and were made at Pueblo Bonito, Hungo Pavi, and several back-filled pithouses. The most striking results were obtained at Hungo Pavi, where the presence of man-made structures was easily seen in the raw data. Fig-

FIGURE 3 - Resistivity profile being conducted at Chaco Canyon

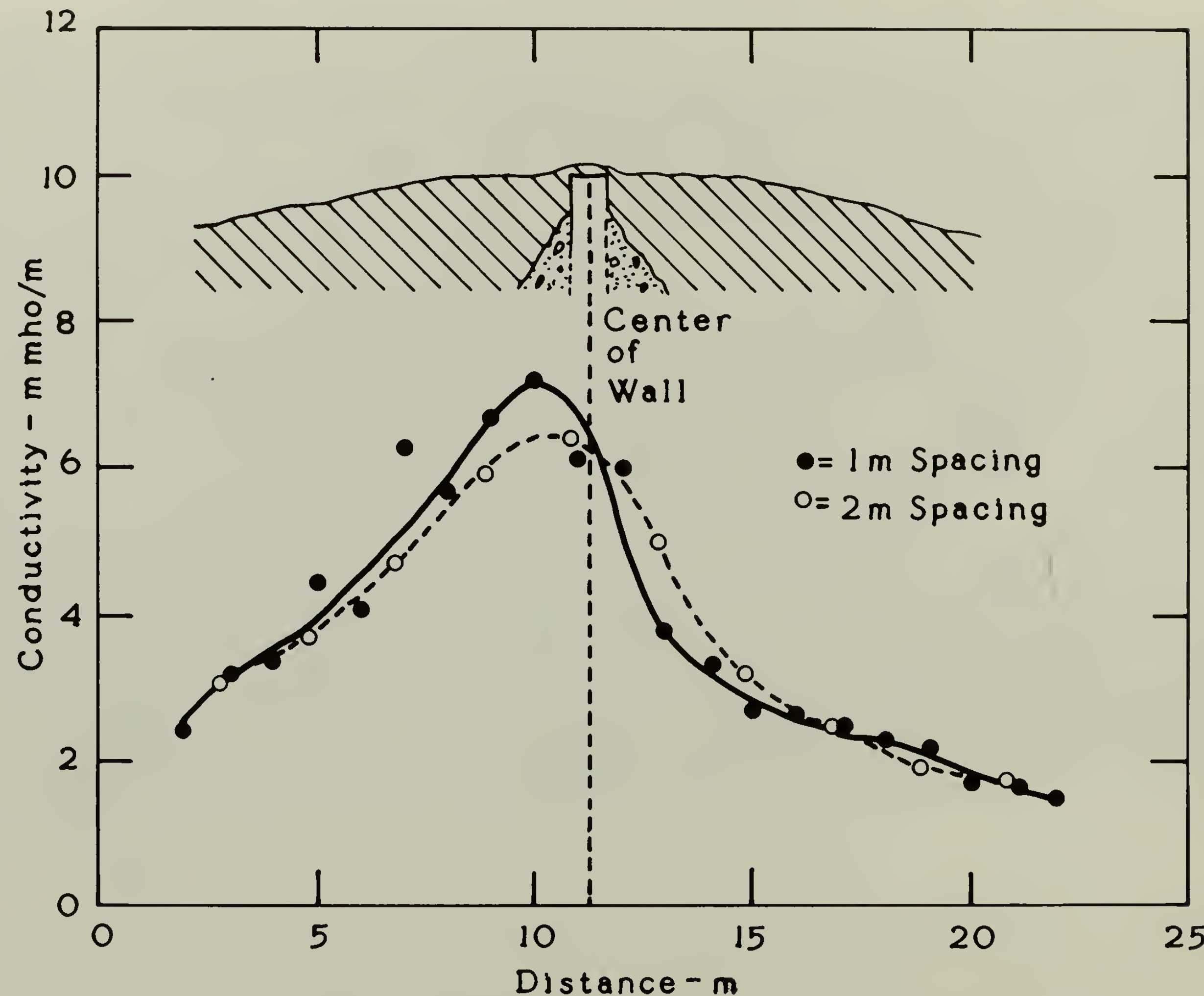

FIGURE 4 - Resistivity profile across causeway at Pueblo Alto

ure 5 shows data from a traverse over a masonry wall and into the plaza area of the pueblo.

To the best of our knowledge, the area traversed at this site was undisturbed, and extended across a prominent mound containing an extension of the main pueblo structure. The mound was some 5 to 6 km. in width and was surmised to contain rooms as well as a portion of the masonry wall. The vertical extent of this record is about 4 m. and the horizontal extent about 8 m. Vertical structures with interconnecting horizontal members are clearly depicted and indicate a man-made origin. From the scale, it is obvious that the horizontal sections are not the floors of successive stories as was first thought, but more probably different levels of partially decayed walls.

The small echo to the upper left was marked during the traverse and subsequently excavated. The uncovered target is shown in figure 6, and was the upper surface of a well preserved wall about 15 cm. below the surface. Despite the shallow burial, there was no discernible surface expression of this structure.

Other areas investigated during this series of experiments, had varying results. These results were generally quite encouraging in that masonry targets could often be detected in soils with low radar losses although known adobe structures with modern fill material were usually missed. In one particular case where excavation and backfilling had preceeded the radar survey, strong echoes were obtained over adobe walls. However, it was not clear whether the echoes were due to the walls or to the difference in soil compaction due to excavation and backfilling procedures.

1975 Survey

A second series of surveys was made in 1975 at the undisturbed site of Pueblo Alto. This site was ideal since it had low radar losses, was comparatively level in the plaza area where we wished to work, and was scheduled for shallow excavation in the summer of 1976. Thus, any structures that were indicated by radar could be verified later by the excavation. One traverse was made over the trash mound for the Pueblo with predictably negative results. The radar showed nothing but numerous scatterers within the soil. In physical terms, this indicated that no objects were present in the mound that were both different in dielectric constant and larger than about half a wavelength. (The frequency chosen for this survey was approximately 300 MHz, giving a value of 25 cm. for one-half the wavelength in soil.) A survey was then made of the plaza using a grid spacing of 5 m., and grid lines 70 m. in length. Several plots of the echoes were prepared, and one of these showing only the major echoes in an area 40 by 70 m. is given in figure 7.

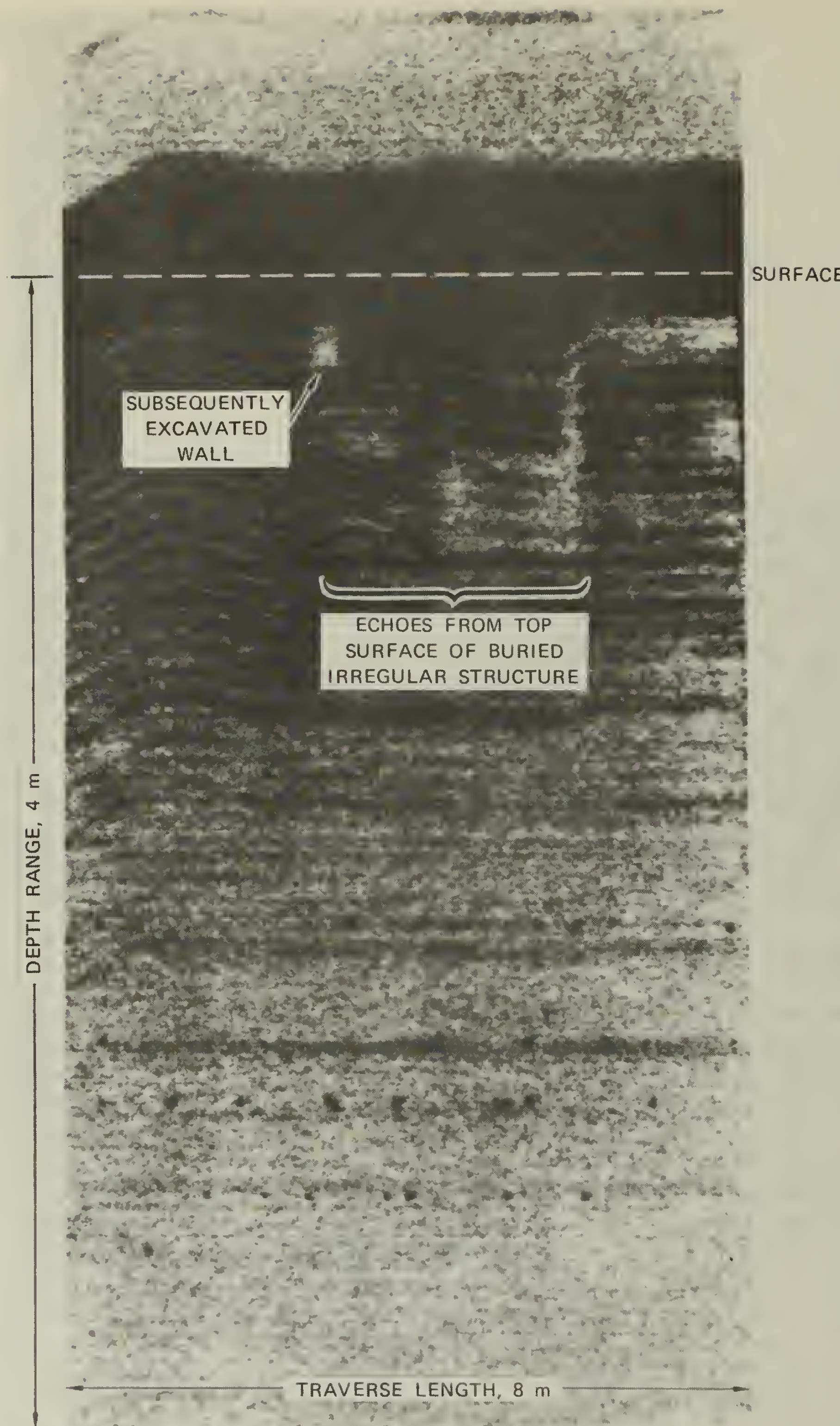

FIGURE 5 - Radar echoes from subsurface targets at Hungo Pavi

FIGURE 6 - Excavated wall at Hungo Pavi

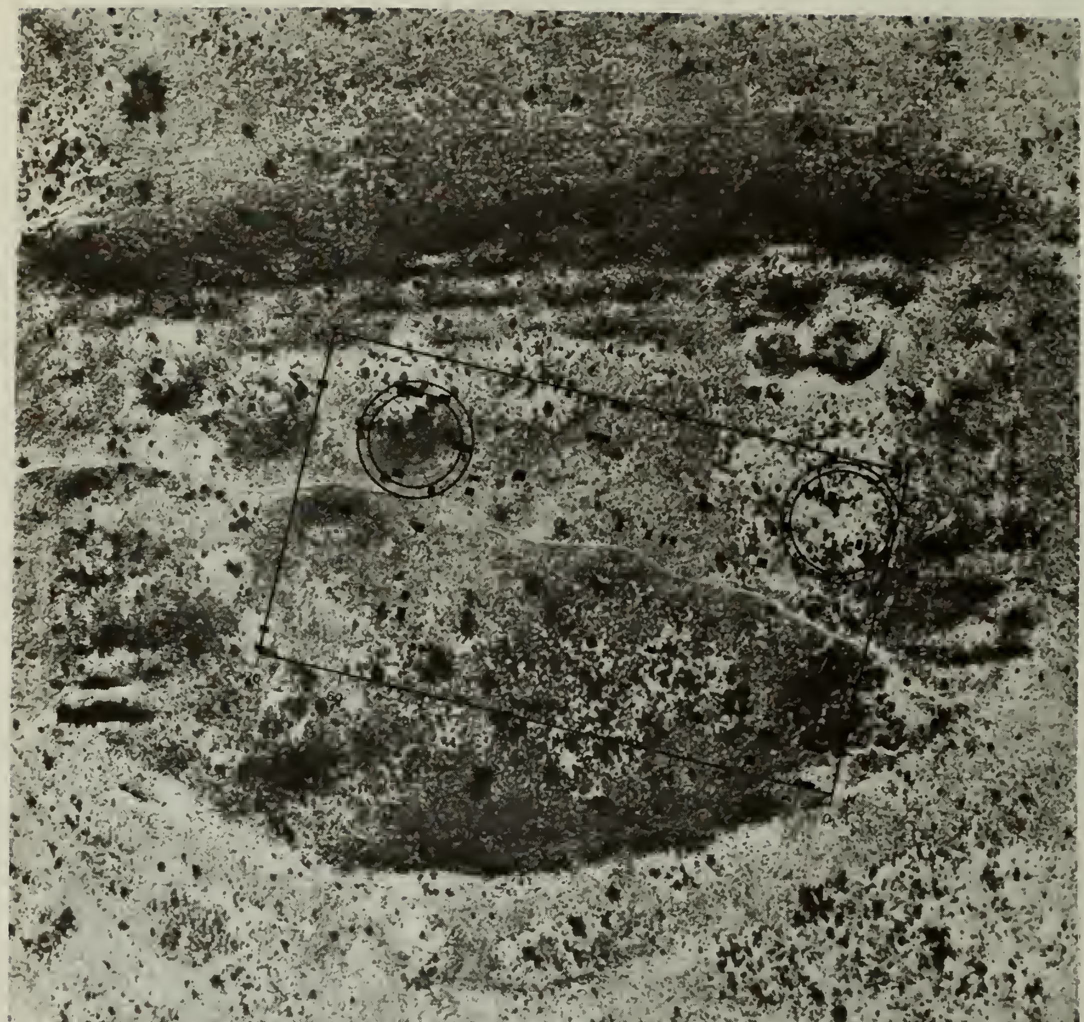

FIGURE 7 - Major echoes from radar survey of Pueblo Alto (distance in meters)

The kiva shown on the left had considerable surface expression, and was used as a control in the search for similar echoes. The one on the right was surmised from the data, since a disproportionately large percentage of the echoes lay on a circle in that region. Based on this and other maps of lesser echoes, a number of locations were suggested to our colleagues at the Chaco Center for testing. Of the two that were tested, one (shown in fig. 8) contained near-surface masonry structures, and the other showed marked deformation of the soil strata (shown in fig. 9), indicating a possible mass at greater depths. These maps depicting all echoes proved to be confusing since the grid spacing was too coarse to allow the individual echoes to be connected with any confidence. It was concluded that a grid would be needed with spacing less than one meter to resolve this problem for the particular site in question. It was further noted that there was a natural tendency to interpret the echoes as being caused by the alignment of linear structures with the traverse axes, a bias that is well known to the geophysics community in the interpretation of aerial line-profiling data. The only way to remove such a bias convincingly would be to survey with a random walk pattern, but this causes problems in locating the source of each element of the data. The solution would be to have a continuously operating positioning system recording accurate location data along with the radar echo data. Such a system was built for the last series of surveys in 1976.

The work in Chaco Canyon also showed that the radar system and the associated recording and data reduction could be improved considerably if the cables connecting the radar cart to the electronics were removed, and an all-digital system was employed. Without the umbilical cables, traverses could be made over greater distances and rougher terrain, and the problems of having to identify and remove cable reflections and re-radiation from the data would be eliminated. It was decided to develop and build a system in which the data would be transmitted via a telemetry link to a nearby vehicle equipped with a computer and display unit. At the same time, a position-location system built into the radar cart would provide an immediate capability at the computer for plotting the location of the radar traverses.

1976 Survey

The system was field tested, again at Pueblo Alto in the spring of 1976. Since there was some doubt as to the moisture content of the soil, resistivity profiles were again made, this time across the center of the plaza. The soil was indeed found to be more lossy than in the previous year, but not enough to rule out the use of radar. After some preliminary testing, surveys were conducted at a frequency of 250 MHz. These were concentrated on

FIGURE 8 - Area underlying a major echo at Pueblo Alto

FIGURE 9 - Area underlying a suspected kiva echo showing curvature in the stratification

several small areas of interest rather than the whole plaza. The radar cart, shown in figure 10 traversed these areas in a random manner while the data were plotted and the position of the cart tracked simultaneously in a nearby mobile laboratory (fig. 11). An example of the tract is given in figure 12 where the cart position was plotted directly onto a contour map of the plaza. The X symbols indicate the position of the three antennas emplaced for position location. Since the scale of these plots is continuously variable, it is just as simple to plot the survey track onto an aerial photograph, which was indeed done at one point in the survey. The ability to view an actual photograph allows the operator in the vehicle to have a good appreciation of the survey at any given time, and to correlate any conspicuous echoes with terrain features. During the data acquisition, the computer operator signaled the cart team when an echo was occurring and a colored marker was dropped at that point. In this manner, the radar cart operator could see the buildup of echoes in any linear or circular pattern and would cross and recross the area to make sure that the gaps in the pattern were filled in, thus avoiding the interpolation problems of the previous year. An example of part of the survey area being filled in with echoes is given in figure 13. A number of linear features are apparent. Again, these data are plotted from a random-walk survey pattern, and any linear features that show up at this site are hard to explain by any other means than the presence of a man-made structure.

While the automatic position-location system can presently locate any echoes to within plus or minus 30 cm., the vertical accuracy of the radar system is harder to define because of the interference between echoes from objects other than the target, or from different sections of the same target. From a classical radar point of view, the accuracy at 250 MHz in Pueblo Alto was approximately 25 cm., but from experimental experience it was probably not better than half a meter. The echoes in figure 12, for example, fell into two categories. One group was apparently just below the surface, perhaps 15 cm. or so, and the other was between 1 and 1.5 m. It was not possible to excavate to this depth because of the excavation scheduled for the following months.

Work is presently underway to program the computer to recognize echoes from different depths and to store their locations for later printout on overlays for each depth cell.

PART VI: CONCLUSIONS

The use of radar data to investigate the near subsurface of archeological sites has been demonstrated. The technique suffers from a severe limitation in that the sites chosen must usually be dry so that the soil attenuation is low. Sites can generally be

FIGURE 10 - "Cordless" radar cart used in 1976 survey

FIGURE 11 - SRI's mobile radar laboratory

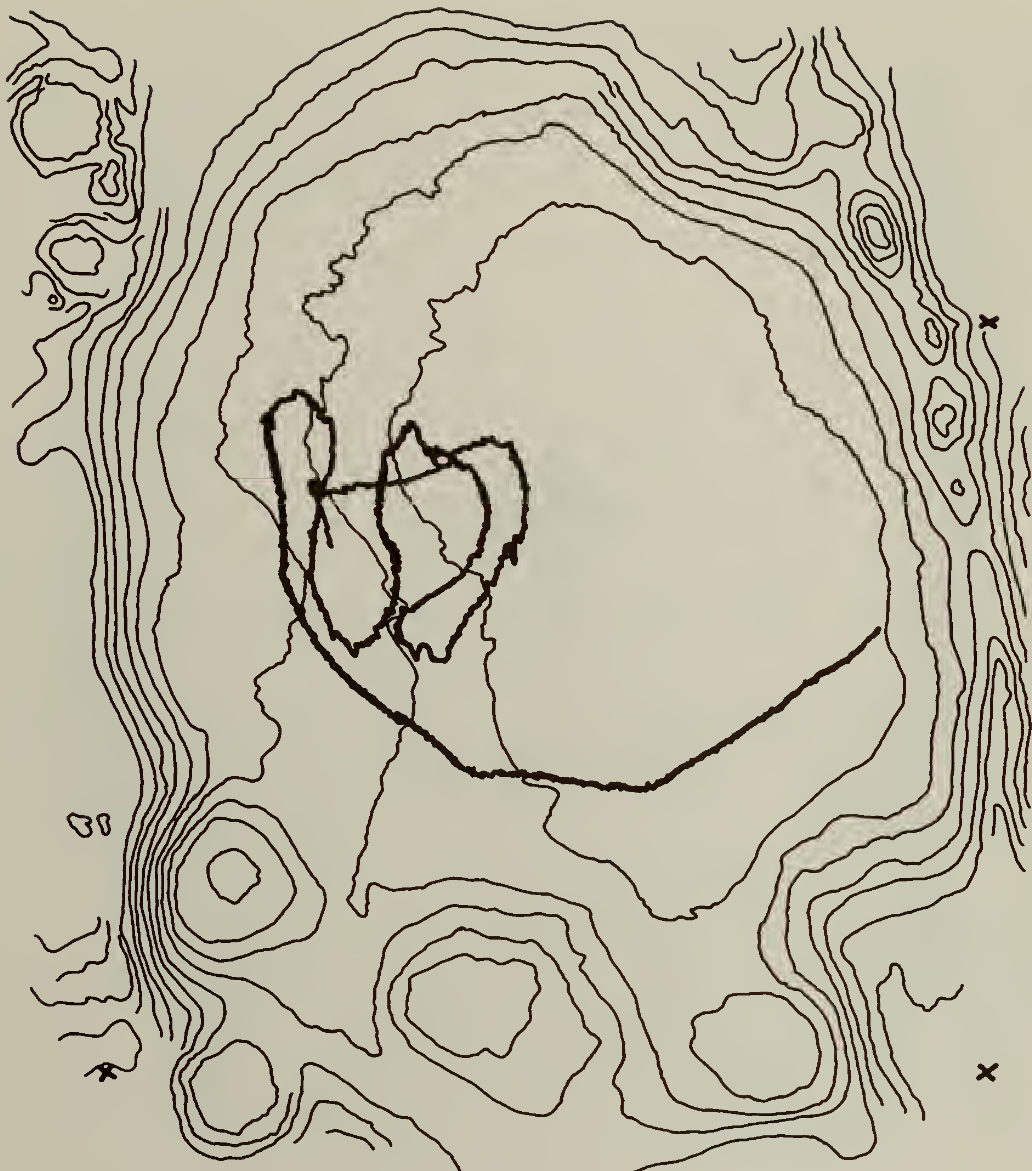

FIGURE 12 - Example of position-location system output

FIGURE 13 - Echoes obtained in the central plaza of Pueblo Alto

evaluated in advance of any radar field work by the examination of carefully obtained soil samples, or by the use of resistivity data. The radar technique can be used with success when the targets are near the surface and have a contrast in dielectric properties from the surrounding soil. The work reported here all took place at Chaco Canyon, but a bank of representative data from other sites is being accummulated to allow better predictions on potential radar performance, and to assist the data-interpretation phase of subsurface surveys. The maximum depth of penetration observed so far at an archeological site was 10 m. at a frequency of 220 MHz. Typical depth penetration is from 1 to 4 m. at frequencies over 200 MHz.

Stanford Research Institute

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PHOTOGRAMMETRIC MAPPING AND DIGITIZATION OF PREHISTORIC ARCHITECTURE: TECHNIQUES AND APPLICATIONS IN CHACO CANYON NATIONAL MONUMENT, NEW MEXICO

BY

BASIL G. POULS, THOMAS R. LYONS, AND JAMES I. EBERT

PART I: INTRODUCTION

Chaco Canyon National Monument, where the experiments described in this report were conducted, lies in what is today a semi-arid and remote part of northwestern New Mexico (fig. 1). A highly developed society which may have been ancestral to some of the modern Pueblo societies of the Southwest occupied this area approximately 1000 years ago. Among the technical accomplishments of the ancient Puebloans or Anasazi are literally thousands of masonry dwellings, some of which contained as many as 800 separate rooms and covered many hundreds of square meters. Standing walls and other features dot Chaco Canyon itself, thus ideally suiting this area to the application of remote sensing techniques in archeological studies.

Much of the emphasis of current remote sensing research at Chaco Canyon, carried out primarily under the aegis of the Chaco Center (National Park Service and University of New Mexico), is directed toward interpretive methodology. Recent experimentation has dealt with the use of aerial photos for the discovery of archeological sites, the study of spatial relationships between sites, intrasite analysis, and environmental studies. The purpose of this report, however, is to examine an area of remote sensing which we feel holds great potential for archeology, especially in a period of increasing demand for assessment of cultural resources, that is, the photogrammetric mapping and locational digitization of architectural data from large archeological sites.

At the International Conference of Remote Sensing in Arid Lands held in Tucson, Arizona, in November 1972, a paper was presented entitled "The Kin Bineola Irrigation Study; an experiment in the use of aerial remote sensing techniques in archeology" (Lyons et al., 1972). Part of this presentation was addressed to

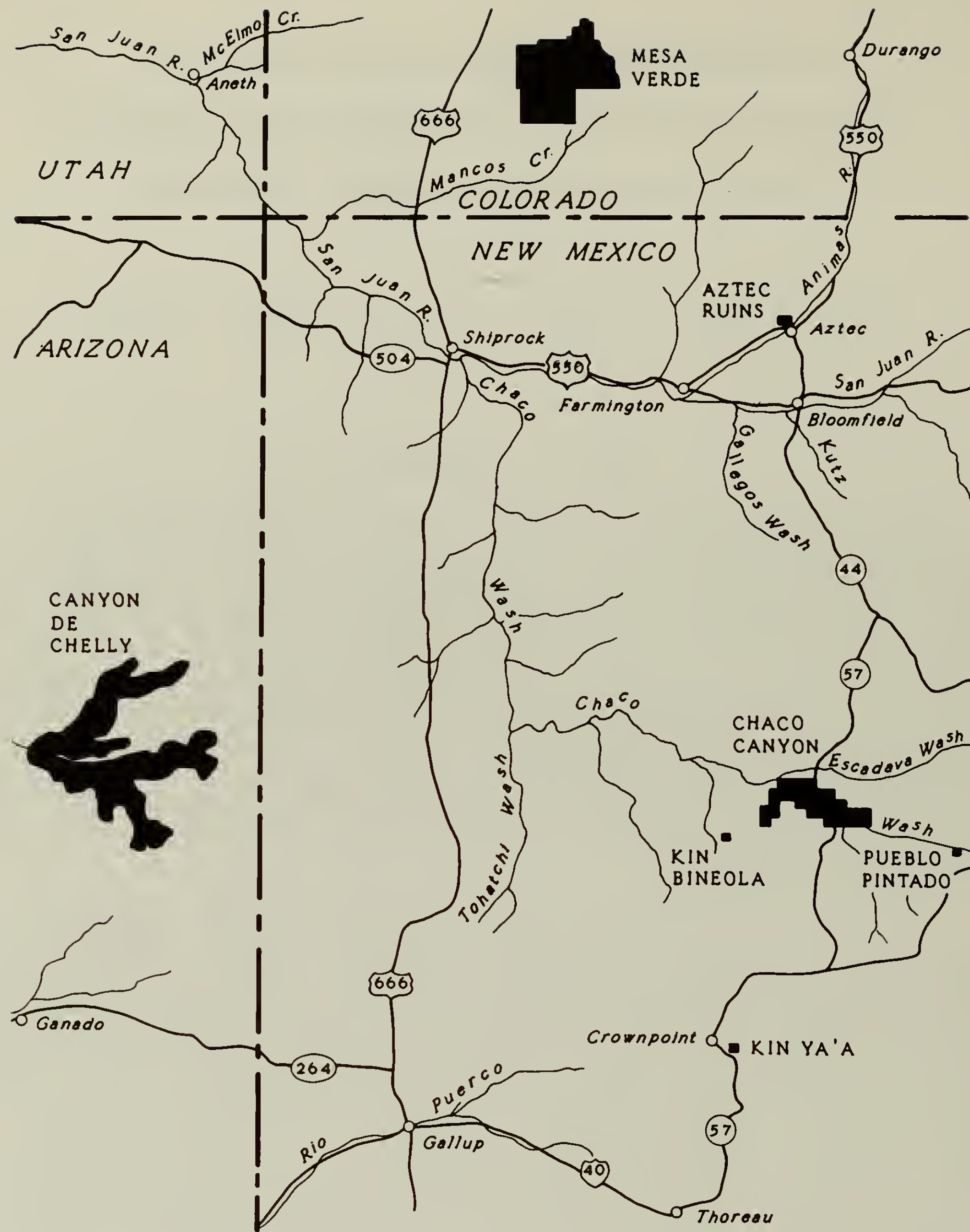

FIGURE 1 - Chaco Canyon National Monument with detached areas, Four Corners area

the use of photogrammetric procedures in the discovery and recording of prehistoric cultural features including habitation sites, irrigation canals, diversion dams, and ancient roadways, as well as ground topography and natural drainage patterns. The evaluation of these techniques clearly demonstrated the effectiveness of photogrammetry both as a tool of discovery in archeology and as an efficient method of archeological analysis of site characteristics and relationships.

An outgrowth of the original Kin Bineola irrigation study has been experimentation with more detailed site investigations of various large pueblos within the Chaco Canyon National Monument. The results of this second phase of methodological study and an evaluation of the cost effectiveness of the procedures used are presented here.

PART II: DISCUSSION

Seven large pueblo sites were selected in addition to Kin Bineola for this study. These included Pueblo Bonito, Una Vida, Chetro Ketl, Penasco Blanco, Kin Ya-a, Old Alto, and Pueblo Pintado. The primary objective was to prepare detailed site maps for each of the selected pueblos. This procedure involved obtaining coordinately controlled aerial photography and the subsequent use of this photo coverage in precision stereo plotters. It was hoped that the utilization of readily available photogrammetric procedures would yield site maps that were far more accurate, detailed, and informative than those prepared by traditional on-the-ground engineering surveys. In addition to increasing accuracy, these procedures also were expected to have the potential of offering the archeologist considerable savings in time and costs. Perhaps even more important to the overall concept of archeological investigation is the fact that in preparing maps through the use of photogrammetric techniques, the archeologist is free to conduct detailed investigations and analyses without the considerable burden of first preparing site layouts in the field. Certainly this is not to say that ground control is eliminated at each pueblo site, but the field control that is required involves basically a simple closed loop of levels surrounding the site and the establishment of several horizontal lines by either electronic distance measuring equipment or chaining methods. The first step, therefore, involved establishing both horizontal and vertical control in the field prior to obtaining aerial photography.

In the Chaco project, field control was set by the archeologist, but could, of course, also have been established by a professional land surveyor. The specific locations of all the control points at each pueblo complex were designed to fall outside the area of potential excavation. Control points so established were monumented with an appropriate length of reinforcing rod so that the monument could withstand weathering better than the usual wooden survey stake or hub. Each of these control points was then marked on the ground using white plastic strips approximately 18 in. wide by 7½ ft. long, so that each point became clearly visible in the aerial photographs. The plastic panels were laid out at each point in a "V" shaped pattern. Since the "neat" model area for a single stereo spacial model covers a ground geometry of approximately 900 ft. x 1600 ft. for a 1:3000 negative scale, the field control points were located so that they fall within these perimeters.

The required field control included an elevation at each corner of the rectangle enclosing the area to be mapped plus an additional vertical point somewhere in the middle of this rectangle along either outside edge. In addition, two horizontal lines were measured with the terminal points monumented and paneled for photo identification. Obviously, any specific paneled point could serve a dual function in marking both the end of a horizontal distance and the position of a vertical point.

Once the panels were in place, black-and-white aerial photography was flown using a Cessna U206 at the flight altitude necessary for the preparation of a final stereo compilation at a scale of 1 in. = 250 ft. The aerial negatives were exposed for a ratio scale of 1:3000 (1 in. = 250 ft.) with the aircraft flight altitude being approximately 1,500 ft. above average ground elevation. All the photography used in this project was obtained utilizing a Zeiss RMK-A 15/23 precision cartographic camera with a nominal focal length of 153 mm. (6 in.) and with a roll film format of 9 in. x 9 in. per exposure.

Since many of the pueblo sites under study exhibit remnants of high standing walls, shadows provided a potential problem in the compilation procedures. Therefore, fly-over time of the aircraft was scheduled as close to solar noon as possible, minimizing the effects of such shadows. In order to obtain the maximum image detail and resolution from the exposed aerial negatives, the diapositive glass plates used in the compilation process were prepared utilizing a Mark II Log Etronic Printer which automatically exposes the negative by sensitive electronic density sensing devices. This procedure yields the maximum detail in both shadowed areas and highlight areas.

Once the aerial photography was obtained and the field survey control information became available, the next step involved stereo compilation utilizing precision cartographic plotters. The stereo plotter used in the Chaco project was a Kern PG-2, compiling at a map scale of 1 in. = 50 ft.

In the stereo compilation operation, the development of data fell into three separate and distinct stages. The first of these consisted of plotting all cultural and planimetric features. This type of information included remnants of existing walls, evidence of ancient roads, modern roads and trails, fences, canals, channels, etc. The second stage involved the plotting of microtopography with a contour interval of 1 foot, numerous spot elevations, and any unusual terrain features of archeological or potential archeological importance evidenced by unusual vegetative anomalies, linear patterns, and subtle soil tone changes. Spot elevations were established in order to facilitate the topographic interpretation between widely spaced contours, to aid in the slope determination along lines defining ancient water channels, and to act as a reference elevation in the center of each room of the existing pueblo complex (fig. 2). These room center elevations thus became the base datum for the wall remnants enclosing the room. The third stage of the compilation procedures involved obtaining digitized information in the form of x, y, and z coordinates, with the x and y coordinates defining horizontal position and the z coordinates defining elevations. Digitized coordinates were established along the center line of wall remnants, at break points along the wall and at wall intersections. All of the digitized terrain data as it was derived was automatically punched on computer cards. The storage of the digitized information on cards affords the archeologist a wide range of computer-oriented functions to assist in site analysis and in stabilization, and restoration of prehistoric architecture. The manipulation of these coordinates can yield such information as accurately defined wall profiles (fig. 3). Through the use of existing computer graphic programs, perspective drawings can be prepared from any vantage point above the pueblo site (fig. 4).

This provides the archeologist with a capability for reconstruction hitherto not available to him. With the use of a computer screen monitor or print-out he can reconstruct graphically the conditions of a site during various phases of ancient occupation. He can use the quantified structural data as a base, and with information gained during excavation, provide input to the computer to: 1) raise a given wall, 2) eliminate a part of the structure built at some later date, 3) retain the configuration of the associated trash dump, etc. Such a procedure is potentially far more reliable than a static "artist's reconstruction" and in addition, would serve the purposes of crews given the responsibility for preservation and stabilization.

An additional use of terrain data in the form of a network of digitized coordinate points over a mounded site is the precise measurement of material volumes. This network, depending on the requirements, can be spaced at some convenient interval such as 1,

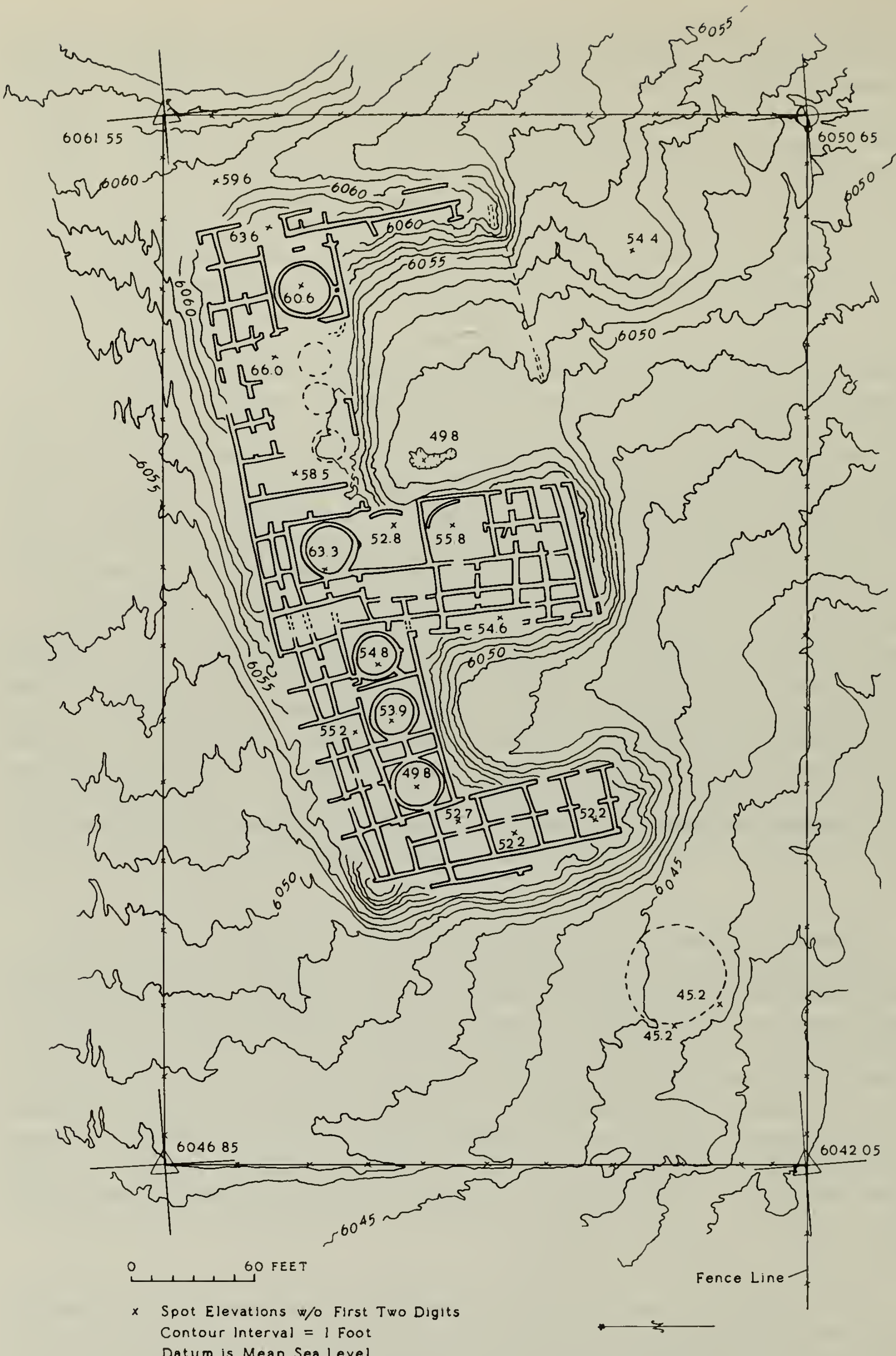

FIGURE 2 - Photogrammetric map of Kin Bineola ruin

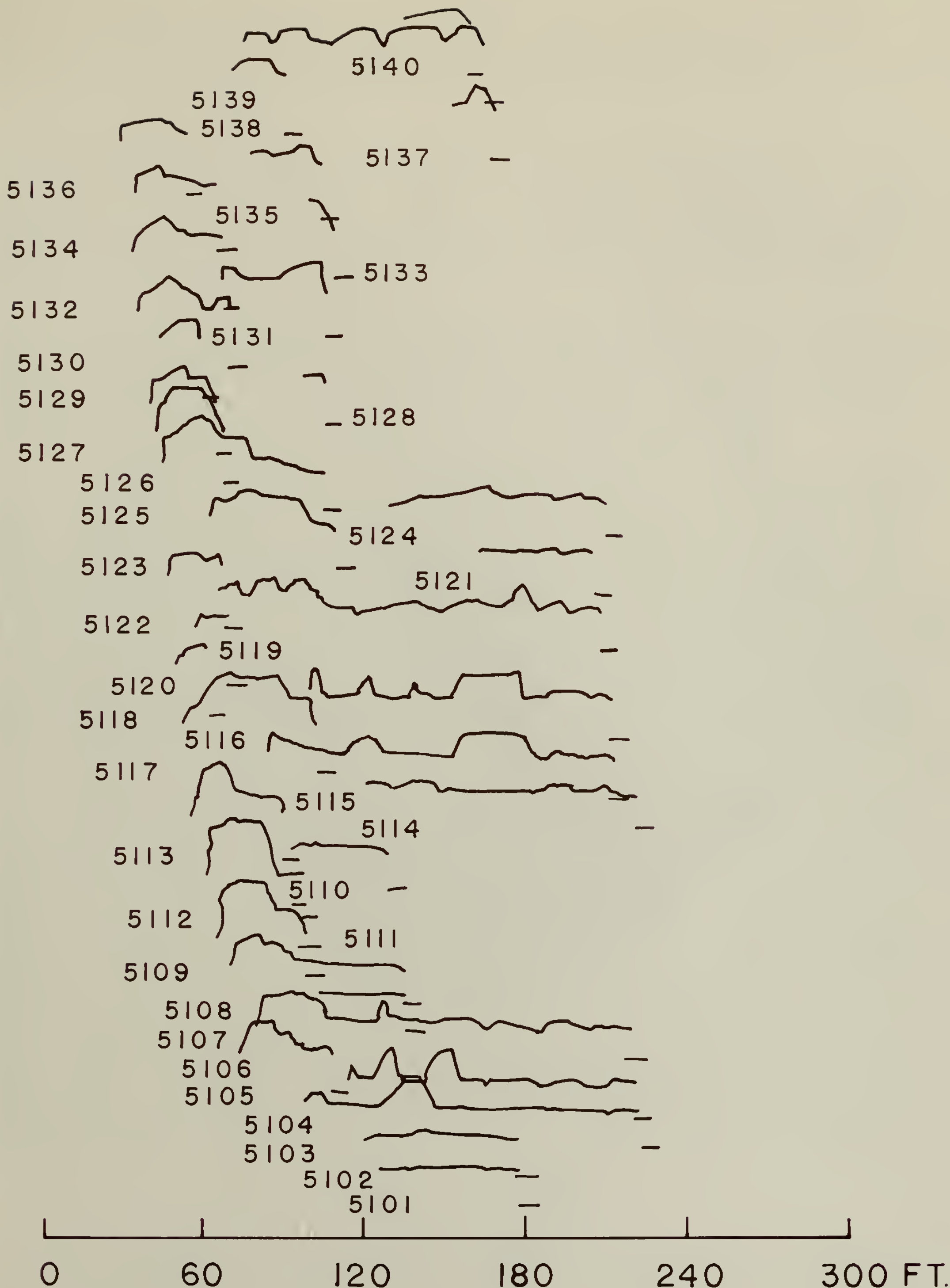

FIGURE 3 - Computer printout of Kin Bineola wall profiles with assigned identification numbers

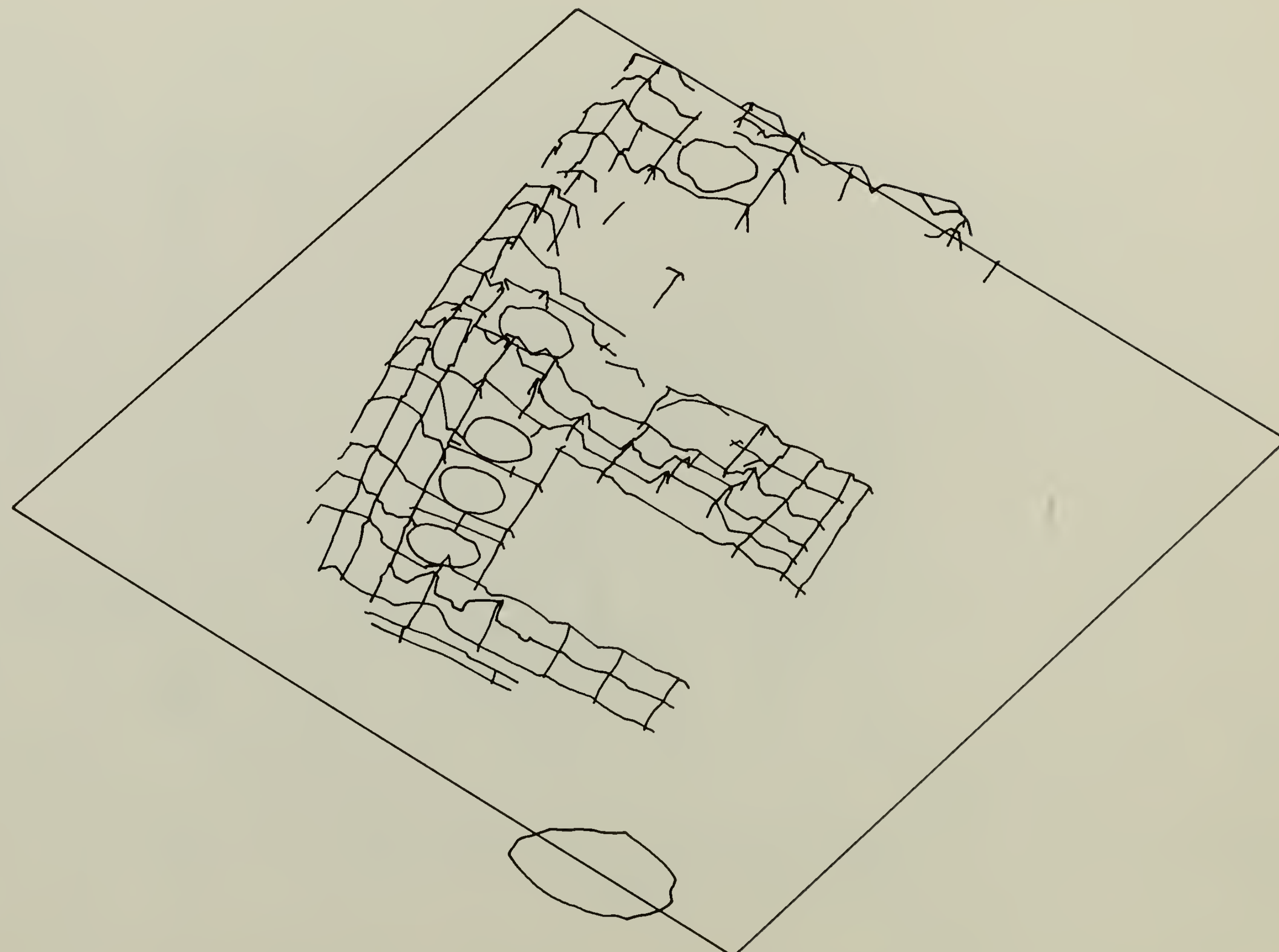

FIGURE 4 - A computer generated perspective drawing of Kin Bineola

2, or 3 meters and the amount of earth and rubble to be moved readily determined. Existing computer earthwork programs are available to facilitate this type of calculation.

Using the map scale of 1 in. = 50 ft, it was possible to define and plot both edges of existing wall structures (fig. 2). As a result of this procedure, the map information was not only more realistically depicted, but also gave the user information regarding the variation of wall thicknesses within the pueblo complex.

The final format of the planimetric and topographic information was compiled and reproduced on a stable based film in the form of a positive reproductible. This means that inexpensive diazo prints can easily be obtained from the plotter manuscript sheets and used for field operations and instruction purposes.

An interesting and unexpected development occurred during the photogrammetric analysis of the Penasco Blanco ruin when the map (fig. 5) was studied in detail. Contours at dashed line "A" indicated a slight lineal depression not unlike the topographic expression of the known prehistoric roadway, "B", from which it stems. A review of the aerial photography and a ground check substantiated the interpretation that the feature was a previously unrecognized branch of the prehistoric roadway giving access to the pueblo proper. This discovery indicates the potential for what may be considered a secondary or derivative analysis of the aerial photo data.

The photogrammetric technique of preparing detailed site maps affords the field and theoretical archeologist a useful tool in preparing accurate maps quickly and economically. The aerial photography obtained in this process should be thought of both as an historical record and as a medium through which an inexhaustible amount of technical terrain data can be derived either in graphic form or through the storage of coordinate positions for subsequent computer use. It should also be noted that in addition to aircraft supported camera platforms from which it is possible to derive mapping documents at scales of 1 in. = 30 ft. or 1 in. = 20 ft, larger scale maps can be produced by utilizing balloons or constructed towers. The versatility of the photogrammetric approach is readily apparent.

PART III: COSTS

In reviewing the economics of the photogrammetric procedures, there are many variables to be considered. Such items as the size of the site, the complexity of the site, the number of sites that can be obtained on one photo mission, and the ruggedness of surrounding terrain all have a significant bearing on the final cost.

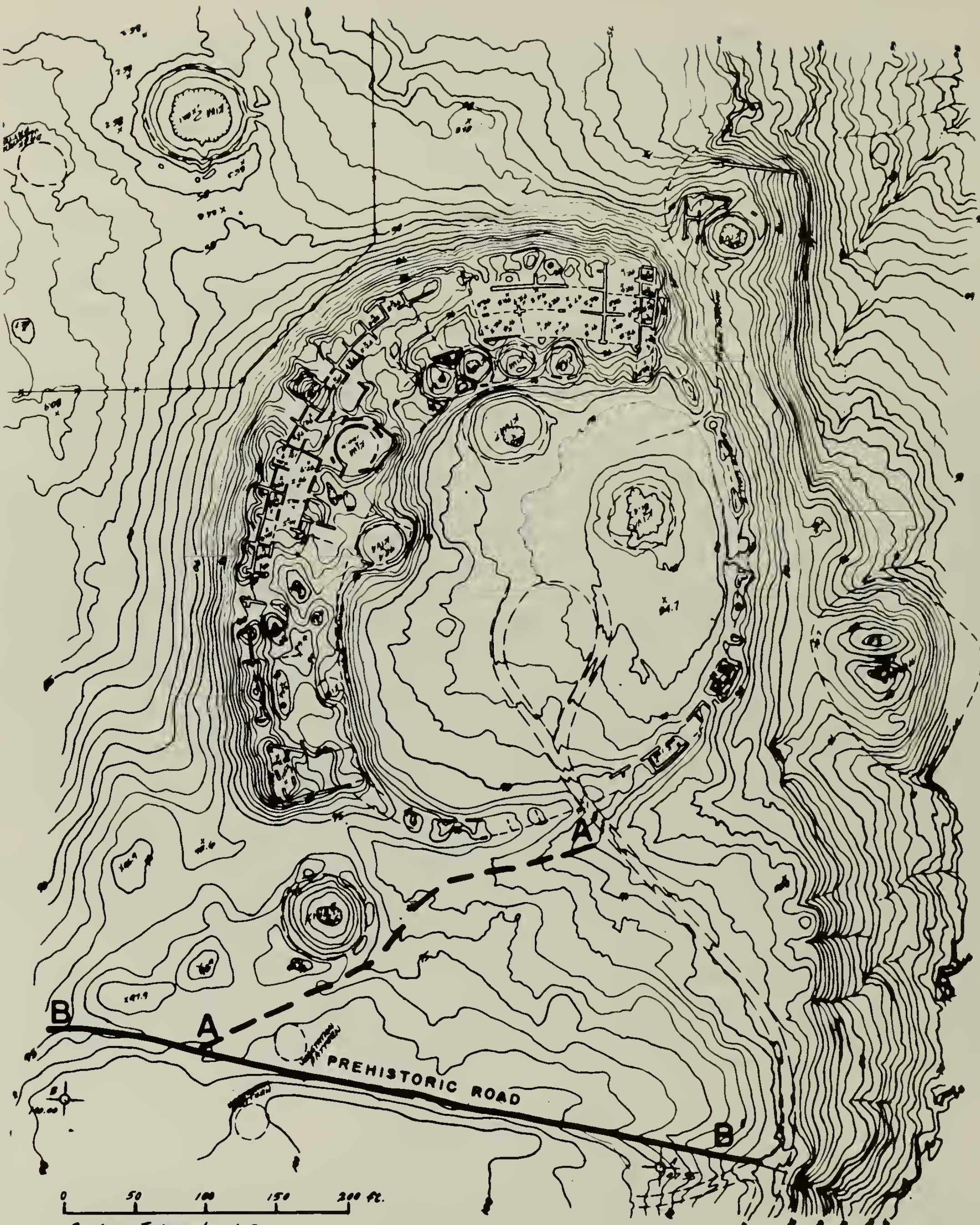

FIGURE 5 - Photogrammetric topographic map of Penasco Blanco ruin. B-B', a known prehistoric road; A-A', a prehistoric road inferred from contours.

If we consider a general situation and take a moderately-sized pueblo site of medium complexity which can be in a square approximately 700 ft. x 700 ft. contained in one Stereo Model, the relative cost for preparing the various map phases could be approximated by the following figures as of 1974: 1) aerial photography, $250.00; 2) stereo compilation of cultural and planimetric data, $225.00; 3) stereo compilation of topographic information and spot elevations, $150.00; 4) stereo compilation to established digitized terrain data, $275.00; and, 5) a fixed setup charge to include coordination, setting up the stereo model, diapositive glass plates, and preparation of stereo base sheets, $125.00. The total cost, then, to provide a complete analysis including aerial photography would be about $1,025.00. Aerial photography costs could be greatly reduced per site if several sites could be obtained during the same flight run. It should also be noted that the figure quoted above does not include the establishment of field horizontal and vertical control, which would take approximately one man day to obtain.

A natural extension of the photogrammetric procedure described so far might be called "phased" photography and mapping. At prescribed times during the excavation of a major site, vertical photography from airplane, helicopter, balloon, or tripod/bipod platforms could be obtained, depending on the size of the excavation or features of interest. The financial investment in obtaining this photography would be relatively small, and it would provide the archeologist an exact historical record of conditions and progress at a specific point in time. Of even greater importance is the photographs providing and preserving a wealth of information on fabric that is removed or destroyed in the excavation process. In order to extract analytic data from this new photography, the same ground control previously established for the initial site map would be repaneled for each new photo mission. This means that no additional field surveys would be required, since the original ground control would be used over and over again. At some later time, the photography could be used to compile additional mapped details. Utilizing this phased approach, it is apparent that the process of excavation need not be interrupted while detailed maps or ground grids are prepared. By minimizing interruptions caused by ground surveys of the exposed ruin, phased aerial mapping would give the archeologist a maximum of productive field time.

PART IV: CONCLUSIONS

The photogrammetric approach utilizing low altitude stereo photography provides the archeologist with an efficient and economic tool for deriving detailed cultural and environmental information under certain defined conditions. The data thus established are accurate, comprehensive, and can be prepared quickly. Phase photography can further serve as a historical and technical record of work in progress. The technique provides the user not only with an array of technical data, but allows the use of systems that have already been developed and are readily available. It is the opinion of the authors that the project completed at the Chaco Canyon National Monument amply demonstrates the effectiveness of this method.

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THE KIN BINEOLA IRRIGATION STUDY: AN EXPERIMENT IN THE USE OF AERIAL REMOTE SENSING TECHNIQUES IN ARCHEOLOGY

BY

THOMAS R. LYONS, ROBERT K. HITCHCOCK, AND BASIL G. POULS

PART I: INTRODUCTION

In recent years, the potential value of remote sensing in archeological research has become increasingly evident. Besides its use in the location of archeological sites, attention has focused on certain problems, such as: (1) the effectiveness of various types of film as tools for archeological reconnaissance (e.g., Harp, 1968; Gumerman and Lyons, 1971; Gumerman and Neely, 1972); (2) optimum conditions for the recognition of archeological sites (e.g., Crawford and Keiller, 1928; Crawford, 1953; Riley, 1946; Solecki, 1957, 1960; Martin, 1971) and (3) types of instruments conducive to archeological reconnaissance (e.g., Whittlesey, 1972a, 1972b). To date however, few tests have been undertaken by archeologists to obtain data through the use of photogrammetric procedures.

It was the intended purpose of this experimental project to determine the effectiveness of photogrammetric procedures in assisting archeological exploratory activities. The experimenters hoped to evaluate these procedures particularly as they pertain to planning a more efficient archeological program prior to actual on-site field investigations. In order to carry out this experiment, an area had to be chosen which: (1) contained features of an archeological nature; and (2) was potentially conducive to the mapping of those features (i.e. it should have conditions which would allow these features to show up on aerial photographs). These conditions were fulfilled by the Kin Bineola area near Chaco Canyon, northwestern New Mexico (fig. 1).

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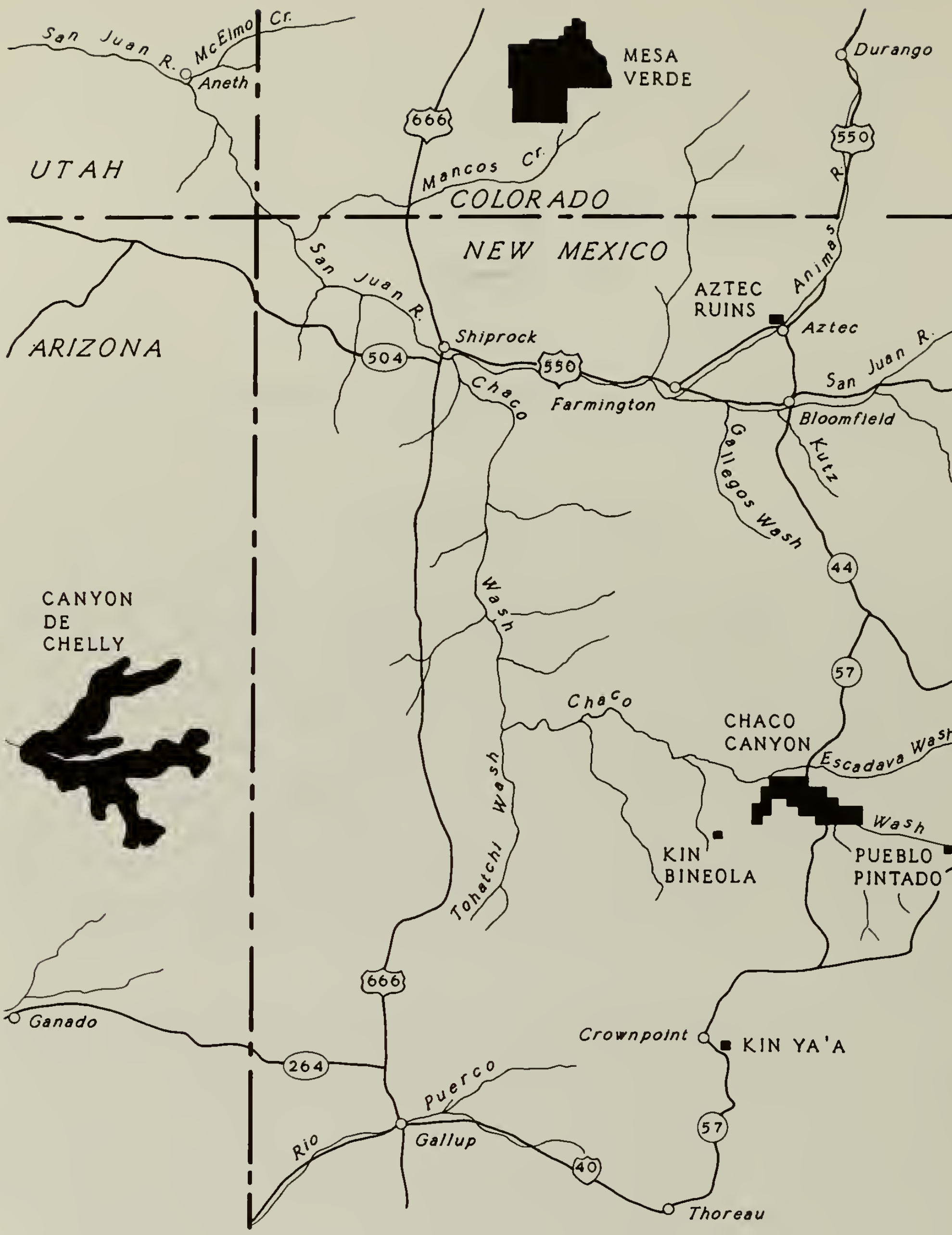

FIGURE 1 - Chaco Canyon National Monument with detached areas Kin Bineola, Pueblo Pintado, and Kin Ya-a in relation to the Chaco basin and the San Juan drainage

The site selected for this project lies approximately fifty miles due south of Farmington, New Mexico in San Juan and McKinley Counties, New Mexico. It has a north latitude of 36°00' and a west longitude of 108°10'. The general area lies in an arid region with a soil type consisting basically of a sandy loam and having a sparse vegetation cover. Kin Bineola Wash, one of the largest tributaries of the Chaco River, runs through the area (fig. 2). Numerous prehistoric ruins exist there which indicate a complex cultural development of ancient origin. The largest of these ruins, Kin Bineola, is a well-preserved pueblo town which had approximately 100 ground floor rooms and which may have been as many as four stories high. Reginald G. Fisher (in Hewett, 1936, p. 159) estimates that approximately 800 people may have lived in the pueblo aboriginally. It has been determined through tree-ring analysis that Kin Bineola was constructed periodically from A.D. 850 to A.D. 1119-1124, a period which spanned the earliest to the latest Chaco Pueblo habitation (Bannister, 1965, p. 168).

The Kin Bineola area is of particular interest in that there reportedly existed a complex network of prehistoric water control and water retention features. S.J. Holsinger, a special investigator for the Department of the Interior, was the first to identify some earthen and masonry features near a low, tear-drop shaped mesa west of the Kin Bineola ruin as the remains of ancient irrigation works (Holsinger, 1901, p. 10). He describes what he felt to be an irrigation ditch as "the best preserved piece of irrigation works on the Chaco" (Holsinger, 1901, p. 37). E.L. Hewett, another early observer, says that the ditch referred to by Holsinger is "fully two miles long", and he, too, feels that the water control features at Kin Bineola are the best examples of irrigation works in the entire Chaco system (Hewett, 1905, p. 329; 1936, p. 124; 1943, p. 320). Historic use of the flood-waters of Kin Bineola Wash by Navajos is recorded by Judd (1954, pp. 55-56), who points out that Navajos in other areas did not attempt the same kind of flood-water irrigation because "no one else had the same kind of valley" (Judd, 1954, p. 56). The topography of the Kin Bineola region, in other words, was well-suited to flood-water farming.

Actual excavations of some of the features of the Kin Bineola water control system have been carried out by R. Gwinn Vivian of the Arizona State Museum (Vivian, 1972). This work was restricted mainly to areas bordering Kin Bineola Wash. Cross-sections were made of features believed to be canals; records were kept of the stratigraphy and the location of associated cultural items; and samples were taken for soil, pollen, and dendrochronological analysis. Cultural features noted by Vivian include canals, diversion walls, sluice gates, dams, and field houses. This water control system, according to Vivian (Personal communication, 1970) is important because: (1) it is an isolated system; and (2) it has water control features similar to those in Chaco Canyon but which occur in a completely different kind of topographic situation. Additional work, he feels, would throw light not only on the water control systems of Kin Bineola but also on those of Chaco Canyon.

In addition to the various ground surveys of the Kin Bineola region, aerial surveys have been conducted. In 1927, Fairchild Aerial Surveys obtained photography at a scale of two inches to the mile, and in 1964, Limbaugh Engineering, Inc. obtained photography at a scale of 1:3000 (Gordon Vivian, n.d.). The first Aerial photographs of the region with archeological applications in mind were taken by Robert H. Lister and Gordon Vivian in 1949 (Lister, personal communication, 1973). These early photographs are valuable, because: (1) they provide us with historic documentation of what the region looked like at various intervals; (2) physiographic and ecological changes can be observed when they are compared with recently-taken photographs; and (3) certain features can be identified on them which are not visible on later photographs.

Since this study is part of an on-going research project, the main concern here will be with the methodology employed and the results obtained. It should be noted that remote sensing should in no way be considered a substitute for ground survey; rather, it is a tool, albeit a valuable one, that can aid archeologists in their field investigations.

PART II: METHODOLOGY

After studying the available government map documents of the Kin Bineola area, it was decided that an extensive area would be covered by conventional black-and-white aerial photography at a negative scale of approximately 1:6000 (1" = 500'). The total area covered by this photography included a rectangle 12,500 feet in a north-south direction and 17,000 feet east and west. This photography was obtained using four flightlines flown in an eastwest direction at an altitude of approximately 9,100 feet above mean sea level (3,000 feet above the average ground elevation).

The photography was flown for stereo coverage with a sixty percent overlap between consecutive photos and with a thirty percent sidelap between adjacent flightlines. All of the aerial photography was obtained with a six inch focal length Zeiss RMKA 15/23 precision cartographic camera with a roll film format of 9 in. x 9 in. per exposure.

In order to provide the necessary terrain detail in the form of topographic mapping, selected areas of interest were delineated for mapping at a scale of 1 in. = 100 ft. utilizing a two-foot contour interval. This mapping area contained approximately 530 acres, with a general orientation along the valley flood plain (fig. 2). To facilitate this mapping, three separate flightlines of stereo black-and-white photography were obtained with a negative scale of 1:6000 (1 in. = 500 ft.) and an overlap between consecutive photographs of sixty percent. In order to obtain the best lighting conditions for both the general photographic coverage and the specific mapping coverage, the photography was exposed only under cloud-free conditions. This necessitated obtaining photography on two separate dates, namely April 7, 1972 (1030-1121 Mountain Standard Time) and April 22, 1972 (0910-0924 Mountain Standard Time).

Prior to obtaining aerial photography, selected survey control points were established on the ground and marked with "T" and "L" shaped plastic panel strips 18 inches wide and 15 feet in length. These control points were readily visible in all of the aerial photography and were later utilized in the stereo compilation. The location of the premarked survey control points formed the horizontal control net required in the mapping operation. The specific location of these points was determined by actual field reconnaissance taking advantage of natural terrain formations.

In establishing the X and Y coordinate positions radial line projection and triangulation methods were employed. Horizontal distance measurements were established through the use of a Model 8 Geodimeter, which uses a laser beam transmitting system. All horizontal angles were measured by Wild T-2 Directional Theodolites. All of the mathematical processing of the field derived horizontal control data was accomplished by electronic computers using automatic data processing techniques. The output of this information was in the form of adjusted X and Y coordinates for each control point. From these data, each horizontal control point was carefully plotted on stable base sheets which were later utilized during the stereo compilation operations.

After the aerial photography was obtained, (fig. 3), a detailed study of photographic contact prints was made to determine the location of the required vertical control points. From this set of annotated photo contact prints, a field survey crew was again sent to the site to photo identify the exact position of the selected vertical control points. Elevations were then established on these photo identified points using both NA-2 Wild Level and Differential Spirit Level methods. The vertical datum was referenced to mean sea level and tied to existing U.S. Coast and Geodetic Bench Monuments.

Using the horizontal and vertical control data, the mapping operation proceeded using standard photogrammetric methods. The stereo compilation was made with a two projector Kelsh plotter equipped with a stereo image alternator. The map compilation was prepared at a scale of 1 in. = 100 ft. with a two-foot contour interval on a sta-

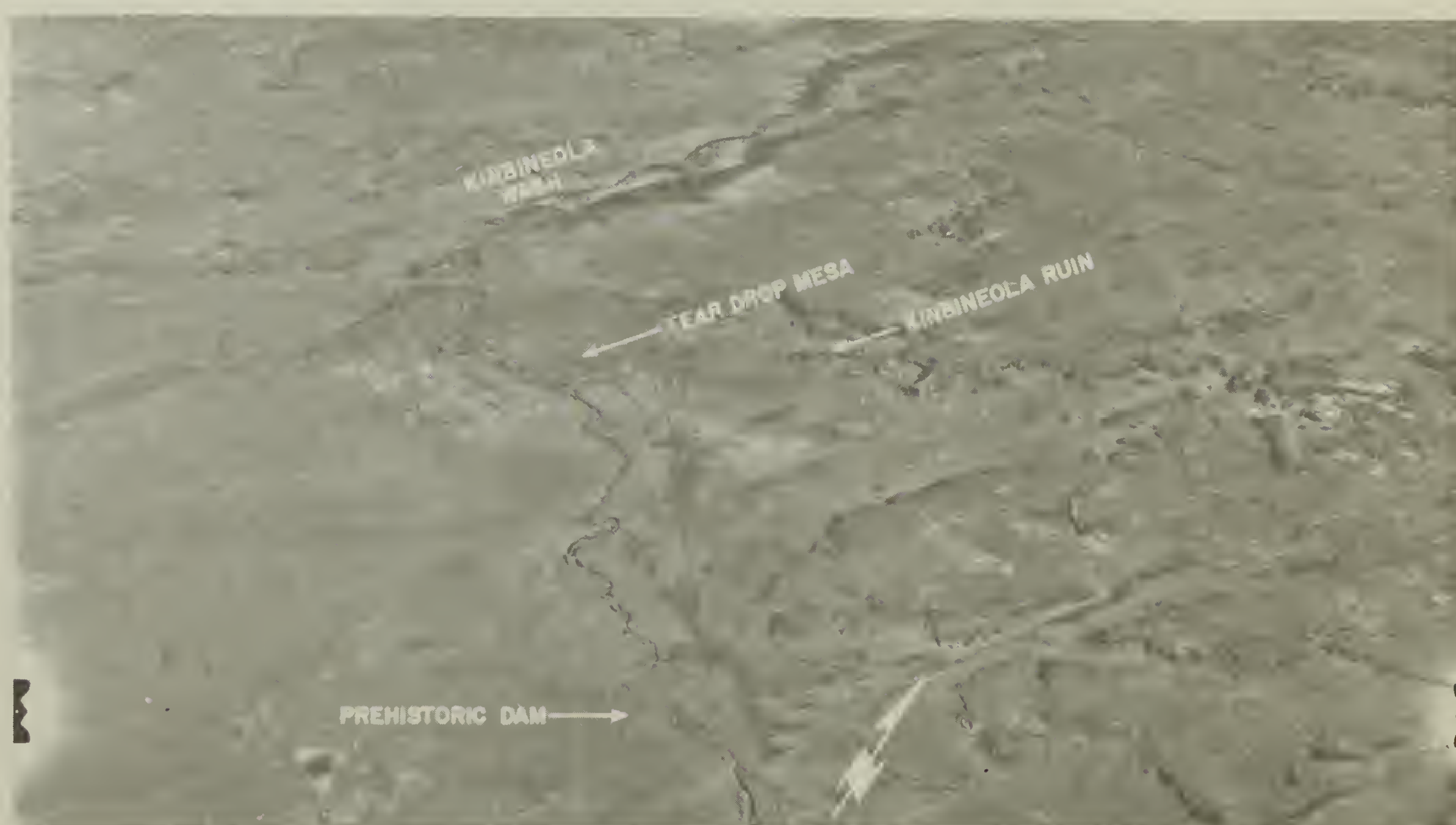

FIGURE 2 - Aerial oblique of the Kin Bineola wash

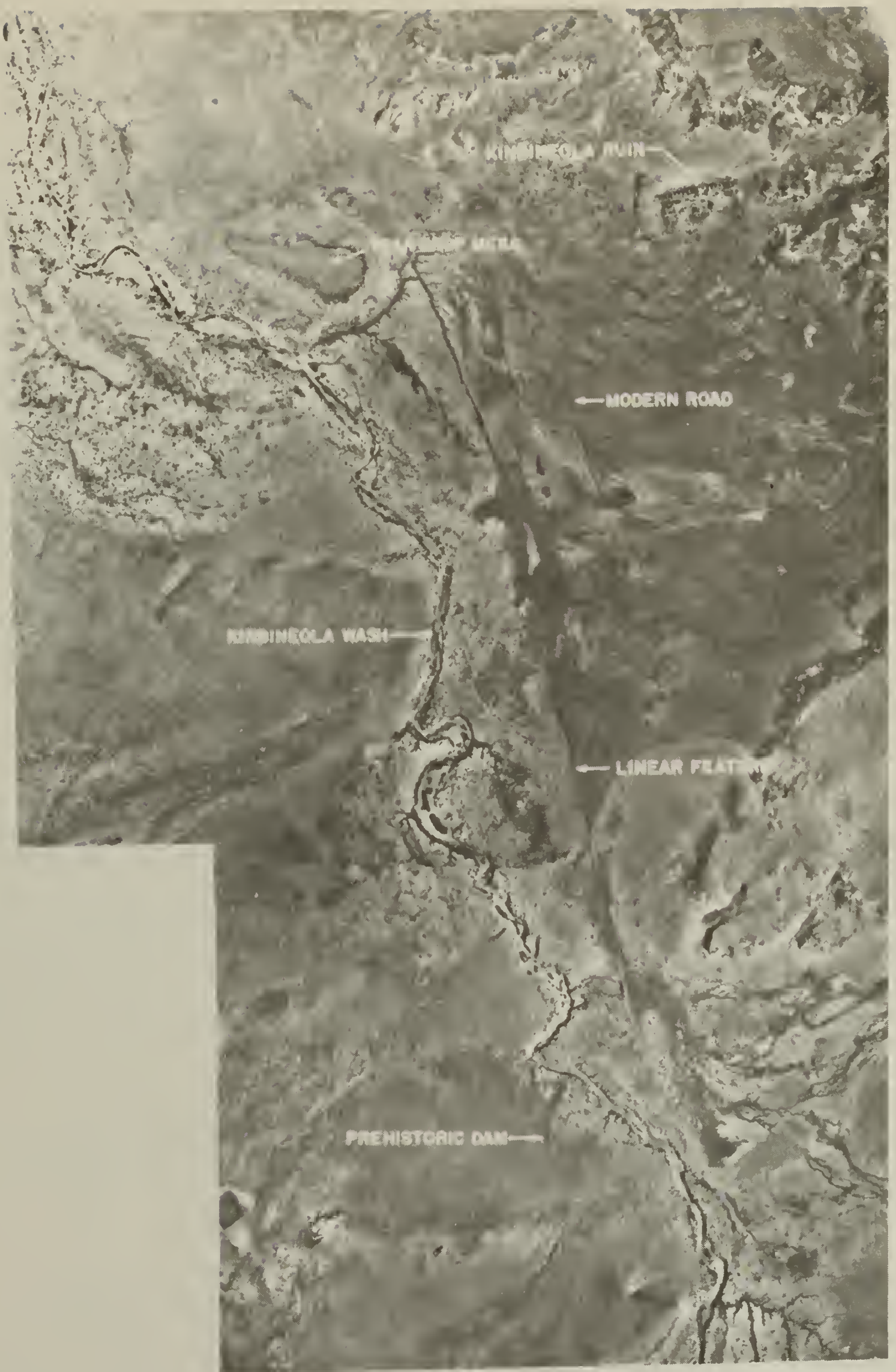

FIGURE 3 - Vertical aerial mosaic of the Kin Bineola Pueblo ruin and adjacent area

ble base mylar film in a positive reproducible form. Because the general flood plain was extremely flat, numerous spot elevations were established to assist in the slope delineations between the standard two-foot contour intervals.

As has been mentioned, the area is one which is fairly flat and which supports relatively sparse vegetation. It was possible however, through careful observation, to establish unusual geometric patterns indicating the existence of ancient water control features. Along these apparent features, which in many instances were on extremely flat slopes, spot elevations were obtained to aid in determining direction of flow (fig. 4). Special emphasis was placed on detailing the actual ruin site of Kin Bineola (fig. 5). Numerous spot elevations were obtained on the remaining walls that stood in various stages of decay (see Pouls, Lyons and Ebert this volume). All the activities of an apparent archeological nature were color coded on the stereo plotter base sheets to facilitate easy delineation.

In this experiment, no attempt was made to actually identify surface anomalies as either prehistoric or modern. An attempt was made simply to locate what appeared to be probable man-modified features in the area of interest. The identification of these mapped features was left to the ground survey crew.

PART III: RESULTS

Before discussing the specific results of the photogrammetric experiment, it should be noted that there are three primary ways archeological features show up on aerial photographs: as shadow marks, crop marks, or soil marks. Each of these kinds of marks resulted in the identification of cultural features in the Kin Bineola area. Shadow marks, which are the result of elevation differences casting shadows at certain times of the day, revealed the existence of prehistoric habitation sites. Crop marks, in which increased or decreased vegetation results in distinctive dark or light patterns on the landscape, revealed the existence of a long prehistoric linear feature. Finally, soil marks, dark or light patterns in the soil, revealed a circular feature near Kin Bineola Pueblo where sand had been piled and subsequently removed during the stabilization of the ruin in the early 1960's.

In order to test the results of the photogrammetric mapping procedure, a ground survey crew under the direction of Alden C. Hayes of the Chaco Center conducted an archeological reconnaissance of the area. The aerial maps were used as guides to areas of possible cultural significance. In addition, areas which did not show mapped features were investigated. The results of the two surveys are given in figure 6.

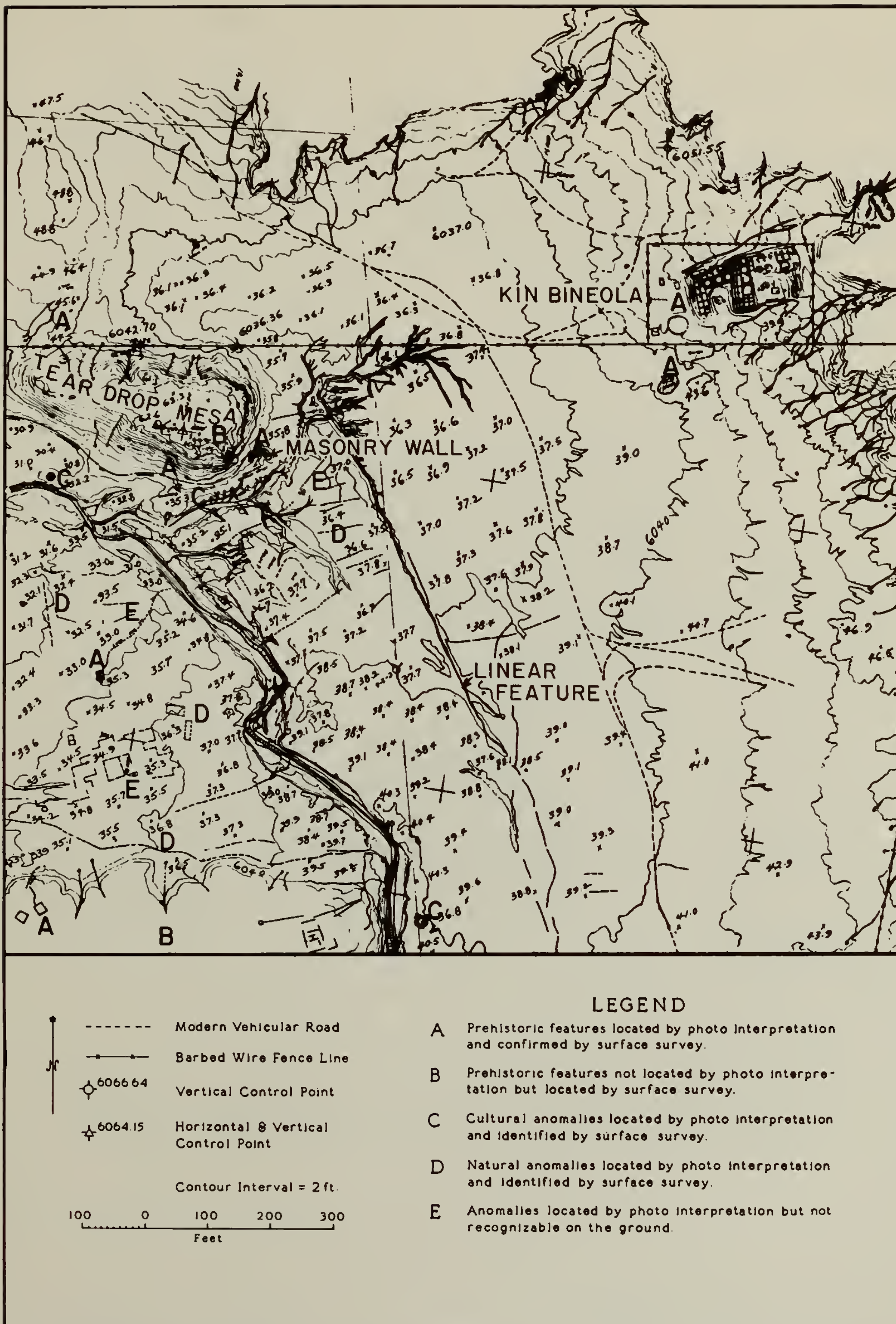

FIGURE 4 - Photo interpretation map of the Kin Bineola area

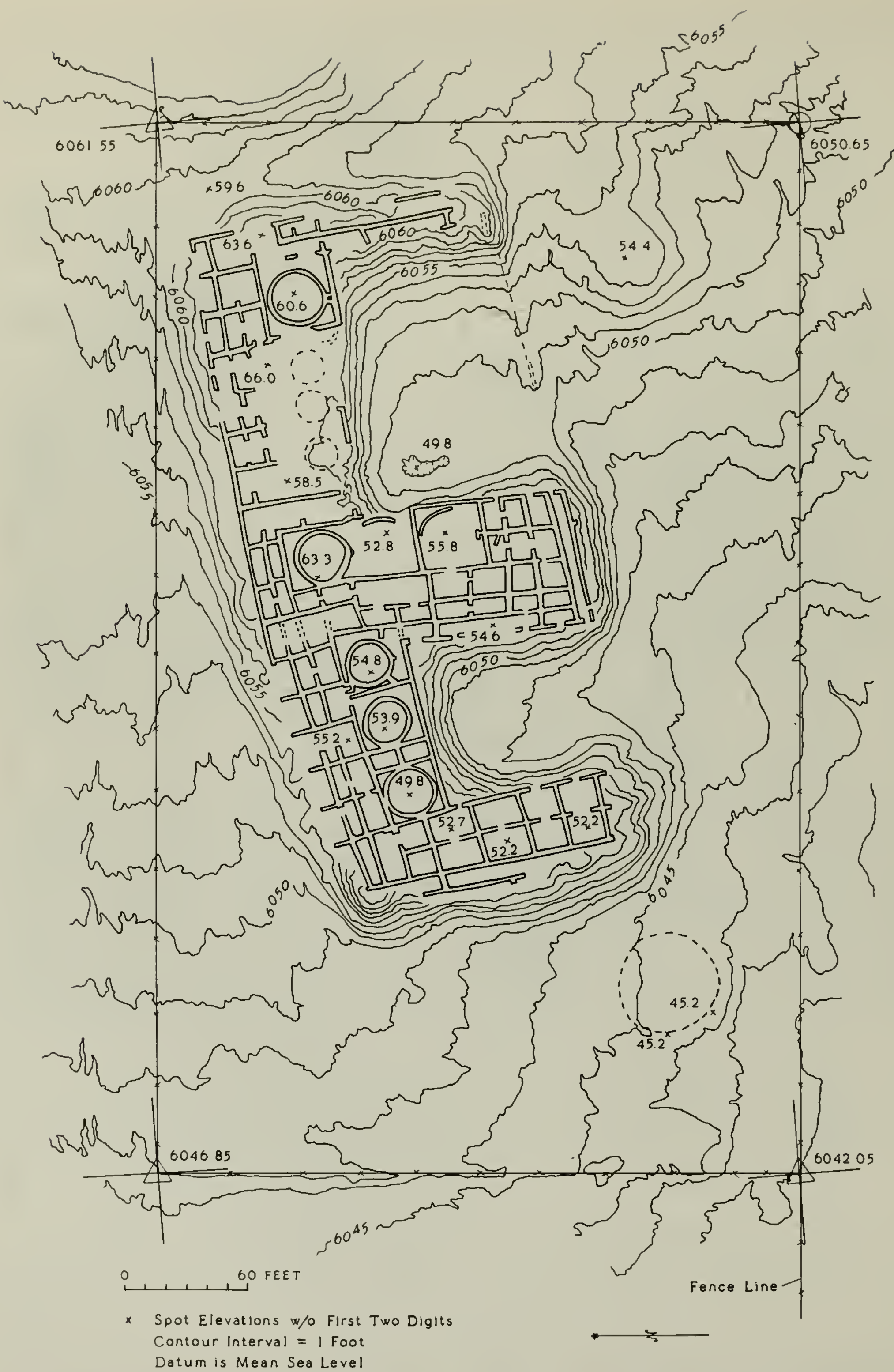

FIGURE 5 - Aerial photo interpretation map of the Kin Bineola ruin

	No.	Percent
A Prehistoric sites located by photo interpretation and confirmed by surface survey.	16	38.1
B Prehistoric sites not located by photo interpretation but located by surface survey.	3	7.1
C Cultural anomalies in the landscape located by photo interpretation and identified by surface survey.	6	14.3
D Natural anomalies in the landscape located by photo interpretation and identified by surface survey.	13	31.0
E Anomalies located by photo interpretation but not visible or recognizable on the ground.	4	9.5
Total	42	100

Figure 6. Tabulation and percentages of recognized or located cultural and natural features in Kin Bineola area

The features that were photogrammetrically mapped and subsequently checked by ground survey fall into two main categories: (1) cultural features, and (2) natural features. The first category can, in turn, be broken down into two sub-categories: (a) prehistoric cultural features and (b) modern cultural features. In addition, there are a number of other features that were identified both from the air and on the ground that were indistinguishable as being either cultural or natural. Finally, there are some features that were located on the photographs but that were not found on the ground. Each of these categories has been given its own letter designation, as shown in figure 4.

The total number of features identified on the photographs and verified by surface survey is 39. Additionally, surface survey resulted in the discovery of three prehistoric sites not previously identified by photointerpretation. Table 1 is a tabulation and percentage breakdown of the recognized variations in the landscape, and the letter notations are correlated with the indicated areas of figure 4. Of 19 prehistoric sites located by surface survey, 16 had previously been identified by photointerpretation - a recognition ratio of 84.2 percent. It must be pointed out, however, that this recognition ratio is not really an accurate measure of the reliability of photogrammetric procedures. There are certain kinds of sites (such as surface scatters of sherds and lithics) that do not show up on aerial photographs. These kinds of features were not taken into consideration in this study. The point of the project was to see what kinds of features did show up during the mapping procedure.

The kinds of prehistoric cultural features that were mapped and later identified by surface survey include field houses, habitation sites, a prehistoric dam, canals, feeder ditches, and some features of unknown use (such as the arcuate mound to the east of the tear-drop-shaped mesa). Of particular significance was the mapping of the ruin of Kin Bineola (fig. 5). Comparison of the photogrammetric map with previously-drawn maps reveals that it is a much more accurate and detailed representation of the site. Modern cultural features include a dam, fences, corrals, roads, and recent archeological excavations. An interesting comparison between ancient and modern cultural features can be made on figure 3 in which a modern road running NNW by SSE stands in contrast to the prehistoric linear feature that parallels its west side.

Even though the features that were mapped were ostensibly cultural features, surface survey revealed that a number of them were in actuality natural features. These natural features include lines and clumps of bushes, sand dunes, cow paths, ant hills, and old prairie dog towns.

Some of the features located both on the photographs and on the ground were questionable in that it was not possible to determine whether they were cultural or natural or both. A line of sacaton bushes, for example, might indicate the presence of a prehistoric irrigation ditch, but only excavation would reveal whether or not this was actually the case. The same is true in the case of a circular depression in which cattle have wallowed as well as in the case of a linear feature which is not being used as a path by cattle.

From the foregoing, it can be seen that there are certain limitations to the use of photogrammetric procedures in archeology. The features identified are not always cultural. Also, of those features identified that are cultural, it is often difficult to make the distinction between prehistoric and modern ones. It is our opinion, however, that results of the use of photogrammetric procedures in archeology far outweight the limitations.

PART IV: CONCLUSIONS

Insofar as this experiment was designed to determine the effectiveness of photogrammetric procedures in archeology, it can be judged successful. Suspected sites were determined from slight subtleties in elevation difference, soil coloration, unusual terrain scars, suspicious geometric patterns, and vegetative anomalies that might otherwise have gone completely undetected by even extremely careful ground reconnaissance studies. The information derived by this procedure yielded data that were much more accurate and detailed than those that could have been obtained using conventional survey methods. In addition, the photogrammetric mapping of the region was a more efficient and economical way to obtain data. It is important to note that the photointerpretation maps can be used not only as a means of locating prehistoric cultural features, they can also be used as aids in the analysis of those features.

Most archeologists will agree that it is important to obtain a good topographic base map from which to work. Photogrammetric mapping of a region provides us with much more complete information on elevation and physiography than could ever be obtained by traditional ground survey methods. Also, the photogrammetric maps enable archeologists to locate and identify prehistoric cultural features. The base maps provide us with information on interrelationships between catchment basins and field areas and between main canals and feeder ditches.

Efficiency and economy are always important considerations in archeological research, given the relatively small budgets archeologists usually have to work with. Photogrammetric procedures such as the one just outlined would enable archeologists to save a great deal of research time and research effort. The aerial mapping of a region takes much less time and costs less than does mapping by conventional ground survey methods.

Photogrammetric procedures are valuable in planning archeological research strategy. Cultural features are located, thus enabling archeologists to determine where the most profitable areas would be to conduct both surveys and excavations. On the basis of aerial maps of a region, it is possible to choose samples for further investigation, and to establish research priorities.

Photogrammetric maps have predictive value. Even though no cultural features may be evident on the surface, knowing the physiography of a region can help the archeologist to predict where cultural features might be. A low, depressed area in a fairly uniform plain such as at Kin Bineola, for example, could be expected to be an area in which water was contained (i.e. a catchment basin). The mapping of elevations and contours, then, can serve as a guide to areas for investigation.

Photogrammetric procedures can provide us with information relevant to the analysis of mapped prehistoric cultural features. In the Kin Bineola area, for example, it might be possible to determine the amount of land under cultivation at a given time. Combining this knowledge with information on corn yields might enable us to roughly estimate the carrying capacity of the agricultural fields. A comparison between the carrying capacity and the size of the population that existed there would enable us to determine whether or not surpluses were being created. If a large enough surplus is indicated, we might expect that it was being shipped somewhere, perhaps into Chaco Canyon. A redistributive system of this nature might indicate that a fairly complex form of social organization existed. Admittedly, this is pure speculation, but it is an hypothesis for which test implications could be generated and which could then be tested. In any case, it is an illustration of how photogrammetric procedures can provide archeologists with information relevant to the generation of hypotheses designed to explain the variability found in the archeological record.

On the basis of the analysis of the aerial photographs of a region, combined, of course, with subsequent field checking, it is sometimes possible to question the conclusions of former investigators. This proved to be the case at Kin Bineola. For years, the feature that wound around the tear-drop mesa was believed to be a canal. Analysis of the photographs of the area around the mesa, however, revealed: (1) anomalous elevation differences along the feature that could not have been easily perceived by observers on the ground, and (2) the disparate character of what had previously been considered elements of a single water control system. Final determination of the nature of this feature as well as the nature of a number of other prehistoric anomalies in the area must await excavation.

A byproduct of the experiment was the realization that photogrammetric techniques could effectively be used in the phase mapping of a large-scale archeological excavation. At appropriate points in the excavation process, stereo photography could be flown at low altitudes. From such photography, highly detailed maps and photographic enlargements can be prepared at large scales such as 1 in. = 20 ft. In addition to being valuable historical records, the maps produced by this method are economical and highly detailed. They are also free from many of the errors that plague map documents prepared by conventional field survey methods. The preparation of these photogrammetric maps could continue without the slightest interference to the actual digging operations.

This experiment has shown that photogrammetric procedures are valuable tools in helping to plan and carry out archeological research. Future tests will include: (1) experiments in the uses of different kinds of film (i.e. color, color IR, black-and-white IR); (2) the analysis of changes in the Kin Bineola region from 1927 to the present through the comparison of the aerial photographs taken at various time intervals; (3) the excavation and analysis of the water control features at Kin Bineola; and (4) the phase mapping of a large-scale archeological excavation. It is our hope that the procedures outlined in this paper have illustrated how a more organized, systematic, and productive survey of a study area is possible through the use of remote sensing techniques.

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THE CHETRO KETL FIELD: A PLANNED WATER CONTROL SYSTEM IN CHACO CANYON

BY

RICHARD W. LOOSE AND THOMAS R. LYONS

PART I: INTRODUCTION

The purpose of this paper is to estimate the amount of land under prehistoric cultivation in Chaco Canyon National Monument by using remote sensing techniques to identify ancient agricultural fields and associated water-control features. Establishing the relationship between Chacoan population size and the agricultural techniques used to support the prehistoric people of the Chaco has long been an unsolved problem. In a project undertaken by the Chaco Center, two parts of the above mentioned problem were addressed: to develop a technique for recognition of Anasazi agricultural features within the canyon, and once the technique was established, to attempt to quantify the total amount of land under cultivation at any given point in time.

The archeological evidence of prehistoric agricultural systems in Chaco Canyon has been fragmentary, but sufficient to identify the existence of many irrigation canals and ditches, terracing, and bordered garden plots (Vivian and Mathews, 1964; Vivian, 1972). Previous investigators have mentioned water control and agricultural features in Chaco (Holsinger, 1901; Judd, 1954), but no comprehensive work on the total amount of land under cultivation has been published. Grebinger (1973, 17) summed up the problem nicely:

> "There is no satisfactory method for estimating the amount of land in Chaco Canyon that was suitable for cultivation of crops such as corn, beans, and squash. We have no way of knowing exactly how much land was cultivated of the suitable land available."

An earth bordered garden near Chetro Ketl (Vivian, 1970, pp. 69-72) was chosen as our initial study area because it appeared to be a pre-planned and "hydraulically engineered" agricultural field (fig. 1). The proximity of the field to Chetro Ketl suggested the possibility of its being contemporary with the large Bonito Phase ruin, and it was assumed that the complex social organization necessary to build the nearby Pueblo "towns" could also have been used to construct an extensive agricultural system. The Chetro Ketl field was the most clearly defined prehistoric agricultural feature in the canyon and the most thoroughly documented in terms of multispectral remotely sensed imagery (see Gumerman and Lyons, 1971). Since this field was clearly defined in many aerial photos but was not visible on the ground (witness the contemporary National Park Service road through the middle of the field in fig. 1), it was felt that remote sensing methodology would be necessary in identifying and quantifying Chacoan agricultural systems, and that the Chetro Ketl field would provide a well-controlled testing ground for finding the most efficient remote sensing technique to use subsequently. Also, the Chetro Ketl field was easily accessible for any test excavations necessary to provide "ground truth".

It was our aim to combine remotely sensed data with geological and archeomagnetic data so that the relationship between Anasazi subsistence techniques and population size might be more accurately interpreted. The geological data would be relevant to deciding how much alluviation or erosion might be masking prehistoric fields, and the archeomagnetic data would be critical to dating and determining the contemporaneity of fields. Ultimately, we hoped to determine if the amount of prehistoric agriculture practiced within the canyon was sufficient to support the local population.

PART II: APPLIED REMOTE SENSING

A low angle oblique air photo taken by Charles A. Lindberg in 1929 (fig. 2) clearly shows the gridded plot and feeder ditch pattern now referred to as the Chetro Ketl field. In Lindberg's photo, more gridded plots are visible than in photos taken in the years from 1960 to 1975. This difference is due mainly to an increase in vegetation density that occurred after grazing in the canyon was stopped in 1946. But even the latest air photos clearly show one rectangular set of plots which measured 145.48 x 111.15 meters and had an area of 1.62 hectares. Individual plots within the field border averaged about 14 x 23 meters or 0.03 hectares. There were six of these small plots in the north-south direction and seven in the east-west direction, or a total of 42 plots within the larger rectangular border (fig. 1).

It must be stressed that there was no adequate method of planning an excavation of the field from the ground data alone. Consequently, one of our first problems in gathering any "ground truth" relating to the gridded plots involved finding a method of locating the features on the ground. This was accomplished by using an

FIGURE 1 - Vertical air photo showing outline of Chetro Ketl field and nearby ruin of Chetro Ketl

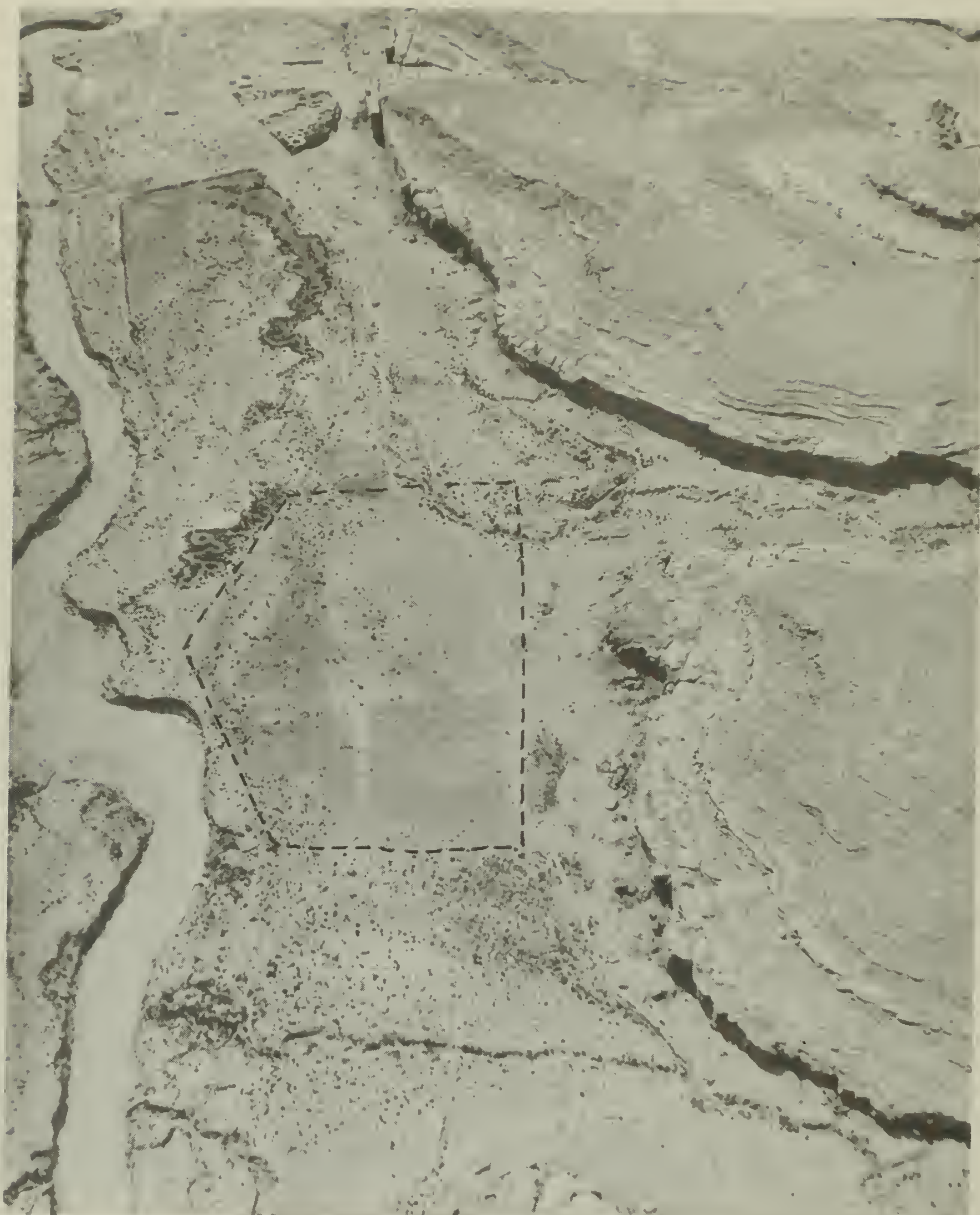

FIGURE 2 - Oblique air photo by Charles Lindberg taken in 1929

ozalid half-tone image produced from a color aerial transparency at an effective ratio scale of 1:1300. Known objects such as bushes or ant hills could be found and the positions of the grid borders could be located by computing the distances on the ozalid print and then measuring on the ground with a steel tape. The ozalid prints were more useful than the original air photos because of larger scale (1:1300, as opposed to 1:6000 on the originals) and because it was easy to write on the ozalid paper surface. The ozalid prints were cheaper to reproduce than air photos and could be folded for ease of handling without being damaged. In short, the ozalid air photo reproduction provided an excellent, detailed map of the Chetro Ketl field area at a known scale.

Because the nature of what might underlie the gridded plots was unknown, two types of near ground level remote sensing devices were utilized to form an initial excavation strategy: 1) a radiographic densiometer to measure small changes in soil density, and 2) an electron spin magnetometer to measure magnetic anomalies in the field area. Although both of these techniques require heights of approximately 1 meter above ground level, they are receptive to phenomena which are not discernable to the human senses and therefore qualify as remote sensing applications. It was hoped that the linear borders of the plots would show up as soil density changes or as magnetic anomalies caused by prehistoric disturbances in the alluvium of the canyon floor.

In the summer of 1973, a transect across the most clearly delineated portion of the Chetro Ketl field was plotted on a 1:6000 black-and-white aerial photo. This transect when taped out on the ground was 110 meters long on an azimuth of 3 degrees and cut across five of the linear garden borders. Next, a series of readings were taken with a radiographic densiometer at 3 meter intervals along the transect. It was disappointing to find no significant variation in soil density which might help locate the grids or help explain what was causing them to be visible on aerial photographs but imperceptible on the ground. A shorter sampling interval might have given better results, but new measurements have not been taken.

A second set of measurements was taken with an electron spin magnetometer. This instrument measured slight precession of electron orbits caused by minute changes in ambient magnetic fields. Changes in magnetic moment of less than 2 gamma (a gamma is a unit of magnetic flux density) were recorded over an area which measured approximately 35 meters on a side. The values obtained were averaged and interpolated by the University of New Mexico's IBM 360 computer, and then printed out as a 2.4 gamma contour interval map (fig. 3). A rectangular feature approximately 15 x 20 meters was apparent in the magnetic contours and was the same size as plots visible in aerial photographs. The center of the plot showed the

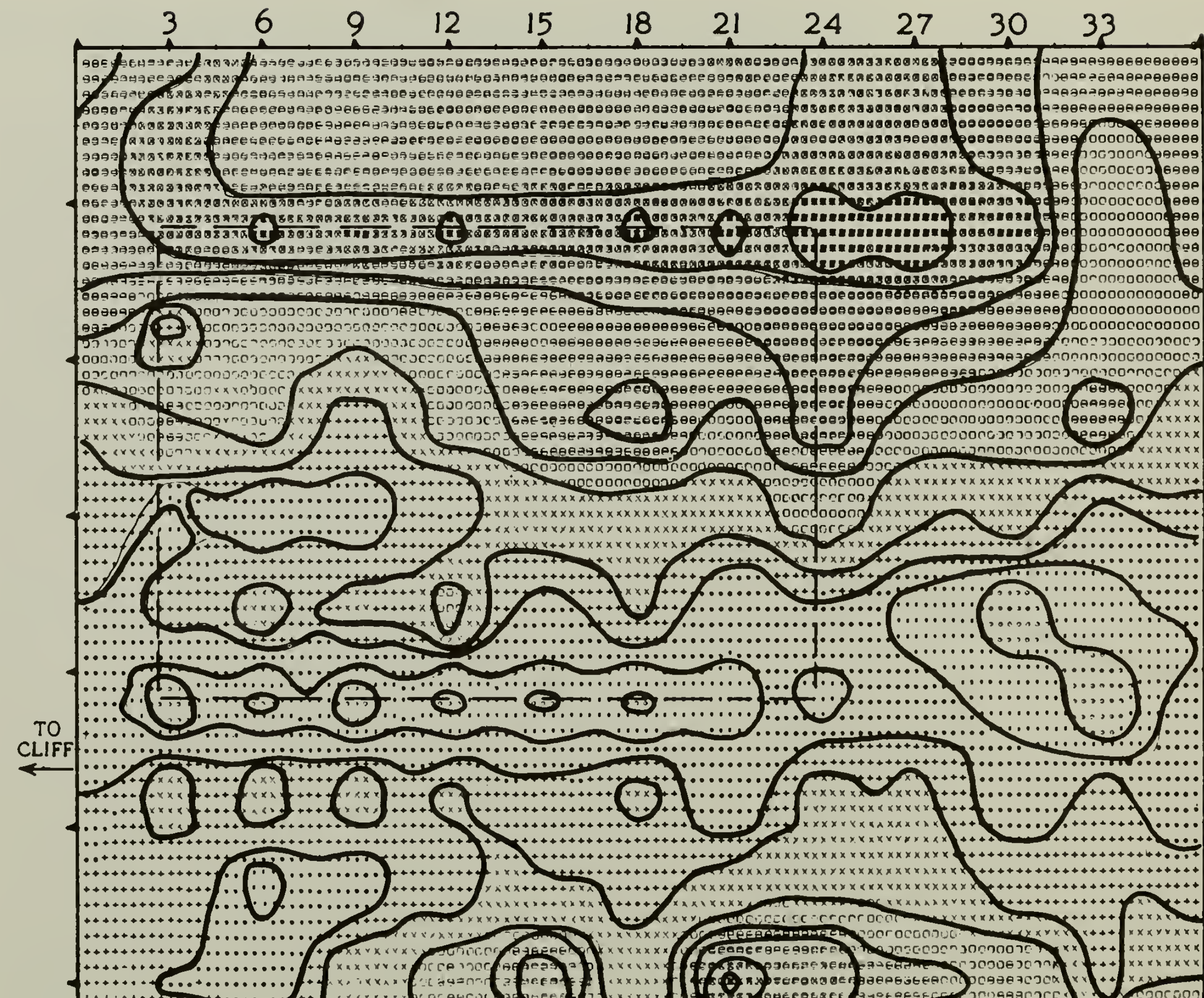

FIGURE 3 - Contour map of magnetic values in the Chetro Ketl field and surrounding area

highest magnetic moment, while the borders had the lowest magnetic alignment. This was good evidence that irrigated, earth bordered garden plots were indeed responsible for the observed rectilinear patterns. In the center of the plots where irrigation water was impounded for some time, iron bearing clays had sufficient time in settling to line up with the earth's magnetic field. The raised earthen borders, which were constructed with fill dirt and periodically repaired, were disturbed enough to show a contrastingly low magnetic moment. This was further substantiated by the good archeomagnetic dates from old field surfaces which will be discussed later in this paper.

In terms of excavation potential, the magnetic data were encouraging because the plots could not have been under heavy alluvium or their residual magnetism would not have been measured by the spin magnetometer. At this point, it was decided that an initial test trench would be excavated along the above mentioned transect, with several additional trenches necessary to give us a reliable sample of the structure of the earth bordered plots.

PART III: EXCAVATION

Beginning with the original transect, seven trenches totaling 211 meters in length were cut in the Chetro Ketl field during the summer of 1974 (fig. 4). These trenches averaged 0.75 meters in width and 1.5 meters deep. After the initial backhoe operation, the trench faces were troweled and brushed to bring out any subtle differences in stratigraphy.

For the first two or three days after excavation no differentiation in the trench profiles could be seen, but as the trench walls began to dry out, the cause of the rectilinear grids became apparent. The light colored plot borders appeared in profile as raised earthen levees which consisted of medium-to-fine grained yellow-tan sand interlaminated with cross-bedded brown sand and finely laminated gray clay. Between levees, at a depth of 40 to 50 centimeters, a bed of finely laminated clay formed a continuous layer ranging from 5 to 20 centimeters thick. This clay layer intertongued with layers in the levees and was interpreted to be an old field surface which was periodically flooded. Above the laminated clay layer was a sandy soil about 40 centimeters thick which was highly disturbed by root and insect activity. A massive gray compact sandy clay ranging from 60 centimeters to 1 meter thick was underneath the laminated clay layer. Near the bottom of the trenches were occasional lenses or layers of a second laminated clay which were not associated with any levee structures. This lower clay had Pueblo I (Kayentan) sherds in it and probably represented sediments from an overbank flood of the Chaco River (fig. 5).

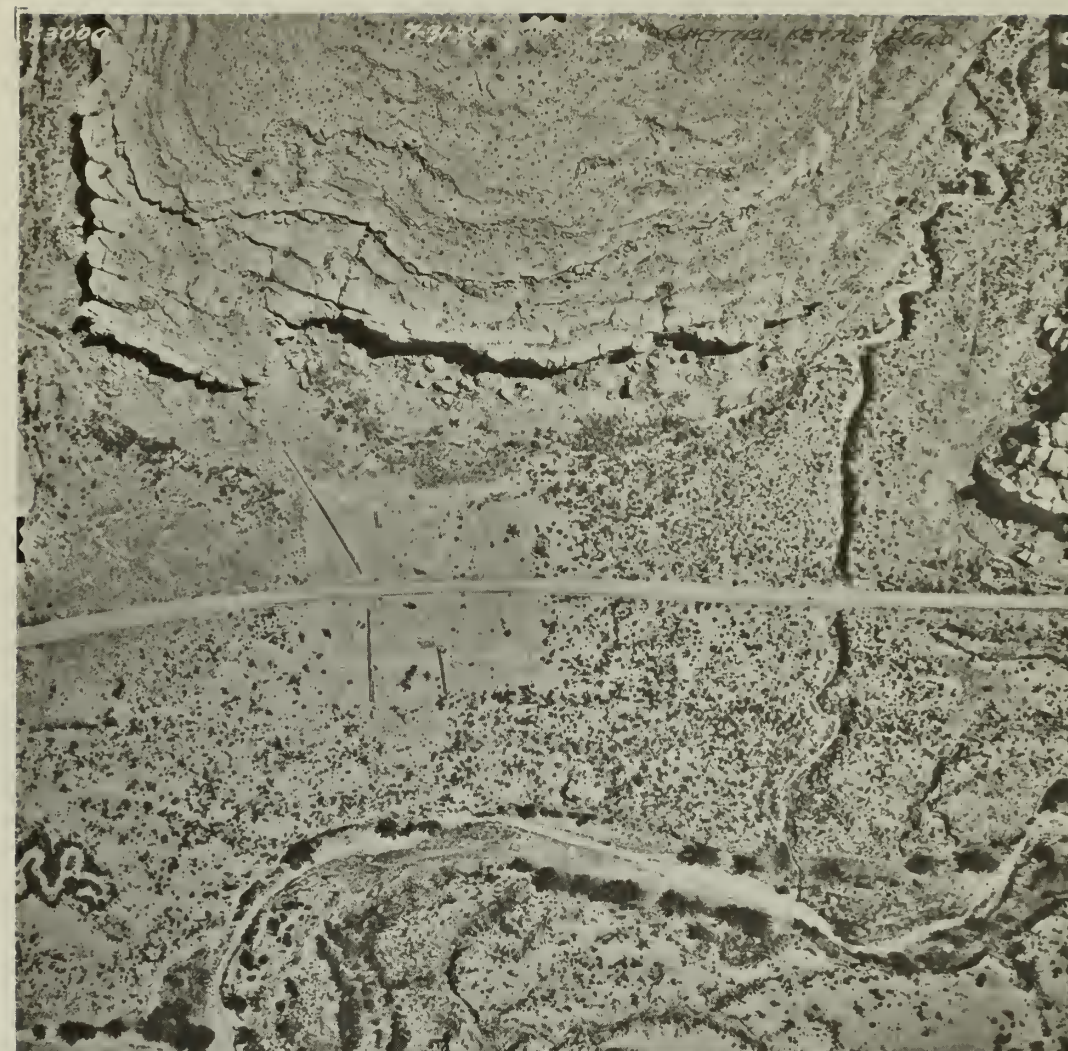

FIGURE 4 - Vertical air photo showing test trenches of 1974 in the Chetro Ketl field

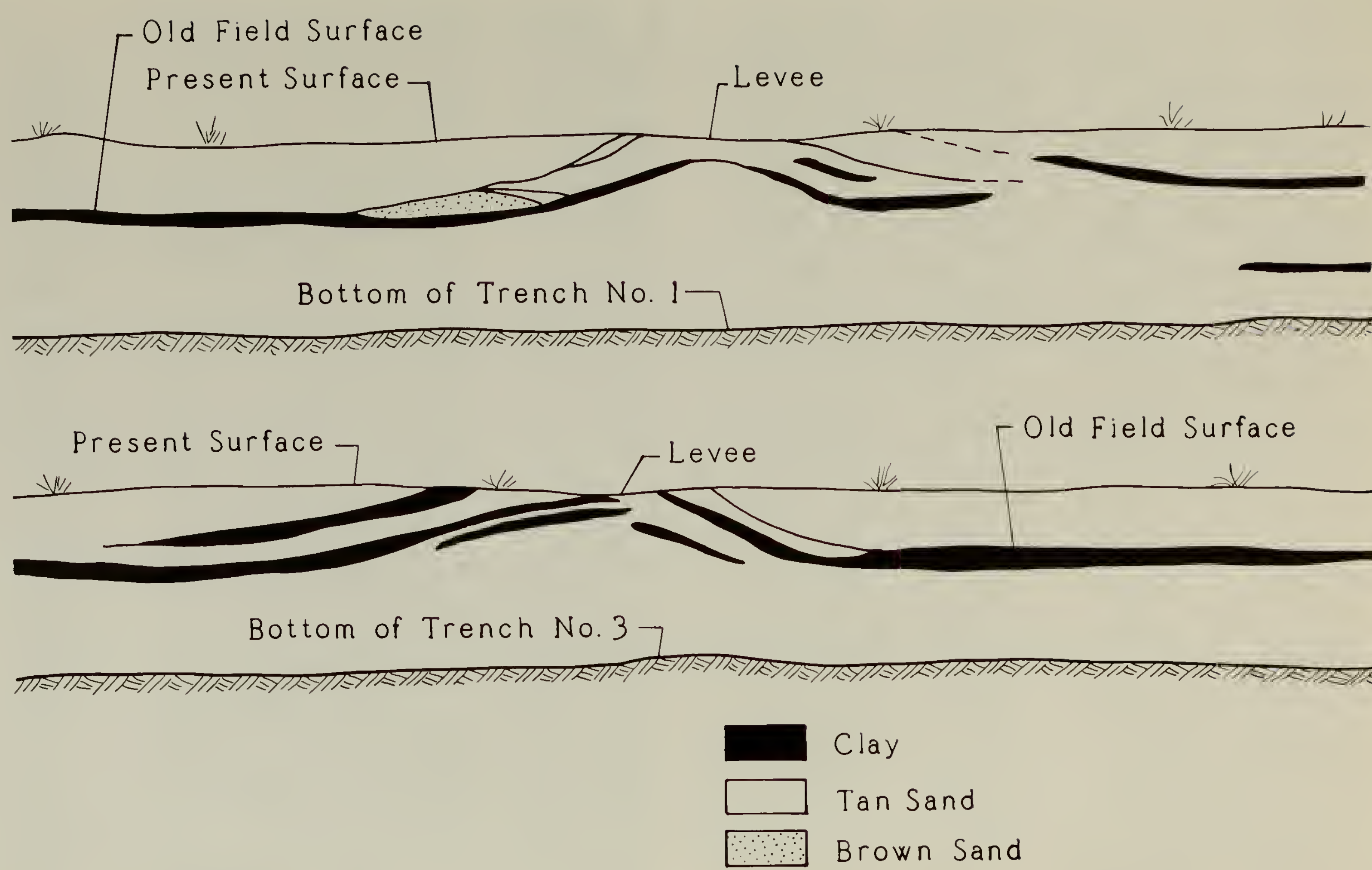

FIGURE 5 - Stratigraphy of trenches in the Chetro Ketl field

The stratigraphy of the field gave us some interesting insights about the geomorphology of the canyon floor during Pueblo III times. According to David Love (personal communication, 1974), overbank sediments as close to the talus slopes as the Chetro Ketl field could indicate that the Chaco River was not entrenched and that periodically almost the entire canyon floor was being flooded. Love calculated that a typical modern 10 year rain event could flood the entire canyon floor if the Chaco were not entrenched. Such flooding might explain the location of the large Pueblo III ruins near the foot of the talus slopes above potential flood levels.

Further evidence that the Chaco was not entrenched during the use of the Chetro Ketl field came from an analysis of the tan and gray sediments which were exposed in the trench profiles. Using a nested sieving technique, Love found the tan sediments were derived from the Cretaceous bedrock of the side canyons, while the gray sediments were from the main Chaco River. Since the distinctive tan and gray materials were intertongued in the man-made levees above the old field surfaces, it seems likely that the field was being watered from both the side canyons and the central wash. If the Chaco River had been deeply entrenched as it is now, it would have been impossible for the Anasazi farmers to get the water up to the Chetro Ketl field from the main wash.

Using both the side canyons and main wash for irrigation water sources would have been the most effective way of insuring the maximum amount of water reached the field. The prehistoric farmers could have taken advantage of local thunder shower runoff from the side canyons as well as regional runoff from the Chaco River to produce the best possible crop yield.

In order to control all the water channeled to the field, hydraulic engineering of bordered garden plots was quite sophisticated. Extensive land leveling was carried out on an area of at least 2.4 hectares and possibly as much as 4.8 hectares (5.9 to 11.8 acres). Modern gradients measured across the prehistoric field were 1.17 percent while gradients just off the field were 1.98 percent. These figures were computed with the aid of a 1:1200 planimetric contour map of the field area which was generated on a stereo plotter from a controlled pair of aerial photographs. This modern, engineering-quality map had contour intervals of 15 centimeters and allowed the accurate determination of gradients on and off the field.

The buried field surfaces exposed in the trenches were incredibly flat. One garden plot which measured 23 meters long varied less than 2 centimeters from true horizontal; a gradient of 0.01 percent. This gradient was partly due to the flood water within the plot depositing sediments in a very uniform manner, but where the original construction cut into the lower massive sandy clay, the gradients were quite similar. This sort of land leveling may have been accomplished by trial and error flooding of the field to see where water ponded (a sort of crude level), but it seems clear that the builders were trying to get the field as level as possible. A low hydraulic head in the leveled field and contoured feeder ditches would have made handling of flash flood water possible with only earthen canals and levees. One feeder canal on the northwest side of the field was sectioned at two points 33 meters apart and showed a gradient of 1.88 percent or slightly less than the natural gradient of the slope around the field. From the air photos and planimetric map it was observed that portions of the northeast feeder ditch nearly followed a contour line, thus keeping hydraulic head in the feeder canal to a minimum and increasing control over the water carried in the ditch.

All prehistoric field surface gradients and profiles were established with the aid of a plane table and alidade. A permanent record of the test trench locations was obtained by taking a controlled stereo pair of aerial photographs before the trenches were backfilled (fig. 4).

PART IV: SECONDARY TESTING

Convincing final evidence that the Chetro Ketl field was indeed a prehistoric feature and not an historic but unrecorded field came from the archeomagnetic date determined by Ron Nichols of the University of Oklahoma geophysics laboratory. As part of his Master's Thesis, Nichols applied a new, more sensitive method of dating clay sediments which were deposited under non-turbulent conditions (1975, p. 4-8). The upper laminated clay in the Chetro Ketl field seemed ideally suited for dating since it was interfingered with the levee structures and could not have been the result of post-use flooding. The fine laminations indicated that the clays had been deposited in still water conditions within the earthen levees, allowing the iron bearing clay particles sufficient time to line up with the earth's magnetic field. This idea was further substantiated by the previously mentioned magnetic contour map which showed high magnetic moment inside the plots but low residual magnetism along the levees which were sandy (low in clay content) and magnetically disturbed by the constant repair necessary to maintain them. This also implied that the plots were not extensively tilled or else the residual magnetism in the clay would have been randomized and thus, effectively destroyed.

Measuring three separate sets of samples from the upper laminated clay, Nichols found a pole position of A.D. 1250 to be statistically valid for all three samples (ibid., p. 43). Unfortunately, the lower clay layer was too disturbed to produce a date, which may further strengthen the possibility that the lower clay represented overbank sediments deposited under more turbulent conditions than water standing inside a gridded plot.

Anne Cully of the University of New Mexico biology department examined six pollen samples taken from the same upper clay unit dated by Nichols. Among the pollen types were found some members of the genus Zea and another large type of pollen which may have been from the genus Cucurbita (personal communication, 1974). There was not enough pollen in the samples for any valid statistical statements to be made, but the cultigen pollen in strata dated at A.D. 1250 allowed a confident assessment of the Chetro Ketl field as a prehistoric agricultural feature constructed by Anasazi farmers in the 13th century.

Thus, with a firm identification of a prehistoric agricultural feature in the canyon, various types of remote sensing systems were tested on the Chetro Ketl field in order to find the most efficient way of surveying Chaco Canyon for other similar prehistoric agricultural features. Once a recognition pattern for Anasazi agricultural fields was established, a quantified estimate of total field area in the canyon could be produced. Of course, this strategy was based on the assumption that all Anasazi fields were as intensively cultivated and disturbed as the Chetro Ketl field. This assumption seems valid if we extend to prehistoric Puebloan agriculture Bradfield's finding (1971, p. 18) that "shifting cultivation" of sand dune fields as described by Hack (1942:32) and Beaglehole (1937) never played an important part in Hopi agriculture.

One of the most promising of the methods tested was an infrared thermal line scan mapping device produced by Texas Instruments and operated by the U.S. Forest Service from a light plane. The thermal IR scanner is sensitive to radiation in the 1 to 14 micron frequency band and records temperature differences of less than 0.5^{o} Centigrade. Features which retain moisture may appear as colder or hotter than their surroundings due to the great latent heat of water. On imagery flown in mid-December of 1974, the Chetro Ketl field stood out in bold relief as a "hot target" since the flight was just before dawn and the moist field had retained heat better than the drier alluvium and nearby talus slopes. The northwest and northeast feeder ditches also were clearly visible. Unfortunately, the system used by the Forest Service could not produce ratio scales larger than 1:40,000 which made fields smaller than the Chetro Ketl field difficult to interpret. This is a critical problem because the Chetro Ketl field is the largest agricultural feature in the canyon.

A ground-based radar imaging system developed by the Stanford

Research Institute had proven useful in delineating buried walls at Pueblo Bonito and at Pueblo Alto. A radar profile was taken along the original test transect in the Chetro Ketl field in the fall of 1974 but results were not encouraging. However, Dr. Roger Vickers, in charge of the system's development, indicated that refinements in his instruments and data interpretation programs may allow detection of subtle soil density changes typical of earthen irrigation systems.

An air-borne closed-circuit TV system and video tape recorder produced favorable results on the Chetro Ketl field. The video recorder seemed to be extremely sensitive in picking up linear features and was instrumental in our discovery of a gridded field pattern just north of Casa Rinconada. It should be noted that R. Gwinn Vivian had discovered this same feature some years earlier on conventional black-and-white imagery independently of our finding. The video system also revealed some long low walls near Pueblo Bonito not previously known (see Air-Borne TV as an Archeological Remote Sensing Tool, R.W. Loose, this volume).

Hand held 35mm false color IR transparencies taken from a light plane gave encouraging results in the early summer months. Vegetation matured faster in areas of disturbed soil such as prehistoric fields and trash mounds, and so the field area appeared as a white rectangle against the surrounding pink vegetation in the false color images. At other times of the year, this effect was not so noticeable. Future work with false color IR imagery taken at 2 or 3 month intervals may give an extremely reliable signature for agricultural fields at some particular time of year.

Finally, conventional Ektachrome 9 x 9 in. aerial transparencies were used by Potter and Kelley (1974) to systematically map vegetative zones within the entire National Monument. One of their categories was what they termed "old field" successions of vegetative communities. They mapped the Chetro Ketl field as one of these old fields as well as the gridded area near Casa Rinconada. The transparencies they used were taken in the summer of 1973 at a ratio scale of 1:6000. Old fields often showed linear borders, and heavy concentrations of mustard and tumbleweed in early spring, but were nearly bare of vegetation by August. The old fields also showed a differential photographic return due to high concentrations of clays and soluble salts in the soil, probably due to concentrated prehistoric irrigation activities.

PART V: USE OF ARABLE LAND

In their article on southwestern water control systems, Plog and Garrett (1972, p. 284) determined the most frequent occurrences of prehistoric irrigation features in terms of slope of the terrain on which they were constructed. Their study showed that most gridding and irrigation agriculture took place on slopes of less than 2.5 percent. While measuring the area and distribution of the old field successions mapped by Potter and Kelley (1974), it was noticed that the fields they described (23 in all) were consistently in one of two vegetative zones, the Sarcobatus-Sporobolus complex (greasewood and sand dropseed grass) and the Atriplex-Sarcobatus complex (saltbush and greasewood). Also, these two vegetative communities were restricted to slope zones of less than 2.5 percent in the alluvial fill of the canyon floor. Assuming that the two zones mentioned above monitored soil and slope conditions suitable for Anasazi agriculture (Bradfield, 1971, p. 13-19), there were 1451 hectares (3584 acres) of potential arable land available between Shabikeshchee Village and the Chaco-Escavada confluence near Penasco Blanco. This figure compares favorably with Hayes estimate (Manuscript, n.d.) of 1295 hectares (3200 acres) of arable land within the National Monument. Our figure of 1451 hectares was determined by measuring the area of the two above mentioned vegetative zones on the map developed by Potter and Kelley, while Hayes measured the area of canyon floor alluvium on U.S.G.S. 7 1/2' topographic maps, assuming that it was the only useful farmland.

The next approach to effectively computing useful arable land involved the variable of available water. Land of the correct soil type with the proper slope would still be useless to Anasazi farmers if they could not supply that land with the water their crops required, so the amount and seasonal distribution of rainfall in prehistoric times is critical to the interpretation of Chacoan agriculture. Since the present climatic reconstructions of Chaco Canyon during the Anasazi occupation do not allow a precise determination of prehistoric rainfall patterns, such information may be approached indirectly from archeological evidence of water control devices and vestigial field outlines. Hopefully, at some point in the future, pollen and tree-ring analysis will enable archeologists to more directly measure prehistoric precipitation. As of this writing, no accurate estimate of prehistoric annual precipitation and available irrigation water within the Canyon is possible, so this variable remained unquantified. Although some Chacoan fields may have been more productive than others because of differential amounts of irrigation runoff, all fields were considered to be uniformly productive per unit area in this study.

Thus, the old fields mapped by Potter and Kelley were assumed to be equally productive. If the fields they mapped were contemporaneous, they would cover a total area of 20.48 hectares (50.58 acres) within the National Monument. As an independent check of this estimate, R. Gwinn Vivian's field map of the Chacoan agricultural systems (kindly lent to the Chaco Center by Dr. Vivian) was measured. A total of 20.60 hectares (50.90 acres) was calculated. Although these workers did not map the same fields, a discrepancy of no more than 10 hectares (24.70 acres) could be possible between the two maps. Thus, combining all fields mapped by Vivian, Potter and Kelley would not give a total of more than 30 hectares (72.90 acres) for the entire canyon between Shabikeshchee Village and the Chaco-Escavada confluence (fig. 6).

The above estimate may be somewhat low because alluviation of the canyon floor may have buried some prehistoric fields so deeply that they cannot be recognized on aerial photos. As yet, no accurate figures on the rate of alluviation within the canyon are available and this problem remains to be solved. Since old fields were visible on both the north and south sides of the canyon from Shabikeshchee to Penasco Blanco, it is probably safe to assume that not many fields lie buried under deep alluvium. If the 30 hectare (72.90 acre) figure is a reasonably accurate approximation of the total amount of land under intensive Anasazi cultivation, then less than 2 percent of the potential 1451 hectares (3584 acres) of arable land in the canyon was actually utilized. If the fields were not contemporaneous, then even a smaller proportion of the available land was used at any given time. A problem yet to be considered involves the possibility that some of the fields may be more recent Navajo agricultural plots.

PART VI: ARCHEOLOGICAL IMPLICATIONS OF THE CHETRO KETL FIELD

As mentioned earlier, of the 23 old fields mapped by Potter and Kelley, the Chetro Ketl field was by far the largest. When the Chetro Ketl field was excluded from statistical computations, the mean field size was 0.71 hectares (1.75 acres) with a standard deviation of 0.39 hectares (0.96 acres). Inclusion of the Chetro Ketl field (4.8 hectares or 11.8 acres) raised the mean value for all 23 fields to 0.89 hectares (2.19 acres) and the standard deviation to 0.93 hectares (2.30 acres). Considering that only the Chetro Ketl field and the large plot near Casa Rinconada (1.18 hectares or 2.91 acres) showed any gridded patterns, it was assumed that the Chetro Ketl field was both quantitatively and qualitatively different from the smaller type fields. Clearly, it would be necessary to obtain reliable archeomagnetic dates and pollen samples from the smaller fields before any analogies between the Chetro Ketl field and other fields could be made.

The archeomagnetic date of A.D. 1250 for the Chetro Ketl field itself was difficult to interpret in view of the existing dendrochronology dates for Chetro Ketl. Bannister (1965, pp. 152-153) writes that the latest dendro date from the ruin of Chetro Ketl is A.D. 1116 and that a date of A.D. 1124 has been proposed for the east Chetro Ketl dump by Florence Hawley. Hawley estimates that some 70 rings were missing from a specimen dated at A.D. 1054 (1934, p. 57). The late date from the field may indicate that it was not

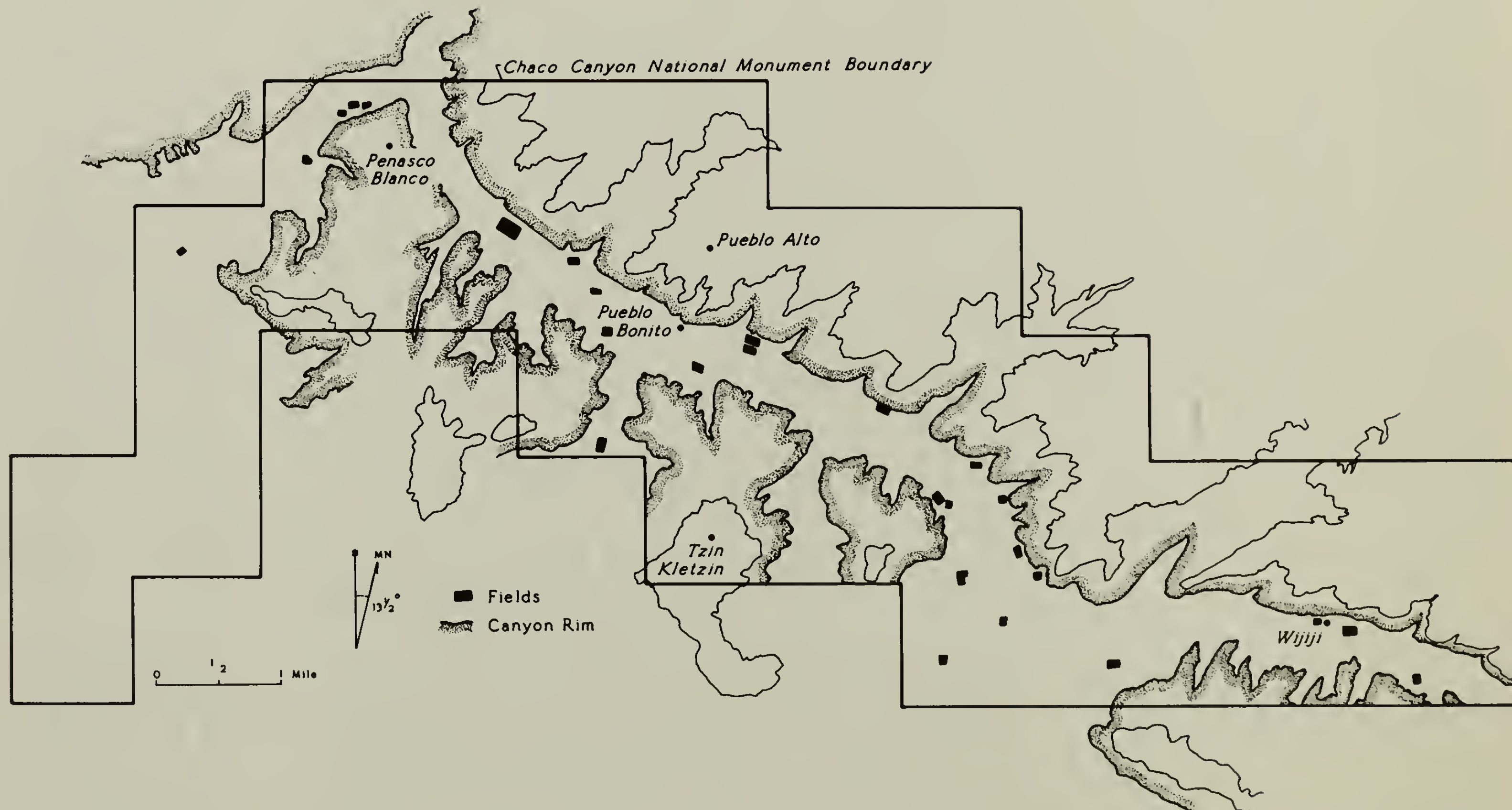

FIGURE 6 - Possible prehistoric agricultural fields in Chaco Canyon National Monument

related to Chetro Ketl. Alden Hayes (personal communication, 1974) feels that there was a sufficient Mesa Verdean population in the canyon at A.D. 1250 to maintain a large feature such as the Chetro Ketl field. Another possibility is that Chetro Ketl was still occupied while the Chetro Ketl field was being used, but that no construction took place in the ruin after the mid 1100's. Obviously, more work with absolute dating techniques will make the relationship between Chetro Ketl and the large fields nearby easier to interpret.

As stated at the beginning of this paper, one aim of this project was to quantify the ratio of Chacoan population size to the area of land under prehistoric cultivation. Dwight Drager (this volume) suggests that about 6,000 people were living in the central portion of the canyon during the peak of the Bonito and Hosta Butte Phases. His figures agree favorably with those of Hayes (in press) and Pierson (1949) and are based on reasonably unbiased photogrammetric techniques. It does not seem feasible that 30 hectares (72.90 acres) under the most intensive cultivation of corn, beans, and squash could possibly support the projected 6,000 inhabitants of the canyon between Shabikeshchee Village and Penasco Blanco.

Evaluating modern Pueblo corn, bean, and squash agriculture may give us some insight into the prehistoric agriculture of Chaco Canyon. According to White (1962, p. 85) the pueblo of Zia in 1936 had 1.09 acres of cultivated land per capita. Tyler (1964, p. xvi) found that about 2,833 acres were under cultivation at Zuni to support a population of 2,671 or about 1.06 acres under cultivation per person. His data from Acoma, Laguna, and Santa Ana Pueblos indicate an average of 1.39 acres per person. It must be kept in mind that these figures are from modern pueblos with many dietary supplements which were non-existent in precontact times. However, Bradfield (1971, p. 36) found that for the period from 1851 to 1865, the Hopi of the Oraibi valley needed 2.5 acres per person when agriculture was their principal economic activity and human labor was the only source of power available. In an extremely detailed study of maize agriculture, Jorde (Manuscript, n.d.) found that at least 0.89 acres per person were necessary for typical Pueblo corn, bean, and squash subsistence. Jorde took into account Puebloan metabolic rates, age and sex structure of populations, Puebloan stature, prehistoric cultigen productivity, surplus and seed storage, and the total portion of the Puebloan diet that corn, beans, and squash provided. Jorde's estimate was the most detailed of any of those mentioned above and also the smallest. To be generous his figure of 0.89 acres per person was used in the following calculations of our study.

The 72.9 acres taken from the combined mapping of Vivian, Potter and Kelley would have supported only 82 people within the entire canyon. If every possible acre which was available to flood water farming (3584) had been utilized by the prehistoric farmers, about 4,027 people could have been supported. When compared to Drager's estimate of 6,000 people in the canyon, which he feels to be a conservative estimate, we have a surplus of 1,973 people who could not have been supported locally. If the possibility that not all of the 23 fields mapped were contemporaneous and that the Chetro Ketl field was not contemporary with the Bonito Phase, then it becomes increasingly difficult to believe that Chaco Canyon farmers were totally self supporting.

Assuming that Chacoan farming practices could not support the local population, then several alternatives could be proposed. Possibly the prehistoric canyon dwellers practiced a considerable amount of hunting and gathering to augment their harvest of cultigens, or food might have been imported along the prehistoric road system associated with the large Bonito Phase ruins. Another possibility is that the Bonito Phase dwellings were occupied by a partly transient population which came into the canyon on a seasonal basis, traveling to outlying farming communities in the spring and summer, and bringing harvested goods back to the canyon along the road system in the fall. This possibility seems reasonable in view of the fact that the above mentioned surplus of 1,973 people would require about 430,436 kilograms (948,950 pounds) of corn and beans per year assuming that these cultigens made up about 80 percent of the prehistoric diet (see Jorde). To import that amount of food into the canyon would require 1,000 men making 10 trips carrying 94.9 pounds each time. The nearest alluvial bottom land similar to that in Chaco Canyon is at Kin Klizhin which is about 10 kilometers (6.2 miles) away and Kin Bineola, about 17.5 kilometers (10.9 miles) distant.

Although the movement of such an amount of bulk goods would have been possible, some compromise between food importation and a migratory segment of the population in the canyon seems the most reasonable, especially in view of the fact that early workers in the southwest such as Bandelier found many Pueblos were nearly abandoned in the summer and early fall months:

> "Last night Juan Jose told me that the pueblos were almost depopulated in summer, nearly everybody going out to the ranchos, where they live till September or October. But few remain in the pueblo. Even the cacique leaves also for his huerta." (From Bandelier's journal, April 17, 1882 as recorded by Lange and Riley 1966, p. 245).

Such mobility would have taken some of the strain off the local agricultural production methods in the Chaco. With enough foodstuffs produced outside the canyon stored for the winter months, the permanent inhabitants of the canyon would have been available for the organized public works evident in the continued construction of the Bonito Phase ruins, irrigation systems and prehistoric roads. Ritualized ceremonialism may have been the binding mechanism which sanctified the organized labor and seasonal congregation in the central canyon.

Additional evidence which could indicate a transitory population for the Bonito Phase ruins includes the low number of burials associated with that phase in the canyon; the extensive road system which converges on the Bonito Phase ruins of Pueblo Alto, Pueblo Bonito, and the Pueblo del Arroyo-Casa Rinconada complex; and the high proportion of intrusive culinary wares found in the Bonito Phase ruins and large Mesa Verde-McElmo "towns" such as Kin Kletso (Vivian and Mathews, 1964).

PART VII: CONCLUSIONS

The Chetro Ketl field was a planned and "hydraulically engineered" agricultural field built and irrigated by organized labor. Many characteristics of the field indicated that it was planned in advance of any construction, planning which can be termed engineering on the part of the Anasazi builders. For instance, the right angles formed by the garden plot borders intersect consistently within 1 percent of 90 degrees, and as determined from both ozalid and original air photos, the east-west axis of the field was aligned on an azimuth of 113 degrees. Williamson, et al. (1975, pp. 34-43) found evidence of solstice markers in Chaco Canyon on azimuths of 119 degrees, which would indicate a 6 degree deviation in the alignment of the east-west borders of the Chetro Ketl field from a summer solstice sunset position. Stephen (1936) claimed that the sunrise and sunset positions at the summer and winter solstices were considered the cardinal directions by the Hopi (see Tyler's discussion 1964, pp. 171-172). Tyler (164, p. 171) found that the Hopi align their fields with the cosmic directions so that they would be "in the right relationship with the points of the Pueblo world". The 113 degree orientation of the Chetro Ketl field may reflect an Anasazi concern for aligning agricultural features with certain cosmic directions. Whether the 6 degree deviation was an "error" on the part of the Anasazi builders or merely a coincidence is probably not critical to the results of this study. More importantly, the parallel garden borders as revealed by aerial photography, which intersect at right angles, required a combination of advanced planning, organized cooperation, and technical sophistication in order to be constructed.

The Chetro Ketl field was definitely in use at A.D. 1250, and was in a different size and type class from the smaller agricultural

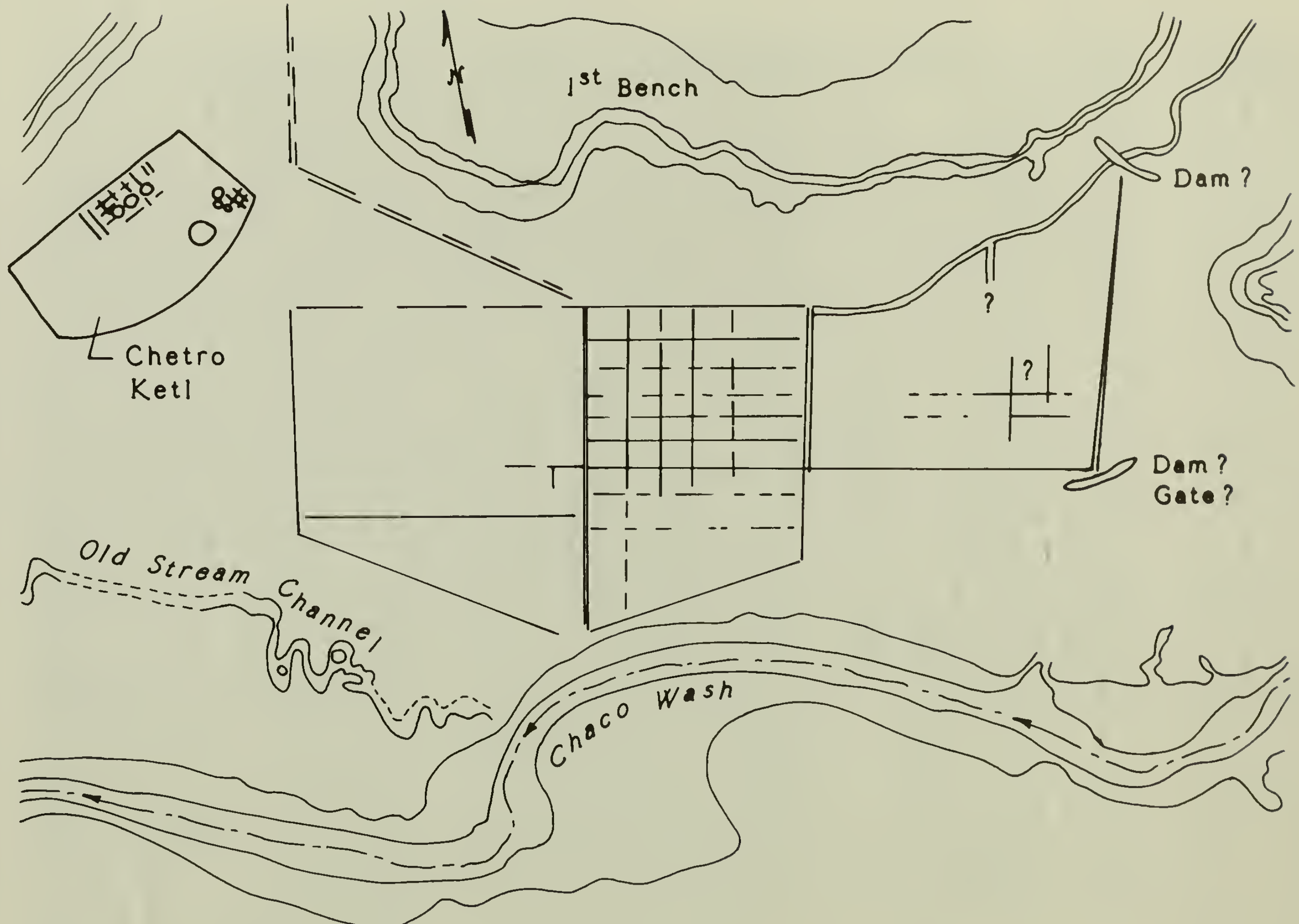

FIGURE 7 - Schematic representation of original Chetro Ketl field outline

fields found in Chaco Canyon. None of the small fields exhibited the land leveling, gridded borders (with the one exception at Casa Rinconada), or multiple feeder ditch patterns which were associated with the Chetro Ketl field. This may indicate that the Chetro Ketl field was not a typical Chacoan agricultural feature, and the date of A.D. 1250 seems to suggest that the field was not contemporaneous with the Bonito Phase or projected maximum population of the canyon.

The best method of mapping this and other similar agricultural features involved a multispectral remote sensing approach. A compilation of imagery which had both a time depth covering a span of several years and a wide spectral range was used to reconstruct the original field and feeder ditch outlines. No single image showed all of the features combined in figure 7. Finally, the Chetro Ketl field and other fields mapped with remote sensing techniques are not considered extensive enough to totally support the projected prehistoric population of the canyon.

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University of New Mexico

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ANASAZI POPULATION ESTIMATES WITH THE AID OF DATA DERIVED FROM PHOTOGRAMMETRIC MAPS

BY

DWIGHT L. DRAGER

PART I: INTRODUCTION

The purpose of this paper is to make an estimate of the size of the prehistoric population of the area now encompassed within Chaco Canyon National Monument in northwestern New Mexico using data derived from aerial photogrammetric maps of Anasazi communities.

Chaco Canyon is a 200-foot-deep, half-mile-wide gash in the high desert Upper Sonoran Zone west of the Continental Divide in the San Juan Basin of northwestern New Mexico. Prehistorically, the canyon was the home of pueblo-dwelling agriculturalists who were preceded by a long sequence of hunter-gatherers and early sedentary peoples. Presently, the area around the canyon is occupied by Athapaskan-speaking Navajos who live as dispersed pastoralists with some agriculture.

The cultural sequence in Chaco Canyon has been studied and described (Vivian and Mathews, 1965; Hewett, 1936; Hayes, in press); this paper will concentrate on one specific part of that sequence. Along a nine-mile segment of the canyon bottom and on the mesa tops just outside the canyon, occur 12 large masonry structures. These structures comprise what are known as the Bonito Phase and the McElmo Phase sites of the Anasazi sequence in Chaco Canyon (Vivian and Mathews, 1965, pp. 108-109). Also occurring in the canyon are a series of smaller sites known as the Hosta Butte Phase sites (ibid.). The Bonito and McElmo Phase sites are large and easily mapped. The Hosta Butte Phase sites are small, scattered, and remain generally unmapped. For this reason, only the Bonito and McElmo Phase sites will be considered in this paper. The rationale for using the Anasazi area of Chaco Canyon to make this population estimate is that unlike the ceremonial centers of the Mississippi Valley or Meso-America where populations lived in temporary abodes adjacent to the center, the Chacoans were one of the few peoples in North America who built and occupied permanent domestic communities which are still extant in a form and condition amenable to photogrammetric mapping.

PART II: PREVIOUS ESTIMATES

There have been a number of previous estimates of the prehistoric populations of Chaco Canyon. In 1934, Reginald G. Fisher based his figures on the amount of land that could be irrigated by the available run-off and concluded that the Bonito and McElmo Phase pueblos could have held as many as 10,000 people (Fisher, 1934, p. 21). He published a suggested site breakdown as follows.

SITE	SIZE
Pueblo Pintado	800
Wijiji	600
Una Vida	700
Chetro Ketl	1200
Pueblo Bonito	1200
Pueblo del Arroyo	800
Pueblo Alto	1000
Tsin Kletzin	800
Kin Kletso	100
Casa Chiquita	100
Penasco Blanco	1200
Kin Bineola	800

Lloyd Pierson (1949) did a complex population estimate based on the numbers of rooms in each site. After looking at the modern pueblos, Pierson concluded that a value of 1.9 people per room was justified (ibid., p. 54). He then totaled the possible rooms in the major sites, considered the possible population in the contemporary Hosta Butte Phase sites, and concluded that 4400 people were living in Chaco Canyon when it had its maximum population (ibid., p. 58).

Most recently, Alden C. Hayes, in conjunction with an inventory survey of Chaco Canyon, using methods similar to Pierson's but with a very different perspective on the meaning of the populations of the Hosta Butte and the Bonito and McElmo Phase sites, reaches a conclusion rather close to Pierson's. Hayes estimates a maximum of 5652 people, of whom 2763 were residents of the Bonito and McElmo Phase pueblos (Hayes, in press).

PART III: CONTEMPORARY STUDY

There have been several studies carried out within the past ten to fifteen years which have attempted to make population calculations of inhabited areas; some have used aerial photography and photogrammetric data, some have not. What is no doubt destined to become a classic in the field is the work done by Raoul Naroll dealing with the relationship between floor area within a site and the population of that site (Naroll, 1962).

Naroll discovered, using ethnographic data, that for a very diverse group of sedentary communities, population and floor area could be related in the manner of F = 10 P, where F is area in square meters under roofs and P is total population (Naroll, 1962, p. 588).

Using Naroll's conclusion as a starting point, Cook and Heizer (1968) set out to test that relationship. Restricting their study to California, they determined that

> "A close correlation between floor space and population can be demonstrated over a wide range of territory, irrespective of local variation. This relationship appears to be stable, generally valid, and applicable throughout the entire province." (Cook and Heizer, 1968, p. 115)

They reach this conclusion after extensive study of both their own and Naroll's data, and after using such parameters as mean floor space per person and mean floor space per house (Cook and Heizer, 1968, p. 93).

With the advent of extremely high altitude orbital imagery, it has become possible to attempt population approximations of very large urban areas. Ogorsky (1975), for instance, has done a sophisticated study employing central place theory which found that for the Puget Sound area of Washington, population correlated closely with area of the site as a whole rather than just the actual living areas as Naroll suggests (1975, p. 711).

All these studies purport to show some correlation between a population and the living area required by that population. The reasons for this relationship are intriguing but will not be dealt with here. However, a possible use of that relationship and a determination of a value for that relationship will be discussed.

PART IV: PUEBLO STUDY

In an attempt to discover a method for estimating prehistoric populations in Chaco Canyon, it was decided that the modern Pueblos could be examined for significant relationships. Fortunately, Stanley Stubbs (1950) published population data and aerial photographs of 25 modern pueblos from as late as 1948. Maps which had been drawn from the photographs were also included.

The method employed to examine the modern pueblos for significant relationships was as follows. The pueblos were first stratified into linguistic groups. A random sample of one pueblo from each of the six linguistic groups was taken with the following pueblos being selected, Oraibi (Hopi) in Arizona, and San Ildefonso (Tewa), Jemez (Towa), Taos (Tiwa), Santo Domingo (Keresan), and Zuni (Zuni) in New Mexico. A series of variables to be measured were selected with regard to several criteria: Pierson and Hayes had suggested room counts could be important; Ogorsky showed population related to site area; Naroll developed a formula for deriving population from floor space; Stubbs' maps listed the number of kivas in each pueblo. Various qualities of these variables also needed to be examined; did population correlate better with total values or only with amounts obtained for occupied areas? All these factors were considered in making up a list of variables to be examined.

Stubbs' maps were then measured with a Bausch and Lomb 7-power magnifier which had a reticle calibrated in 1/10 mm. divisions. The variables which were measured on the maps were: 1) Total room number; 2) First floor room number only; 3) Occupied room number only; 4) Occupied first floor room number only; 5) Total room number plus kivas; 6) Kivas only; 7) Total site area; 8) Total area under roofs; 9) Total site area minus area under roofs; 10) Plaza area; 11) Total area under roofs minus kiva area. A matrix of values was obtained giving the amounts for each variable and for each site. All areal measurements, variables 7 through 11, are given in square meters. The sites are listed in the order: 1) Oraibi, 2) San Ildefonso, 3) Jemez, 4) Taos, 5) Santo Domingo, and 6) Zuni.

ORIGINAL DATA MATRIX

Sites	Pop.	1	2	3	4	5	6	7	8	9	10	11
Oraibi 1.	87	217	182	188	153	219	2	43843	4217	39626	3137	4109
San Ildefonso 2.	170	206	194	201	189	208	2	126499	7195	119304	11344	7047
Jemez 3.	883	418	401	404	387	420	2	101469	13545	87924	6341	13321
Taos 4.	907	535	398	535	398	542	7	53698	12004	41694	9094	11389
Santo Domingo 5.	1106	516	505	514	503	518	2	130132	21920	108212	7889	21707
Zuni 6.	2671	259	257	242	240	259	0	86357	16143	70214	6109	16143

A number of statistical manipulations were then applied to these data seeking associations between population and any other variables. The first of these manipulations was done to generate a matrix of linear correlation coefficients. From this, important relationships could be seen and other manipulations could be compared with it. The variables correlated with population in the order listed with the following values.

.118 .211 .115 .203 .112 -.340 .072 .644 -.040 -.117 .652

It can be seen that variables 8 and 11 correlate much better with population than any other variables. A factor analysis was also run on the same data with a brief accounting given at the end of this paper. The results of the factor analysis essentially duplicated the results of the correlation matrix with variables 8 and 11 behaving most predictably with population. In both the correlation matrix and the factor analysis, variable 11, total area under roofs minus kivas, carried a higher value than variable 8, total area under roofs. For this reason, the areas of kivas were left out of further calculations. However, the difference made by the kivas is very small and would have little effect on the outcome.

Variable 11, area under roofs minus kivas, then was taken as the most relevant variable and another sample of the pueblos shown in Stubbs' book was selected in an attempt to further refine the relationship. Since only four linguistic groups were left, two sites each were taken from the Hopi and Keresan groups and one each from the Tewa and Tiwa groups. The sites selected were Shipaulovi and Shongopovi in Arizona, and Sandia, Nambe, Zia, and Cochiti in New Mexico. The areas under the roofs minus the kivas were now measured for all twelve pueblos and the values were recorded for all floor levels. Since Taos has five stories, it was necessary to carry the computations to this point. A pueblo having only one story, such as Sandia, was given the same value for all stories. Again a correlation was calculated with the following results.

1 Floor	2 Floors	3 Floors	4 Floors	5 Floors
.759	.739	.738	.738	.738

It can be seen that first floor area correlates higher with population and may therefore be a better indicator of population when it is considered alone than when upper story areas are added to it. This is extremely convenient for archeologists, and its immediate implications should be apparent. It suggests that the gross area within the walls of a pueblo minus the areas which can be identified as kivas, plazas, and non-roofed spaces is the best indicator of population.

The rest of the 25 modern pueblos pictured by Stubbs were then measured for area under roofs minus kivas and the following relationship was noted. When the total floor area for all pueblos 181,082 square meters, is divided by the total population for all pueblos, 16,879 people, the ratio obtained is 10.73, a value extremely close to Naroll's original F = 10 P. For this reason, the equation F = 10 P will be considered close enough to make a rough approximation of the prehistoric population of the Bonito and McElmo Phase ruins of Chaco Canyon. (See fig. 1 for display of relationship and linear regression of population and floor area of modern pueblos.)

PART V: CHACO MAPPING PROJECT

In 1972, the Remote Sensing Project of the Chaco Center of the National Park Service and the University of New Mexico began mapping the large Bonito and McElmo Phase ruins in Chaco Canyon National Monument (Pouls, Lyons and Ebert, n.d.). Topographic maps were made on stereoscopic plotters from aerial photography. All the Bonito and McElmo Phase sites have now been mapped as well as many other sections of the monument. Ground-based checks have proved the accuracy of maps of this type. Their use in planning and documenting excavations has already been tested in the field (Drager, 1975). It is precisely this accuracy that makes these

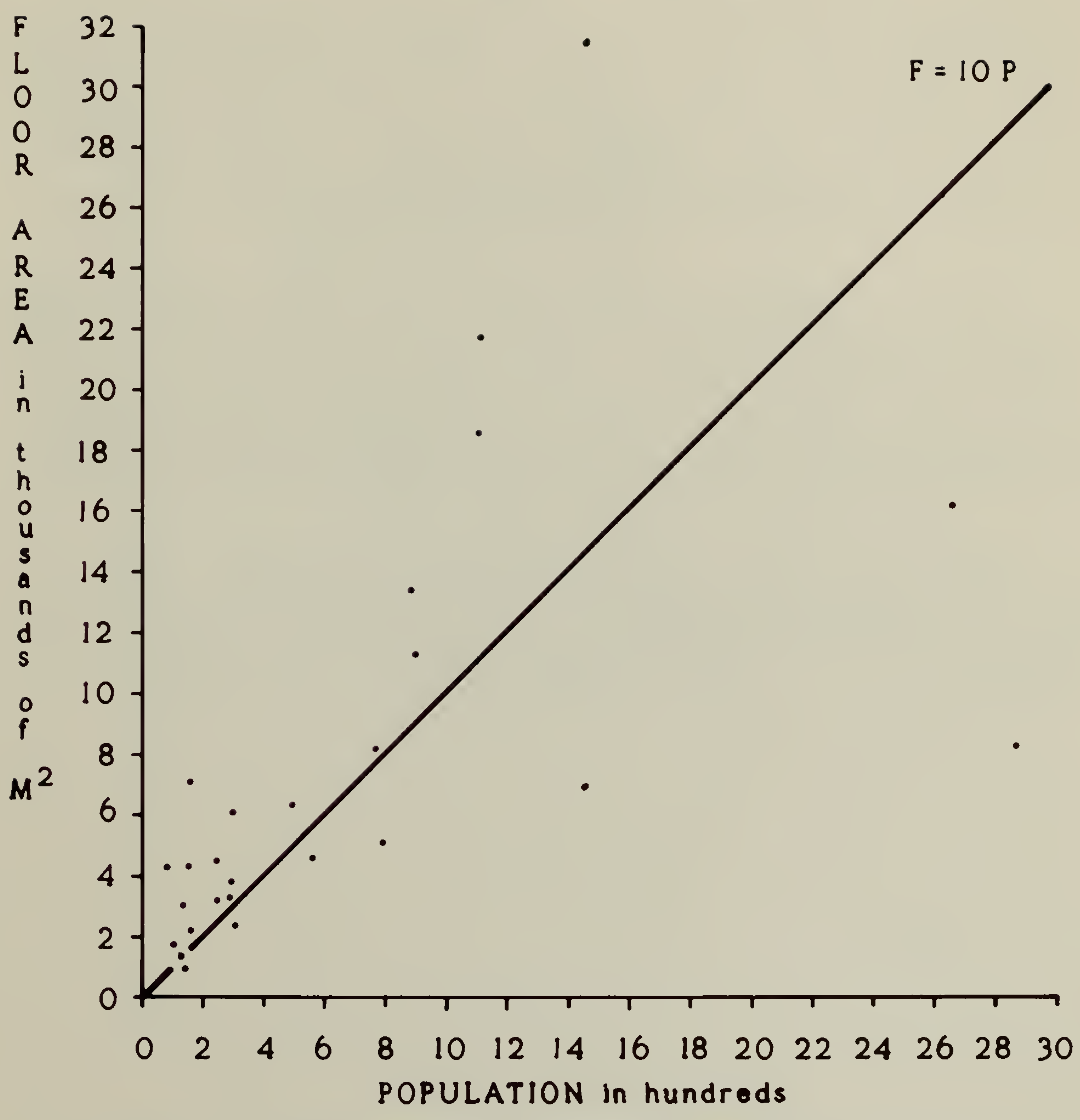

FIGURE 1 - Relationship of population to floor area among modern pueblos with regression line F = 10 P

maps so useful in the present study.

On a topographic map of a pueblo site, there is little difficulty in identifying walls and rooms which protrude above ground level (see fig. 2). It is possible, however, that much of a site may be weathered to the point where few constructed features are visible. In this case, it is possible to trace an outline which will very closely approximate the shape of the site at its maximum extent. This can be done by noting elevation differences, by following topographic contour shapes, and by extending visible features. Depressed circular areas or circular walls will show where some kivas are located. Internal plaza areas can usually be delineated fairly easily leaving only the outline of the actual living areas to be measured for the population estimation. Figure 3 shows how this was done for the site Casa Chiquita.

With the exception of Pueblo Alto and New Alto, dendrochronological dates are available for all the major sites in Chaco Canyon (Robinson, Harril and Warren, 1974, p. 10). There is no single date for which there is specific evidence that all the sites were still under construction. However, shortly after 1100 A.D. when the final sites were completed, we can imagine that the canyon was fully occupied and had its maximum population.

Each site, then, is given a population value equal to one tenth of the area under the roofs minus the area of all identifiable non-living spaces. Following is a list of each of the major Bonito and McElmo Phase sites with its dates, area, and estimated population.

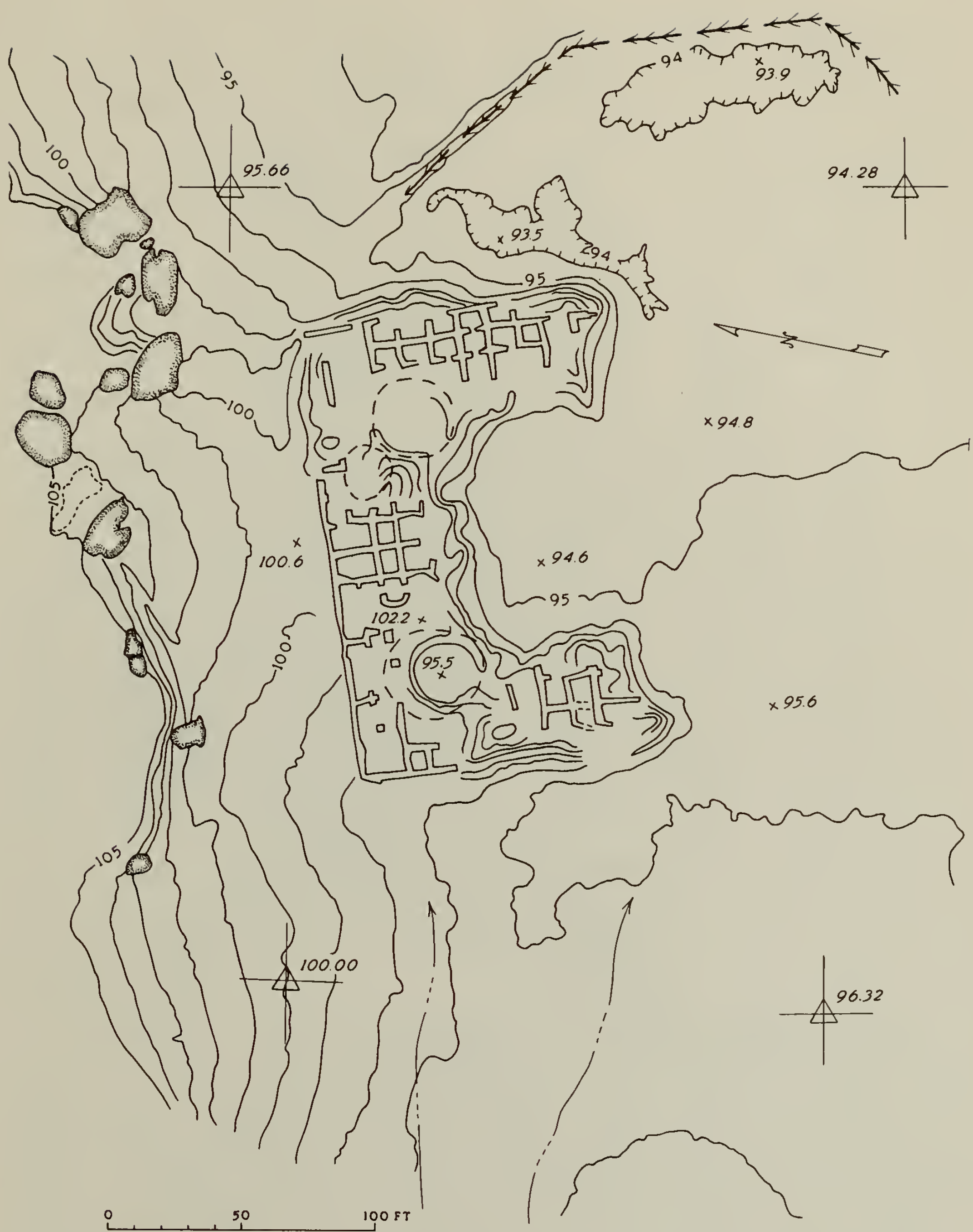

FIGURE 2 - Topographic map of Wijiji ruin showing walls protruding above rubble fall

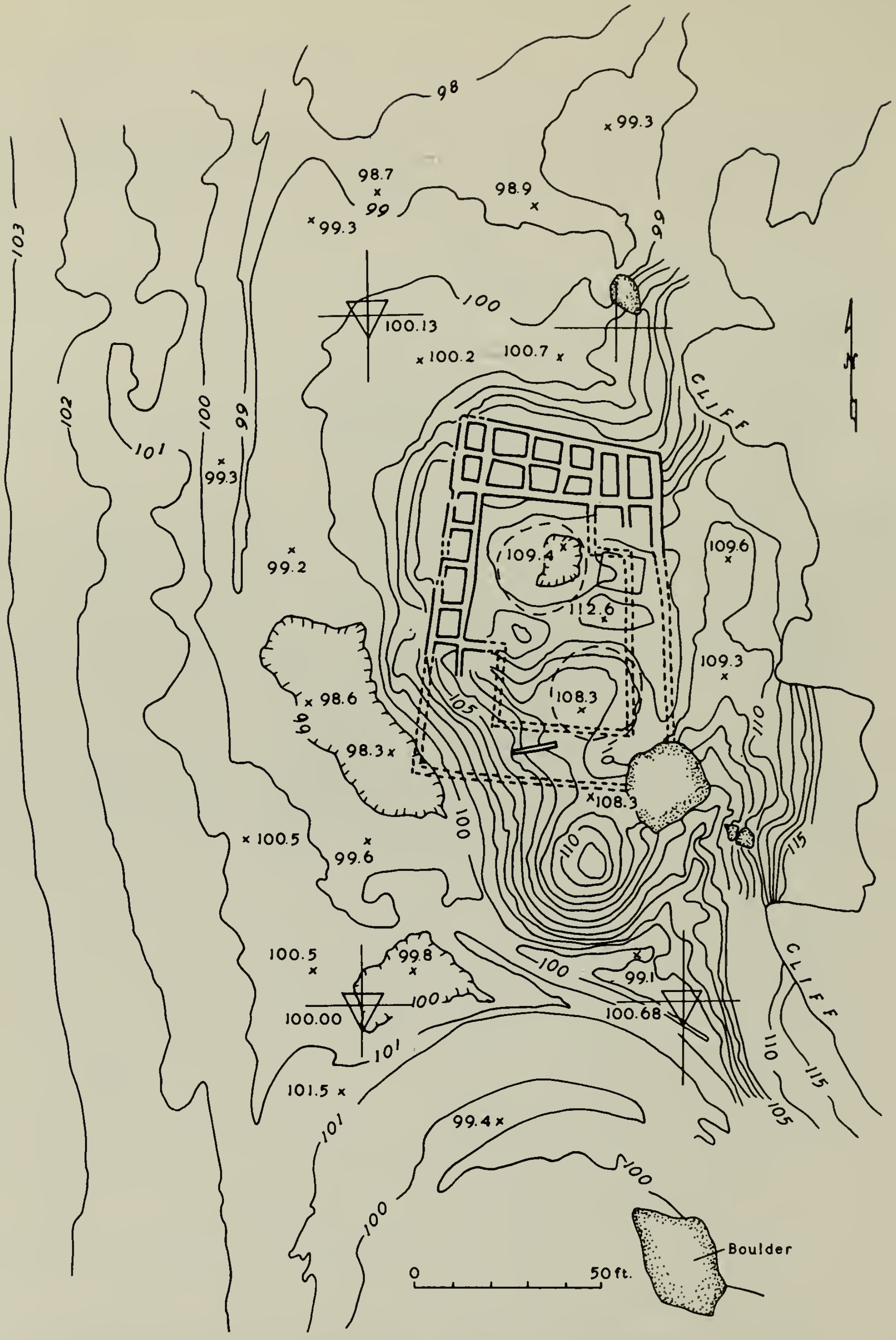

FIGURE 3 - Map of Casa Chiquita ruin showing visible walls and possible original outline (dotted lines)

SITE	DATES A.D.	AREA IN SQ. METERS	POPULATION
Pueblo Bonito	825-1130	4975.31	498
Penasco Blanco	850-1090	4380.07	438
Una Vida	850-1090	3330.95	333
Chetro Ketl	880-1110	4850.01	485
Kin Bineola	921-1119	3001.52	300
Hungo Pavi	940-1075	2737.61	274
Pueblo del Arroyo	1005-1110	2625.19	263
Casa Chiquita	1050-1075	326.61	33
Kin Kletso	1050-1175	924.07	92
Pueblo Pintado	1053-1061	1807.01	181
Kin Klizhin	1084	480.02	48
Kin Ya'a	1097-1106	937.61	94
Tsin Kletzin	1100	748.08	78
Wijiji	1105	939.92	94
Pueblo Alto		3173.12	317
New Alto		418.72	42

This gives a total population for the major sites of 3570. If the outlying sites of Kin Bineola, Kin Ya'a, Kin Klizhin, and Pueblo Pintado are eliminated, then the central canyon Bonito and McElmo Phase population becomes 2947. This value is very close to Hayes' central canyon Bonito and McElmo Phase estimate of 2763 people. It is also interesting to note how close these two figures are to Pierson's amount of 4400 when the entire canyon is considered. If Hayes' value of 2889 for the population of the Hosta Butte Phase sites is added to this paper's estimate of 2947, then the total of 5836 is reached as a maximum population for the entire central canyon area.

PART VI: CONCLUSION

It is probably justifiable to conclude that there were never more than 6000 people living contemporaneously in the Bonito, McElmo, and Hosta Butte Phase sites in Chaco Canyon.

This method is a straightforward way to arrive at a population estimate for an area, map the area photogrammetrically, measure the area encompassed by the site in square meters, eliminate plazas, kivas, and non-roofed spaces such as streets, and divide the results by 10. In cases where kivas cannot be identified from the maps, the amount that they would change an approximation of the prehistoric population is probably not enough to worry about.

While no claim is made that such estimates will be absolutely correct, they are probably more accurate than those arrived at by any other technique presently available. In addition, this method has the advantage of not requiring excavation to determine room counts.

THE FACTOR ANALYSIS

The factor analysis used in this study was performed by the IBM 360 computer housed at the University of New Mexico Computing Center with the IBM prepackaged program STATPACK. The original data matrix listed above was entered into the program and yielded the following eigenvalues and cumulative proportions of eigenvalues.

EIGENVALUES

6.504	2.919	1.886	.659	.3E-01	.8E-06	.7E-06

CUMULATIVE PROPORTIONS OF EIGENVALUES

.542	.785	.942	.997	1.000	1.000	1.000

The decision was made to retain four factors since they accounted for 99 percent of the covariance within the matrix even though the fourth factor did have an eigenvalue less than 1.000. After varimax rotation, the following factor matrix was obtained.

VARIABLE	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
Pop.	.05735	-.04768	(.99212)	-.04984
1	.98337	-.07613	.06437	.15003
2	.96759	.18758	.16028	-.03255
3	.97755	-.04810	.06565	.19374
4	.96493	.20601	.15710	.02711
5	.98203	-.08331	.05809	.15750
6	.52204	-.51104	-.36613	.57559
7	.12221	.97869	.11647	.11513
8	.66410	.37679	(.63147)	-.09990
9	.00651	.98883	.00647	.14366
10	.12170	.47537	-.05695	.86927
11	.64271	.39092	(.64141)	-.11863

It can be seen that population loads heavily in factor 3 along with variables 8 and 11, the same two variables which correlate highly with population.

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National Park Service
University of New Mexico

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ECOLOGICAL APPLICATIONS OF LANDSAT IMAGERY IN ARCHEOLOGY: AN EXAMPLE FROM THE SAN JUAN BASIN, NEW MEXICO

BY

RANDALL F. SCHALK AND THOMAS R. LYONS

PART I: INTRODUCTION

The kinds of data which archeologists consider relevant to the scope of their discipline are increasing rapidly. It is evident, too, that what are now considered essential varieties of data were all but ignored until recently. In view of these accelerating trends and the fact that questions being asked of archeological data are continually changing, it would seem that archeologists are confronted with the necessity of collecting ever increasing amounts of data with greater efficiency and economy.

Environmental information, in particular, is receiving greater attention. Ecological relationships between man and his environment are critical to understanding cultural variability and the processes of cultural change, two major concerns of archeology. In fact, environmental data is no less important than the actual contents of archeological sites, for the latter can be understood only in terms of adaptations between human populations and their environments. An archeological site for which there is no information concerning its ecological setting lacks scientific value in the same way as artifacts without proveniences. Substantive archeological reports now almost invariably contain a great deal of environmental information and may include maps of ecological zones, soil and vegetation maps, precipitation patterns, drainage structure, and physiography of the study area. The manner in which human populations are linked with and constrained by these environmental variables must be of central importance to the science of archeology.

Another significant trend in recent years has been the increase in size of the study area. This trend is the result of certain theoretical developments in the discipline on the one hand, and more pragmatic considerations on the other. The theoretical shift has been from the former emphasis upon single sites as representatives of cultures to populations of sites representing cultural systems. This is generally referred to as the "regional approach", and such an emphasis focuses upon a much larger area as a unit of study. This also implies that ecological data at the regional level is now becoming a necessary part of many, if not most, projects.

A second reason that the unit of study has become larger is that vast areas of land are now coming under closer scrutiny either in salvage or contract archeology, or as a part of stewardship efforts of governmental agencies such as the National Park Service, U.S. Forest Service, Bureau of Land Management, Army Corps of Engineers, and the Bureau of Reclamation. Obviously, all these interests are attempting to cope with the multitude of cultural and natural processes which seem to increasingly threaten the archeological record.

Only recently has the potential use of remote sensing techniques for monitoring environmental variables received any attention in archeology (Ebert and Hitchcock, n.d., Jorde and Bertram, this volume). Most applications of remote sensing technology to archeological research have involved the search for the results of human activities - sites, features, etc. Because orbital imagery is of relatively small scale when compared to more conventional forms of aerial photography, its utility in the location of specific archeological sites is negligible. Nevertheless, the value of a remote sensing technique is not diminished by its inability to distinguish the products of human behavior, if the same tool is useful in monitoring the environmental conditions which shape human behavior. Also, small scale imagery is a logical starting point for photo-interpretative techniques which properly should move from small scale to large scale (Stone, 1964).

The remainder of this paper is an examination of some potentials of Landsat imagery for acquiring environmental data and a discussion of the ways such information is being applied to the archeology of the San Juan Basin, New Mexico (see fig. 1). Before proceeding, a brief description of the present Landsat system will be given with particular emphasis on its use in the acquisition of ecological data.

PART II: THE LANDSAT SYSTEM

The Landsat I and II satellites have been generating repititive imagery of virtually the complete surface of the earth every eighteen days since 1972. The instruments aboard the craft were designed for monitoring earth resources, and information derived from the system has already proven useful in such disciplines as forestry (Heath, 1974), geology (Baker, 1975), agriculture (Hay,

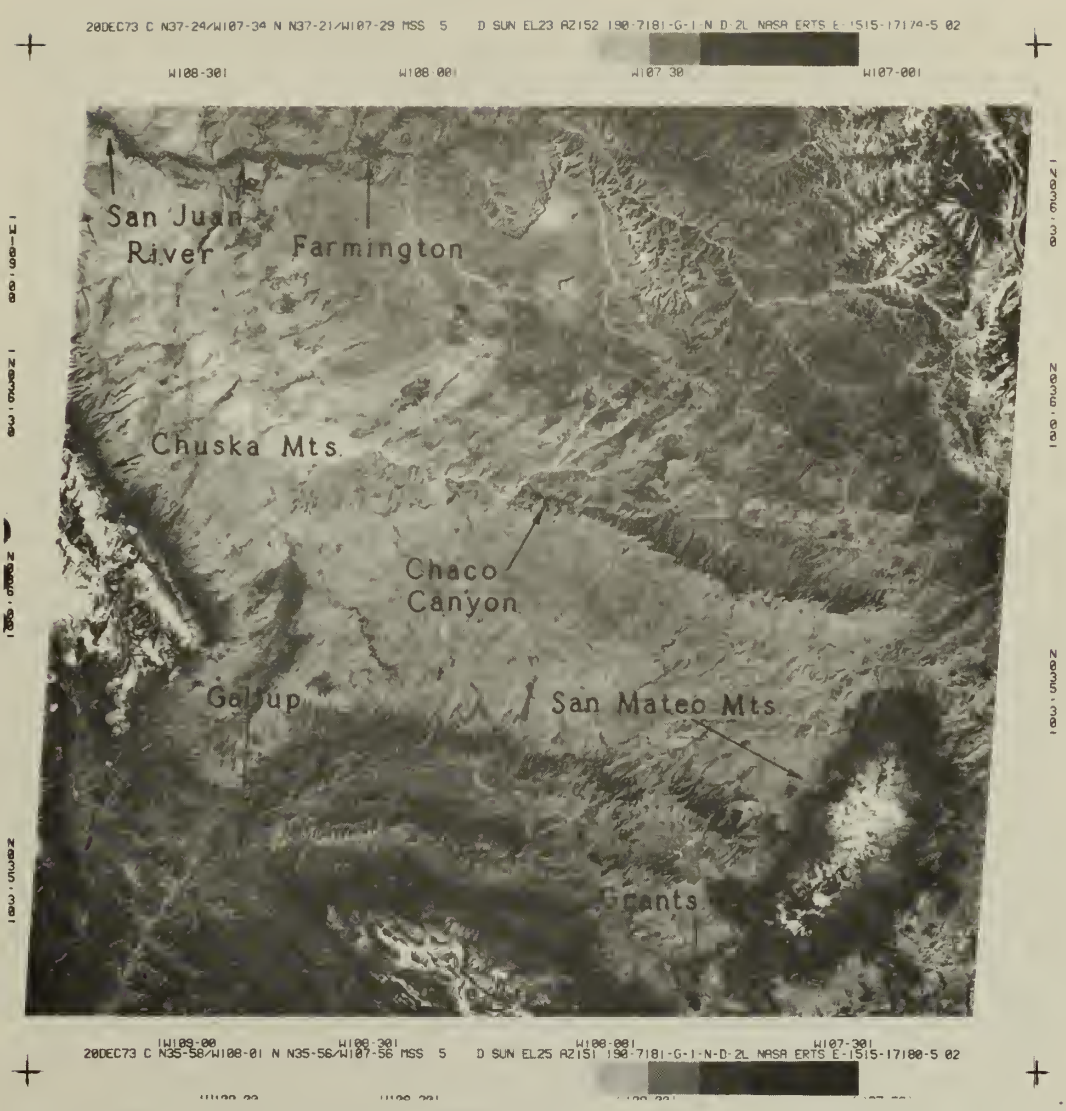

FIGURE 1 - Landsat image of the San Juan basin, Four Corners area

1974, geography (Ulaby and McNaughton, 1975), urban planning, and others. Such multi-disciplinary application suggests the tremendous amount of environmental data contained in Landsat imagery.

Perhaps one of the most celebrated characteristics of space imagery in general is that it provides the ultimate in the "birds-eye" view. Very large areas of the landscape are included on a single frame of Landsat imagery. Such a frame typically covers an area of roughly 34,000 square kilometers (13,000 $mi.^2$), or a parallelogram with sides approximately 115 miles each. To cover a comparable area with low altitude aerial photography would require hundreds or even thousands of separate frames. Furthermore, mosaics of aerial photographs do not facilitate comparison of tone for widely separated areas within a region. Since tone is a valuable means for identification and recognition of vegetation, soils, etc., the evenness of tone for the large areas within a single Landsat image permits valid inferences about the significance of similarities and differences in tone.

A second characteristic of Landsat imagery of particular significance to ecological studies is that it includes four separate bands in the visual and infrared range. These bands were selected for their potential in the discrimination of various environmental parameters. Band 6 and band 7 were chosen for their capacity to emphasize vegetation as well as land-water boundaries. Similarly, band 5 was chosen to deal with soils and cultural features and band 4 to emphasize depths and sediment content of water bodies. Bands may be selected to discriminate whatever is required, or composite false color images can be produced from combinations of various bands.

The Landsat imagery's resolution is significantly greater than any of the previous weather satellites (e.g., Nimbus), although it is not comparable to the hand-held photography of manned satellites (i.e., Gemini, Apollo, Skylab). The resolution of Landsat imagery has been reported to be 80 meters with linear features detectable down to 10 meters. It has been our experience that two-lane roads as well as railroad lines are distinguishable in many areas of northwestern New Mexico.

Another important characteristic of this imagery for ecological information acquisition is the sequentiality of the imagery. The availability of images of the same area as regularly as every eighteen days means that dynamic environmental phenomena can be surveyed (Wobber, 1969). Annual changes in vegetation (phenological changes) for example, have proven useful in forestry and in vegetation mapping where deciduous and evergreen trees may be distinguished (Morain, 1974).

Still another quality of Landsat imagery is that it is one of the most economical forms of remotely sensed data presently available. For most research projects, one or at most a few frames are necessary to include the area of interest and probably much of the surrounding area as well. In those studies where resolution requirements are not high, interpretation time and costs may be considerably reduced (c.f. Colwell, 1973).

PART III: APPLICATIONS OF LANDSAT IMAGERY TO THE ARCHEOLOGY OF THE SAN JUAN BASIN

One particularly useful application of Landsat imagery is the stratification of a large area into gross ecological zones. Such stratification is now essential in the very initial stages of most archeological projects. Since decision making in the implementation of a research project of any kind seems to be most effective when informed by some knowledge about the environmental variability which exists within a region. Though considerable archeology has been conducted in the San Juan Basin during the past century, there have apparently been no attempts to treat the physiographic unit defined by the basin as a unit of study. There have, however, been efforts to define the ecological settings of smaller areas within this larger unit (Jones, 1972; Potter, 1974; and Witter, n.d.), but the "big picture" of regional variability has been lacking.

The use of Landsat imagery overcomes certain difficulties which any archeologist attempting to ecologically stratify a region might encounter. For instance, the boundaries of any particular study area as defined by salvage projects, parks, or government ownership almost never coincide with the boundaries of extinct cultural systems. Because funding provides limitations on the extent to which work is conducted beyond these arbitrary boundaries, most archeologists are dependent upon published sources for ecological information needed in addition to that collected within the study area. Though maps showing the distribution of soils, vegetation, topography, and drainage structure are frequently available for most areas, the ecological zones to which humans respond are almost certainly the product of all these interacting variables. And, it has been our experience in northwestern New Mexico that many of these maps have proven highly inaccurate and inconsistent from one author to the next. Unlike these other types of representations, Landsat imagery combines all this information on a single visual format. Though such synergistic relationships between these different aspects of the environment may make interpretations difficult, the tremendous amount of information contained can only be appreciated as a very graphic display of many complex interactions.

The problem of working with taxonomies not designed for the immediate purposes at hand (e.g. soil and vegetation types) is one only too well known to archeologists. For this same reason, no programmetric procedure for stratifying a region is offered here. Though it is not our intention to elaborate upon the problems inherent in the classification of vegetation into acceptable units (see Kuchler, 1967: 30), suffice it to say that the archeologist who generates his own vegetation or ecozone map will probably have units far more meaningful to his particular interests than will one who is using a taxonomy designed for some other problem or situation.

Figure 2 indicates the broad environmental zones which were delineated by means of the Landsat imagery of the San Juan Basin. With the assistance of a color additive viewer, these boundaries were defined primarily on the basis of differences in the tone on the film positives. "Ground-truth" checking this large area involved referring to several published sources (Harris, 1967; Kuchler, 1964), ecological data reported in archeological works of specific areas within the basin, our own familiarity with the region, and limited use of low-altitude aerial photographs. In this way, one can extrapolate from the known to the unknown areas on the Landsat imagery.

In the process of producing this map, some interesting observations were made. It was immediately apparent that the San Juan Basin is by no means an environmentally homogeneous region, though it might appear so to an observer driving or even flying across the basin. Chaco Canyon itself lies on an ecotone between the northeastern portion of the basin and the southwestern portion (see fig. 2). Though vegetational distinctions between these two areas seem slight, the primary difference being the greater presence of juniper, pinyon, and big sagebrush in the northeast section, geological differences and resultant differences in soils are significant. The difference is basically one of deposits of terrestrial origin (sandstones to the northeast), and deposits of marine origin (the shales of the southwestern part of the basin). Chaco Canyon is an erosional feature which has eroded into the landscape at the contact zone between these two deposits.

Awareness of this sort of environmental variability within the region allows the formulation of expectations about how prehistoric subsistence practices would respond to such variations. Since this region, in particular, is an arid one, it might be expected that the degree to which different soils retain moisture after periods of precipitation would determine the success with which different agricultural strategies might be practiced. Because sandy soils, like those in the northeast part of the basin, are capable of retaining moisture for long periods, agricultural practices in this area should differ from those of the southwestern part of the basin where clay soils would result in rapid run-off and poor water retention. Water control features may have played a much more important role

FIGURE 2 - Gross ecological zones of the San Juan basin, New Mexico

1: Grama-Galleta Steppe (associated with clay soils)
2: Grama-Galleta with Juniper
3: Juniper-Pinyon Woodland
4: Ponderosa Pine-Douglas Fir Woodland
5: Saltbush-Greasewood
6: Southwestern Spruce - Fir Forest

where populations had to cope with rapid run-off, and social organization may have varied as a function of differences in subsistence practices.

It is interesting to note that "complex" (large scale and redistributive) forms of social organization frequently are said to arise in situations where regions are internally differentiated environmentally, and that redistribution of products between these various zones is facilitated by an administrative hierarchy (c.f. Sahlins, 1960). One of the paradoxes of the archeology of the San Juan Basin is the scarcity of evidence suggesting any degree of local specialization in the food crops produced in different localities and at the same time, the abundant evidence suggesting the development of a "complex" system between A.D. 850 and 1150.

Some of the evidence which can be offered in support of such an argument for "complexity" would include: (1) the lack of sufficient arable land in the Chaco Canyon proper to support the population estimated to have lived there contemporaneously (Drager, this volume; Loose, this volume; (2) the differentiation of settlements into towns and villages (Vivian, 1967), or at the regional level, into a three-level hierarchy of primary towns, secondary towns, and villages; (3) the presence of a complex road network linking up the major sites in the Chaco Canyon and extending outward to sites many miles away (Lyons and Hitchcock, in press); and (4) the indication that there were irrigation systems which were cooperative enterprises involving more than a single Chacoan town (Vivian, 1967). In any case, it is sufficient to point out that all this evidence points to the presence of a complex economic system despite the lack of any indication of intra-regional specialization.

It is tempting to speculate about another possibility suggested by the above mentioned soil differentiation within the basin. It is possible that different localities within the basin would have had very different regimes in the production of the same basic crops. In arid environments, very slight variations in effective moisture from year to year cause substantial fluctuations in rates of primary and agricultural production (Noy-Meir, 1973). In light of the sandy soil/clay soil distinction drawn above, it is conceivable that wet years would allow surplus production in areas of clay soil while sandy soils would produce better in dryer years due to the water retaining properties of sand. Given this inverse relationship within the region, the emergence of a complex economic system with mechanisms for redistribution of resources would allow the damping out of local fluctuations in crop production at the regional level.

One other observation made from examination of the Landsat imagery of the San Juan Basin was the patterns of the location of major sites or unusually dense clusters of sites. For instance, several of the largest sites known in the southern San Juan Basin are associated with major canyons, and often where several large canyons converge (see fig. 3). In the southern and eastern parts of the basin, such situations occur at the bases of the mountains which define the basin. That such areas are well watered is indicated by their tonal signatures on the Landsat imagery (particularly the infrared bands) which are anomalously dark when compared to surrounding areas but remarkably similar to each other. This suggests that the environmental determinants of settlement locations might be indicated on such imagery.

In any case, it should be evident that the big-picture perspective of environmental variability of very large areas offered by orbital imagery is useful for generating questions at the very outset of a research project. The fact that complex social systems extend over extremely large areas is an additional demand for more efficient means of gathering information on ecological phenomena of equal scale. Comparison of different cultural systems, regardless of complexity, is also only possible with such a broad scale perspective.

Finally, another potential application of Landsat involves its use as an aid in the placement of survey transects. If on-the-ground vegetational surveys are coupled with archeological surveys of an area, as they often are, it is likely that the placement of transects will be done with respect to the gross pattern of vegetational associations in the environment. In so doing, variation is maximized within the sample (Witter, in press). The Chaco Canyon area of the San Juan Basin is shown in figure 4 as it appears after enlargement of a portion of a Landsat image. It is evident in this figure that the general pattern of physiography and vegetation is apparent enough to help in the placement of transects. We are presently using the Landsat imagery to select areas within the basin for more extensive surveillance with low-altitude multi-spectral photography and as an aid in positioning aircraft flight lines. In areas which are poorly known and for which little conventional imagery is already available, Landsat imagery could provide a useful basis upon which to make well-informed decisions about subsequent research strategy. In areas where conventional imagery is available, Landsat images can facilitate the identification of areas of interest and thereby aid in selection of the required images.

PART IV: CONCLUSIONS

One could easily get the impression that satellite imagery in general and Landsat in particular, is a poor substitute for other, more conventional varieties of aerial photography. To the extent that archeologists are interested in remote sensing as a reconais-

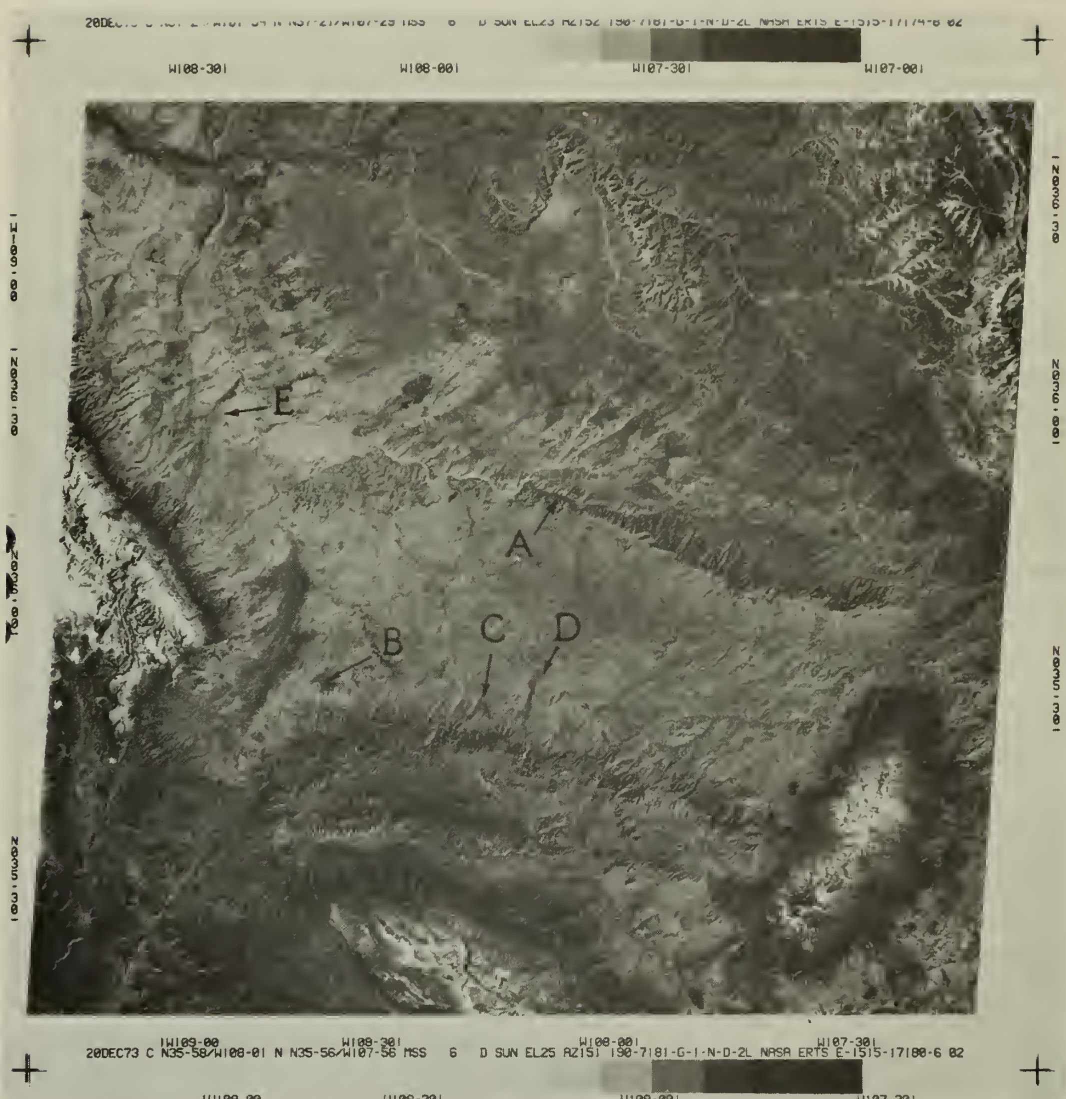

FIGURE 3 - The location of five large Chacoan sites and their relationships to canyon systems

FIGURE 4 - An enlargement from a Landsat image of the Chaco Canyon area

sance tool for location of sites, this may be accurate. However, it has been suggested in this paper that ecological information at a regional scale is, in fact, represented most effectively in orbital imagery. For research designs or management practices which are structured for moving from the general to the specific, such imagery can be effectively used from the very outset of a project. Similarly, it provides a logical starting point in any multi-stage procedure for acquiring environmental data and can be integrated with conventional aerial photography and ground surveys. In addition, it is clear that Landsat imagery has many classes of information which are visually combined in a way that is not approximated by low-altitude photographs or by maps showing distributions of soils, vegetation, landforms, and other environmental variables. Finally, it appears that orbital imagery will prove to be of utility in the definition of gross environmental zones of significance to past human adaptations.

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