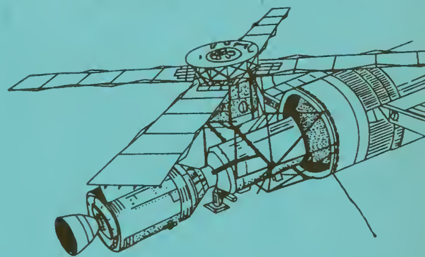
CULTURAL RESOURCES

REMOTE SENSING



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CULTURAL RESOURCES REMOTE SENSING

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Southwest Cultural Resources Center
NATIONAL PARK SERVICE
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Albuquerque

1980

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INTRODUCTION

During the past few years, the Remote Sensing Division of the National Park Service has had three major goals: 1) to research and develop remote sensing methods which can be employed by archeologists and cultural resource managers, especially those involved in archeological projects; 2) to apply these methods in various areas where different environmental and spatial conditions, as well as economic considerations, influence the specific methods appropriate for the tasks at hand; and 3) to disseminate information on the results of these experiments. This volume is one of a series of collected papers (Lyons 1976, Lyons and Hitchcock 1977, Lyons and Ebert 1978) which endeavors to fulfill this last goal. In addition to these volumes, there is a Handbook series which provides basic information on remote sensing methods and their applications (Lyons and Avery, 1977, Avery and Lyons 1978, Morain and Budge 1978). This Handbook series is being expanded to include more detailed information on various aspects of the remote sensing methodology as well as overviews of their applications in different environmental settings. Four reports in this series are now in press and eight others are in various stages of preparation.

An emphasis of the Remote Sensing Division has been on the concept of non-destructive archeology (Lyons and Scovill 1978), and it is felt that the methods developed and applied are most useful for today's archeologists, cultural resource managers, and land managers who are confronted with the task of inventorying and determining what cultural resources are present. These resources in turn must be evaluated as to potential use, protection, and/or possible mitigation when such problems as energy extraction need to be solved to insure the survival of modern society.

Research and application at the Remote Sensing Division provides new approaches which will aid today's archeologist to handle the increased volume of work. While the reports in this volume have been divided into four sections, they also overlap in discussion of methods developed and employed by the various investigators. For example, the creation of ecological/cover-type maps from Landsat imagery and the use of these to implement sampling strategies have been applied in two different environments: the Alaskan tundra (Ebert et al) and the arid Southwest (Fanale and Drager, in preparation).

Recent emphasis on regional studies has made the task of sampling an indispensible one. Therefore, it is necessary to develop explicit techniques which can be utilized by many investigators in such a context. Both papers in the section on Sampling and Survey emphasize methods developed to handle problems encountered in a large region in which planning, mapping, surveying, and projection of land use were important considerations. The sample strategy developed for the study of the National Petroleum Reserve in Alaska discussed by Ebert et al covers over 23,000,000 acres of land for which a cultural resource assessment was required. Similar methods can be utilized by other government personnel who have been commissioned to survey our national cultural resources within the next few years. The article by Brown and Ebert on Teshekpuk Lake, on the Arctic Coastal Plain, describes a limited portion of the larger area in which continued research was carried out in order to further refine the use of geological, ecological, and other data to arrive at an informed cultural resource sampling stategy.

Emphasis in the next section is on Vegetation and Environment. Drager discusses the assumptions and methods employed using information obtained from various scales and types of remote sensor data to arrive at useful sampling stratifications. In contrast, the vegetative mapping project carried out in Chaco Canyon by Kelley and Potter began with an evaluation of aerial imagery to obtain ecological information about the area, but resulted in a number of interesting cultural conclusions. J. Ehrenhard was confronted with a different type of vegetative problem when he surveyed the swamp environment of Big

Cypress. Rather than developing a sampling stategy, his problem was to detect sites in a densely vegetated zone which he was able to solve using color infrared imagery.

Often one must be concerned with detection and analysis of cultural resources which are not always apparent from a ground station perspective or with those parameters of sites which are difficult to measure using conventional on-the-ground methods. The section on Ephemeral Archeological Features discusses ways that remote sensing can be applied to the discovery and recording process. Ebert and Lyons make several suggestions concerning the mitigation of prehistoric roadways in the San Juan Basin which are currently threatened with destruction. Obenauf outlines the history of research on roads, especially the work of the Remote Sensing Division from 1970 to present on the prehistoric roadway system found within the San Juan Basin of northwestern New Mexico. She presents field-checked maps of the system as it is known to date. Ebert and Hitchcock had utilized the data collected up to 1973 on this road network. They applied the work of economic geographers to model prehistoric behavior and to explain the system in a regional and anthropological framework. In addition to the roadway system, information on prehistoric canals in the Hohokam culture area of southern Arizona has been expanded by the work of Ebert and Lyons. These are linear irrigation features, some of which have been reused by modern inhabitants or have sculptured the current land patterns. The final paper in this section by E. B. Ehrenhard and Wills discusses the use of remote sensing techniques in a non-arid climate with dense vegetation cover where ground survey had again yielded little information on a historically documented site. The major concern in this project was to employ non-destructive techniques to discover the location of the site.

The final section of this volume discusses Photogrammetry, or the technique of measuring from photographs. For the archeologist who would prefer stereophoto coverage of an excavation, the bipod provides a platform from which one or several stereo pairs can be obtained. Klausner focuses on an example of the use of the bipod in archeological investigations and emphasizes its use in recording objects as they are located on the site. Boyer discusses problems in rectification of optical images when using the bipod. Borchers' description of his work in terrestrial photogrammetry of prehistoric pueblo dwellings in Arizona demonstrates a different approach to mapping sites which often may not be easily approached from the air. His techniques, however, are not limited to sites with difficult access, but can be applied to any standing structure whether modern or prehistoric. The final paper by Ireland compares the costs for various types of mapping procedures. Specifically it describes a mapping procedure, the products of which are not as accurate as photogrammetric maps which have been rectified for tilt and distortion on the air photo, but which does provide a quick and inexpensive method of obtaining maps of high accuracy.

Finally, while there are a diverse number of topics covered in this volume, it is hoped that they will be useful to those concerned with the discovery, sampling, analysis and management of cultural resources.

T. R. L.
F. J. M.

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REMOTE SENSING IN LARGE-SCALE CULTURAL RESOURCES SURVEY: A CASE STUDY FROM THE ARCTIC

Compiled and Edited by

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We gratefully acknowledge the support and encouragement of the National Petroleum Reserve in Alaska Work Group 4, headed by Dick P. Hsu (Staff Archeologist, National Park Service, Anchorage Area Office at the time of this study) for its farsightedness in incorporating remote sensing in their overall research design and for access to archeological data on which a portion of this report is based. In addition to these more tangible contributions to this report, many members of the Work Group 4 staff aided with comments and suggestions at all stages of the work reported here. Although we have incorporated many of these suggestions in this and other reports, we must of course accept full responsibility for errors or inconsistencies appearing in this publication.

This case study is actually a compilation of a number of reports on various aspects of the overall remote sensing contribution to the National Park Service's project on the North Slope of Alaska. Since the project took place over a number of years, and with the lag time between the writing and printing of publications what it is, the reader will find a number of temporal inconsistencies in verb tense and nomenclature throughout this article. One of the most immediately confusing of these is occasioned by the fact that the name of the study area changed during the project. At the initiation of the cultural resources survey, the Naval Petroleum Reserve No. 4, which had been established in 1923 by President Harding, was usually referred to as NPR-4 or "PET-4," as it appears in some of the paragraphs included here. In 1977, jurisdiction was transferred from the Navy to the Department of the Interior and the area became the National Petroleum Reserve in Alaska, or NPRA.

It is our hope that, regardless of problems such as this, the following papers may serve as an illustration of the process by which remote sensor data can be applied to the problems posed by large-scale cultural resources survey in the Arctic and, by extension, anywhere.

A comprehensive final report on cultural resources remote sensing in the NPRA project will appear in the Work Group 4 final project report which is presently in preparation and should appear in the near future. Those interested in receiving this report should contact the Alaska Area Office of the National Park Service, 540 W. 5th Avenue, Room 202, Anchorage, AK 99501.

FOREWORD

by

James I. Ebert

This paper is a collection of statements describing the National Park Service's cultural resource assessment of the National Petroleum Reserve in Alaska (NPRA), especially with reference to remote sensing applications and plans in the early stages of that project. Much of what is contained in this paper was written in the form of reports during the planning and execution of the remote sensing phase of the NPRA project. The rationale behind the publication of these reports is not to provide a comprehensive overview of the NPRA project or even the remote sensing activites involved, but rather to avail the cultural resource manager embarking on large-scale survey some insight into the planning and coordination of remote sensing input. A more detailed final report on the methods used and results obtained in the course of remote sensing applications in the NPRA will be forthcoming as part of the Alaska Area Office's final report on the survey there. This may not be published for some time, however; and it was felt that the timely appearance of this paper could be of help as the impact of large-scale survey increases in the United States.

The INTRODUCTION, written by Dick Ping Hsu, principal investigator and field director of the NPRA Project in Anchorage, describes the regional and analytical scope of the study and its basis in managerial needs. Some of the problems inherent in such a survey are discussed; while some of these--such as an extremely short summer field season--are unique to the Arctic; other difficulties such as large, remote areas which must be covered, plague cultural resources surveys in many parts of the country. One solution to these very real problems, as will be suggested in the sections which follow this introduction, lies in the application of remote sensing methodologies.

The REPORT ON FIELD AND LABORATORY OPERATIONS OF THE REMOTE SENSING PHASE OF THE NATIONAL PARK SERVICE CULTURAL RESOURCES ASSESSMENT OF NPRA, which appears next, discusses the project in the context of remote sensing activities taking place during June and July of 1977. The development, goals and organization of the project are summarized, laboratory remote sensing operations and plans are discussed, and the results of fieldwork by Remote Sensing Division personnel set forth. In a number of cases, observations made in the field have resulted in the modification of previous plans, and these changes are explained and enumerated.

Appended to the June-July research report is a report entitled PRELIMINARY PLAN FOR A CULTURAL RESOURCES SAMPLING DESIGN INCORPORATING REMOTE SENSOR DATA IN THE PET-4 AREA, ALASKA, which served as a basis for early thinking about sampling in the NPRA Project and which is referred to several times in the prior report. The sampling plan discusses some of the problems encountered in large-scale cultural resources management, posits solutions to these, and suggests a multistage, feedback sampling design based on remote sensing input as well as on-the-ground data. While time constraints prevented the use of the ecological stratification discussed in this report in the pre-field planning of summer 1977 NPRA fieldwork, the results of the 1977 survey can be applied--through reference to stratification derived from remote sensor data--to a predictive statement on site types and distributions to be expected in the Reserve.

It is the hope of the Remote Sensing Division that, in addition to informing those interested in National Park Service activities in Alaska, these reports will illustrate courses toward a union of remote sensing, research planning, and non-destructive data gathering that should help revolutionize American cultural resources management in general.

INTRODUCTION:

CULTURAL RESOURCES SURVEY OF THE NATIONAL PETROLEUM RESERVE IN ALASKA (NPRA)

by

Dick Ping Hsu

An archeological survey of the National Petroleum Reserve in Alaska (NPRA) was undertaken during the summer of 1977 in order to provide an assessment of the cultural values and resources of the Reserve (Fig. 1). This study was mandated by Public Law 94-258, the National Petroleum Reserve Production Act, and the project was assigned to the National Park Service (Task Group 4), of the Department of the Interior. The project is under the leadership of Mr. Dick Ping Hsu, with the assistance of Messrs. Craig W. Davis, Dana C. Linck, Kenneth M. Schoenberg and Harvey M. Shields.

Basic Objectives of the Project

Since a survey of this scope and magnitude had not been undertaken in the Arctic before (NPRA covers 23 million acres), a basic objective of the project, besides the location, description and evaluation of archeological sites, was the assessment of certain methods and techniques to establish standards for future survey work within NPRA and the Arctic region in general. These include the study of the applicability of various survey techniques to Arctic regions such as remote sensing, pedestrian survey and helicopter survey. The development of predictive models was also a concern of the project. The remote sensing phase of the study, which is ongoing, is being undertaken by the Remote Sensing Division, SW Cultural Resources Center, Albuquerque, New Mexico; principal investigator in the remote sensing phase of NPRA

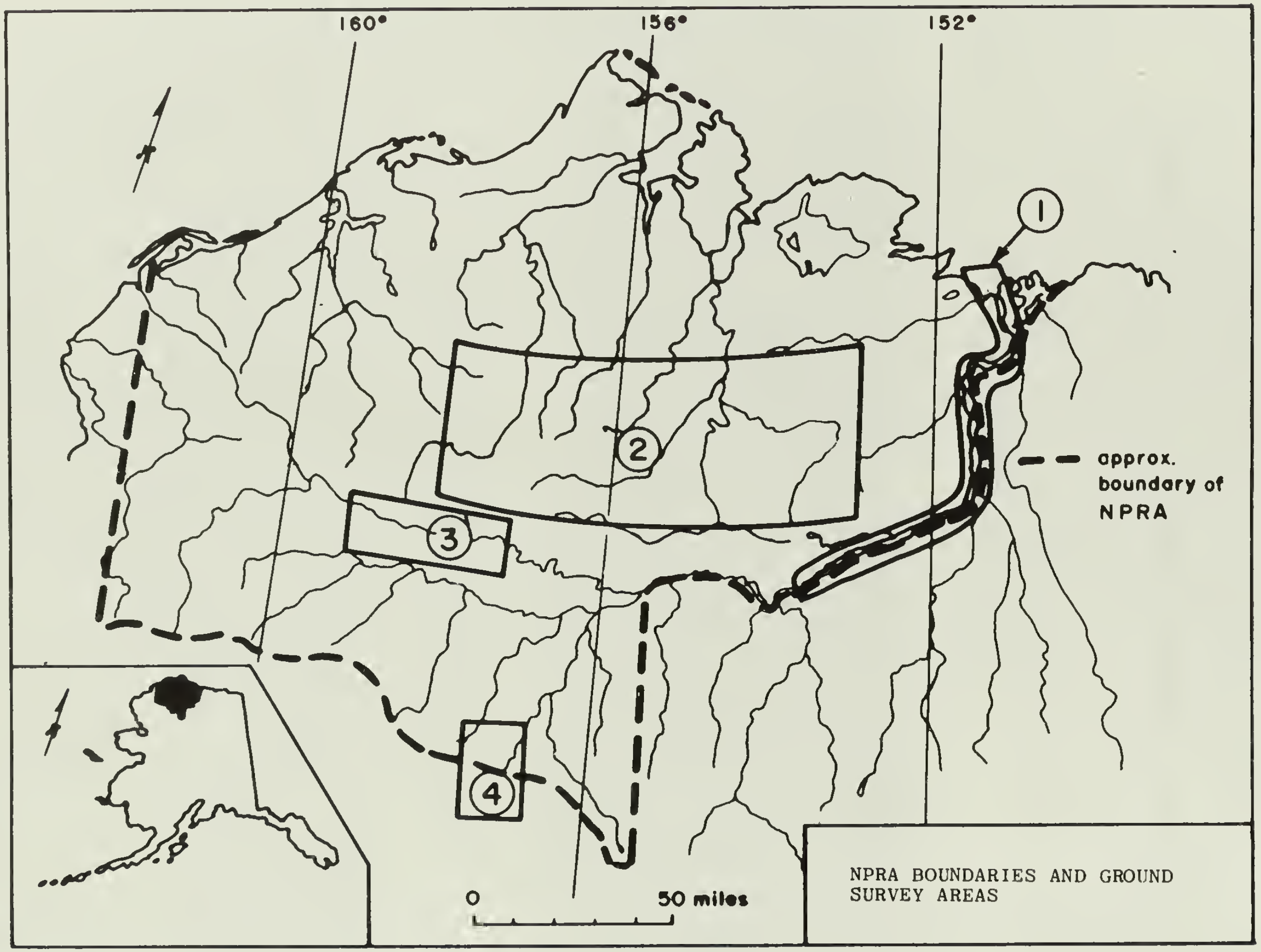
160°
156°
152°
1
2
3
4
approx. boundary of NPRA
0
50 miles
NPRA BOUNDARIES AND GROUND SURVEY AREAS

Figure 1

work is James I. Ebert, assisted by Galen N. Brown. The survey was also designed to yield site data necessary for the application of the Criteria of Eligibility of the National Register of Historic Places, and when applicable, the completion of National Register forms. Previously available existing information has been synthesized and interpreted as part of the survey effort, complete with preparation of an annotated bibliography (Schneider and Bowers 1977).

A comprehensive survey and evaluation of all archeological values within NPRA was beyond the scope of one summer of field work, so the project was limited to the survey of selected geographic and environmental areas. The intensive survey of these areas was expected to produce the hard data, relative to archeological values, such as resource locations, distributions, significance, state of preservation and correlations with discernible environmental factors. The efforts of the summer of 1977, then, are to be seen as the first step in a comprehensive archeological study and evaluation of cultural resources within the region. These efforts presumably will be followed by several years of further study.

Surveyed Areas: Summer 1977

The areas chosen for study were intended to reflect the variety of geographic and environmental zones within NPRA. Demands of high-intensity oil research also had some bearing on survey area selection. Utilizing an intuitive model, four study areas were selected with those factors in mind.

The first of these areas, as planned, comprised the corridor of the Colville River from approximately 150 miles west of Umiat to the river's mouth (Fig. 1, Area 1). One crew of five archeologists, utilizing motorized rafts, travelled down the river, camping overnight on river bars and beaches. The archeological survey consisted of a ground survey of the Colville River environs.

The second area of operations included a cross-section of environmental zones up to approximately 2000 feet or less in the foothills, with coordinates 158° West to 152° 30' West, and 69° North to 69° 45' North (Fig. 1, Area 2). Two teams surveyed the foothills province. One group operated in the area delimited by the headwaters of the Ikpikpuk River on the north, including the Kigalik River and Maybe Creek drainages, to Knifeblade Ridge on the south. The higher elevations to the immediate east and west of the sector set off by these boundaries were also included in the survey. Upon completion of the survey of the Ikpikpuk area, the crew was transferred to the Killik Bend area of the Colville River. Another group surveyed areas within the Lookout Ridge Quadrangle, covering the ridge proper and sections of the Meade River and Carbon Creek drainages (Fig. 1, Area 3). Also, the ridge between the Lookout and the Awuna Rivers, east to the confluence of the Awuna and the Colville Rivers, was covered.

Howard and Inyorurak Passes and their environs, within the Brooks Range Province, were chosen as the fourth area (Fig. 1, Area 4).

The Arctic Coastal Plain was not surveyed during intensive summer 1977 field season, but a one-week helicopter survey of selected lakes and drainages gave the area some coverage. Weather conditions in September severely limited access to the Arctic Plain; therefore, survey of sections of the Colville River in the vicinity of Umiat were substituted. This was a useful exercise for planning of future surveys in this area. Selections of starting points or sectors within each area was based upon an overflight survey to pinpoint snow conditions and logistically favorable areas.

A more detailed discussion of field methods and preliminary description of sites located during the summer 1977 field survey are contained in the Preliminary Report on the History and Cultural Resources of the National Petroleum Reserve in Alaska, by NPRA Work Group 4, Alaska Area Office, National Park Service, Anchorage.

REPORT ON FIELD AND LABORATORY OPERATIONS OF THE REMOTE SENSING PHASE OF THE NATIONAL PARK SERVICE CULTURAL RESOURCES ASSESSMENT OF NPRA

by

James I. Ebert
Dwight L. Drager
Galen N. Brown
Thomas R. Lyons

Introduction and Project Background

When plans for the National Park Service's NPRA archeological assessment began to solidify in April and May of 1977, it became apparent that this project would in many respects entail more effort and planning than most other cultural resources management surveys. Perhaps the most immediate problem to be faced was the extreme size of the study area, which covers some 23,000,000 acres of Alaska's North Slope. The overwhelming inaccessibility of most of this area to ground-based survey crews was compounded, as well, by a short 8-week season during which the ground is free of snow and field survey is possible. While archeological work had been carried out in the NPRA and surrounding areas in the past, the North Slope was, for its size, poorly represented in the archeological literature, and detailed knowledge of the distribution of sites and site types was virtually nonexistent.

During the course of telephone conversations and subsequent meetings in Albuquerque and Washington it was decided that the application of advanced technical methods--desirable but not mandatory in many small surveys--was absolutely necessary in the case of the NPRA survey. One of the most important of these is remote sensing; the application of aerial and space imagery to archeological discovery and measurement has, in the last few years, been shown to result in considerable savings of time and money--considerations doubly important in the NPRA cultural resources assessment. It was decided that the remote sensing phase of the NPRA assessment efforts would be coordinated through the Remote Sensing Division of the Southwest Cultural Resources Center in Albuquerque. While remote sensing had been applied to many previous cultural resources management efforts at specific stages and with specific goals in mind, it was felt that remote sensing input was necessary at all stages of the present effort--that it would be beneficial both in terms of the actual product delivered at the termination of the project, and as a source of ideas and creative feedback during the course of the work. This report, which details the efforts of the Remote Sensing Division in the field and laboratory in conjunction with NPRA assessment activities in June and July, 1977, should serve to illustrate some of the contributions that remote sensing can and has made in the present survey and in cultural resources management in general.

Research carried out in the NPRA during the summer of 1977 was primarily of an inductive nature, clearly necessary in an archeological region for which little prior information had been recorded. A preliminary plan for archeological sampling formulated at the Remote Sensing Division during the planning stages of the present survey (Ebert 1977; Appendix I lists other RSD-NPRA reports), describes the input which remote sensing methods can introduce to a large-area regional sampling scheme of an inductive nature, and is outlined via the following sampling/fieldwork stages:

1. Stage I: Initial stratification of the survey area on the basis of landform geology, vegetation/ground cover, and other ecological factors using Landsat and other remote sensing imagery.

2. Stage II: Choice of sampling fraction and units on the basis of prior archeological knowledge, available time, personnel and funding.

3. Stage III: Determination of the utility of the Stage I stratification scheme on the basis of the Stage II sample, readjustment of strata if necessary to improve predictive utility, and determination of a Stage III sampling fraction and choice of units on the basis of the Stage II sample.

This sampling plan was for the most part greeted with approval by the director and crew of the NPRA ground-based effort, although certain restrictions and practicalities of fieldwork necessitated changes which will be discussed at a later point in this report. It was expected that the output of a scheme such as this will be a model which will allow the prediction, with certain qualifications, of:

1. the locus of occurrence of different site types and sites of different chronological periods;

2. the frequency with which each type of site should be expected to occur within each stratum; and

3. the reliability of present and subsequent ground and aerial survey methods in the detection of specific site occurrences in any area.

Such output would be of advantage in the present survey and in subsequent mitigation efforts in several ways. First, it should provide a means by which estimates of the potential impact of petroleum exploration and exploitation on cultural resources in different parts of the NPRA area can be made; in addition, it would serve as a basis for estimating the requisite cost and time for intensive survey of specific areas to be disturbed and for mitigation of resources which might be destroyed as the result of future economic operations.

Perhaps most important in terms of overall National Park Service goals in NPRA, however, such a predictive plan could direct and streamline the next year's cultural resource management work there. In order that the full potential of these cultural resources be realized, it is necessary to go beyond prediction, to focus on specific sites and areas which typify our prehistoric heritage in the Arctic and have high potential for increasing the archeologist's knowledge and public's appreciation of past adaptations there. The means to this end may include National Register nominations of certain sites, conscious cultural resources conservation for limited areas of high archeological potential, and the intensive survey or excavation of some sites. Knowledge of site locations and densities is essential to the planning and carrying out of such activities, and the output of the 1977 fieldwork and analysis would be invaluable for this reason. It should be noted at this point that, in the opinion of this office, it was absolutely necessary that this second level of research--the focus on specific site loci--be funded and carried out in 1978 if the full potential of the research already in progress was to be realized.

Laboratory NPRA Remote Sensing Activities, June-July 1977

Laboratory activities in support of the NPRA cultural resources assessment have consisted primarily of imagery acquisition and interpretation, the compilation of cover-type maps of the study area, an ongoing search of the literature in remote sensing, archeology and related areas dealing with Arctic regions in general and NPRA in specific, and the formulation of a preliminary cultural resources sampling plan.

Acquisition and Interpretation of Imagery

Landsat imagery in black-and-white print format, bands 5 and 7, covering the NPRA area were acquired after the first 22 April 1977 memo describing imagery on order. Interpretation of this imagery, especially band 7, with vegetational patterning in mind was the basis of the preliminary cover-type mapping effort described below. Band 5 Landsat imagery was expected to be employed in the delineation of bare-earth areas in which archeological site visibility is higher than in heavily vegetated areas, and interpretation of band 5 would result in the compilation of a site visibility map which should provide valuable input to the sampling design for NPRA (described in detail in a later section of this report).

During the preliminary cover-type mapping it became apparent that subsequent cover-type map refinements would need to be based on higher-quality imagery. For this reason, ten scenes of Landsat EDIES (EROS Digital Image Enhancement System) enhanced imagery were ordered from EROS Data Center; this imagery is geometrically corrected and enhanced in a number of ways by computer, and cover-type maps produced through its interpretation should serve as a completely adequate basis for sample stratification and other studies of vegetational diversity and geomorphological phenomena which would enhance ongoing NPRA research.

To fill the need for lower-altitude aerial imagery of the NPRA area, many parts of which were not represented in aerial archives, the Remote Sensing Division participated jointly with the Bureau of Land Management, Anchorage in a NASA/Johnson Space Craft Center overflight of NPRA. The specified imagery was to be photographed from an RB-57 aircraft, at scales of 1:120,000 and 1:60,000 over the entire NPRA area and 1:30,000 over a limited portion of the study area in which intensive field sampling is taking place. A description and discussion of this overflight and imagery applications is included at a later point in this report.

A Bausch and Lomb Zoom Stereoscope designed for use with roll film on a light table was ordered to facilitate the interpretation and analysis of this and other transparency imagery.

Compilation of Base Map

The graphic presentation of distributional and spatial data requires a base map of sufficient scale that delineations are useful to those incorporating such data into their research, yet small enough for convenient handling. U.S. Geological survey maps of NPRA are available in scales of 1:1,000,000 and 1:250,000 for the entire area, and 1:63,360 (15-minute quadrangles); it was determined that none of these scales were appropriate for ecological and other mapping efforts projected at the RSD. Taking all factors into consideration, a base map at a scale of 1:500,000 was selected as most appropriate for planned vegetation, cover-type, geologic, and other environmental cartography. In the interests of ease and compilation, two USGS World (North America) 1:1,000,000 sheets--Barrow and Umiat--were enlarged 2x; this map served as the base of our preliminary cover-type map. Certain drawbacks are inherent in this base map, however, including overly-heavy (enlarged) lines and overbearing contour shading. Future maps will be based on another 1:500,000 map constructed from reduced 1:250,000 USGS Topographic Series quads; this base map was kindly provided by Ray Thomas, Branch of Photogrammetry, Bureau of Land Management, Anchorage.

Preliminary Cover-Type Map of NPRA

Rather than setting out to map vegetative communities or imputed ecological zones as the basis of sampling stratification of the NPRA, we decided to expend early efforts on cover-type mapping. In our preliminary map, this simply meant differences on the ground which we think we could interpret from remote sensor imagery; because of lack of controlled ground-truth testing or experience on the North Slope, there was little suggestion that we could be certain of just what those differences are. This is a completely acceptable means of stratifying a first-stage sample, which is then tested in later stages of the sampling design.

Imagery employed in preliminary cover-type mapping was primarily 1:1,000,000 scale Landsat band 7 black-and-white prints, although several band 5 prints of the study area were used as a check. Band 7 was particularly useful on the North Slope because of its ability to delineate open water and wet areas. Our preliminary classification of cover-types in NPRA relied heavily upon differentiation between land subject to different drainage regimes. Five major cover-type distinctions were interpreted:

Wet or Dry Sandy Surface (Beach)
Moist Tundra
Very Moist to Wet Tundra
Wet Tundra (Standing Water in Places)
Brush

The category "brush" always occurred in conjunction with another type. In addition, transitional zones between the types were distinguished and are marked with diagonal bars of alternating zones on the map.

Each Landsat scene was overlain with a clear mylar sheet and the interpreted boundaries drawn on this cover. The transparencies containing boundary information were then transferred to our 1:500,000 base map with the aid of an Art-o-Graph Incorporated Map-O-Graph Model 55. Because of geometrical distortion inherent in uncorrected Landsat imagery, some cartographic corrections were made before final boundaries were drawn on the base map. Future small-scale mapping at the Remote Sensing Division will utilize Landsat EDIES imagery and will require far less geometrical manipulation.

The 1:500,000 cover-type map was subsequently reproduced and is accompanied by a short paper describing its compilation and limitations in detail (see Appendix I).

Upcoming Laboratory Investigations

The preliminary cover-type map described above was intended only as a starting point for sampling stratification, and the next stage in laboratory work here was to be the compilation of a refined cover-type map incorporating Landsat EDIES imagery, on order from EROS. This second map should allow a finer discrimination of cover-types and may incorporate other distinctions important in a cultural resources sampling design, such as bare-earth areas and geological features, as well. One interpretive tool not used in the construction of the preliminary map, but available at the RSD laboratory, is an International Imaging Systems Digicol. This device, essentially a closed-circuit television system, splits the density range recorded in an image into as many as 32 different levels and displays each in a separate color on a screen; early tests using standard Landsat imagery suggest that the Digicol will allow extremely fine discrimination of boundaries and different types of ground cover.

An additional source of data for subsequent cover-type and other mapping are the products of the NPS/BLM July RB-57 overflight of NPRA, described in detail later in this report.

Field Reconnaissance in NPRA, 27 June - 14 July, 1977

While the term "remote sensing" connotes measuring things at a distance, and while many of the things that remote sensors do can be accomplished from thousands of feet above the ground, it is vital to the interpretation, analysis and use of such methods that all personnel involved be familiar with the situation on the ground. During the course of "ground truth checking," a necessary adjunct to all remote sensing applications, the researcher must determine whether he is really seeing and measuring what he thinks he is. For this reason, two members of the Remote Sensing Division NPRA project crew (Ebert and Drager) left Albuquerque on 27 June 1977 for a two-week field reconnaissance. A secondary objective of this trip was to allow RSD personnel to participate in the on-the-ground NPRA assessment efforts with the object of more efficient coordination between the two phases of research there. Both of these objectives were successfully fulfilled.

An additional advantage was gained due to the fact that we were able, both before and after spending time on the ground in the NPRA, to confer with NPS and other government cultural resources management personnel in Anchorage and Fairbanks, and to explore some of the many sources of supportive data which are available in the State of Alaska. It was immediately apparent that there are many agencies and individuals in Alaska with ongoing interest and competence in archeological research and cultural resources management; these include the National Park Service, the Bureau of Land Management, and researchers from the University of Alaska and elsewhere. At the same time, as is the case in many regional archeological situations, there has, in the past, been a certain lack of coordination and communication among archeologists in Alaska.

Our mutual interchange with Alaskan archeologists and cultural resources personnel was helpful in a number of ways, not the least of which was an increase in our understanding of the "archeological picture" in the Arctic. Survey and excavation has been avidly pursued in Alaska since the 1920's, and a large body of data on the material remains of past inhabitants of that state has been amassed. Nonetheless--especially in view of the vast areas encompassed by the state--there has been little work of a predictive nature accomplished. Sub-regional "traditions" and "cultures" have been defined largely on the basis of artifact appearance with little concern for the nature of the adaptations represented, and often without reference to reliable dating or other controls. It is clear that efforts such as the present NPRA assessment, if carried out in a well-planned manner, have the potential of increasing our knowledge of Alaskan archeology as well as suggesting better and more efficient ways to go about cultural resources management in Alaska.

Consultations with Federal and State agencies was also helpful in revealing additional remote sensor imagery sources and sources of supportive data in such areas as ecology, geology and climate. The Branch of Photogrammetry, Bureau of Land Management in Anchorage holds an archive of aerial imagery for all Alaska, some of which includes the NPRA area and should be of use in the present project as "back-up" data; the existence of such imagery taken at times in the past is also important in comparative studies of land disturbance and climatic or environmental fluctuations over time. Research being conducted by the U.S. Geological Survey Water Resources Office, the University of Alaska Geophysical Institute, and the U.S. Army Cold Regions Research and Engineering Laboratories (CRREL) should also provide valuable supportive information for use in remote sensing analyses in NPRA. It was particularly edifying for us to meet with Alaska Task Force and Alaska Regional Office personnel at the NPS office in Anchorage, who are conducting a wide range of research and resources assessment projects throughout the state.

While in Anchorage we were privileged to attend a conference entitled "Landsat Alaska: Information on Remote Sensing Projects in Alaska" which was conducted by the Anchorage District Office of the Bureau of Land Management (30 June 1977). Centered around the BLM Landsat project in the Denali area, this meeting also offered an opportunity for other agencies carrying out remote sensing research or applications in Alaska to describe their work. Several of the projects presented at the conference were of immediate interest in the NPRA cultural resources project, especially a vegetation mapping effort currently being pursued in the NPRA area jointly by the BLM and USGS Geography Program at Ames Research Center, Moffett Field, CA. This program began with the computer spectral analysis of Landsat EDIES imagery, and will proceed through the mapping and field checking of vegetation distributions. Although the Remote Sensing Division's cover-type stratification map, discussed earlier in this report, was designed to fulfill a different purpose than the BLM/USGS product, the maps should be complementary and each should be useful to the other project as an independent check of accuracy and precision. All RSD cover-type maps and refinements will be forwarded to Bill Fowler, Biogeographer of the BLM/NPRA field crew, for use in his field-checking operations.

Also of interest at the Landsat Alaska conference was the extent to which remote sensing projects were being pursued for resources management purposes in other parts of Alaska by such agencies as the Soil Conservation Service (USDA), Fish and Wildlife Service, Army Corps of Engineers, and the Alaska Division of Lands and Department of Fish and Game. Large volumes of aerial imagery were flown during the summer of 1977 over Alaska to supplement the imagery already available, and should be of use to the National Park Service not only in the NPRA but other areas of potential assessment and managerial planning as well.

A panel discussion at the meeting pointed out that while data collection methods were being constantly upgraded, there was a certain lack of direction in the measurement of information due partly to lack of continuous feedback between management and staff scientists. It is the feeling of this office that problems to which remote sensing can be profitably applied spring not only from immediate and pressing need, but can be recognized before the event by careful planning and scientific research as well. The realization, coupled with the ever-increasing

NPS management load in Alaska, has prompted a consideration of an all-Alaska remote sensing research and applications program, discussed later.

Umiat

On 3 July, Ebert and Drager flew from Fairbanks to Umiat on a DC-3 supply plane to begin the field reconnaissance phase of their trip. Field operations being carried out in NPRA under the directorship of Dick Hsu, were based in Umiat, with crews consisting of approximately 8 archeologists dispersed within the intensive sampling areas illustrated in Fig. 2. These areas were chosen with a number of factors in mind. Perhaps the foremost of these was the degree to which these areas are representative of the ecological and topographic conditions which were encountered in other parts of NPRA. While it would clearly be impossible to cover the entire NPRA area in an intensive manner, the choice of sampling areas encompassing much of the environmental variation found throughout the study region allows the extension of a predictive model to the rest of NPRA. Of course, the formulation of a predictive model entails more than this, for it is not possible even within these "narrowed down" areas to survey all of the land or detect all sites. These and other sampling problems and some possible solutions will be discussed later in this report.

Another way of detecting sites--really a sort of intuitive sampling-- is to anticipate site locations and functions on the basis of ideas about past behavior and its relation to environmental features. The sampling areas concentrated upon by the NPRA crews in the summer of 1977 were also placed with such considerations in mind. The long east-west trending ridges which parallel the Colville River in Areas 1 and 3 (Fig. 2), for instance, have apparently served as travel and trade routes for thousands of years; these also direct the spring caribou migration and would serve as ideal hunting areas. The fall caribou migrations, somewhat more concentrated and sudden than those in the spring, are dispersed (in the long term) much more evenly between the Brooks Range passes, such as Howard

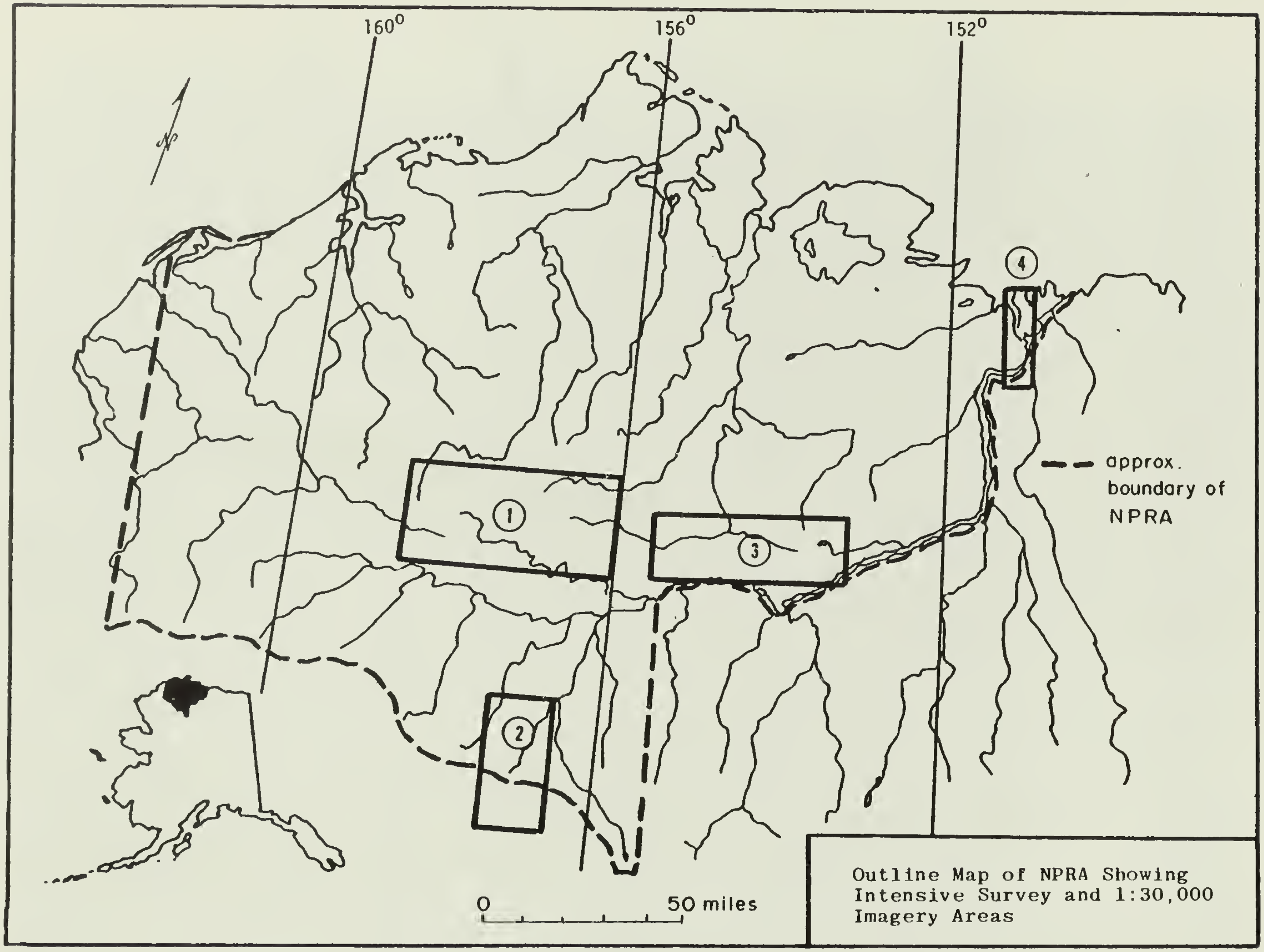
160°
156°
152°
N
approx.
boundary of
NPRA
0
50 miles
Outline Map of NPRA Showing
Intensive Survey and 1:30,000
Imagery Areas

Figure 2

Pass (Fig. 2, Hemming 1971), and such places would be more likely to host winter habitation sites in which occupants lived from stores of fall meat. The Colville River delta area, Area 4 on Fig. 2, has been ethnohistorically documented; living natives there also offered one of Hsu's crews an opportunity for ethnographic work.

Additional criteria employed in the choice of the intensive sampling areas were access, prior knowledge of the occurrence of archeological sites, and site visibility. The latter consideration is likely to be of considerable importance in generating predictive site distribution models in the study area, and will be discussed later.

NPRA Archeology

Archeological materials recovered in the NPRA conform in appearance for the most part with pan-Arctic assemblages found in the past. Most of the sites discovered in the course of the NPS assessment are located along ridges and in high places, with other site loci being confined to scattered lithic material, bone and wood along gravel bars in rivers. Exceptions to this patterning are historic sites (some apparently as recent as the late 1800's) and stone cairns which marked meat caches, both of which have been found in more vegetated areas. Sites on ridges have been located primarily in areas of vegetative denudation, and assemblages found at such places consist for the most part of small, portable tools, often microblades or tools with multiple transverse edges. Materials from which these artifacts were made are to a large extent exotic, originating at some distance from site loci. At least one quarry site, in Howard Pass has been located but it is not certain that materials from other areas originated there. Ridge-top sites, which comprise by far the bulk of sites discovered to date, probably represent mobile, expeditionary hunting camps or game overlooks. The spring migration of the Arctic caribou herd has in historic times been observed to slowly funnel through the more eastern passes of the Brooks Range and thence to parallel and cross the Colville (where it flows east-to-west) and continue along Lookout Ridge and other ridges in the area toward the calving grounds in the extreme western part of NPRA. In contrast to the fall migration, the spring migration consists of many smaller, "straggler" groups and hunting strategies are likely to have included relatively long trips (high mobility) from residential sites to more likely hunting areas. Tools taken on such trips would be small, probably multi-purpose implements; it is apparent that a core-carrying strategy which resulted in the manufacture of microblades was also employed. Microblades are excellent general purpose tools, and could be struck from cores, used, and discarded in relation to the value of the raw material--that is, how far away the material source lies. In contrast, multiple-use or specific-use tools would be curated to a greater extent, and the frequency with which they are found on ridgetop sites would be dictated by their breakage and discard, or simple loss.

The implications of this sort of reasoning are interesting, and provide the basis for making several testable propositions about the behavior which resulted in these expeditionary hunting sites. For instance, without even having to guess about specific tool functions, it can be reasoned that the number of microblades found at a site will reflect the amount of activity which occurred there (perhaps conditioned by natural factors such as abundance of game or "luck"), while the number of discarded or lost tools of a more specific nature would be more closely indicative of the number of individuals creating the site, or the number of episodes of site re-occupation.

Remote Sensing Experiments in NPRA

A Bell Jet Ranger helicopter utilized by the NPRA assessment and survey crews for personnel and supply transport provided an ideal platform for photographic experiments carried out by the RSD. Two 35mm hand-held Nikkormat cameras equipped with 50mm lenses were flown simultaneously, one loaded with Kodachrome-X color film (ASA 64) and the other with Ektachrome color infrared (IR) (ASA approximately 100). The IR camera was also equipped with a Wratten 12 filter. An attempt was made to coordinate camera exposures so that similar scenes would be photographed with both emulsions.

The primary objective of this experiment was to provide an interpretive basis for the use of color IR imagery of the region on or around 18 July 1977 over NPRA. This imagery and its uses will be discussed in detail later. In order to increase the usefulness of the hand-held experimental imagery, the following were areas of concentration:

1. Boundaries between one general cover type and another;

2. Boundaries between areas characterized by different topographic features (such as foothills with dry tundra vs. the coastal plain with its wet tundra);

3. Areas appearing to exhibit contrasting vegetation "diversity"--i.e. variations in plant spacing and distribution; and

4. The locations of known and possible archeological sites.

It was expected that the approximately 960 frames of 35mm color and color IR film exposed in the course of this experiment would be of considerable use in the interpretation of NASA imagery and in the use of the Landsat and Landsat EDIES as well. A full report on this experiment will be forthcoming.

Several observations made during the field reconnaissance at Umiat bear on the feasibility of remote sensing input to the NPRA cultural resources assessment. The vegetation and cover observed by Ebert and Drager was, if anything, less diverse than they had expected, reinforcing the conviction that a simple taxonomy of 4-5 major ecological divisions should be a sufficient basis for sample stratification. In addition, it was apparent that vegetative cover was highly dependent upon topography; there should be a high correlation between geomorphic and cover-type maps of the area. One of the most striking aspects of the distribution of archeological sites in NPRA, mentioned above, is that the great majority of located sites are found in areas devoid of vegetation--a condition which, in the tundra, represents only a very small proportion of the total landscape. Denundation of vegetation in the

NPRA area is for the most part caused by wind erosion, and bare earth is found primarily along and immediately below ridge tops, on steep slopes, and occasionally around the margins of the many lakes which dot the coastal plain. While most archeological sites are found in bare-earth areas, this does not necessarily mean that most of the actual sites are located there--only that sites in these places are more readily detectable by survey crews.

This is not to imply any fault on the part of fieldworkers or research design; it is virtually impossible to discover non-structural sites in tundra-covered areas. One of the NPS crews, located at Howard Pass (Fig. 2, Area 2) intensively inspected some 18 miles of transect through dry-tundra tussock vegetation, in an area that almost certainly should have been visited by prehistoric man, and found no archeological evidence. In fact, it can be argued that the total archeological picture in Alaska and other northern environments is biased and to a great extent misleading due to the effects of vegetative cover on site visibility. For this reason, the extent and distribution of bare-earth areas or sparsely vegetated places must be considered when formulating any sort of predictive site location model.

Fortunately, there is a means close at hand by which denuded areas can be detected and the density of sparse-to-absent vegetation measured--color infrared photography. An ideal starting point for the compilation of a bare-earth distribution map of NPRA would be Landsat Multispectral Scanner (MSS) Band 5 imagery, which responds to wavelengths radiating from bare soil and rock to a far greater extent than those reflected from vegetated areas. The July NPRA imagery, at scales of 1:120,000 to 1:30,000, should also be useful in this mapping. The RSD has gathered imagery for a bare-earth/site visibility map of NPRA, and this project was scheduled to be completed by late August 1977.

NPRA Cultural Resources Sampling--Refinements of Previous Plan

Much Remote Sensing Division participation in the NPRA project was involved in one way or another with the design and application of a sampling plan to result in a predictive model which would inform cultural resources management personnel about the nature of the distribution and location of cultural sites in the study area. As pointed out previously, such predictive models are a necessary first step in any program of specific cultural resource management, conservation or mitigation. The RSD's Preliminary Plan for a Cultural Resources Sampling Design Incorporating Remote Sensor Data in the PET-4 Area, Alaska (Ebert 1977) sets forth a multi-stage sampling design which could be employed to arrive at a basis of predictive generalizations.

In the course of field reconnaissance and especially during discussions with personnel actually involved in site survey on the ground in NPRA, several areas in which the preliminary plan could be refined and revised were pointed out. Whereas the original sampling plan called for sample units to be systematically dispersed within each sample stratum with a sampling fraction proportionate to the proportion of NPRA occupied by that stratum, the dictates of time, economy and access required that intensive survey during the summer of 1977 be carried out in several areas on and near the Colville River (Fig. 2). The survey sample derived that summer should be applicable to a modified version of the original sampling plan, because the ecological zonation found in other parts of NPRA is also, for the most part, represented in the 1977 survey areas. The only ecological/cover-type stratum not fully represented in these units is the wet and very wet, lowlying tundra of the northern coastal plain; while a survey crew concentrating on historic ethnology and ethnoarcheology near the Colville River delta probably covered some areas of this sort, the more inland reaches of the coastal plain would be expected to have been exploited prehistorically in a very different manner. It was recommended that some attention be given to the coastal plain area during the 1978 phase of the NPRA effort; in an area of such low accessibility and topographic relief, the use of remote sensing as a locational and logistic aid would be doubly valuable.

Another problem which becomes apparent when attempts are made to implement the preliminary sampling plan is the difficulty of defining and measuring the areas of sample units. The suggestion was made in the original sampling plan that the total proportionate areas within each stratum be broken down into 10-acre sample units; the actual size of these units is unimportant, and 10 acres was used for illustrative purposes only. Objections raised by the field crews were not concerned with such specifics, but rather with how, given the difficulty of accurately locating oneself in the tundra, a survey crew could be certain that they had surveyed exactly 10 acres. The answer, of course, is that in all probability they could not--an answer which has grave implications for any sampling plan based on the survey of areal units. A possible solution lies in the "ex post facto" adjustment of numbers and densities of sites actually found in the course of survey with regard to area actually surveyed during the course of the summer. This would relax the requirement of physically delimiting sample units of any specific size or shape; the only information required would be the accurate estimate of the amount of ground physically covered by each crew. This could be accomplished through the use of aerial imagery on which the areas covered by each survey party would be marked and measured at the completion of the field season. 1:30,000 scale imagery flown over the intensive survey areas (see NPS/BLM overflight section of this report, below) could be compiled into uncontrolled mosaics covering each survey area and used for this purpose.

NPS/BLM Overflight of NPRA

Early in the planning stages of the NPRA cultural resources assessment it was realized that there was a pressing need for medium to small scale aerial imagery. While Landsat imagery is an ideal medium for ecological mapping and the analysis of environmental features at a regional level, it has the drawback of extremely small scale and relatively low resolution. Some of the activities which must be carried out in conjunction with a project such as the NPRA assessment, for instance the mapping of vegetative communities and periodicities, the use of imagery for "navigation" in the field, the recognition of specific site areas or possible areas, and the recording of sites or features actually located, require larger scales and greater definition. An imagery search of the NPRA area revealed that while a substantial amount of imagery had been flown in the past there, the great bulk of available coverage consisted of single spot-shots or small areas flown at different times in the past and at various scales and emulsions. USGS mapping photography covered only part of the NPRA, leaving large areas unphotographed. In the interests of maintaining consistency, insuring quality, and controlling such factors as cloud cover and scale, it was decided that the NPS would undertake an overflight of NPRA. Shortly thereafter, it was discovered that the BLM (Anchorage) had similar plans to fly NPRA, and that a joint effort would be mutually advantageous.

A search for a contractor with suitable aerial photographic capabilities revealed that the NASA-Houston (Johnson Spacecraft Center) RB-57 aircraft, carrying two cameras with 6" and 12" lenses, would fulfill the NPS/BLM joint requirements. It was determined that the entire NPRA area would be flown at an altitude of 60,000 feet, resulting in imagery at scales of 1:120,000 and 1:60,000. NPS activities in the NPRA also required larger-scale imagery, though in the interests of economy it was decided that this would only be necessary over intensive survey areas. Accordingly, arrangements were made to fly those areas (Fig. 1) at 30,000 feet, producing 1:60,000 and 1:30,000 imagery.

The choice of emulsions to be flown on this mission presented a problem, for the archeologist is forced to use his imagery in two contrasting situations--the laboratory and the field. Superior color rendition, definition and flexibility of use are offered by transparency films, but these are difficult to handle and easy to damage in the field, where print (negative) films are more desirable. NASA-Houston preferred not to deal with negative films, however, so this choice was not available. With two cameras to be loaded with transparency positive film, then, it seemed reasonable to equip one with color infrared (IR) and one with true color film, providing two different "views" of the study area. At some point in time, however, this specification was confused and it appears at this date that all film flown during this mission was color IR. In order that problems in communication and "line of command" such as those which caused this confusion be avoided in the future, we strongly recommend that the Remote Sensing Division be specified as principal or co-principal investigator in all future cooperative projects of this sort.

The NPS/BLM overflight, which is in progress as this report is being written, will result in the total coverage (weather permitting) of a large and important area of Alaska not previously covered. The flying of 6,234 miles of flight line will produce some 2,750 feet of original film. The aircraft and flight crew, based in Anchorage, will log 22 hours and 30 minutes of ferry time and over 20 hours of actual photographic flight time.

The product of this overflight, in transparency, print and uncontrolled mosaic formats, will be an invaluable aid in NPS and NPRA cultural resources assessment efforts during 1977-78. In addition, it will provide a valuable data base for future management efforts in the area. Not only should the NPS and BLM, charged with the immediate responsibility of managing resources in NPRA, benefit, but also such agencies of the U.S. Geological Survey will be interested in this imagery. The archival nature of aerial imagery--its ability to record conditions as they were on the ground at some point in the past--makes each successive overflight invaluable to future planners, even if an area has been heavily photographed. In the case of NPRA, parts of which have never been photographically flown, this is even more important. In co-sponsoring the 1977 overflight, the National Park Service has fulfilled its responsibility not only to its own immediate efforts but to the future of NPRA management as well.

The NPRA RB-57 imagery, flown by and for Federal agencies, is automatically part of the public domain, and copies should be available to all potential users. The appropriate repository for this imagery is the EROS Data Center, which not only maintains facilities for the proper handling and storage of aerial and space imagery, but can supply copies to prospective users at minimal cost.

Upcoming NPRA/Remote Sensing Activities

The success of preliminary laboratory remote sensing work at the Remote Sensing Division with regard to the NPRA and the 27 June - 14 July field reconnaissance by Ebert and Drager has convinced us that remote sensing has a continuing role to play in the NPRA cultural resources assessment. Some immediate contributions to be made through remote sensing and which we are presently pursuing and planning are listed below.

Analysis of NPRA Photographic Experiments

During the June-July field reconnaissance, approximately 1000 frames of color and color infrared 35mm film were exposed from a helicopter platform. Photography was directed at points dictated by research interests in NPRA and included boundaries between vegetative and physiographic zones, bare or sparsely vegetated areas where sites were likely to be found, vegetated areas (such as willow stands in larger valleys) where sites were likely to occur but would be difficult to locate, and lakes and lake terraces in the coastal plains province. At present the film has not been developed; when it is, it will be viewed and analyzed. It is expected that this hand-held photographic experiment will enhance the usefulness of color IR imagery flown in the NPS/BLM overflight, and may have a bearing on the interpretation of Landsat and Landsat EDIES color composite imagery as well.

Analysis of NPS/BLM RB-57 Overflight and Manipulation of Data Formats

When the imagery resultant from the NPS/BLM joint overflight, discussed at length above, arrives at the Remote Sensing Division laboratory, it will be reviewed with respect to degree and quality of coverage, planned laboratory research, and the necessities of analysis of the results of 1977 fieldwork and the planning of the 1978 field season. While transparency coverage will be superior to prints for laboratory analysis, these are difficult to handle and store in the field. For this reason, 1:30,000 imagery covering the intensive survey areas (Fig. 2) will be printed on a paper base; if determined feasible, an uncontrolled mosaic will be constructed for each of these areas for field use. (An uncontrolled mosaic differs from a controlled mosaic in that, due to the lack of previously-set field control, it cannot be fully geometrically corrected. This should not present problems with imagery taken from the altitude at which the RB-57 operates, and uncontrolled mosaics from this imagery will be far superior for plotting and locating sites to the 1:250,000 scale USGS maps upon which field crews must now depend.) In addition, imagery from other areas of interest not included in the 1:30,000 scale areas (1:60,000 and 1:120,000 scales) may also be printed and mosaics made for field use. If 1:60,000 proves to be too small a scale for fieldwork, enlargements of certain areas could be devised.

Secondary (Revised) Cover-Type Mapping

The Preliminary Cover-Type Map discussed previously in this report, while useful in the early stages of sampling design and planning, suffers from a number of problems encountered in its compilation. Foremost among these is the fact that we were restricted to available imagery at the time, Landsat Band 7 black-and-white prints, and that several of the scenes (ordered "blindly" from EROS Data Center) were of poor quality or partially snow-covered. The use of Landsat EDIES enhanced imagery at a scale of 1:500,000, presently on order from EROS, and the RB-57 imagery which should arrive soon at the Remote Sensing Division, will provide a greatly improved data base from which a revised cover-type map will be compiled.

Cover-Type/Geomorphology Correlation

An observation made by interpreters early in the preliminary cover-type mapping effort was that cover type is to a great extent influenced by terrain, drainage, soil differences, and other physiographic features of the study area. Following the completion of the revised cover-type map a geomorphological map of the NPRA will be compiled using EDIES and RB-57 imagery and drawing on published and previously-mapped material for NPRA. Such a map should provide not only another check on stratification to be employed in the sampling design, but should have a direct bearing on some of the contingencies of locating archeological materials from different time periods as well. The distribution of Early Man sites, for instance, may be heavily biased toward higher-lying, east-west trending areas which were unglaciated in the past.

Cover Density/Site Visibility Study

Success in locating archeological sites and materials in the course of a survey such as that conducted in NPRA is dependent not only on where sites actually are, but on their visibility to the present-day archeologist. There are several factors which contribute to archeological visibility; one of the most damaging of these to archeological science is that some past human activities leave little or no material evidence to be found. In a practical sense there is nothing to be done about this--other than to regard the amount of material found at each site as another category of information about the past. Another factor in visibility is preservation of material remains, which may be disturbed, decomposed, or "hidden" through natural processes. It is a subset of this factor which biases site visibility in NPRA--the effects of often dense, difficult-to-penetrate vegetation. It would of course be possible to recover a much wider spectrum of archeological materials if blanket excavation were carried out across large portions of the study area; given NPRA's 23,000,000 acres, this is obviously impossible, and the dictates of environmental preservation make it even more so.

In a very real sense, as a matter of fact, it can be argued that no archeological survey or locational effort, no matter how stringent and concentrated, can recover <u>all</u> of the material evidence in an area. Even in excavation, the amount and nature of materials recovered depends on excavation methods, screen size, and other less easily controlled variables such as the care taken by excavators. Change in any of these results in a different array of material evidence; theoretically, for instance, screen size could be made smaller and smaller forever. Obviously, even if it is construed as being possible, setting out to collect and handle "all of the data" is not practical.

Nor is it scientifically necessary. In reaching knowledge through generalization and hypothesis testing, science depends on sampling--drawing a representative population from a universe of potential individual observations. All sampling is biased, and this is perfectly permissible as long as these biases are understood and controlled.

One area in which sampling bias can be controlled for in the NPRA survey is site visibility, especially that due to differences in vegetative density. Ideal media for measuring differential cover densities are Landsat infrared band 5 imagery and color IR aerial photography, both of which are sensitive to reflections from plant cover and bare earth. A site visibility mapping effort will begin with the application of Landsat band 5 imagery, which responds to radiation of wavelengths reflected from bare soil and rock. This will be checked, and discrimination improved, using the RB-57 imagery flown. The finished map will be produced at a scale of 1:500,000; the intensive survey areas may be mapped at 1:250,000 or even a larger scale.

Implementation of Sampling Design

Some of the above research and mapping can serve as direct input to the NPRA cultural resources sampling design. Because many factors must be considered and because the input of the analysis of materials and site distributions noted during fieldwork is the primary factor in this implementation, close direction by principal investigator Dick Hsu will be necessary.

Remote Sensing Course for Field Personnel

Another activity which might be warranted in the light of assuring the usefulness of remote sensing input in the NPRA cultural resources assessment is an instruction course in remote sensing methods for field personnel. While much can be accomplished in the laboratory, it is absolutely essential that all those involved in fieldwork and on-the-spot analysis understand and be able to employ remote sensing in their immediate work as well. One of the activities of the Remote Sensing Division over the last several years has been the formulation and conducting of instructional courses for cultural resources management and scientific personnel in basic and advanced remote sensing methods, techniques and applications. An extensive syllabus and body of class materials has been compiled, and the Remote Sensing Division's Handbook Series is intended to accomplish a similar purpose. (The RSD Handbook Series was initiated with Remote Sensing: A Handbook for Archeologists and Cultural Resource Managers by Thomas R. Lyons and Thomas Eugene Avery [1977, U.S. Government Printing Office] and will include a number of technical and regional supplements, including one concerning Alaska.) Classes might be arranged for the NPRA assessment personnel either in Alaska or the lower 48, to take place at some time during the winter of 1977-78, if this is deemed feasible.

Coastal Plain Lakes Study

One of the most difficult-to-survey areas of the entire NPRA area is the coastal plain, where poor drainage and lack of topography make mobility and navigation extremely difficult. Nonetheless, this area was almost certainly exploited prehistorically, and may contain some of the most helpful types of supportive data such as climatic indications and methods of relative dating in the survey area. In particular, it appears that the many closed- and open-basin lakes which dot the coastal plain may provide indications of past wet and dry periods through the existence of dry lake basins, shifting basins, visible terraces marking past shorelines, and variously-oriented basins which may indicate seasonal wind patterns. Archeological sites found between or above basins might be dated relatively with one another, or the seasons of their occupation and use determined.

A portion of the hand-held aerial imagery exposed during the recent RSD/NPRA reconnaissance was directed toward the determination of whether remote sensing methods could be applied to the investigation of these phenomena, and a part of the analysis of this and other imagery which is to be acquired will focus on these problems.

Bibliography

During the course of the Remote Sensing Division's participation in the NPRA project, an extensive bibliography on remote sensing methods and techniques, archeology, ecology, geology, and other literature concerning NPRA and the Arctic has been collected. This bibliography will be compiled and computer printed using a key-word cross indexing system, and will be distributed to NPRA, National Park Service and other interested personnel so that its usefulness will be enhanced.

This bibliography will be published as part of the Reports Series of the NPRA Remote Sensing Project. Released and planned reports in this series are listed in Appendix I of this report.

A condensed summary of the projects listed above is provided in Appendix II of this report.

Acknowledgements

The acknowledgement of those who have helped substantially with support and input to the remote sensing phase of the NPRA cultural resources assessment effort must, of course, begin with NPRA archeologist Dick Hsu, his energetic crew and dauntless pilots, as well as the other National Park Service personnel who have contributed their time and suggestions, including Doug Scovill (Chief Archeologist, National Park Service) and Zorro Bradley (NPS Fairbanks). The members of the NPS Alaska Task Force in Anchorage, especially Al Henson, Jim Larson, and Stell Newman, were kind enough to discuss NPRA and other Alaskan activities with us and to make our stay in Anchorage productive by suggesting contacts and providing us with transportation.

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Leonard Gaydos (U.S.G.S. Geography Program, Ames Research Center, Moffett Field, CA)

Jim Keough and Tom O'Brien (U.S.G.S. and N.C.I.C., Denver)

Paula Krebs and Page Spencer (University of Alaska Geophysical Institute, Fairbanks)

Ray Leicht (Archeologist, BLM Anchorage)

Stan Morain (Technical Applications Center, NASA/ University of New Mexico, Albuquerque)

Sid Morgan (Special Agent, U.S. Fish and Wildlife Service, Juneau and NPRA)

Bob Reeves (EROS Data Center, Sioux Falls, SD)

Ray Thomas (Branch of Photogrammetry, BLM Anchorage)

The staff of the Umiat Hilton, Umiat, Alaska

To these people, and to others who have aided in our work and who we have undoubtedly forgotten to list, we extend our heartfelt thanks.

APPENDIX I

REPORTS OF THE NPRA REMOTE SENSING PROJECT

Remote Sensing Division, SW Cultural Resources Center
Albuquerque, New Mexico

Current Reports

1. Report and Supplement Materials for Phase I of the Alaska Remote Sensing Handbook/PET-4 Cultural Resources Assessment Project: Basic Data Sources. James I. Ebert. 22 April 1977.

2. Preliminary Plan for a Cultural Resources Sampling Design Incorporating Remote Sensor Data in the PET-4 Area, Alaska. James I. Ebert. 5 June 1977.

3. Plants Found in or Adjacent to PET-4, North Slope, Alaska. Galen N. Brown. 8 July 1977.

4. A Preliminary Ecologic/Cover-Type Map of NPRA Utilizing Landsat Infrared Imagery. Galen N. Brown and James I. Ebert. 26 July 1977. With map, scale 1:500,000.

5. Report on Field and Laboratory Operations of the Remote Sensing Phase of the National Park Service Cultural Resources Assessment of NPRA, June - July 1977. James I. Ebert, Dwight L. Drager, Galen N. Brown and Thomas R. Lyons. 1 August 1977.

Upcoming Reports

1. Report on the utility of BLM Anchorage 1:24,000 scale color imagery of parts of NPRA (Ebert)

2. Report on photographic experiments in NPRA, July 1977. (Ebert and Drager)

3. Report on NPS/BLM joint RB-57 overflight of NPRA.

4. Arctic Remote Sensing Bibliography with special reference to NPRA.

APPENDIX II

PLANNED PROJECTS AND PRODUCTS

Remote Sensing Division NPRA Project

Project	Proposed Completion
1. Analysis of NPRA Photographic Experiments Inspection and analysis of color and color-IR handheld imagery exposed in field (NPRA) from helicopter platform.	15 August 1977
2. Analysis of NPS/BLM RB-57 Overflight and Product Interpretation and analysis of 1:120,000, 1:60,000 and 1:30,000 imagery resulting from July overflight of NPRA area.	contingent upon receipt of imagery
3. Secondary (Revised) Cover-Type Mapping of NPRA Refinement of preliminary cover-type mapping of NPRA using Landsat EDIES and high-altitude RB-57 imagery.	contingent upon receipt of imagery; est. 15 September 1977
4. Cover-type/Geomorphology Correlation Mapping of correlation between cover type and geomorphology in NPRA area.	concurrent with #3
5. Cover Density/Site Visibility Study Plotting of bare-soil or low density vegetated areas in NPRA survey area to correct for site visibility bias; input to sampling design.	1 September 1977

APPENDIX II (continued)

6.	Implementation of Sampling Design Remote Sensing Division input, from remote sensor data, to NPRA cultural resources sampling design including planimetry and calculation of different ecologic and cover-type areas.	25 September 1977
7.	Remote Sensing Course for Field Personnel Design of remote sensing course to aid NPRA field personnel in use of remote sensor data and products during 1978 summer field season.	plan immediately
8.	Coastal Plain Lakes Study Analysis of the utility of study of coastal plain lakes in NPRA cultural resources assessment and the capabilities of remote sensor data in the measurement of depths, levels and other significant attributes of lakes.	planning stages
9.	Arctic Remote Sensing Bibliography with Emphasis on NPRA Area Compilation, tabulation and cross-indexing by computer of references and sources collected in course of Remote Sensing Division research on NPRA.	October 1977

PRELIMINARY PLAN FOR A CULTURAL RESOURCES SAMPLING DESIGN INCORPORATING REMOTE SENSOR DATA IN THE PET-4 AREA, ALASKA

by

James I. Ebert

A problem inherent in all cultural resources assessment efforts is the relatively large physical areas which must be covered. In the other continental United States, environmental and archeological surveys encompass at times hundreds of square miles, and the costs and requirements of maintaining a field crew for on-the-ground total inventory mounts into millions of dollars. Nonetheless the National Park Service, Bureau of Land Management, and other cultural resources managers requiring such surveys frequently call for total inventory samples--that is, locational and other information for all archeological and historical sites within an area to be disturbed by construction or mining. Such a sample is obviously not practical for an area the size of PET-4, where transport difficulties, extremely short field season, and sheer size militate against the "total sample" concept. More importantly, however, is the fact that it might not be possible in a practical sense to ever gather a total inventory of archeological and other sites on <u>any</u> area, regardless of size. In any event, it is extremely difficult or impossible to test a final inventory sample to determine whether it is a faithful representation of all sites in an area.

It has been suggested in the sampling literature that the way to overcome such problems is the formulation of a multi-stage, "feedback" sampling design which can inform the researcher or manager about variation within an area in such a manner that not only the nature of the sampled parameters, but the accuracy and precision of the sample as well, are evident. The sampling design detailed below is intended primarily to serve as the basis of predictive generalizations concerning the distribution, density and specific nature of resources of interest in the PET-4 area.

Predictive generalizations of this sort can be incorporated as direct input to the upcoming congressional report. It is also hoped that in addition to helping NPS resources assessment personnel resolve immediate problems in PET-4, the proposed sampling design will 1) be useful in the future management of resources in the PET-4 area, and 2) will serve as an illustration of methods and techniques which can be applied to other cultural resources assessment efforts in Alaska and elsewhere.

Although recent discussions of archeological sampling have suggested random, arbitrarily stratified, or systematic samples, this assumes a total lack of information about the distribution of sites or other items to be sampled. This is clearly not the case with archeological assessment efforts, especially those which focus on hunter-gatherer adaptations in the past. A recurrent theme in hunter-gatherer studies, both archeological and ethnological, suggests that much of the behavior of hunting and foraging groups--subsistence strategies, mobility for different purposes, and of course the location of archeological sites created by these people--is conditioned by the nature of their environments. Although causality in many cases is complex and not yet well determined, it is empirically evident in most archeological surveys that there do exist significant differences between material remains in different environmental zones, even over relatively small distances. One of the most useful tools at the disposal of the archeologist in making differentiations between environmental zones is remote sensor data. The use of remote sensor data in dividing an area to be sampled into different environmental zones results in a non-arbitrarily stratified sample. Non-arbitrary stratification, in that it embodies relevant information prior to the beginning of field efforts, is a far more efficient method of sampling than is any random or arbitrary design.

Sample Stage I

The first stage in the formulation of a multi-stage sampling design of the sort recommended here consists of the definition of presumably relevant strata. This will be accomplished using 1:1,000,000 scale Landsat and Landsat

EDIES (EROS Digital Image Enhancement System) imagery as a primary data source; both of these sources are currently on order from the EROS Data Center. The initial basis for stratification using such imagery will be:

1. Landform and Geology. Landform and geology are immediately relevant in any cultural resources survey because the nature of the present-day terrain and the processes which shaped it in the past bear directly on the detectability of and access to sites. For instance, while early man sites undoubtedly do occur in the PET-4 area, the accessibility of early man remains to the archeologist may be affected largely by the extent of Pleistocene glaciation and other geomorphic factors in a negative manner, and by the existence of uplifted or otherwise exposed geological strata in a positive way. Both of these factors can be assessed through the inspection of Landsat imagery.

   In addition, gross geological factors such as uplifts, erosion, and other quantities measurable using remote sensor imagery can serve as an indicator (or in fact a cause) of much variability in other environmental patterning which would in turn be relevant in predicting differences in human strategies in the past--things such as vegetation, faunal and floral distributions, and climate. Even if the exact reasons for differences in the above are not explicated, it is certain that a stratification scheme based on landform and geology would be valuable in the selection of an efficient sample.

2. Ecological Zonation. Again, stratification of the area by ecological criteria is relevant both for the physical contingencies of fieldwork and the distribution and patterning of the occurrence of cultural resources. The false-color infrared rendition provided by the EDIES Landsat mosaic will be especially helpful in delineating vegetation zones within the survey area; the use of positive transparency Landsat imagery for multispectral viewing with the Remote Sensing Division's Mini-Addcol Viewer will also supplement simple interpretation for this purpose. It is to be expected that the prehistoric inhabitants of the PET-4 area were probably influenced by faunal

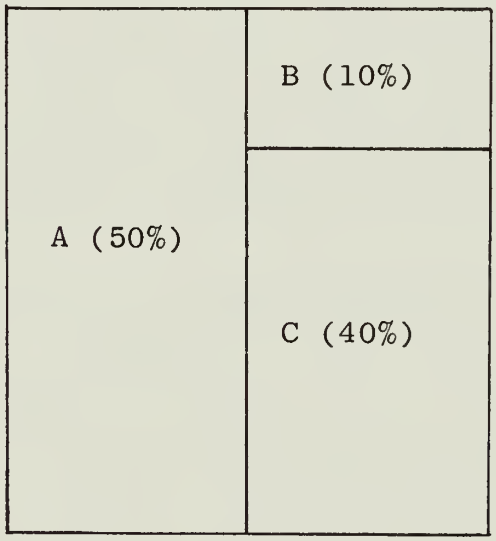
distributions to a far greater extent than by plant resource locations; faunal behavior and patterning are, however, themselves influenced by primary productivity. An ecological stratification on the basis of vegetational zones, therefore, should be valuable in the non-arbitrary stratification of the survey area.

Sample Stage II

Stage II of the sampling design will consist of a test of the utility of the stratification initially made in Stage I, and would additionally serve as an initial indication of the nature of patterning in the survey area. While it would be desirable to conduct this stage of the sampling effort across the entire PET-4 area, it is expected that time and other fieldwork constraints will for the most part make this impossible. The summer 1977 survey area, which has been placed to subsume most of the sorts of environmental variation that occur within the entire PET-4 area, will probably contain examples of all or most of the strata identified in the stratification of Stage I, and the summer 1977 survey sample can probably serve as the basis of most of the Stage II sampling. Additional strata not found within the summer 1977 survey area could be added to the sample taken in Stage II.

The purpose of this stage is not to collect a total sample but to test the relevance of the strata defined earlier, and a sampling fraction (the percentage of area to be sampled within each stratum) should be selected with this in mind. A very low sampling fraction, possibly on the order of .001%, should be permissible for this purpose. Within each stratum, sample units should be as evenly dispersed as possible since the objective is to determine whether strata are homogeneous within their boundaries. While a very large number of small sampling units is ideal under such a requirement, it will probably not be practical in the field because of transportation problems and time requirements. Stage II sample units should be distributed between strata in proportion to the total amount of the survey area occupied by each stratum, and should be dispersed systematically within each stratum.

Under such a scheme, if for instance a sampling fraction of .001% was chosen as workable, then 2300 of PET-4's 23,000,000 total acres would be surveyed. A compromise between precision and the economics of fieldwork might dictate that these 2300 acres be divided into 10-acre sampling units; there would be 230 such units within the area dictated by the sampling fraction. Assuming (in a hypothetical way) that PET-4 had been initially stratified into the following 3 strata:



then distributing the 230 sample units between strata in proportion to their area would result in the survey of 115 10-acre units in stratum A, 92 in stratum B, and 23 in C. Actual sampling fraction and the proportion of the total area within each stratum would, of course, become evident upon actual stratification and measurement, and upon the assessment of time, labor and funds available for this stage of sampling.

Samples derived in Stage II can be used in a number of ways to test the utility of Stage I stratification. The point of sampling is to draw units which when grouped together possess the same degree of diversity as the universe from which they are drawn, and non-arbitrary stratification must result in the furtherance of this. Sampling theory holds that, to maximize the precision of a sample, strata should be selected so that their sampled averages are as different as possible, and their variances are as low as possible. (The closeness of the distribution of sample means about its average compared to the population variance is a measure of precision.) This can be tested on the basis of the Stage II sample for the stratification scheme devised in Stage I.

It will be necessary to formulate a set of measures of site attributes which will be considered relevant to be recorded in the field, and this will of course require careful coordination with the archeological personnel involved in the PET-4 project. In addition, there is a possibility that some remote sensor imagery interpretation could be applied to this stage; experiments with color infrared emulsions by Stringer and Cook (1974) have indicated that in Arctic environments, some classes of prehistoric sites (particularly large sites or those with structures) can be detected with reasonable accuracy from the air. The accomplishment of this would depend on experimentation in the PET-4 area and ground-truth checking of areas flown with color IR imagery. As part of their reconnaissance visit to the PET-4 summer 1977 survey area, Ebert and Drager plan to carry out a preliminary experiment of this sort using color infrared films in hand-held 35mm formats from an aerial platform. If this proves successful, signature recognition patterns can be devised and subsequent identifications will be made from 1:60,000 color IR imagery (which will be flown in July 1977) or other IR imagery by trained interpreters. It would be ideal for these interpreters to also be field personnel in the on-the-ground survey, and arrangements might be made for instruction and training at the Albuquerque lab during the winter of 1977-78.

Sample Stage III

Sample stage III, the final sampling stage in the proposed research design, would consist of the gathering of data from which final conclusions on the nature of cultural resources patterning in the area would be made, and would (along with the sample gathered in Stage II) also serve as the basis for setting aside specific sites and areas to be either more intensively researched or administered by the NPS or other agencies. The value of the results of stage III would depend on an adjustment and refinement of a number of characteristics of the previous sample design, including:

1. Sample stratification. Using the suggestions detailed in the discussion of Stage II above, the boundaries of sample strata could be adjusted. In addition, it will probably be feasible to lump two or more individual strata into a larger uniform stratum in many cases. The relevance of the strata used in the final sampling stage will also be dependent upon an assessment of the utility of the information gathered in stage II for the purposes of the PET-4 cultural resources assessment in general--something which will take close coordination between all parties concerned.

2. Sampling fraction. Although unique cultural resources are often concentrated upon to the detriment of more "common" types of sites or other evidence, it is actually in redundancy that the most anthropologically useful information is to be found. Informed stratification allows the "oversampling" of more variable strata resulting in an increase in sample precision. For maximum precision, the sampling fraction within each stratum should be proportional to the square root of the variance within that stratum (Stuart 1962), and thus can be set using Stage II statistics.

Remote sensor data sources can play an important role in Stage III. During both Stages II and III, aerial imagery will be an aid to the location of sample units on the ground in areas where navigation is difficult by other means; sites and other features located can be conveniently recorded by marking or "pin-pricking" black-and-white or color prints or mosaics as sites are recorded in the field and later transferring this information to maps. In addition, remote sensor imagery will be of use in Stage III as a means of measurement of independent variables to be determined through a consideration of just what we want to know about human/ environment relationships, and possibly as site-locational aids as discussed under Section II. These techniques should be employed by field personnel, and could also be taught and illustrated in the context of a training course for PET-4 field personnel conducted in Albuquerque during the winter of 1977-78.

Summary

Sampling under the sampling design proposed here would consist of three basic stages, each of which would be aided by remote sensor data input. The order in which different aspects of each of these stages would be implemented is as follows:

STAGE I

Stratification of survey area on the basis of:

1) Landform and Geology

2) Ecology (primarily vegetation)

↓

Initial Stratification

↓

STAGE II

Choose Stage II sampling fraction on the basis of available time, personnel and funds and access factors

↓

(continued from page 52)

Locate sample units--systematic dispersal within strata on map in proportion to percentage of PET-4 occupied by each stratum

↓

Fieldwork with remote sensing input

↓

Compilation of data

↓

STAGE III

Determination of the utility of Stage I stratification on the basis of Stage II sample

↓

Readjustment of strata if necessary

↓

Set Stage III sampling fraction on the basis of proportions of total site numbers as sampled in Stage II

↓

Stage III fieldwork with remote sensing input

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CORRELATIONS BETWEEN COVER TYPE AND LITHOLOGY IN THE TESHEKPUK LAKE AREA, ALASKA: A REMOTE SENSING ANALYSIS

by

Galen N. Brown and James I. Ebert

Introduction

The Remote Sensing Division's (RSD) involvement in the cultural resources assessment of the National Petroleum Reserve in Alaska began in May 1977 when it was realized that ground survey alone would not be sufficient for the inventory of cultural resource sites in the 23,000,000-acre reserve. Based on the assumption that cultural activities are patterned over space according to the environmental necessities which face people living in different sorts of places, a first step in the RSD's portion of the project was an environmental stratification of the study area. This was accomplished through the visual interpretation of Landsat imagery at scales of 1:1,000,000, 1:500,000 and 1:250,000, the latter two scales having been enhanced by EROS Data Center's EDIES package. A total of ten Landsat scenes were interpreted with respect to tone and texture, resulting in the compilation of an "Ecologic/Cover-Type Map" at a scale of 1:500,000. The interpretation and compilation of this map is described in more detail by Brown and Ebert (1978). This base map has subsequently served as the basis of planning and analyzing on-the-ground sampling in NPRA.

The interpretation and mapping discussed in this paper, that of an area surrounding Teshekpuk Lake in NPRA's Arctic Coastal Plain, constitutes a finer-grained "follow up" to the Ecological/Cover-Type mapping. With the goal of aiding on-the-ground cultural resources assessment efforts to be undertaken in the Teshekpuk Lake area during the summer of 1978, 1:250,000 scale Landsat imagery and color infrared (IR) transparencies at scales of 1:120,000 and 1:60,000 were intensively analyzed. The results of this analysis illustrate that physical environmental data which can be derived through remote sensing can be indispensable to the cultural resource manager, and that (in much the same way) remote sensing efforts directed toward cultural resources can be interesting and relevant to earth scientists.

Teshekpuk Lake Area Cover-Type Map

At the request of the field crew working in NPRA during the 1977 and 1978 field season, a cover-type map of Teshekpuk Lake area was produced at a scale of 1:120,000 (Fig. 1). The cover-type classification is consistent with the earlier revised edition Ecologic/cover-type map of NPRA, scale 1:500,000 (Fig. 4).

Teshekpuk Lake is the largest fresh-water lake on the Alaskan Arctic Plain, and centers around the geographic coordinates of 154°50' east longitude and 73°30' north latitude. The area surrounding the lake has been stratified into cover-type units based on tonal and textural elements interpreted from two computer-enhanced Landsat scenes. This imagery was exposed during the summer season, a time of maximum vegetative vigor. Scene numbers 2557-21150 and 2182-2194 were necessary for complete coverage of the study area.

Prior to interpretation of cover types from the imagery, base map construction consisted of assembling twelve 15-minute (1:63,360) USGS topographic quadrangles into a mosaic. These in turn were photo-reduced to the present scale of 1:120,000. Interpretation and cartographic procedures were essentially the same as those detailed by Ebert and Brown (1977). It should be pointed out that because of the enhanced resolution of EDIES (Eros Digital Image Enhancement System) computer processing of the Landsat color composite imagery, 1:120,

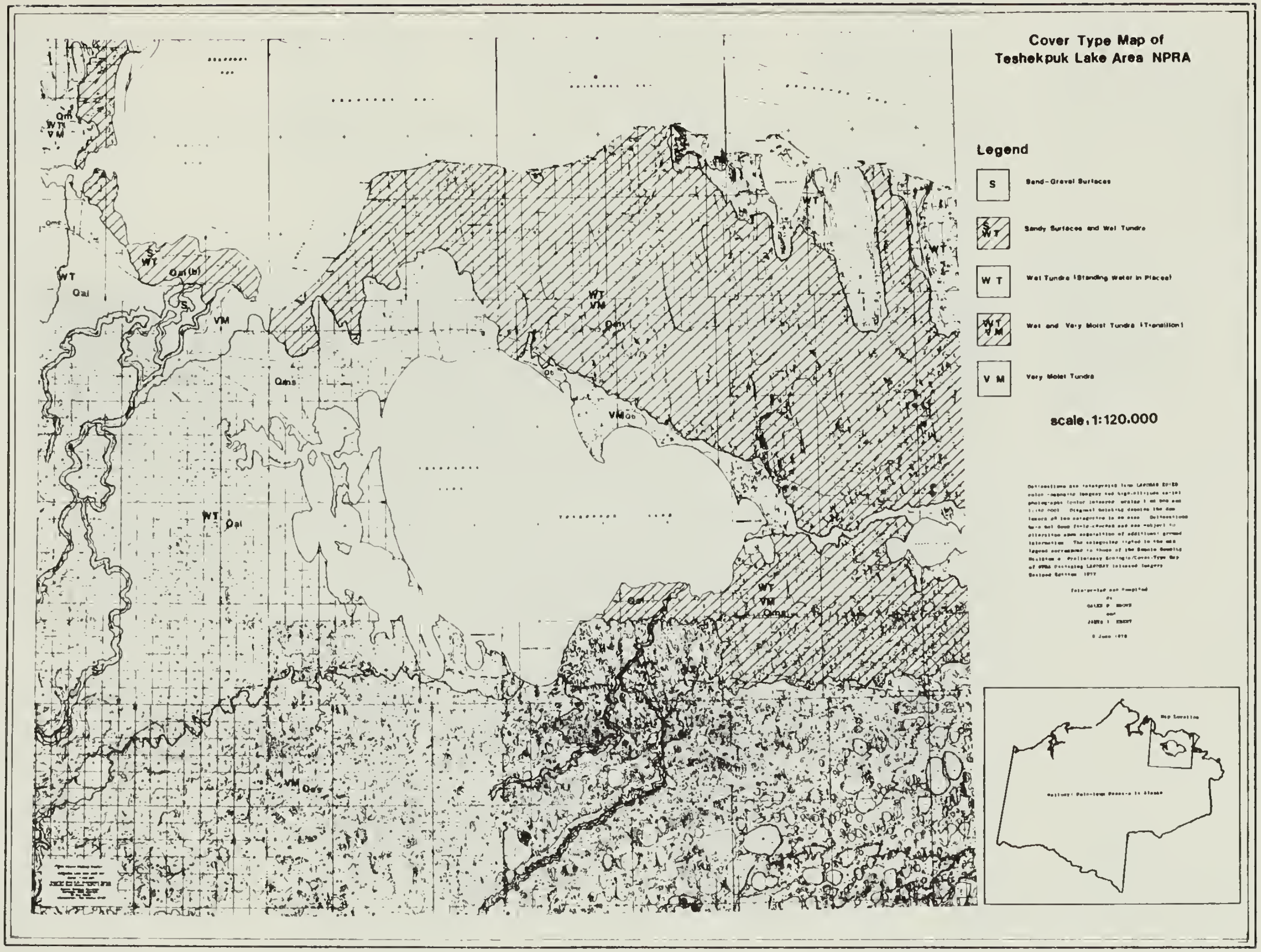
Cover Type Map of
Teshekpuk Lake Area NPRA
Legend
S
Sand-Gravel Surfaces
S WT
Sandy Surfaces and Wet Tundra
W T
Wet Tundra (Standing Water in Places)
WT VM
Wet and Very Moist Tundra (Transition)
V M
Very Moist Tundra
scale, 1:120.000

Figure 3

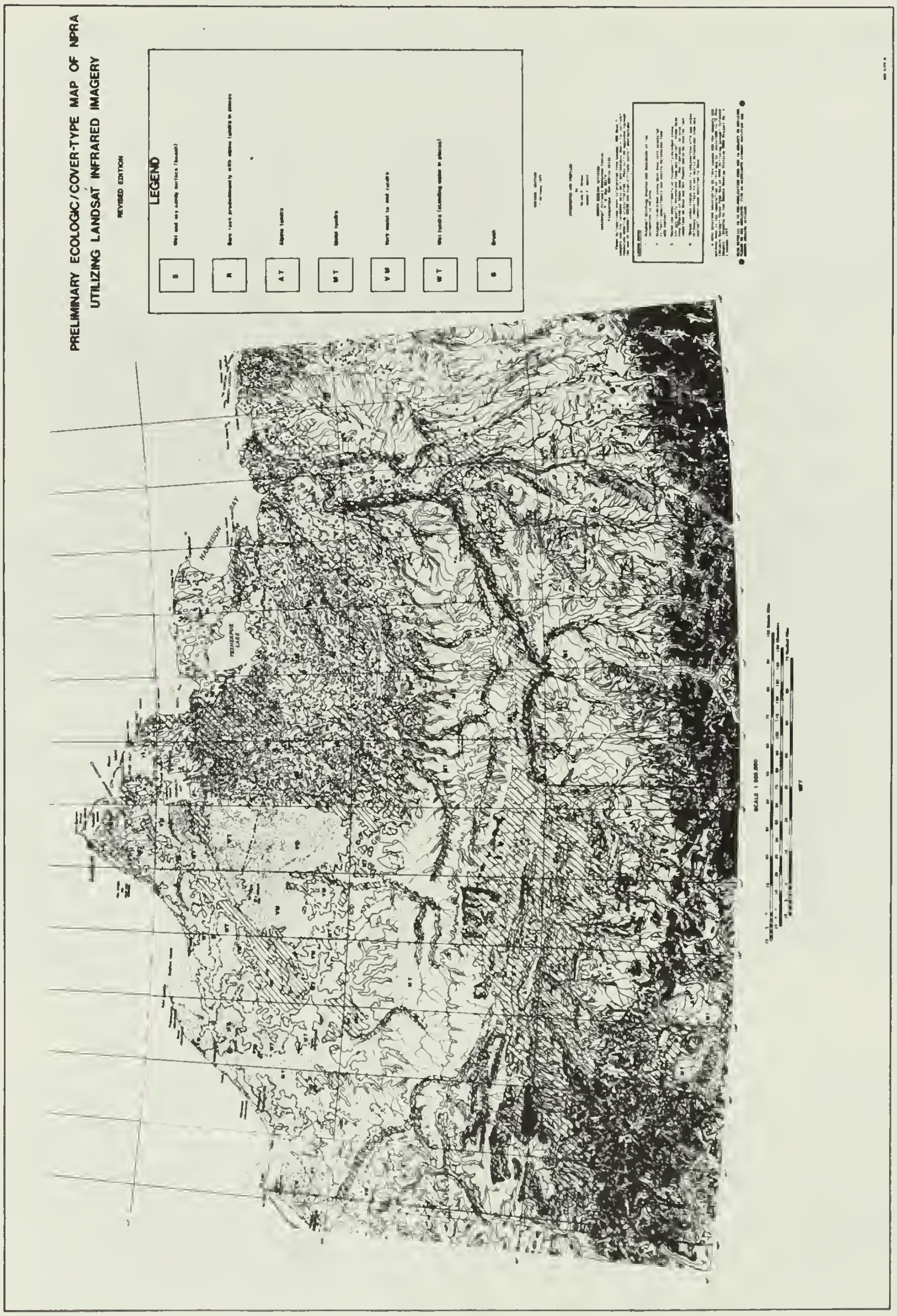
PRELIMINARY ECOLOGIC/COVER-TYPE MAP OF NPRA
UTILIZING LANDSAT INFRARED IMAGERY
REVISED EDITION
LEGEND
AT
MT
WT
HARRISON BAY
TESHEKPUK LAKE

Figure 4

000 scale delineations for the cover-type units and their boundaries were drawn without regard to the previous Ecologic/Cover-types Map of NPRA. Consequently, though the cover-type unit names on this map are identical to those of the previous map of NPRA, interpretation from the enhanced imagery has resulted in some changes in the location of strata on the new map, and reflects a higher degree of accuracy.

Field checks were not carried out for the Teshekpuk cover-type map, and of course the delineations are subject to revision upon acquisition of additional ground truth information. NASA high-altitude color infrared imagery was available for some of the area covered, and was used for checking the accuracy of some of the delineations.

Because of the physiographic setting of this map is such that variation in relief, drainage and other such environmental parameters is slight and aerial coverage of the map is small, delineation of the cover-type strata was somewhat difficult; in fact, even for an experienced Arctic remote sensing investigator, the lands surrounding Teshekpuk Lake appear very monotonous. Interestingly, even during the warmest summer months ice covers much of Teshekpuk Lake and many of the more northern of the oriented lakes.

Morphologically, it can be hypothesized that Teshekpuk Lake has reached its massive size by the process of coalescing smaller oriented lakes; the exact nature of this process is still subject to speculation. Curvilinear islands within the lake are evidence of older and earlier shorelines.

The Strata

Four categories of cover type could be mapped readily from the Landsat imagery. Transitions between these types are included as separate units, in contrast to the design of the categories of the Preliminary Ecologic/Cover-types Map of NPRA. Although the term "transition zone" is arbitrary, it is defined here as a situation observed on the ground where two categories or cover types co-exist. This occurs often where hard, sharp, observable differences of tone and texture are difficult to discriminate on the imagery.

The imagery which forms the basis of this discussion is derived from Landsat satellites. Three Landsats are currently in orbit about 530 miles above the earth, although the sensors of Landsat-1, which was launched in 1972, have been deactivated. Landsats-2 and -3 carry multispectral scanners (MSS) which record a 185km swath of the earth's surface in four spectral bands, 500-600nm, 600-700nm, 700-800nm, and 800-1100nm. A fifth thermal infrared channel on Landsat-3, which is only partially operative, and the return beam vidicon (RBV) sensors on both operational Landsats, are not discussed in this paper.

Because the spectral signature from water is critical, band 7 of the color composites is most important of the three bands (4,5 and 7) utilized. The incredibly high moisture content of the upper layers of soil absorbs infrared radiation; thus, the wetter or more poorly-drained the surface is, the darker the surface will appear on the image. Impermeability is characteristic of the Arctic plain. This is primarily due to permanent permafrost beneath a very shallow thawed active layer during the summer. Drainage is also impeded because of the very low relief on the plain. For this reason, the primary criterion for defining differences in the cover-type strata is ground moisture, and except for the term "sandy," all of the units in the legend refer to this ground moisture. The categories in the legend are as follows: Sand-gravel surfaces, Sandy surfaces and wet tundra, Wet tundra (standing water in places), Wet and very moist tundra (transition), and Very moist tundra. Consistency has been sought as evidenced by the adherence to the moisture factor in these covertype categories.

Although the constant reference to tundra brings to mind the mapping of vegetation, it must be noted that this is not exclusively a vegetation map. While much of the tonal difference visible on Landsat imagery is due to differences in vegetative community mixture and vigor variation in growing plants, soil moisture content also accounts for tonal changes. This is because of the relatively high absorbtion (and thus low reflectance) of near infrared radiation from water bodies or moist soil on Landsat's band 7. Deep water without a sediment load (on the order of 5 feet or more deep) absorbs radiation in band 7's frequency range almost totally, and thus such water appears black. Water of such a depth that the bottom of the water body reflects ranges from dark to light blue in Landsat color composites. Tundra contains many smaller and larger pockets of clear water which are smaller than those technically referable to as "lakes," and the black to blue water tones which they cause tend to blend in with the redder vegetation tones.

In a less direct way, the subsurface stratigraphy influences tonal and textural differences in Landsat imagery. The ground surface in the Teshekpuk Lake region is underlain with permanent permafrost; while in most places this frozen layer lies within 10cm of the ground surface, this distance is quite variable under areas with different water content. Beneath lakes, the permafrost layer is lower than the lake bottom, and in other situations it lies somewhere between 10-15cm and 10cm deep. This affects the availability of moisture, root depth, and microclimate--which in turn can cause variation in vegetative vigor, even for identical plant communities.

For these reasons, we have purposely not referred to plant species composition or community differences in compiling the Teshekpuk Lake map. Instead, it has been called an "Ecologic/Cover-Type Map," emphasizing that general differences in the environment are being differentiated. These, we feel, are completely adequate for purposes of cultural resource stratification and sampling--perhaps <u>more</u> so than a simple plant species taxonomy. The prehistoric and historic inhabitants of NPRA were not responding, in the settlement and mobility patterns or their resource use, simply to plant types but to plant spacing and diversity, terrain and landform differences, animal movements and density, ease of travel, and a number of other properties of the environment which transcend botanical classification. That such an interpretation and stratification can be applied to non-anthropological problems--such as geology--as well is illustrated in later sections of this paper.

Landsat Imagery as a Superior Classifier

After comparison of NASA high-altitude color IR imagery with the Landsat color composites it became apparent that the Landsat scenes are superior for discriminating the slight tonal or chroma differences, especially for extensive regional overview. At this time it became clear that the surficial geologic framework is also detectable--not directly but instead via color chroma or tonal differences influenced by vegetation and moisture in underlying deposits. While the primary purpose of the Teshekpuk Lake cover-type map was an ecological discrimination of cover-types for archeological survey purposes in NPRA, the map is interesting geologically as well, something which was pursued after the acquisition of a preliminary surficial geology map of NPRA received from the US Geological Survey. The value of Landsat in mapping the surficial geology on the Alaskan arctic coastal plain has never been fully addressed, and the remainder of this paper will discuss that topic.

Correlation Between Cover Types and Surficial Deposits

Recent interest in mineral and fossil fuel exploitation in Alaska has been the impetus for the gathering of many new types of environmental information, and for intensifying the accuracy and completeness of data previously available. One such area is that of geological information, especially surficial geology and geomorphology. These categories of data are vitally important, of course, to present and future resource development in the Arctic, especially with regard to engineering problems of soil stability and ecological protection.

In addition, however, the geological framework influenced to a great extent the environment within which prehistoric men lived and deposited cultural material, and the environment within which these materials are preserved today. Much of the Remote Sensing Division's sample stratification of NPRA was interpreted on the basis of geological features in recognition of this fact.

Proof of the value of space-borne imagery as a geologic surveying and mapping tool for surficial deposits has been clearly demonstrated. Wells (n.d.) and others have shown that in arid environments surficial deposits can be detected and quantified based on their tonal characteristics on Landsat imagery. Densitometry and computer data processing have been employed in addition to visual interpretation. Pattern recognition of geologic deposits is best undertaken using imagery obtained during optimum climatic or environmental conditions--usually with minimum ground cover. Such conditions are often found in arid or semi-arid areas. Unfortunately, the problem of lithologic discrimination in more humid areas from Landsat data has been met with little success; rock-type detectability is very low in humid areas utilizing high-altitude or space-borne imagery. This is because of a visibility factor: tree canopies and ground vegetation mask rock and soil from view, although microwave sensors can penetrate to some extent through tree and other plant cover. Secondly, in humid areas having abundant rainfall, chemical weathering and subsequent alteration of rock and soil cause change in color and tone in many lithologies. Neither of these two factors are as significant in arid lands.

In contrast to arid environments, surficial geologic investigations using Landsat have not been thoroughly addressed in Arctic environments. Anderson et al (1973) discussed a preliminary investigation of the value of satellite imagery in synoptic surveys of the distribution and environmental interrelationships of terrain features in Alaska. Though this report is extensive in geographic content, surficial and structural geology are not covered in depth. Mentioned in the report is the fact that low incident solar illumination (8^{o} or so) tends to enhance mountainous topography and detailed geomorphic features; snow cover also makes subtle relief features such as glacial morain topography, thaw lake morphology and riverine features easily detectable.

Investigations of the suitability of Landsat imagery for detection and mapping of Arctic surficial geology was undertaken at the Remote Sensing Division beginning with the cover-type mapping of the Teshekpuk Lake Area. Upon completion of this map, five categories or strata had been delineated from the color composite imagery. As already discussed, color and tonal levels are controlled by ground moisture, and this in turn reflects soil-rock permeability during the summer season.

As in any remote sensing investigation, ground truth check of delineations and conclusions is vitally important. Unfortunately, such field checking could not be carried out by Remote Sensing Division staff, and while supportive ground data were expected from NPRA archeological field personnel at the end of the 1978 summer season, a more immediate source was sought. This was provided by a map compiled by the US Geological Survey under the directorship of John R. Williams (Williams et al 1977) detailing the surficial geology of NPRA at a scale of 1:500,000. Williams' map was based for the most part on previously published material, and was refined through aerial photointerpretation and ground-based fieldwork by geological crews during the summer of 1977. The USGS map was preliminary in nature, and it was expected by its compilers that its reliability would be improved after additional fieldwork in 1978; delineations, nonetheless, seem relatively sharp, probably due to the use of low-altitude aerial imagery. No mention was made of the use of space-borne sensor data in the compilation of the map.

Information presented on Williams' map was compared with the Remote Sensing Division's cover-type map of the Teshekpuk Lake area. While this was undertaken initially for the purpose of providing "ground truth" data, it immediately became apparent that such a comparison reveals a number of interesting correlations between differently-interpreted strata which may be significant in cultural resources analysis and assessment.

The Surficial Geologic Framework of The Alaskan Coastal Plain

The Arctic Coastal Plain is a flat, generally featureless area characterized by thousands of oriented lakes. The Gubik formation, named by Schrader in 1904, is the youngest surficial mantle and is composed of unconsolidated lenses and admixtures of silts, sands, and gravels, with clay locally abundant in some areas. This Quarternary formation occurs throughout the arctic coastal plain and unconformably overlies Tertiary and Cretaceous marine shales, siltstones, and sandstone. Exposures of Tertiary and Cretaceous rock are only rarely seen in low bluffs along the shore of the Arctic Ocean and along some rivers. Locally the Gubik formation reaches a thickness of 70m, but in most places it is only 1-10m in depth. The Gubik has been subdivided into three members based primarily on appearance of the lithology. Faunal and floral correlates have not been fully established. Black (1964) labels these three members the Barrow unit, the Meade River unit, and the Skull Cliff unit. Some of the diagnostic features of these three are:

Barrow Unit (youngest)--poorly-sorted to well-sorted mixtures of clay, silt, and gravel; unit grades from yellow, tan, and brown to black; in part, contemporaneous with and grades laterally into the Meade River sand and in part, younger; rarely deposited directly on the Upper Cretaceous rocks; mostly marine; locally, in upper part, fluvial deposits and lacustrine deposits are characteristic.

Meade River Unit (intermediate)--white, yellow, buff or light-tan sand; generally clean and well sorted; marine; conformable to disconformable on the Skull Cliff unit, but in places deposited directly on the Cretaceous rocks. Locally, whipped into surface dunes; in the south and southeast commonly loess-like.

Skull Cliff Unit (oldest)--sticky or greasy, generally poorly sorted, blue-black to dark-gray, marine clay-silt-sand-cobble unit; possibly glacially derived, in part, and deposited unconformably on the Upper Cretaceous rocks in much of the coastal plain west of the Colville River.

Age and Correlation of the Gubik Formation

Much of the following discussion is abstracted from Black (1964). Evidence for the age of most of the Gubik is inconclusive or conflicting, having been derived from studies of the modification of geomorphic features, carbon-14 dates of organic matter incorporated in the Gubik, marine invertebrate fossils and terrestial vertebrate fossils, archeological finds and growth rates of ice wedges. Fossil evidence suggests that the lowermost Gubik sediments west of the Colville River are Pliocene in age. Driftwood buried beneath coastal sediments has been C-14 dated to be up to 38,000 years old (Coulter 1958). If the oldest dates are correct, the Barrow Unit must represent deposition during much if not all of the Wisconsin Glaciation (Fig. 5). One might then correlate the Meade River unit with the Sangamonian Interglacial period and the Skull Cliff with the Illinoian Glaciation. Unfortunately, no evidence of early Pleistocene deposition has yet been found except for the correlation of the Early Gubik invertebrate fossils with Early Pleistocene or Late Pliocene times. Smith and Mertie (1930) point out that the original surface features are most modified farthest from the sea, and those nearest to the coast are affected least. This suggests that the Barrow Unit must be younger than the Meade River Unit, but does not indicate a specific age or definite means of correlation with the Pleistocene Glaciation. Textural and lithologic maturity of the Meade River Unit in contrast with the Barrow or Skull Cliff Units suggests non-glacial times or at least the absence of easily obtainable clastics of great diversity of size range composition.

INDEX MAP OF NORTHERN ALASKA, SHOWING PHYSIOGRAPHIC PROVINCES AND DISTRIBUTION OF THE GUBIK FORMATION WEST OF COLVILLE RIVER (from Black 1964)

Figure 5

Eolian Deposits of the Meade River Unit-Gubik Formation and Interpretation from Landsat Imagery

Eolian deposits in the vicinity of the Teshekpuk Lake area map have formed longitudinal, parabolic, and multicyclic dunes. The dune field location is indicated on Fig. 1 by the stippled pattern. This is also the location of the Meade River unit of the Gubik formation. Active dunes are presently being formed along rivers and streams; the majority of ancient stabilized dunes are of longitudinal and parabolic type. Most of the longitudinal dunes are less than 100m long and the longest are up to 270m in length. It has been calculated that the entire dune field represented in the Meade River Unit covers about 13,000km^2 west of the Colville River. Individual dune ridges are very shallow, ranging from 2m in height to 8m. For this reason it is almost impossible to detect and map the location of the dune field from satellite imagery during the summer months.

A thick exposure of cross-bedded eolian sand is found along Kealok Creek south of Teshekpuk Lake. The morphology and stratigraphy of this deposit is described in depth by Carter and Robinson (1978). Stabilized dunes, of which the Meade River unit is composed, are being destroyed by the migration of lakes and rivers, by frost heave, ice polygon growth and other weathering processes, and it is believed that some of these stabilized dunes were much larger prior to the action of erosional process. Dunes in this area are not easily recognized from ground level because of thick vegetation cover and relatively low profile of the dune ridge. For this reason the identification and aerial distribution of the dune field was not completely known prior to the applications of remote sensing techniques. Deflation areas are clearly visible on aerial imagery and therefore indicative of active dune forming activity. Stabilized dune fields south of Teshekpuk Lake and west of the Colville River are also very difficult to discern from summertime satellite imagery. The value of shadow enhancement, however, is clearly seen in wintertime satellite imagery. Winter scenes of low sun angle and apparently uniform snow cover accentuate hills (dune ridges), which are difficult to observe on Landsat imagery exposed during other times of the year because of low relief and gentle slopes (Carter and Robinson 1978).

The stippled pattern on Fig. 1 marks the extent of the dune ridges interpreted from three Landsat color composite winter scenes, ID nos. 2394-21142, 2395-21193, 2414-21244.

The age for the majority of these dune fields is not precisely known. It is believed that they were formed from glacially-derived materials and alluvial deposits left by receding glaciers to the south. In addition, the climate was probably warmer than that of today and the active layer above the permafrost thicker, allowing the topmost layers of soil to dry out. Loose dry soil was then available for transport into the dunes (Black 1951). Such a climate would probably have prevailed during the post-Pleistocene optimum. Carter and Robinson report that the Kealok creek exposure south of Teshekpuk Lake radiocarbon dates indicate the following: (1) 5 meters of accretion of sand about 11,000 years before present, (2) minimum accretion of sand (1-2 meters) between 10,000 to 5,000 years before present, and (3) 4 meters of accretion within the past 5,000 years. Prior to 11,000 years before present, the climate had ameliorated and dune activity had subsided enough to allow for at least local growth of vegetation on the dune fields; between 11,000 and 5,000 years before present, the dune field was probably stabilized. Thaw lake development commenced at the onset of dune stability in the Teshekpuk area. Thaw lake erosion has cut bluffs into the dune ridges indicating that thaw lake development postdates the major episode of eolian activity (Carter and Robinson 1978).

Interpretation of Surficial Deposits Using Space Imagery and Correlation to Cover-Types on the Teshekpuk Lake Area Map

Black, in his report on the Gubik Formation (1964), mapped the distribution of this formation and the three units or "members" that comprise it (Fig. 3). A continuous linear contact running east-to-west separates the Meade River unit to the south from the Barrow unit. This contact is delineated on the Teshekpuk map, and just touches the southern tip of the lake. Because a sharp color or tonal difference could be seen on the Landsat color composites, a line could easily be drawn separating two cover-type strata; Wet tundra (WT) is labeled for the area north of the line, and Very moist tundra (VM) to the south of the line. Later, after investigating low-sun-angle Landsat imagery, eolian ridges aligned in a ENE-WSW direction could be detected in the Very moist tundra area. The stippled pattern indicates the areal extent of this feature.

At this point the value of Landsat in terms of surficial deposit discrimination was apparent. A remarkable correlation is visible between the Barrow unit with Wet tundra and the Meade River unit with Very moist tundra. With the fact that tonal differences are controlled by ground moisture in mind, and a knowledge of the lithologic composition of these two surficial units, it can be reasoned that the darker tone of the Barrow unit Wet tundra area results from the lower permeability of silts and clays versus the more permeable, better-drained sands of the Very moist tundra-Meade River unit.

After acquisition of the Preliminary Surficial Geologic map of NPRA, further investigation of Landsat imagery continued. The USGS Preliminary Surficial Geologic Map was produced at a scale of 1:500,000 for all of the NPRA area, and thirteen categories of surficial lithologic units were mapped. We were interested in only that portion of the map that covered the area of the Teshekpuk Lake Cover-types map. In this locality are found only five of the thirteen geologic units. The following surficial geologic units are found in the Teshekpuk Lake area (for a complete lithologic composition of these units refer to the descriptive sheet accompanying the USGS Open File Report 77-868):

Qes-- eolian sand
Qal-- alluvium

Qal (b)	alluvium specifically beach and deltaic deposits
Qm--	marine silt
Qms--	marine sand
Qb--	marine beach deposits (because of the very limited occurence of Qb no quantitative measurements were made; see tables 1, 2, and 3.)

With the aid of a Map-O-Graph projector, it was possible to enlarge the Teshekpuk area of the Surficial Geologic map to geologic units found in the Teshekpuk Lake area. This qualitative classification readily shows correspondence of cover-type units with surficial geologic units. Reliability of correlation in terms of deviation in extent for the geologic and cover-type decreases down the list. For this reason correlation of WT/VM and Qm and Qms is equally shared (Black 1964).

Table 2 is the quantitative result of measurements of the aerial extent of both cover-type and surficial geologic units. Figures in this table are in both square kilometers and percent of total areal coverage. Again as in Table 1 reliability of correlation between cover-types and surficial geology decreases down the list.

Table 3 is a simple listing showing the difference of correlation in percent for cover-types and surficial geology. The remarkable close correlation of Qes and VM is apparent with only a .10% difference in areal coverage between the two. Qm correlates to WT/VM with only a 1.12% difference in areal coverage as compared to a WT/VM correlation with Qms having a 4.59% difference in areal coverage between the two units. This may mean that correlation tendency for WT/VM is closer to Qm than Qms.

This Remote Sensing Division's Cover-Type Map of the Teshekpuk Lake area is, of course, preliminary. The close correlations with other data, however, illustrate that even preliminary interpretations based on Landsat color composite imagery can, for the most part, be "trused" in the Arctic. Because of the gradual nature of

Table 1. - Correlations of Cover-Type Unit with Surficial Geologic Unit in the Teshekpuk Lake Area

Cover Type Unit	Surficial Geologic Unit*
VM	Qes
WT	Qal
S, S/WT	Qal (b)
	Qm
WT/VM	Qms

* Geologic Unit not listed in Chronological Sequence.

Table 2. - Areas of Cover-Type Units Interpreted from Landsat and Surficial Geologic Units Mapped Previously

Geologic Unit	Percent Coverage	Areal Coverage KM^2	Cover Type Unit	Percent Coverage	Areal Coverage KM^2
Qes	28.10	1718.64	VM	28.00	1711.57
Qal	18.86	1153.32	WT	27.77	1698.72
Qal (b)	1.25	76.42	S,S/WT	1.18	72.40
Qm	25.42	1554.93	WT/VM	26.32	1609.97
Qms	11.73	717.72	WT/VM		
Teshekpuk Lake	13.90	850.00	T. Lake	13.90	850.00

Table 3. - Percent Coverage Difference between Surficial Geologic and Cover Type Units

Cover Type Units	Surficial Geologic Unit
Qes:VM	.10%
Qal:WT	8.9 %
Qal(b):S,S/WT	.07%
Qms:WT/VM	4.59%
Qm:WT/VM	1.12%

change between zones in many cases, it may be possible to more accurately and precisely define boundaries using small-scale imagery such as Landsat than by interpretation of lower-altitude aerial photographs or on-the-ground investigation. Future interpretation and mapping may alter the boundaries drawn here slightly, but the authors surmise that differences will be less than 1%.

Discussion

This study is more than a purely academic exercise, for it illustrates the value of utilizing a "layered" or "tiered" approach to ground truth checking of conclusions reached through the interpretation through reference to many (rather than just one) classes of information. Traditionally, remote sensing technicians have called for the physical, on-the-ground inspection of boundaries and anomalies detected from imagery. Problems arise, however, in the applications of this approach. In some cases, such as that of the present Teshekpuk Lake stratification, on-the-ground field checking of zones and boundaries may be economically impossible; the qualities or features mapped from imagery may, in addition, be extremely difficult to even see or measure on the ground, as is illustrated by the low-relief dune fields discussed above. Other experiments carried out in the NPRA and elsewhere by the Remote Sensing Division have suggested that one alternative to walking on the ground in the performance of a field check is to use other data.

One class of "other data" which can provide an alternative to on-the-ground checking is other information derived from remote sensing sources. Conclusions drawn on the basis of Landsat imagery as a primary data base can be checked with high- and medium-altitude aerial imagery as illustrated in this paper. This procedure was also employed in the overall stratification of NPRA, and was further supplemented with both true color and color infrared imagery exposed with hand-held 35mm cameras from a helicopter platform. This allowed the positive identification of specific interpreted features, insuring the accuracy of the stratification; for instance, it allowed the differentiation of residual snow and aufeis from limestone outcrops, both of which appear white on Landsat color composites.

Another check on the accuracy and appropriateness of zonations interpreted from remote sensor data is its significance in terms of cultural variation. Such a check is made on the basis of archeological and other cultural materials and sites found on the ground, and can be made whether ground survey was the direct result of sampling after the interpretation of imagery, or if it occurred prior to remote sensing stratification or independently. A stratification is culturally significant if site densities, types, distributions, and attributes (such as artifact assemblage types or artifact distributions) vary between strata more than they do within each stratum. This, of course, is the aim of sample stratification in general--that variance be less within each stratum than between them. It is readily apparent that judging the significance of any stratification quickly becomes complicated, for while a stratification may be adequate or "true" for one parameter, it may not be for another. This is when sampling stratification begins to approach explanation, for by noting discrepancies between expectation and observation one knows what must be explained.

A final type of information which can be used for "truth checking" is mapped or measured data collected by other scientists for purposes which are not always congruent with that of the cultural resource manager. As demonstrated above, geological maps compiled for purposes of minerals exploration can, in this case, be closely correlated with the cultural resource sample stratification, providing support for the boundaries interpreted from Landsat imagery. Traditionally, archeologists have had difficulty with the concept of "borrowing" from other sciences, and much has been written on this topic of "whether we should borrow." Perhaps this is because nearly all of archeology's techniques are borrowed. Hopefully, this paper illustrates that such use of data collected for other purposes is not only conscionable, but helpful as well.

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VEGETATIVE STRATIFICATIONS FROM AERIAL IMAGERY

by

Dwight L. Drager

One of the problems archeologists are addressing more and more often is the relationship of a prehistoric group of people to their natural environment. In areas where prehistoric remains are generally post-Pleistocene, or can be shown to be in a natural setting that has changed little since the prehistoric occupants left the area, the modern vegetation may be similar or identical to the vegetation at the time of occupation. It may, then, be useful to map the distribution of present-day vegetative communities in order to gain some idea about prehistoric vegetative distributions.

Many techniques are already being used to map the present distribution of vegetative communities--ground-based surveys, low-altitude aerial photography, high-altitude aerial photography, and mapping from satellite imagery. Cost figures on these various techniques are difficult, if not impossible, to obtain. However, a brief examination of each of the methods may give some idea about the particular scope, the applications, and efficiency of each method.

Ground-Based Field Survey

Probably the oldest method of vegetative mapping is that of ground-based field survey. This technique requires that someone, usually a trained botanist, actually walk over the area being studied in such a manner that he can see all the different portions of the area of interest. He can then record on a map all the various types of vegetation and the exact locations of changes from one type of vegetation to another. This is an extremely time consuming task but it can produce very detailed results. Percentages of individual species can be calculated from samples taken within each zone. In this way, even minor changes in the environment can be monitored.

Large-Scale Aerial Photographs

Aerial photographs ranging from scales of 1:1500 to 1:24,000 can be used in two different ways to denote vegetative boundaries. In a manner similar to that discussed for ground-based field survey, the photos may be carried into the field and species identifications written on the appropriate areas of the photographs. Later, in a laboratory, boundaries can be drawn between the various zones and the boundaries can be transferred to a smaller scale map. This is a technique that has been used on Bandelier National Monument in north-central New Mexico (Scott Berger, personal communication, 1975). This procedure is less time consuming than ground-based field survey and yet can maintain the accuracy of that method.

The second way to use large-scale aerial photographs is to interpret species types or vegetative communities directly from the photographs without actually taking the photos into the field. Boundaries can be drawn on the photos just as in the previous method, but the species within the boundaries must be interpreted from the photographs rather than sampled in the field. In order to verify the accuracy of this method, a field check must later be made of the map. However, a well-designed sampling procedure can be used which will certify the overall accuracy of the map. It is possible to perform a field check by allowing the map maker to identify plant types by flying over the area prior to making the map. In this manner, ground-control is in effect acquired from the air prior to mapping and further field checking can be held to absolute minimums. The feasibility of this procedure has been established during an environmental mapping project in western Colorado (Ed Kelley, personal communication, 1977).

Both of these mapping techniques are capable of minute discrimination and might be able to show such distinctions as the differences between the kinds of plants that grow on or off archeological sites. Maps of this kind could be, thus, used directly for archeological site location.

Small-Scale Aerial Photographs

Aerial photographs of scales ranging from 1:48,000 to 1:150,000 can be used very effectively for mapping much larger areas than the larger scale imagery. Recently, a false-color infrared 9 x 9 single transparency frame at a scale of about 1:114,000 was used to map a large section of the Pajarito Plateau in central New Mexico (Drager and Loose 1977). This area wholly contains Bandelier National Monument and could thus be compared to the Bandelier map for accuracy. The single image used to perform the mapping was about 24.68 km. on a side, thus containing about 609 sq. km. The vegetative areas were transferred directly onto a set of nine USGS 7.5-minute topographic quadrangle maps and later drafted to produce a publishable-quality map. Measurements of drainage basin area, distance to zone change, and other attributes were taken directly from the USGS maps. The imagery was available from missions that had been flown by the National Aeronautics and Space Administration and could be purchased from the EROS Data Center. The total time required to produce the original map and the supporting report was approximately 75 man-hours. A field check of the map's accuracy, resulting in minor changes, was subsequently made.

The existence of maps made by different people from both large and small scale aerial photographs of the same area allowed the opportunity to compare the two maps for agreement. Since both original maps had been made on the same medium, 7.5-minute USGS topographic quads, the comparison consisted of merely overlaying one map on the other. The agreement between the two maps was significant. The major differences were found to be errors in the identification of particular species on the map made from the high-altitude, small scale imagery. This mistake was also noticed in the field check of this map and would have been corrected as a result.

Archeologically, this type of map is extremely useful for determining such data as distance between sites, areas of important vegetative communities, distance of sites from particular environmental features.

Satellite Imagery

In the past, satellite imagery has been little valued in archeology. Individual sites can almost never be seen or located on satellite imagery and it has therefore been felt to be of little utility. However, a recent study of the San Juan basin of northwestern New Mexico may show some uses for satellite imagery that are not at first obvious (Schalk and Lyons 1976).

Landsat multi-spectral images are actually composites of many different qualities of the natural environment. Soils, vegetation, elevation, atmosphere, geologic structure, and others all combine to produce a single representation of the surface of the earth. Also, in the case of Landsat multi-spectral images, differing portions of the electromagnetic spectrum can be combined to yield differing types of data about the area considered. But perhaps the most important characteristic of satellite images is that they present a truly regional view of the area of interest. Each Landsat image is about 185 km. on a side--a total area of about 34,253 sq.km. There are few areas of archeological interest that cannot be well accomodated within an area of this size.

For the San Juan basin in general, and the relationship of Chaco Canyon to the basin in particular, the regional view afforded by Landsat imagery was especially enlightening. With the aid of electronic density slicing equipment, it became possible to identify a major division running from the northwest corner to the southeast corner of the basin. Only minor differences in the vegetation were noted on the surface for these two different areas, primarily the existence of juniper and sagebrush in the northeast portion. Reference to soil maps, however, showed a difference in the origin of the soils of the two areas. The soils to the northeast are of terrestrial sandstone origin; the soils in the southwest portion of the basin originated as marine shale. The differences in the water retention characteristics of these two types of soils may play a significant part in what is beginning to solidify as an idea about the way the prehistoric populations of the San Juan basin were conditioned by their environment.

There is much evidence that what could be termed a "complex" society grew up in the San Juan basin between A.D. 850 and 1150. Insufficient arable land to support the probable population (Loose and Lyons 1976; Drager 1976), differentiation of settlements into a two- or three-level hierarchy (Grebinger 1973), the presence of a complex road network tying the various areas together (Lyons and Hitchcock 1977; Obenauf this volume), the presence of sophisticated irrigation systems in the basin (Vivian 1974), all point to the development of complex social systems. However, complex social systems usually are the result of specialization, brought about by the differential distribution of various resources throughout a region. In the San Juan basin, rather than resources being unevenly distributed, what appears to have caused the development of a complex social system is the differential production of basically the same resources.

In arid environments, very slight variations in effective moisture from year to year can cause substantial fluctuations in rates of native growth or agricultural production. Sandy soils like those in the northeast portion of the basin retain moisture for long periods after a storm, but the shale-formed clay soils of the southwest portion experience rather rapid run-off. These two types of water retention properties strongly condition the production of basic agricultural crops given a variable climatic regime. During dry years, the sandy soils to the northeast should produce well since the soils would retain water. The clay soils to the southwest, conversely, should be associated with extensive water control features and might produce an excess of crops during wetter years.

Conclusions

It can be seen that vegetative stratifications can be performed with almost any type of aerial imagery. The factor playing the largest role in the type of vegetation that can be identified is the scale of the imagery. Differing scales, however, allow the researcher to approach the area of interest with different types of questions in mind. It then becomes the problem of the individual researcher to determine not only what are the best distinctions he can make about the area of interest, but also how those distinctions can best help him solve his research goals.

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AERIAL PHOTOINTERPRETATION OF VEGETATION

OF

CHACO CANYON NATIONAL MONUMENT

by

L. D. Potter and N. E. Kelley

Abstract

After a vegetational survey of Chaco Canyon by the use of line transects was completed, a vegetational map was made from aerial color transparencies at a scale of 1:6000. During the mapping, field trips were taken to check the identification of vegetational types difficult to delineate. This report emphasizes the correlations of physiography, soils, vegetational growth form, and species composition to the photo imagery for each of the major vegetational types. Also included are suggestions for the identification of man-made features and the ecological basis for their distinction.

Introduction

A map of the vegetational types, defined by distribution of principal plant species, was developed from stereo pairs of conventional Ektachrome nine by nine in. aerial transparencies of Chaco Canyon National Monument. The transparencies used were taken in the summer of 1973 at a ratio scale of 1:6000. Some initial mapping was completed prior to 1973 using black-and-white aerial photographs at a scale of 1:3000 taken in June 1964, in the vicinity of several of the major excavations. These were useful in establishing textural and tonal appearance of most of the vegetational types on the color photos when they became available.

An ecological survey performed by Potter (1974) prior to the initiation of the vegetation map provided information on the species composition and foliar coverage values for the various vegetational types mapped. This information produced the nomenclature used to designate the various vegetational types represented on the map and the information used to describe each type in this paper.

In addition to the utilization of existing information, several trips were made by the authors to Chaco Canyon National Monument during the development of the map to verify the vegetational types and to determine in the field boundary lines that were not readily discernible on the photos. Even in the field, determination of these lines was sometimes rather arbitrary.

The reference areas for establishing boundaries were chosen from the aerial transparencies at points that were easily located on USGS topographic maps of Chaco Canyon National Monument. These reference points included such sites as road intersections, convergence points of arroyos, fences, identifiable pueblo ruins, specific cliff faces, and other specific points that could be easily identified and located in the field.

Mylar positive transparencies were used to make black line prints of the Chaco Canyon area at a scale of 1:12,000 with a silk screen inserted to soften the contour lines of the topographic base map. Outlines of the vegetative types were transferred from the aerial photo overlay sheets at a scale of 1:6000 to the 1:12,000 scale map by use of an overhead reduction projector. Each vegetative type was coded by an overlay of symbols plus the inclusion of the letter symbol of the type. Fig. 6 is a copy of the Preliminary Vegetative Type Map of Chaco Canyon.

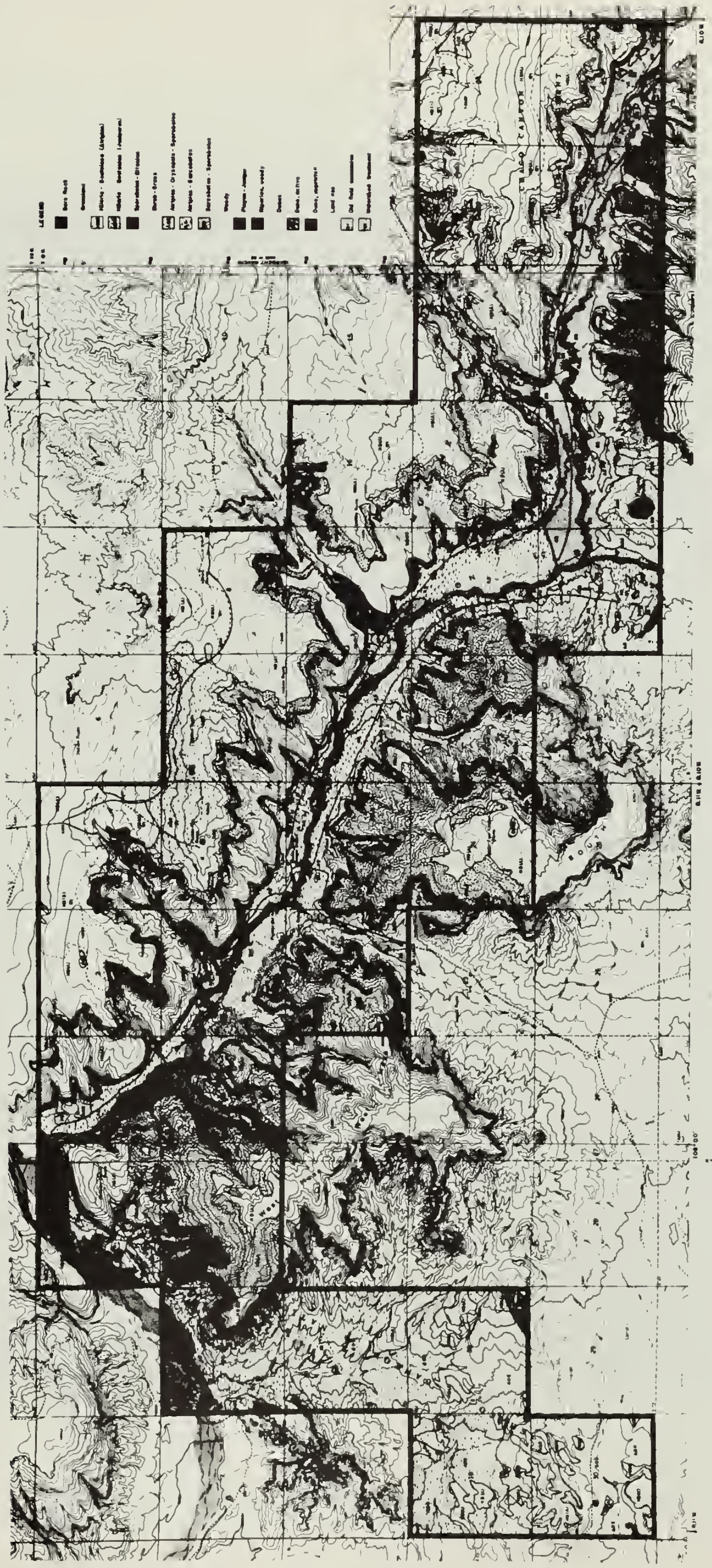

Figure 6

Description and Photointerpretation of Vegetational Types

Code PJ--pinyon (*Pinus edulis*)-one-seed juniper (*Juniperus monosperma*)

This woodland zone is found only along the southeastern edge of the Monument on the upland plateau of Chacra Mesa, Fig. 7 . The total foliage cover is 10%, of which juniper is 43%. Understory shrubs consist of mountain-mahogany (*Cercocarpus montanus*) 13%, and black sage (*Artemisia nova*) 10%. Lesser dominants are sandhill muhly (*Muhlenbergia pungens*) 7%, galleta (*Hilaria jamesii*) 7%, pinyon 7%, rubber rabbit-brush (*Chrysothamnus nauseosus*) 3%, threadleaf snakeweed (*Gutierrezia microcephala*) 2%, and white ragweed (*Hymenopappus lugens*) 2%. Numerous other species of grasses and herbs occur in minor amounts.

Both young pinyon and most junipers are characterized by a dense, bushy growth form with branching from the ground and no prominent trunk. They are not readily distinguishable from each other. The woodland type does not exhibit a closed tree canopy. About one-fourth of the vegetative cover is composed of 2- to 5-ft.-high shrubs forming a secondary vegetative layer, above a nondescript ground layer of grasses and herbs and about 90% bare rock surface--in this case horizontally layered sandstone.

Code HB--galleta (*Hilaria jamesii*)--blue grama grass (*Bouteloua gracilis*)

This grassland type of mixed species is the dominant grassland on the relatively thin, silt- and sand-textured soils of the upland plateau. Galleta is widely distributed, dominant in coverage (46% of the total cover of 18%) and is relatively resistant to grazing pressure. It prefers heavier soil types. Blue grama increases on intermediate-textured soils and makes up an average of 14% of the cover. As soils become more sandy, the percentage cover of sand dropseed (*Sporobolus cryptandrus*) and Indian

Figure 7 - Aerial view of Chaco Canyon illustrating pinyon-juniper, PJ, and watershed treatments, Wt.

rice grass (*Oryzopsis hymenoides*) increases. They average 21% and 5% of the vegetative cover. Other common species are the low shrub winterfat (*Eurotia lanata*), Russian thistle (*Salsola kali*), and desert hiddenflower (*Cryptantha angustifolia*).

In areas of deeper sand, which were at one time drifting sand and still retain some evidence of dune topography, there is an increase of Indian rice grass and four-wing saltbush (*Atriplex canescens*). These areas are designated as a subtype HB(A), Fig. 8. On thin soils or bare fractured sandstone the presence of junipers leads to a subtype HB(J), Fig. 3. An associated large shrub, cliffrose (*Cowania* sp.), is difficult to distinguish in aerial photos from juniper.

Within the general type there is a texture on the photos produced by two levels of shrubs. Those that are 2-3 ft. tall and dark grey are four-wing saltbush; the lower 6- to 12-in.-high shrubs, greener than saltbush, are snakeweed and Russian thistle. The ground cover distinguishable only by color from the tannish dune sand represents a great variety of grasses and forbs. As the mantle of sand becomes thinner, the vegetative cover decreases and the sand surface is obvious. Where it has eroded away the underlying light-colored sandstone is obvious. Along fractures, junipers occur and are readily distinguished by their greater height, dense foliage, egg-shaped crown, and scalloped margins. The area in which juniper is present in the galleta-blue grama grassland is separated as HB(J) in contrast to areas in which only shrubs occur in the grassland--subtype HB(A).

Code AOS--four-wing saltbush (Atriplex canescens)--Indian rice grass (Oryzopsis hymenoides)--sand dropseed (Sporobolus cryptandrus)

This type is indicative of recently blown, deep deposits of dune sand. When the shrub, four-wing saltbush, increases to a point of co-dominance with the principal grasses, the type is classified as a

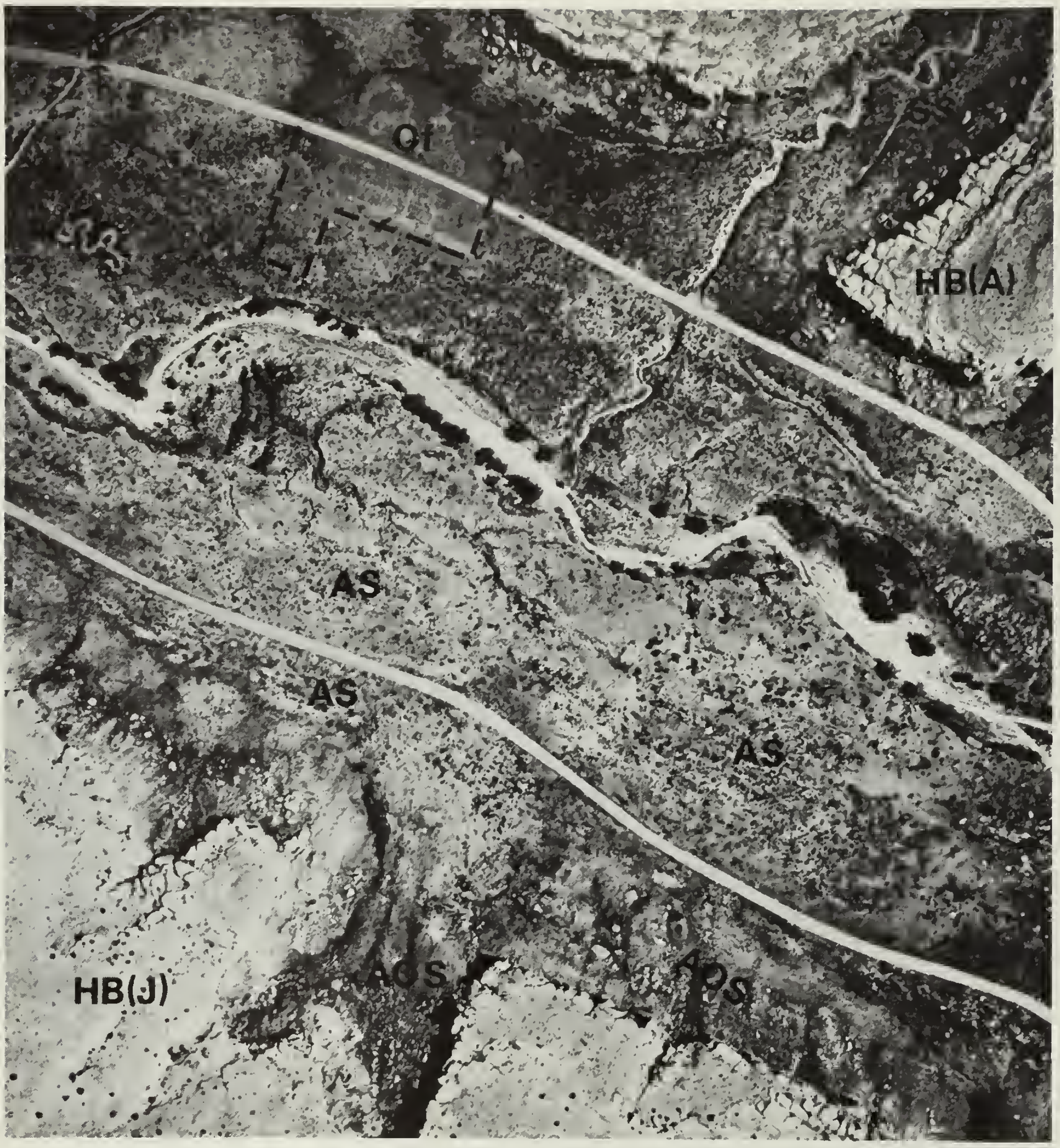

Figure 8 - Aerial view of central part of Chaco Canyon illustrating galleta-blue grama grass with four-wing saltbush, HB(A), and with juniper HB(J); four-wing saltbush-Indian rice grass-sand dropseed, AOS, along tributary outwash from the south; four-wing saltbush-greasewood, AS, along intermediate slopes; greasewood-alkali sacaton, SS, on the alkaline clay flats; the woody riparian type, Rw, along the wash; and old fields, Of.

shrub-grassland. The total foliage cover of this area is 14%. The dominants and relative coverages are Indian rice grass 25%, four-wing saltbush 25%, galleta 18%, snakeweed 11%, and sand dropseed 9%.

This type, which contains a great variety of species of grasses, forbs, and shrubs, occurs in three situations. First, there is an extensive area along the north boundary north and east of Pueblo Alto where deep blowsand overlies the bedrock of the plateau. Second, it is found along the base of the cliffs of Chaco Wash in the sandstone talus and extensively on the blowsand and coarse outwash of the tributaries entering Chaco Wash from the south, Figs. 8 and 10. Third, it is most extensive in the western section of the Monument, where there are widespread dune areas, Fig. 9.

In the upland areas the type is distinguished by the dune topography and by the density of the medium-sized greyish-green shrubs of four-wing saltbush rising from a nondescript, sparse, herbaceous ground cover. Along the channels and valley bottoms, the edge of the type is distinguished by the presence of greasewood (Sarcobatus vermiculatus), which appears as a taller and much darker green shrub generally common to heavier soils of lower and wetter sites.

Code AS--four-wing saltbush (Atriplex canescens)--greasewood (Sarcobatus vermiculatus)

The zone of transition from upper slopes of outwash to lower slopes, from sandy soil to clay soil, from low alkalinity to high alkalinity, and from greater to lesser depth to the water table is represented by an admixture of four-wing saltbush and greasewood and classified AS. This mixed-shrub type dominates the intermediate and lower slopes in the central part of the Monument, where it extends all the way to the banks of Chaco Wash, Fig. 8. There are patches of greasewood in lower areas but scattered young shrubs of four-wing saltbush occur throughout, even in heavy soils in which great amounts of soil piping is occurring. In this central portion

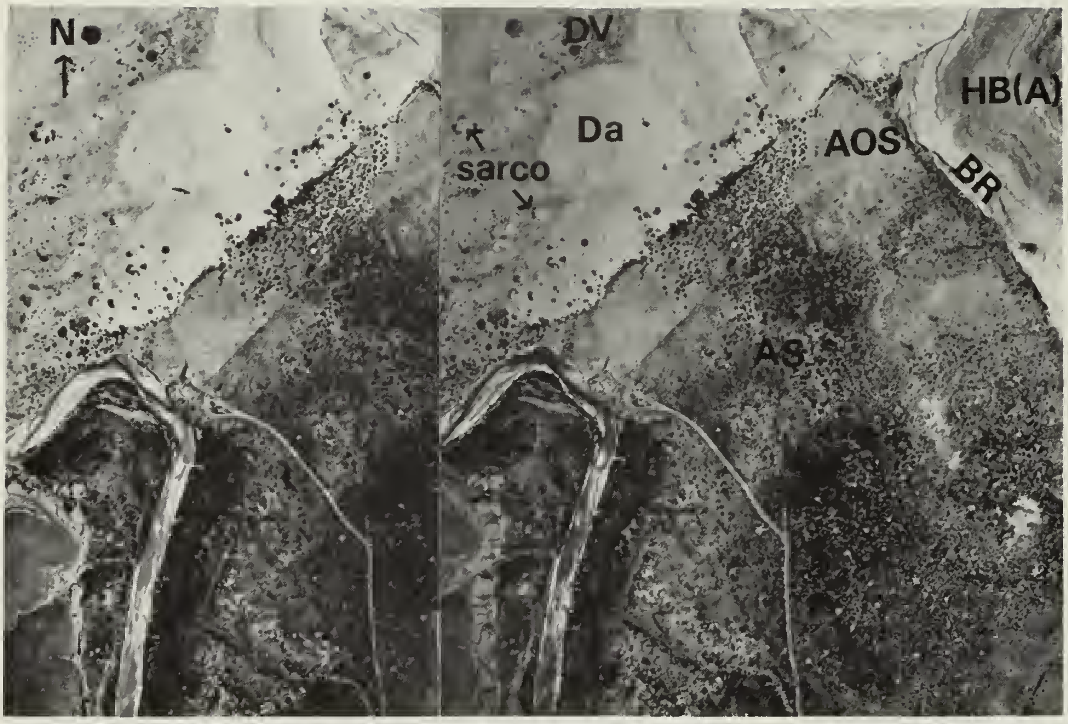

Figure 9 - Aerial view of the west end of Chaco Canyon illustrating four-wing saltbush-Indian rice grass-sand dropseed, AOS, in dune areas; active dune areas, Da; vegetated dunes, Dv; and bare rock areas, BR, of Plateau edges.

of the Monument these stands are on soils of finer texture than is usual for four-wing saltbush and at higher terrace levels than one would expect for a dominance of greasewood. Stands of the former seem to be of younger age, as though more recently invading; stands of the latter often appear much older and sometimes decadent. Both conditions may be the result of increased cutting of the wash resulting in a lowering of the water table. As the surface becomes drier and blows, this favors four-wing saltbush and the greasewood continues to exist only by the continually deepening growth of its taproot system.

It is of interest to note that when the road system parallels a wash it is frequently close to the point of transition between AOS and AS, Fig. 8, not higher where the slope is too steep and not lower where the soils are higher in alkalinity and clay concentration, which makes travel almost impossible during periods of rain.

There are several species of grasses. In decreasing order of coverage they are: alkali sacaton (Sporobolus airoides), brome grasses (Bromus spp.), bottlebrush squirreltail (Sitanion hystrix), galleta, and Indian rice grass. Shrubby species include the dominants four-wing saltbush and greasewood plus rabbitbrush (Chrysothamnus spp.), prickly pear (Opuntia sp.), mammillaria (Mammillaria sp.), false tarragon sagebrush (Artemisia dracunculoides), threadleaf snakeweed, and fringed sagebrush (Artemisia frigida). There are numerous grasses and forbs.

In the low-lying areas, where soils might be finer-textured and water more available, one can identify greasewood by the plant's denseness, the dark green color, and greater height in comparison with four-wing saltbush. Where there is an admixture of the two, the area is designated AS, Fig. 8. However, it is extremely difficult to distinguish tall four-wing saltbush from short greasewood, even in the field (unless individual plants are examined). It is a questionable distinction with color photography and for practical purposes impossible with black-and-white.

Code SS--black greasewood (*Sarcobatus vermiculatus*)--alkali sacaton (*Sporobolus airoides*).

When 80%-90% of the vegetative cover is greasewood and the soils are alkaline silt and clay, the type is designated SS. Especially along lower drainage channels rubber rabbitbrush occurs. The presence of species of wheatgrass, such as western wheatgrass (*Agropyron smithii*) and alkali sacaton, indicate a heavy soil; increased alkalinity is indicated by shadscale (*Atriplex confertifolia*) instead of four-wing saltbush. Total foliage cover is about 23%, of which 49% is greasewood, 23% rubber rabbitbrush, 17% alkali sacaton, 4% western wheatgrass, and 3% shadscale. Other species, mostly herbs, include wheatgrass (*Bromus tectorum*); tansy mustard (*Descurainia pinnata*); aster (*Aster* sp.); threadleaf snakeweed; miscellaneous grasses: bottlebrush squirreltail grass, galleta, and bearded bluebunch wheatgrass (*Agropyron spicatum*); miscellaneous forbs: globe mallow (*Sphaeralcea* spp.), goosefoots (*Chenopodium* spp.), Indian wheat (*Plantago* spp.); and miscellaneous shrubs: four-wing saltbush, black sage, and prickly pear.

This type is distinguished by the scattered, tall, dark green forms of greasewood, more compact and darker than any other shrub species, Fig. 8 . Intermixed are shorter shrubs--rabbitbrush, snakeweed, and shadscale. The grass cover is nearly textureless. The frequent occurrence of a brownish-red color is interpreted as tansy mustard or goosefoot herbaceous cover.

The distinction between this type (SS) and AS is the presence in the former of shadscale instead of four-wing saltbush. From the aerial photos it is impossible to distinguish between the two closely related plants. The line of separation therefore, is based on topographic position and the increased density of greasewood in the SS type. This distinction is arbitrary and requires field delineation. Note the similarity of the two types in the upper center of Fig. 8 .

Code RW--riparian woody vegetation

This type is composed of pioneers of a river sandbar succession, river bank and terrace species, and shrubby species of adjacent plateau and rubble sites. The most distinct of the woody species, and the only one that grows as a tree with a distinct trunk, is Fremont cottonwood (*Populus fremontii*). The leaves are relatively large and the canopy of the open-grown trees becomes very broad, but large, coarse branches produce an irregular canopy surface. The color is brighter green than the other woody species (tall trees of Fig. 8). Along the edges of floodplain terraces are stands of tamarisk (*Tamarix pentandra*). The larger-sized shrubs of this species are up to 15 ft. high and are distinctly more bushy than the cottonwood. Their foliage is a darker olive-grey color and because of the scale-like leaves and fine branches, produces a lacier, more delicate appearance than cottonwood, Fig. 8. It would be difficult to distinguish large tamarisk from large willows, especially coyote willow (*Salix exigua*), which is present here and which has small narrow leaves. Also, both of these species reproduce from seeds dispersed by wind and water and must germinate soon after deposition on wet sands along the stream margin, a habit that results in their linear alignment along a flood level.

Along the sandbars and lower terraces are commonly found dense stands of short shrubs that are an indistinguishable mixture of young tamarisk and coyote willow plus several species of rabbitbrush, greasewood, four-wing saltbush, shadscale, and black sagebrush, Fig. 8. The great variety of grasses and forbs in the sandy soils and favorable water result in a higher foliage cover, averaging 23%.

A similar vegetation occurs in the alcoves or rincons where there is shade, protection from the wind, and an extra moisture supply. Additional species here include the shrubs of squawberry (*Rhus trilobata*), currants (*Ribes* spp.), chokecherry (*Prunus* sp.), and singleleaf ash (*Fraxinus anomala*).

Code D--dune areas; subtypes Da-active dunes, and Dv-vegetated dunes, Fig. 9.

The sand dune areas are distinguished by the expanses of light-colored dune sand and the relief of dunes. The active dune areas are uninterrupted by a color change or mottling of vegetation. The dunes that are vegetated are occupied by species typical of dune sand. Dominants include the shrubs rubber rabbitbrush and sand sagebrush (Artemisia filifolia). Principal herbs include lemon scurfpea (Psoralea lanceolata), wild buckwheat (Eriogonum sp.), Indian rice grass, wire lettuce (Stephanomeria exigua), inland saltgrass (Distichlis stricta), sand-hill muhly, dropseeds (Sporobolus spp.) and others distinctive of sand dune areas.

An exception to typical sand dune species is the presence of greasewood growing out of dune mounds; the plants were originally rooted in the silt and clay floodplain and have been buried by the accumulation of drifting sand, which was then held in place as a pillar due to adventitious roots. An example is illustrated by an arrow in Fig. 9.

Code Sp-Si--alkali sacaton (Sporobolus airoides)--bottlebrush squirreltail grass (Sitanion hystrix)

Two small local areas of this special grassland type have been designated. The sites are on low, level, undissected, drainageways composed of light grey clay soils of high alkalinity. About 70% of the area is barren clay surface. Of the 30% vegetative cover, 62% is tansy mustard, a weedy, annual mustard increasing in moist springs. About 33% of the cover is the large bunch grass, alkali sacaton, and about 3% is bottlebrush squirreltail grass. Other weedy species typical of disturbed alkaline soils include: Russian thistle, spreading fleabane (Erigeron divergens), salsify (Tragopogon sp.), common sunflower (Helianthus annuus), wooly Indian wheat (Plantago purshii), goosefoots, threadleaf snakeweed, globe mallow, aster, and thistle (Cirsium sp.).

This type is distinctive because of the uniform greyish color of the exposed clay flats and the minimal texture resulting from the lack of shrubs, Fig. 10. Relief within the area is also minimal, as it represents a flat zone of accumulation of fine silt and clay outwash.

Code BR--bare rock

These areas are designated where no distinguishable vegetation is present. It is recognized, however, that some herbaceous vegetation does occur along fractures and in small depressions where sand accumulates. This type occurs most commonly along the rim of the plateaus, steep slopes of the canyon walls, and benches separating plateau levels, Fig. 9. The expanses of bare rock are almost all on the north side of Chaco Wash.

The type is distinguished by its location next to escarpments, its light color (the type is devoid of vegetation and a mantle of darker soil) and the presence of a fracture pattern in the light-colored sandstone bedrock.

Codes Wt--watershed treatment, and Of-Old field succession.

Specific man-made features such as buildings and roads that are presently in use can be identified easily from the 1:6000 scale aerial transparencies of Chaco Canyon because they are entities that are familiar by shape, size, and pattern, are distinct anomalies in the natural patterns of the environment, and are symmetric, straight, or perpendicular geometric forms that rarely occur in this area as natural features.

Other historic man-made features such as earthen dams, fencelines, and old, inactive, revegetated road sites, Fig. 10, can often be identified on the aerial transparencies by their distinct geometric features in contrast to the surrounding natural topography. A difference in color tone created by a

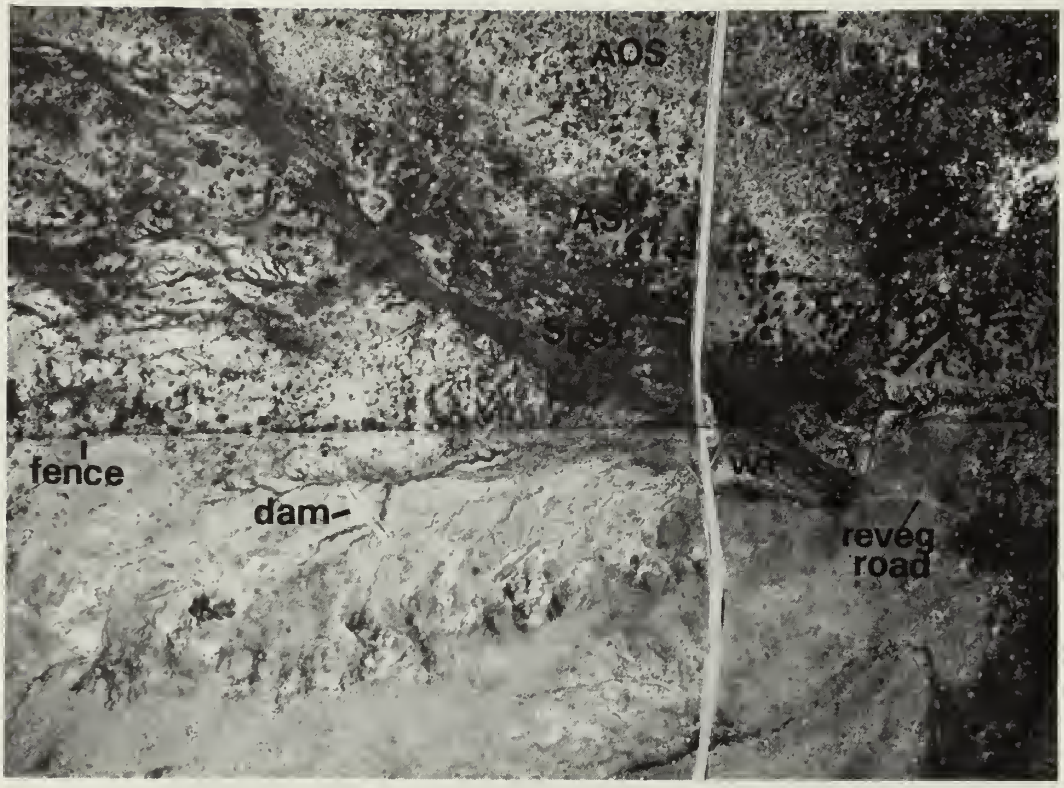

Figure 10 - Aerial view of the south gate area, illustrating the alkali sacaton-bottlebrush squirreltail grass type, SpSi, in low alkaline flats; man-made features such as watershed treatments, Wt, and a variety of other features, e.g. dams, fencelines, revegetated roads.

change in soil conditions or by a change in species composition of the vegetation assists in the identification of geometric features of man-made entities. It is from these types of anomalies that the classifications of watershed treatment (Wt) and old field succession (Of) were developed and plotted within the various types represented on the map.

The watershed treatments (Wt) are identified by a pattern of linear or curvilinear continuous parallel features, Figs. 7 and 10. This type of pattern is produced by tractor-pulled tilling machinery. The disturbance lines are usually oriented at right angles to the natural drainage pattern; the practice is apparently an attempt to reduce gullying in the more erodable soils of the area.

Old field succession areas (Of) are identified by parallel truncated linear features and/or by linear features that outline distinct geometric units of land, Fig. 8. These features are produced by slight changes in the soil conditions, topography, and/or species composition, density, and coverage of the vegetation.

Not included in the vegetational type map is the complex system of prehistoric roads reported elsewhere by Lyons and Hitchcock (1977) and Ware and Gumerman (1977). Some of these roads are visible on the ground; others are visible on the photos but not readily discernible to the untrained observer on the ground. Analyses of transects across the area of the linear features so designated have revealed that two vegetational features provide identifiable characteristics of the prehistoric roads in relatively sandy upland soils. In some areas large clumps of the shrub Mormon tea (Ephedra sp.) grow adjacent to the roadway but not on the road itself. There is an accompanying decrease on the roadway of several other shrub species including four-wing saltbush and snakeweed. All three of these shrub species are more common on loose, sandy soils. On several roadways, an increase in coverage of galleta (which during the summer has a characteristic greyish color) contrasts with adjacent vegetation. It is suggested that these changes in vegetation within the roadway result from compaction of the soil.

Summary

In summary, changes in vegetation in the arid and semiarid Southwest occur in response to relatively minor environmental conditions, especially as these affect the soil-plant moisture relationship. Thus, there is a close link of vegetation to features of geology, physiography, and soils. It is almost imperative that the investigator become familiar with these relationships before mapping from the aerial photographs. With these basic relationships in mind, one can turn to the aerial photos and apply an understanding of a multiplicity of ecological factors to the interpretation of the photos and, thus, produce a more meaningful designation of vegetational types.

It must also be recognized that when the investigator is dealing with the species of a vegetation, only a few species (usually of a unique growth form or height) may be identified. Young and shorter plants of a species may be indistinguishable from other species. Some species are distinguishable because of a peculiar texture or color. It is important to remember in this regard the change that may occur with season of the year. Different distinctions may be made in spring versus fall, for example.

Finally, many species in this area, especially annuals, have great fluctuations in density and coverage in response to drastic fluctuations from year to year in annual precipitation.

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CULTURAL RESOURCE INVENTORY OF THE BIG CYPRESS SWAMP: AN EXPERIMENT IN REMOTE SENSING

by

John E. Ehrenhard

Abstract

In compliance with Section 106 of the Historic Preservation Act of 1966 and Executive Order 11593, the Southeast Archeological Center undertook initial archeological investigations at Big Cypress National Preserve. This effort represents "Field Phase 1" of a four-phase field project.

Time/cost comparisons were made of four reconnaissance techniques employed. These were: 1) false IR color photointerpretation, 2) use of informants, 3) random sampling of hammock islands, and 4) maps giving site locations. The efficiency of using color IR photos for locating cultural features is adequately demonstrated.

Introduction

During the current decade Federal archeological centers have become increasingly immersed in cultural resource inventories. This rises out of the obligation the Service has, through congressional mandate, to locate, identify, evaluate, preserve, manage, and interpret the heritage found within the areas it administers. Accordingly, the Center has initiated actions to provide cultural resource inventories of all areas within the southeast region of the National Park Service System.

Although many southeast park properties are small and easily accessible, there are a number of areas that encompass thousands of acres (Cumberland Island National

Seashore, 47,000 acres; Canaveral National Seashore, 67,500 acres; Big Cypress National Preserve, 560,000 acres) and numerous topographic features. These low-lying densely vegetated land masses present formidable transportation and logistical problems. These difficulties, coupled with the necessity to achieve high standards for research design and execution, and to conform to Service timetables, result in unique inventory challenges.

In the past few years the Southeast Archeological Center has made improvements in its archeological techniques that have provided for more efficiently controlled and systematic methods of field data recovery. Two techniques receiving considerable use are composite mapping (Ehrenhard 1979) and the archeological interpretation of high-level false color infrared photographs. The cultural interpretation of such photographs, used in phase 1 of the Big Cypress cultural resource inventory, is the subject of this paper (Fig. 11).

Tartaglia (1977) pointed out that archeological sites can be detected on high level photos from soils, crop marks, and shadow marks. Preliminary studies with color IR photos of the Big Cypress indicate that subtle changes in elevation and the associated change in vegetation are the key to the location of archeological sites. In contrast to the experiences of Gumerman and Kruckman (1977:22) who felt that color imagery did not permit identification of small environmental zones, we found that the dense vegetation of the swamp quickly revealed the location of cultural features. This probably results from the fact that small differences in elevation permit extreme changes in vegetation. As small a rise as 15cm. provides the difference in elevation necessary to support a hardwood hammock or a grass-covered marsh. For an excellent discussion of the unique natural environment of South Florida, see Gleason (1974).

Big Cypress Vegetation Association

There are six fresh-water vegetation associations within the Big Cypress--pine forest, hammock forest,

Figure 11 - Big Cypress Swamp

cypress forest, mixed swamp forest, prairies, and marshes (McPherson 1974:10-11). All are directly tied to natural phenomena such as fire, elevation, water depth, and period of inundation.

1. Pine forest (Fig. 12)...open areas of pine, cabbage palm, and saw palmetto, low grasses and scattered bushes. Considerable open area. This is a sub-climax association maintained by fire, which restricts the spread and density of hardwood trees. Elevation is 20-50cm. higher than the surrounding cypress.

2. Hammock forest (Figs. 12,13,14)...land is slightly higher than the marshes, prairies, and cypress forests. Vegetation includes hardwoods, palms, and shrubs. This plant community usually represents a climax development created in the absence of fire.

3. Cypress forest (Fig. 12)...open areas of cypress trees, cypress domes, and strands. Sparse growth of herbaceous plants on a thin marl soil or sand overlying limestone cap rock. Strands may be kilometers long and follow past or present drainage depressions.

4. Mixed swamp forests (Fig. 12)...dense vegetation of trees, shrubs, and vines occurring as elongated strands that follow low drainage areas. Elevation varies; some areas are subject to seasonal flooding.

5. Prairies (Fig. 12)...associations of mixed grasses, sedges, and other herbaceous plants; few trees. May be seasonally flooded for months (wet prairies). Dry prairies occur at slightly higher elevations and throughout the northern portions of the swamp; wet prairies are concentrated in the southern areas.

6. Marshes (Fig. 12)...dominated by tall sawgrass. Water is normally deeper than in the surrounding prairies.

Archeological interpretation of these environmental zones was accomplished using color infrared imagery purchased

Figure 12 - Big Cypress Vegetation Associations

from the Mark Hurd Corporation (scale 1:80,000). Site signatures for the Preserve generated were from this imagery data gained from previous research in the Glades area undertaken by Carr (1974), and Cumberland Island National Seashore (Ehrenhard 1975).

Site Model

Archaic coastal cultures of South Florida display definable relationships to Holocene sea level transgressions and regressions, outlined by Fairbridge (1974). Land use patterns indicate that most middens, campsites, and sand mounds are situated on the higher dry hammocks along banks next to deep slough or wet marshes (Figs. 13, 14). Such locations, formed during a period when the water level within the swamp was much higher, provided both dry living areas and proximity to canoe access points.

These site model factors could be easily recognized on the IR imagery by their texture, location, relationship to surrounding objects, and color. The signatures, first located on the Hurd imagery, were plotted on 7.5 minute topographic quadrangles as primary areas for ground verification. Locations of possible sites were reached via helicopter. On-site assessment of the target areas revealed that 80% of the selected areas contained cultural remains. The success of the method and the site model was adequately demonstrated by the partial survey of the hammock island chain between U.S. 41 and the Loop Road (see top half of Fig. 12). A preliminary ground survey of six hammock islands using swamp buggies without the aid of aerial photos revealed no sites. A second investigation of the same area through photointerpretation resulted in the detection of five possible site areas. Ground survey revealed that four of the five were sites. It is significant that three of the four sites located exhibited no surface material that would have indicated the presence of a site. It is unlikely that these sites would have been discovered without the aerial imagery.

Synopsis of Survey Methodology

Four reconnaissance techniques were employed and compared during our field studies. These were: 1) color IR photointerpretation, 2) use of informants, 3) random sampling of hammock islands, and 4) earlier maps indicating site locations. A variety of transportation was used. A four-wheel-drive "swamp buggy" and ATV's (Honda three-wheeled all-terrain vehicle) were used when attempting to find sites located on maps, described by informants, or by the random selection of hammock islands. Cultural manifestations suggested on the high-level photos were reached via helicopter.

Each method and the associated mode of transportation has advantages and disadvantages (Table 4) relative to the geography, weather, equipment, and personnel carrying capacity (Ehrenhard, Carr, Taylor 1978). Informants frequently mistook exact site locations which resulted in considerable back-tracking. In some instances a single site was known by three or four names, which resulted in duplication of effort. Early maps giving site locations were found to be misleading. One explanation for this is the fact that early archeologists working in the Glades frequently deliberately mislocated sites to prevent their destruction by treasure hunters. A random sample of hammock islands provided a pleasant outing but yielded few sites. From ground level the hundreds of hammock islands revealed no distinguishing features and created problems of accurate site location. The high resolution of the aerial photos and the ability of the helicopter to rise above the forest canopy provided for easy identification of individual hammocks and proved to be the most successful method used through the survey.

Summary

The size and natural environment of the Big Cypress National Preserve has generated special reconnaissance problems that are best solved through the interpretation of high-level color infrared imagery. Future fieldwork in the area will be enhanced by the predetermination of

Figure 13 -- Aerial view-Hammock forest

Figure 14 - Ground view-Hammock forest

TABLE 4

TIME/COST COMPARISONS OF FOUR RECONNAISSANCE TECHNIQUES

METHOD*	Sites Indicated	Sites Located	Percent Efficiency	Man Hours	Cost***	Cost/Hour	Cost/Site Located	COMMENTS
Photointerpretation, Helicopter	31	25	80	48	$2222	46	89	Excellent mobility, efficient use of time, low carrying capacity. Open country fair weather use only.
Informants, Swamp buggy, ATV**	30	21	70	360	7315	20	348	Variable mobility, but slow. Large capacity, not weather dependent. Time loss due to faded memories and backtracking through cypress.
Random Sample, Swamp buggy, ATV	25	15	60	300	6163	21	411	Time consuming. Involves a high degree of "luck." Variable mobility, but slow.
Maps, Swamp buggy, ATV	5	2	40	60	1552	26	776	Time consuming, expensive.
TOTAL	91	63		768	$17,252			

* All methods employ a three member reconnaissance team.

** Honda three-wheeled "All Terrain Vehicle"

*** Includes salaries and per diem, transportation rental ($80/hr. for Helicopter, $60/day for Swamp buggy & ATV).

possible cultural features. This will result in more accurate research designs and systematic on-the-ground investigations. The integration of aerial remote sensing data with information on site and environmental characteristics that influenced the location of camps/ habitations will provide new insights into Glades prehistory.

Photointerpretation for cultural features in Big Cypress as opposed to more "long-established" techniques, suggest potential economic/managerial benefits not only in cultural resource management but for other phases of park operations as well. Applications could be generated to facilitate land acquisitions, preservation of natural resources and wilderness, or law enforcement. Although each speciality has differing objectives and goals, potential or specific sites could be detected because of the individually distinctive signatures created by the cultural, social, environmental (or any combination thereof) conditions associated with the particular field of endeavor.

Cultural interpretation of high-level color infrared imagery can provide substantive data needed to formulate preservation, management, or maintenance proposals. Though such proposals are subjected to ecological, economic, or social changes, the research flexibility and easy data access provided by aerial remote sensing will not be compromised by modification of management objectives.

Identification and delineation of cultural, geological, environmental features, etc., through photointerpretation prior to actual fieldwork will help reduce the large funding base necessary for such research. Most important, it will allow for more balanced allocation of time and monies and provide for more controlled and systematic management.

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THE DETECTION, MITIGATION AND ANALYSIS OF REMOTELY-SENSED, "EPHEMERAL" ARCHEOLOGICAL EVIDENCE

by

James I. Ebert
Thomas R. Lyons

While the term archeology usually conjures up visions of excavated sites containing obvious structures and large amounts of artifactual material, the advent of recently-developed techniques such as remote sensing to cultural resource analysis has demonstrated that there are a number of other, less immediately obvious, sorts of sites. Many of prehistoric (and historic) man's modifications of the natural landscape are ephemeral at best when viewed from the ground, and some of these features may have minimal artifactual associations. Nonetheless, the information content of these features can be as high or higher than excavated sites. Methods must be developed to extract the greatest possible information from such features. There are numerous examples of this kind of phenomena obscure or unseen from proximate landbased perspective. The classic types are the soil marks, shadow marks and crop marks long identified and used for site discovery and location in Europe.

A particularly outstanding example of archeological features not immediately or extensively visible on the ground is provided by the San Juan Basin prehistoric roadway system which connects Chaco Period sites in northwestern New Mexico. Only a few miles of prehistoric roadways were known to exist at Chaco Canyon National Monument prior to the application of aerial remote sensing photography. Beginning in the early 1970's, intensive interpretation of aerial photos and other remote sensor data at the Remote Sensing Division of the Southwest Cultural Resources Center (then part of the Chaco Center) allowed the identification and mapping of more than 200 miles of these features extending throughout the San Juan Basin and beyond. Roadways so interpreted and plotted were ground-truth checked in the field; in many cases, while short segments visible on the ground provided positive proof of the existence of the interpreted features, there was little or nothing to be seen along most of the roadway routes. Structural evidence associated with roadways include stairways, ramps, curbs along roadway margins, flagging or paving of their surfaces, and a number of diverse masonry structures--but these are for the most part restricted to very short segments of roadway, especially in the vicinity of large archeological sites. It has been suggested that pottery and other archeological evidence is distributed more densely along roadway routes than in similar but untravelled areas; and while this is almost certainly true, absolute sherd and artifact densities along roadways at any distance from prehistoric population centers is so low as to present serious problems in sampling and analysis.

Similar situations are presented in New Mexico and elsewhere by agricultural fields and their boundaries, certain classes of water-control features, organically-caused soil discoloration and other sorts of archeological features which do not necessarily co-occur with artifactual evidence. While some of these may have aspects which are detectable on the ground, others may never be unambiguously detectable by digging, surface collecting, or even chemical or other physical analysis. This raises a number of very real problems which must be resolved if our responsibilities for the preservation, recording and analysis of cultural resources are to be conscientiously met.

One of the foremost of these problems is the determination of proper mitigation procedures. Perhaps the best way to approach any mitigation requirements is to begin with the question of just what sorts of information can be recovered which are important in a theoretical sense--i.e., if a site or feature were destroyed, what information of importance to our understanding of the past would be lost? By far the most important information contained in such features as roadways is their location--where they are and where they go. This is precisely the information which is revealed to the maximum possible extent in remote sensor data. For this reason, identification and mitigation efforts should in all cases begin with remote sensor imagery, and in some cases the collection of remote sensor data may prove to be the only data collection necessary.

In most areas, previously-flown U.S.G.S. or other mapping imagery exists on which ephemeral features can be identified, if in fact they do exist in a project area. Not all imagery is identically useful in revealing roadways or other features, however; such factors as sun angle, scale, and season of year are extremely important. Remote Sensing Division studies indicate that black-and-white imagery at scales between approximately 1:20,000 and 1:30,000 is probably optimal for roadway identification if other factors such as sun angle and direction are correct; color infrared imagery can also aid greatly in the detection of segments early in the vegetative growth season. In areas where roadways are suspected--and this must be taken to include the entire San Juan Basin and adjacent areas--any and all available imagery should be analyzed by a qualified interpreter to determine whether or not ephemeral prehistoric features occur.

If the determination is made that ephemeral locational features do exist in the study area, a second remote sensing stage is warranted. Just as in the use of any technique, the most useful applications can be made when the tool is suited to the purpose for which it is intended. Manipulation of scale, sun angle, photographic emulsion or sensor type, and other aspects of the total remote sensing methodology must be carefully designed for maximum information gains. This can only be assured by planning and flying imagery specifically suited to the features which are to be detected. Such a stage is necessary even when portions of the features in question have been detected on pre-existing imagery.

Ground-truth checking is of course essential to any remote sensing analysis, and the third stage in the mitigation of features detectable primarily from the air would entail the use of different sorts of techniques of inspection to determine to what extent the features can be detected by means other than those employed in their initial discovery and plotting. At one time, "ground truth checking" in remote sensing held the implication of being accomplished only by walking on the ground. The realization that a person conducting survey on the ground is actually performing remote sensing at an altitude of about five to six feet sheds a different light on this problem. In a very real sense, all observation and measurement of any physical phenomena involve differing degrees of "remote" sensing, and no one method is necessarily more accurate, efficient, or believable than another in all circumstances. Ground-truth checking might be accomplished with the use of lower-altitude remote sensor imagery or actual inspection from light aircraft or a helicopter as well as on the ground. For most archeological features, naturally, either surface survey or test excavation should be undertaken. The object of these activities, like other sorts of ground truth testing, would be to determine if any visible, physical evidence concurrent with the ephemeral features could be detected by different means. In many cases, such as that of most segments of the San Juan Basin roadway system, this may not be the case.

This fact raises another potentially difficult question, that of just what constitutes "truth" in the detection and measurement of archeological data. Certainly the fact that a feature can be detected in one manner and not in another does not rule out its existence, for arguments based on the validity of data can go on forever without resolution. Fortunately, the method of science in general provides the solution to this problem. The existence or non-existence of any physical phenomenon can only be tested by drawing theoretical implications from the data believed to be present and testing these for consistency against both the observed phenomena and independently measured observations of other sorts. In the case of the San Juan Basin roadway system, for instance, once a certain pattern of roadways was believed to exist, the theoretical implications of that particular network pattern in contrast to a different pattern might be deduced. If supportive data, such as the distribution of pottery with designs or temper for which origins could be determined supported the first network pattern rather than the second, the existence of the first would be supported. Independent evidence to the contrary would, of course, cast doubt on the existence of the network system believed to exist, or at least the completeness of the interpretation. Any other approach to the question of whether or not data exists is counter to the scientific method.

A HISTORY OF RESEARCH ON THE CHACOAN ROADWAY SYSTEM

by

Margaret Senter Obenauf

Introduction

The prehistoric roadway system of northwestern New Mexico first observed in Chaco Canyon in the early 1970's has been the subject of discussion and speculation for the past few years. It is thought that this network connects outlying Chacoan sites with Chaco Canyon and with each other. Several papers on the roads have been published (see References) but up to the present only a map of the area around Pueblo Alto in Chaco Canyon National Monument (Lyons and Hitchcock 1977:119) and two schematic maps of the roadway system (Lyons and Hitchcock 1977:122; Lyons, Ebert and Hitchcock 1976:306) have been published. Therefore, the first purpose of this paper is to make available to interested archeologists detailed maps of the roadway system as it is known to date. The second purpose is to identify all those who have played a significant part in the discovery and documentation of the roads.

Briefly, the roadways are engineered features which may be characterized by cleared road beds and borders of banked earth or, especially near major sites, masonry walls. Features such as stairs (Fig. 15), ramps (Fig. 16), or causeways (Fig. 17) were constructed where roadways encountered some sort of obstacle. The roadways are quite straight and often go through or over natural obstacles rather than veering to avoid them. The roads may be up to 9 meters wide and seem to have been laid out on a preconceived route. When the roads change direction, they do so abruptly with a "dogleg" rather than with a slow turn like modern roads in the area. The Chacoan roadways have been described in greater detail by Ware and Gumerman (1977) and Obenauf (1980).

Figure 15 - "Jackson's Staircase," located near Chetro Ketl in Chaco Canyon National Monument has no known roadway association.

Figure 16 - A ramp near Penasco Blanco in Chaco Canyon National Monument.

Figure 17 - A causeway (or wall) crossing a ravine near Penasco Blanco in Chaco Canyon National Monument.

The roads are not easily seen on the ground. A few segments stand out distinctly at dawn or dusk and a few appear as a line of changed vegetation, but most are invisible from the ground. The situation from a vantage point above the roads is quite different. On aerial photographs at scales of 1:6,000 to 1:32,000 the roads appear as almost perfectly straight lines, whereas modern vehicular roads in the area have a curvilinear or erratic pattern which comes from avoiding topographic and vegetational obstacles. Most of the road segments have been mapped with the aid of a stereoscope since stereoscopic viewing often exaggerates the slight depression of the roadbeds, making them easier to map accurately. About twenty percent of the roads were discovered with the aid of a sophisticated electronic image enhancement device which exaggerates another attribute of the roads, their linearity.

The maps contained in Appendix I are the result of several years of photointerpretation and mapping by the personnel of the Remote Sensing Project of the Chaco Center, now the Remote Sensing Division of the Southwest Cultural Resources Center. The maps cover Chaco Canyon, several outlying Chacoan communities, and intervening areas. The road traces identified on photographs were transferred visually to USGS topographic maps prior to field check. Since the procedures now employed to make this transfer are somewhat more accurate, these maps should be considered preliminary and subject to change with further investigation. Maps resulting from a Master of Arts thesis to be published by the author will more fully incorporate the results of field check. Continued research as described below will no doubt fill in some of the gaps in these maps and identify roadways in other areas (see Obenauf 1980).

Early Investigations

Because of the low ground visibility of the Chacoan roads, it is not surprising that the network of roads was not discovered earlier, even though isolated roadway segments had been reported in Chaco

Canyon as early as 1901. The "discovery" that the roadway segments were part of an extensive network was actually a gradual process of each new investigator building on earlier findings. This process started with Special Agent S. J. Holsinger, who had been sent out in 1901 by the General Land Office to survey Chaco Canyon and to make recommendations on its inclusion in the National Park System.

Although William Henry Jackson, the well-known frontier photographer, described several of the rock-cut stairways in 1877, including the impressive one known today as "Jackson's Staircase" (Fig. 15) (Judd 1964:143), the earliest mention of roads in Chaco Canyon is by Holsinger in his 1901 report. He talks of (Holsinger 1901):

> "...an ancient road-way, which can be traced from Chettro Kettle stairway to Alto ruins. This road-way was 20 feet wide and walled up to a grade with loose rock and soil. It commenced near the top of the stairway referred to and followed a narrow shelving or terrace of the rock, westward, parallelling the canyon. It followed this ledge for about half a mile to a point where there are indistinct remains of a broad flight of steps, twenty-one in number. At the top of this stairway there appears to have been a shrine, around the rude carved figure of some animal, now mutilated beyond recognition. It is near this point where the first traces of the groove is found and it follows this road-way to a point where it crosses a wash and enters the sand covered mesa where both disappear."

While Neil Judd was excavating in Chaco Canyon in the 1920's he questioned two elderly Navajos on a number of subjects, including the roads. Reporting his conversation with Hosteen Beyal, who was about 95 years old at the time, Judd says (1954:346):

> "When asked about the so-called 'roads' on both the north and south cliffs, Beyal remarked that they were not really roads, although they looked like them. He says they were built by the Chaco people. One road led from Pueblo Pintado to Pueblo Bonito and on to Penasco Blanco. Another led from Pueblo Bonito to Kin-yai; a third, from Kinbiniyol to Kin-yai; still another, from Kinbiniyol to, or through, Coyote Canyon and on to a point near Fort Defiance. On each of these 'roads' one could see, until recently, cuts where the road passed through small hills."

The other informant, Padilla, said that a cut at the south end of The Gap which some Navajo called a canal looked more like a wagon road to him. Judd, however, believed that it was part of a ceremonial highway (Judd 1954:350). Fig.18 is a schematic map of the routes suggested by Beyal.

In 1964 in _The Architecture of Pueblo Bonito_, Judd again remarked on the roads. He states that a stairway "is to be seen near every other major Pueblo III ruin in Chaco Canyon and broad pathways lead from one to another. The Navajo refer to these pathways as 'roads' and my guess is no better" (Judd 1964:142). Judd was at a loss to explain the roads (1964:142):

> "Jackson's stairway is one of the best, but what was its purpose? The diverse 'roads' are equally beyond convincing explanation. There is the broad pathway extending southeast from Pueblo Alto with 10- to 20-foot-wide hammer-battered steps at every ledge and a pecked groove throughout much of its length; there is the retaining wall edging a 30-foot cliff in a rincon back of Chettro Kettle and a stairway at the end of the trail. There is another step series across the canyon, irregular and cramped, and a cleared path from rimrock toward _Tsin Kletsin_. There is a magnificent stairway overlooking

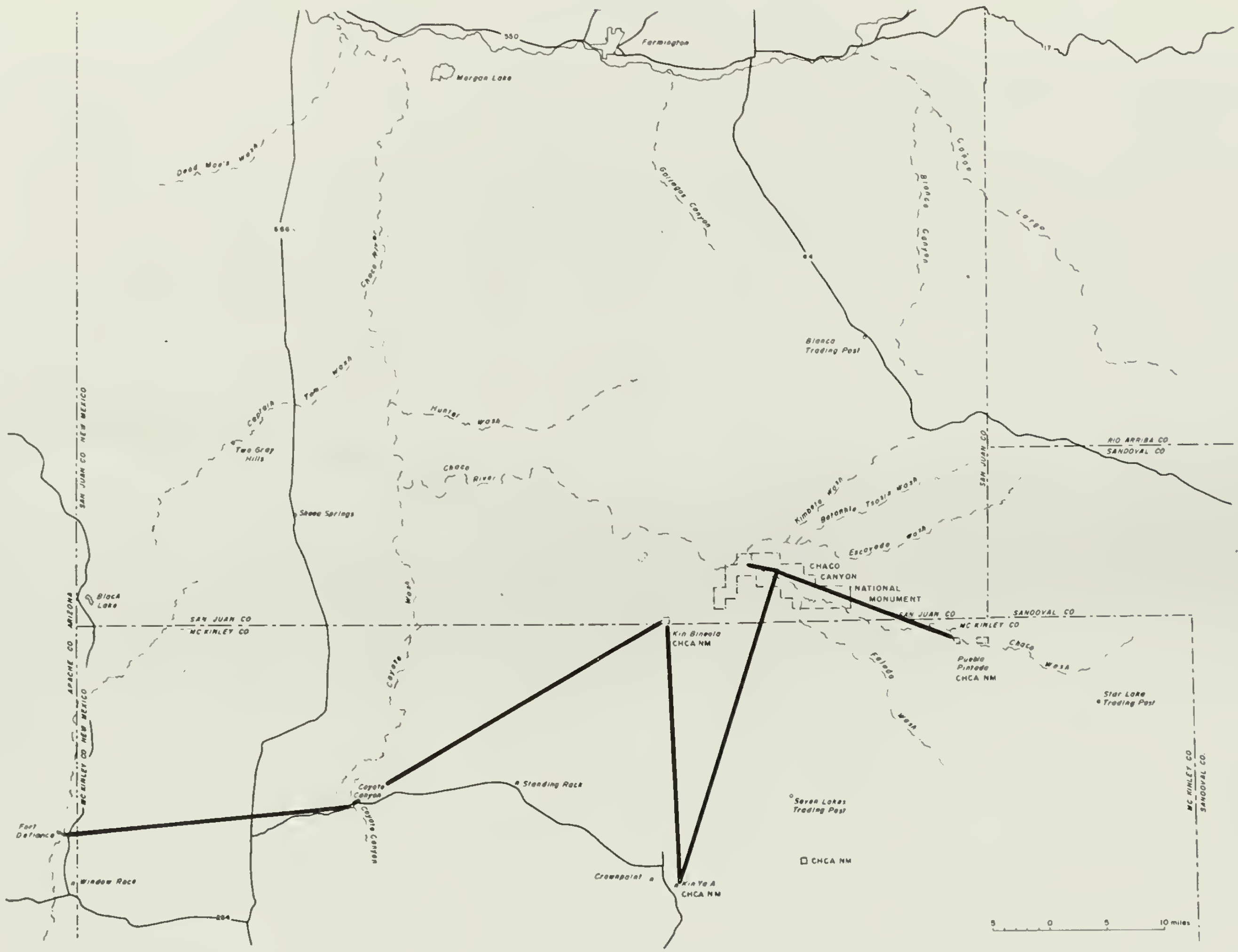


Figure 18 - Schematic Map of the routes of Anasazi roadways suggested by Neil Judd's Navajo informant, Hosteen Beyal.

Hungo Pavie and a conspicuous 'road' dug through a sand ridge south of The Gap. Each was a prodigious undertaking of which the Late Bonitians or their contemporaries were thoroughly capable but each remains a mystery."

Judd's knowledge of roads in the Chaco area was not available until 1954 and 1964 when these brief references were published. In the meantime, Edgar L. Hewitt of the University of New Mexico and the School of American Research excavated at Chetro Ketl. He made no reference to the roads in his published reports; nevertheless, he did talk about the Chacoan roadways to his students. He took them walking on road segments on the north mesa of the Canyon, and told them there was a road connecting Chaco Canyon with Aztec Ruin. This road, however, was never mapped. Hewitt also believed that roads linking Chaco Canyon with Mexico would eventually be found (Marjorie Lambert, personal communication, 1978).

Later, Gordon Vivian began work in Chaco Canyon. He also knew about at least one roadway segment, for in a memorandum to Superintendent McNeil of Chaco Canyon National Monument dated October 29, 1948, he gives an account of an interview with Richard Wetherill's widow, Marrietta, in which she told him that "north of Alto in certain lights you can still see what appears to be a wide roadway running down to the Escavada. In the old days this was very clearly defined in the spring or early summer because the vegetation on it was different from any other and it could be traced clear to the San Juan" (Lyons and Hitchcock 1977:130).

In the late 1940's Vivian noticed lineaments on Soil Conservation Service photographs which had been taken over Chaco Canyon in the 1930's. Vivian believed that these linear features were related to water control. In 1964 he contracted with Limbaugh Aerial Mapping in Albuquerque, now a division of Bovay Engineering, for a series of photographs of selected areas of Chaco Canyon. From these photographs he mapped more sections of what he believed to be an extensive water control system in Chaco Canyon (R. Gwinn Vivian, personal communication, 1977).

In 1967, R. Gwinn Vivian, Gordon Vivian's son, began additional research in Chaco Canyon. This work was primarily a more intensive investigation of the "Pueblo Alto Water Control System" (Vivian 1970:69). At the time this research was done, Vivian believed that Judd had been mistaken about the purpose of several features on the mesa top. For example, he felt that the "ramps" and "stairs" were in fact "pour-off structures" designed to slow and hold water, and the road between Pueblo Alto and Chetro Ketl was designated "Canal 3" (Vivian, personal communication, 1977).

Gwinn Vivian again conducted field work in Chaco Canyon from August 1970 through May 1971, the purpose of which was an intensive survey of water control in the central canyon and several outlying areas. Early during this field work it became obvious that several of the canal systems identified during the 1967 survey were not canals but prehistoric roads (Vivian 1972:3). Vivian came to this conclusion as he and Robert Buettner, a graduate student at the University of Arizona, were excavating a section of "Canal 3." This section of the Alto-Chetro Ketl road referred to by both Holsinger and Judd is lined with masonry walls laid on bedrock, and is unmistakably not a canal (Fig. 19). Realizing that some of his previous work was in error, Vivian decided to devote some project time to a pilot study of the roadway systems. Buettner was given responsibility for this project (Vivian 1972).

Several areas suggested by Judd and his Navajo informants were included in this brief roadway survey. Six road systems were identified and named: Kin Ya'a, Tsin Kletzin, Chaco East, Chaco West, Chaco South and Chaco North (Fig. 20).

The portion of the "Kin Ya'a Road" mapped by Vivian and Buettner consisted of a section of banked roadway extending from approximately .5 km south to .3 km north of the ruin. Other possible sections of it were noted from the air and on aerial photographs but were not mapped.

Figure 19 - Masonry-lined section of roadway excavated by Vivian and Buettner.

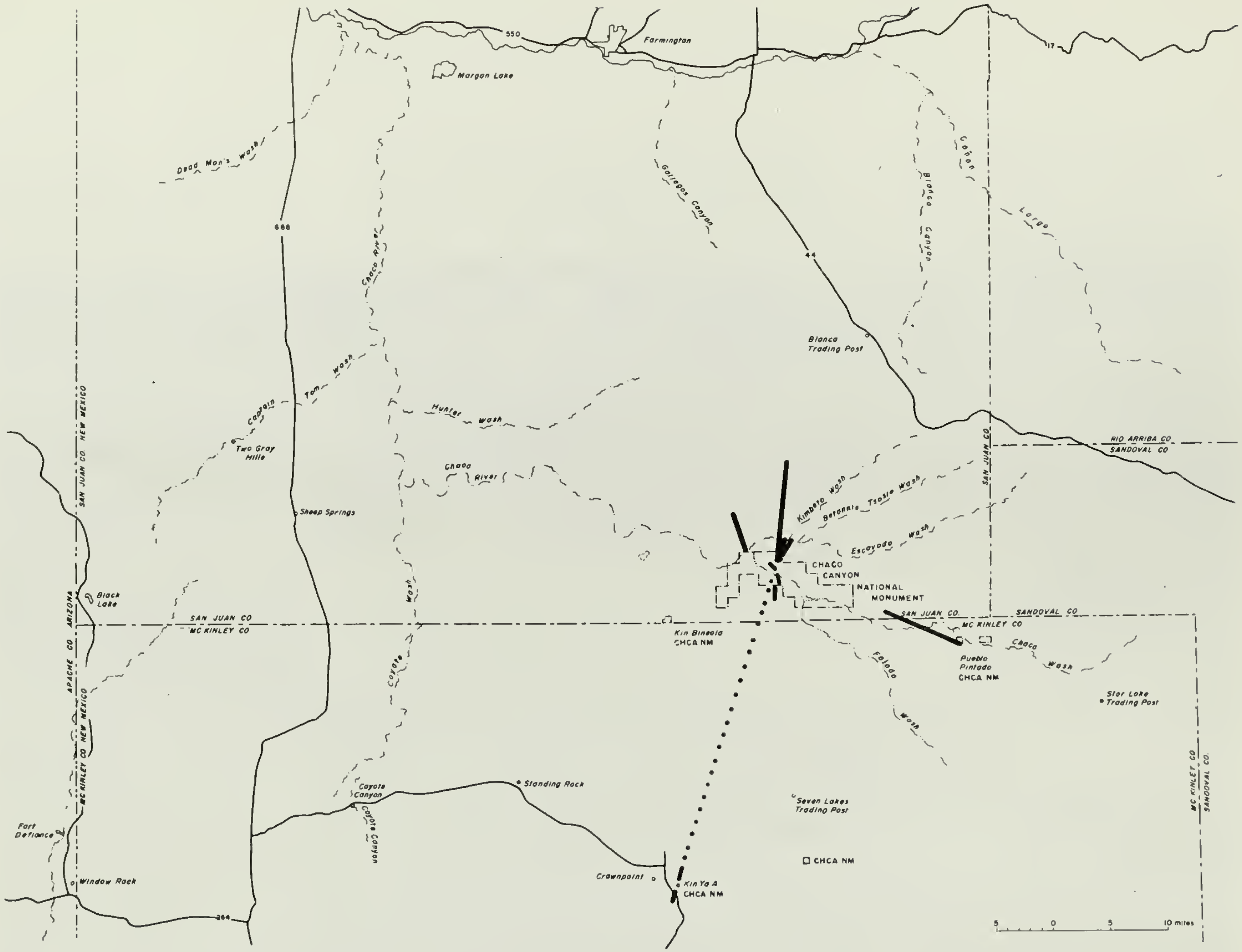


Figure 20 - Schematic map of the roadway system investigated by Vivian and Buettner.

An .8 kilometer segment of the "Tsin Kletzin Road" was mapped from aerial photographs. This section extended from the ruin to the edge of the mesa. Extensions of this same alignment revealed a series of rock-cut stairs leading toward Casa Rinconada on the canyon bottom. A possible spur of this road, pictured by Judd (1964: Plate 40, top), is located on the cliff top east of Rinconada. It consists of less than .5 kilometer of rock-bordered roadway and a rock-cut stairway.

Buettner mapped the "Chaco East Road" from the eastern head of Chaco Canyon to the southwest corner of Pueblo Pintado. This road followed an almost direct route for 4.5 kilometers. The "Chaco West Road" was traced from the western edge of Chaco Canyon four kilometers to Ah-she-sle-pah Canyon. Vivian and Buettner mapped the "Chaco South Road" from a point opposite Pueblo Bonito through South Gap southwest about two kilometers. The last section visible was at the edge of Chacra Mesa. A possible spur of the "South Road" branching south near the southwestern end of the road was noted on several photographs but could not be located on the ground and so was not mapped (Vivian 1972).

The "Chaco North Road" system was the most complex mapped by Vivian and Buettner (Fig.21). They mapped three major roads converging on Pueblo Alto from the north and four spur roads linking Alto with the Pueblo Bonito-Pueblo del Arroyo-Chetro Ketl complex (Vivian 1972).

National Park Service Investigations

Soon after Vivian and Buettner began their 1970 roadway survey, Thomas R. Lyons of the New Mexico Archeological Center (later called the Chaco Center), which had just been established by the National Park Service to study Chaco Canyon, happened to be visiting the Canyon. Lyons had been hired by John Corbett, then Chief Archeologist of the National Park Service, to experiment with the applications of

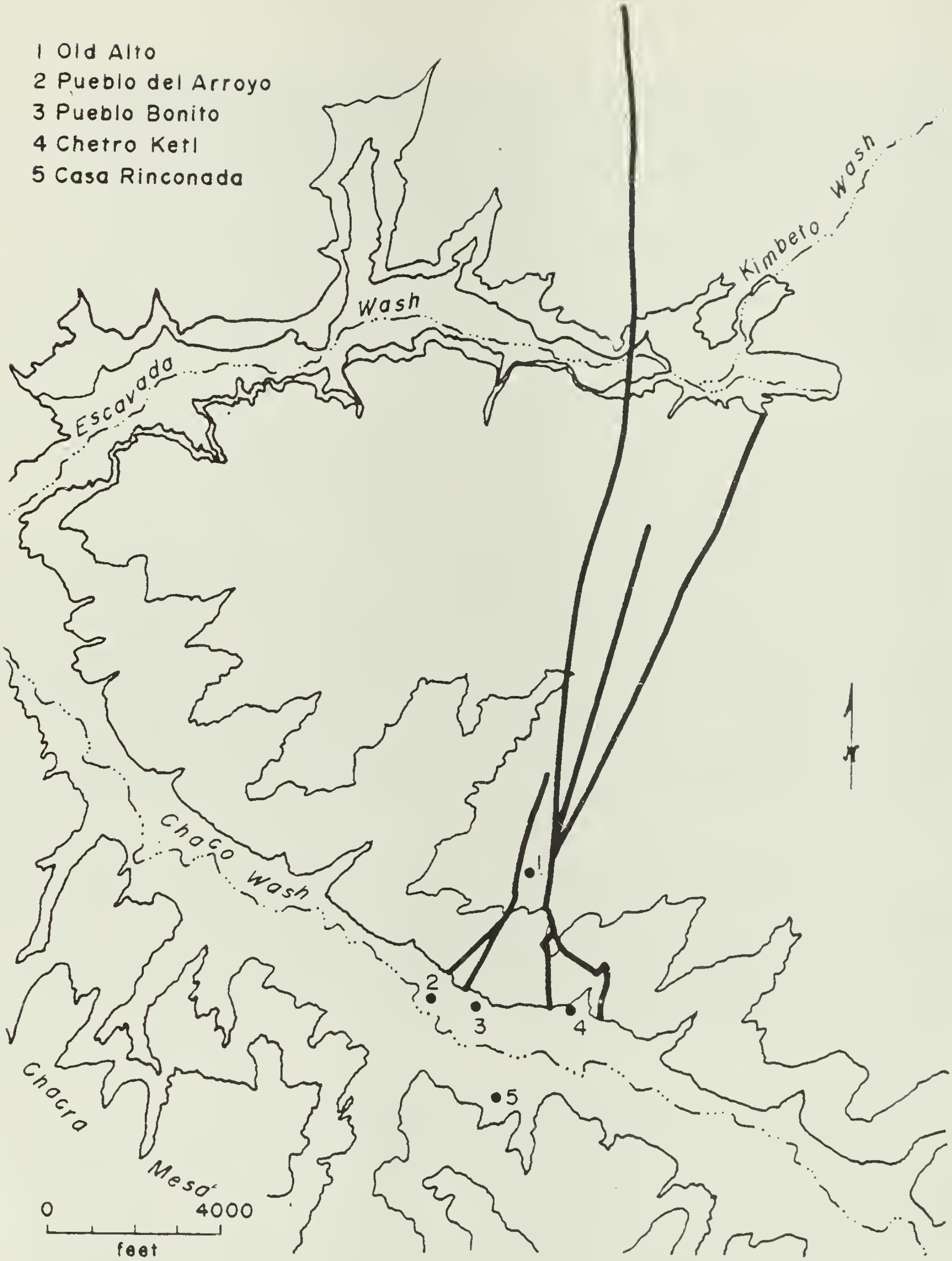


Figure 21 - The "Chaco North Road" system as mapped by Vivian and Buettner (redrawn from Vivian, 1972).

remote sensing to archeology. Corbett had been interested in this problem for some time, having commissioned the Itek report, <u>Archeological Photo Interpretation</u> (Itek Data Corporation 1965), and in Tom Lyons he saw the opportunity to apply some of his ideas to the new Chaco project. Gwinn Vivian pointed out to Lyons some of the roadway segments both on the ground and on aerial photographs. This was a case of the right person's being in the right place at the right time. Though Neil Judd believed in the existence of the roads, he did not have access to the tools needed to see more than a couple of miles of the roadway. Gordon Vivian had used remote sensing technology, but to locate what at that time were thought to be water control systems in the immediate vicinities of major ruins. Tom Lyons was not only familiar with the use of remote sensing techniques, but he was also aware of the roads.

Since he had used aerial photographs extensively in his work as a geologist, one of Lyons' major interests as an archeologist was the application of remote sensing techniques to archeology. He saw in the roads an excellent opportunity to experiment with the possibilities of these techniques. On his return to Albuquerque he ordered U.S. Geological Survey and Soil Conservation Service aerial photography of the Chaco area. Lyons spent a good deal of time during the fall and winter of 1970 examining these photographs stereoscopically, concentrating on the Monument itself. The USGS imagery, flown in the 1960's at scales of about 1:32,000, turned out to be excellent for mapping the roads, while the 1930's SCS imagery, at similar scales, provided a valuable time depth. Taken before grazing was prohibited in the Monument, the SCS imagery presents a very different landscape on which some of the roads are much more prominent than on more recent imagery.

Since the road system was turning out to be considerably more complex than either Lyons or Vivian had guessed, Stephan Shure, a graduate student at the University of New Mexico, was hired in May, 1971 to work on the project. Shure, a pilot in the Air Force, was accustomed to the aerial perspective and quickly became proficient at photointerpretation. The summer of 1971 was spent on photointerpretation, with Lyons and Shure making several trips to Chaco Canyon to field check their photointerpretations. A recognition pattern for the roads began to emerge and some of the more visible roadway segments were mapped at this time.

Late in 1971 Shure left and was replaced by Robert K. Hitchcock, a graduate student at the University of New Mexico. Hitchcock and Lyons continued photointerpretation of the USGS and SCS imagery. In April of 1972 the first of a series of flights was made over Chaco Canyon for the specific purpose of locating prehistoric roads. The new black-and-white photographs, flown at a scale of 1:6,000 proved useful in mapping the complex network of roads within the Monument boundaries. Experimentation with scales, however, showed that the smaller scale imagery, such as the USGS imagery at 1:32,000, was better suited for locating and mapping the roads.

In 1972 the New Mexico Archeological Center contracted with George J. Gumerman, then of Prescott College, to do research on two aspects of the roadway system. The first was the physical characteristics of the roadway network; the second was to determine the capabilities of different types of remote sensor data in delineating the roads. The imagery evaluated included varying scales of black-and-white and true-color photography, as well as multi-band photography. Also tested were a color-additive multispectral viewer and an isodensitometer. Prescott College students assisting in the field and laboratory were L. Barker, L. Capper, C. Chang, D. Hanson, K. Jones, M. Reed, S. Sessions, and S. Wilson. Results of this project are reported in Ware and Gumerman (1977).

The Pueblo Alto area was chosen as the test target because of the large number of roads converging on that site. The available imagery was examined both to relocate previously known roadway segments and to identify new ones. The scales of this imagery ranged from 1:3,000 to 1:32,000. As before, the Prescott College group found that the smaller scale imagery was best suited for mapping the roads. The true-color photographs were found to contain some additional information, but not enough that the investigators felt the greater expense of color photography was justified. The color-additive multispectral viewer and isodensitometer tests were inconclusive.

The field phase of the Prescott College project consisted of a ground survey and a series of test excavations to determine the morphological characteristics of the roads. This group found little evidence of prepared roadbed surfaces; instead, they found that most of the prehistoric roads in the Pueblo Alto area were constructed by clearing away surface sand and rubble down to a natural compact surface, either a hard caliche layer or bedrock. The dirt or rubble from this operation was piled up on either side of the roadway, forming a border. One of the road segments was chipped into the bedrock. The Prescott College group noted that the roads in the Pueblo Alto area converge on a point in a wall which extends east of the site. This point was trenched and a one meter wide "gate" in the wall was discovered (Fig. 22).

Late in 1972, James I. Ebert, also a graduate student at the University of New Mexico, was hired to assist Lyons and Hitchcock in photointerpretation and research. A few months later the New Mexico Archeological Center purchased a color density slicer and an edge enhancer. Ebert specialized in the use of this sophisticated electronic image enhancement equipment which proved useful in delineating the prehistoric roads. Hitchcock did research into historical references to roads in the Southwest and Mexico and into roadway systems in other areas of the world. All three researchers continued with stereoscopic photointerpretation.

In March of 1973 the New Mexico Archeological Center's Remote Sensing Project was awarded a $12,000 grant by the National Geographic Society. About half

Figure 22 - The "gate" in the north wall of Pueblo Alto, Chaco Canyon National Monument.

of this money was allocated to photogrammetric mapping of several of the major Chaco Canyon ruins. A large part of the other half was to be spent in support of an intensive roadway project planned by the Center for the summer of 1973.

By early 1973 about 80 miles of prehistoric roadway had been mapped. The investigators felt that the summer 1973 roads project was necessary for three reasons. First, they suspected that many miles of roadway had still not been mapped. Second, they wanted to check their recognition pattern with ground truth--that is, they wanted to confirm that they were indeed mapping prehistoric roads. Finally, they wanted to assess the engineering nature of the roads and identify features associated with the roads. With the aid of both new photography paid for by the NGS grant and the older USGS and SCS imagery, over 200 miles of suspected roadway were mapped by the end of the summer. About 20% of this total was discovered using the newly acquired electronic image enhancement equipment (Fig.23).

C. Randall Morrison, a graduate student at the University of Arizona and a former UNM graduate student, was hired as the fourth member of the field crew. Each of the student members of the crew had a special topic of investigation to pursue in addition to the general project goals. Morrison was interested in the dating of the roads and in road alignments. Ebert was interested in performing a network analysis on the roadway system. Hitchcock's topic was the implications of the roadway network for the social system of Chaco Canyon. Following up on their interests, Ebert and Hitchcock presented a paper entitled "Spatial Inference and the Archeology of Complex Societies" to the October 1973 Mathematics in Social Sciences Board Conference on "Formal Methods for the Analysis of Regional Social Structure" in Santa Fe, New Mexico (Ebert and Hitchcock 1973).

In preparation for the field portion of the roads project, all of the suspected roadway segments identified on the photographs were transferred to

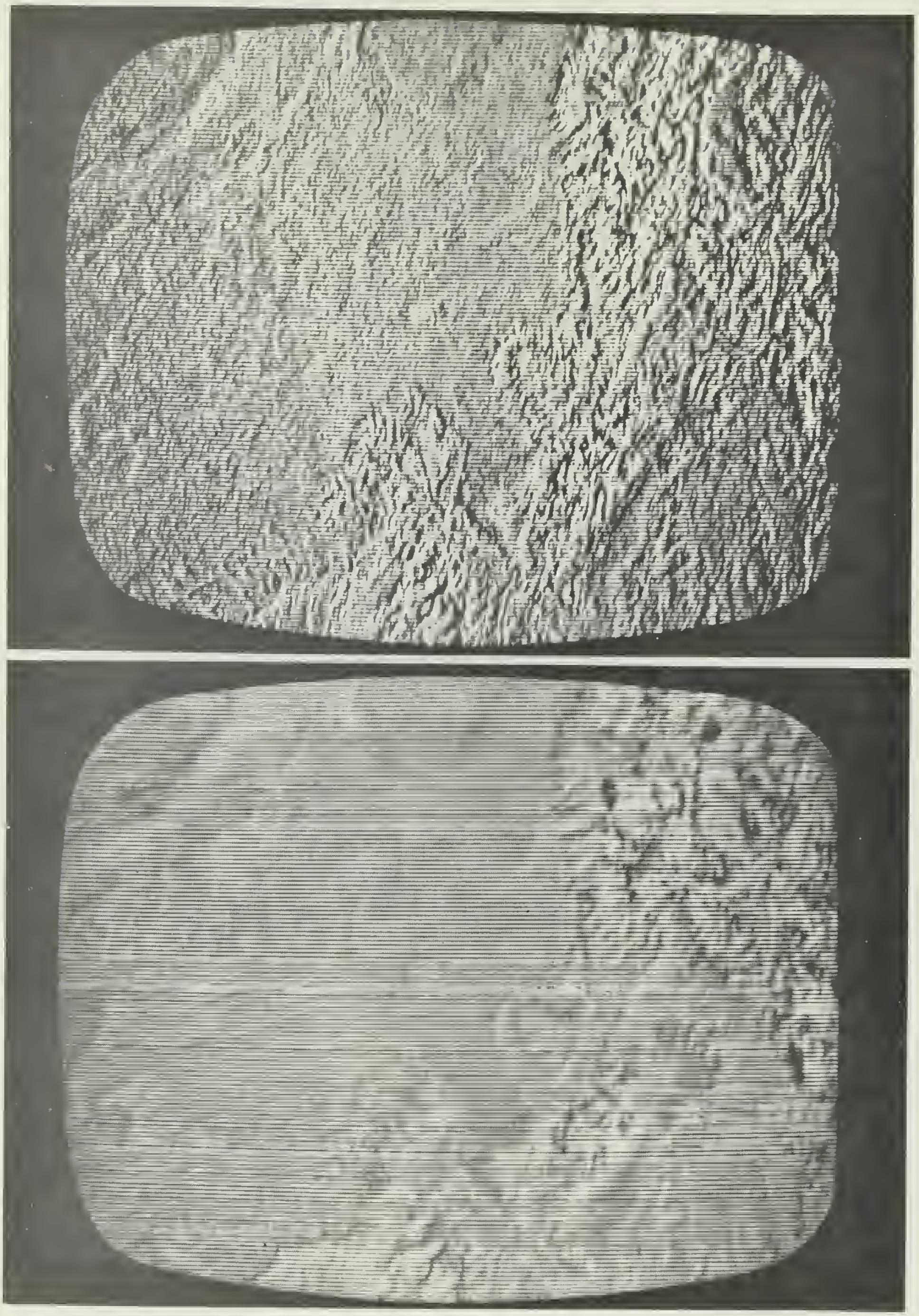


Figure 23 - Top: A portion of the Great North Road, unenhanced.
Botton: The same view, edge-enhanced.

USGS 7½ minute topographic maps. These maps are included as Appendix I. Working in two-man teams, the survey crew members alternated weeks in the lab with weeks in the field. In the lab photographs were examined stereoscopically and with the electronic image enhancement equipment. Both the maps and the photographs were used in the field.

The procedure followed was to pick the spot of the possible road segment which was most likely to be visible on the ground and then to locate that spot in the field. If the lineation could indeed be seen there, the crew noted the road as "verified" and then walked in both directions on the road searching for associated features such as ramps, stairs, and ruins. If the road itself could not be seen, the crew looked for other evidence of it, including cuts through low hills, linear scatters of potsherds, stairs, and ramps. The crews found that a road was most visible when viewed, not from the roadbed itself, but from a few feet to one side.

The summer of 1973 was one of the wettest on record for Chaco Canyon. The abnormally abundant vegetation which resulted hindered visibility of the roads on the ground. This liability was turned into an asset when the Remote Sensing Project hired a light plane for an infrared photography mission. The photographers on this flight were James Ebert and Richard Meleski of UNM Photo Service. They took about 150 35mm false-color infrared transparencies, which, as expected, proved useful in delineating roads. Segments of suspected roadway not previously discernible appeared clearly on the photographs because of the lush growth of mustard weed and other plants in the old roadbed (Lyons, Ebert, and Hitchcock 1974).

About half of the mapped roadway segments, or about 100 miles were ground checked. Survey notes are on file at the Remote Sensing Division. The results of the 1973 roads project were encouraging. The researchers felt that the roadway recognition pattern that they had formulated in the laboratory had been confirmed (Fig. 24).

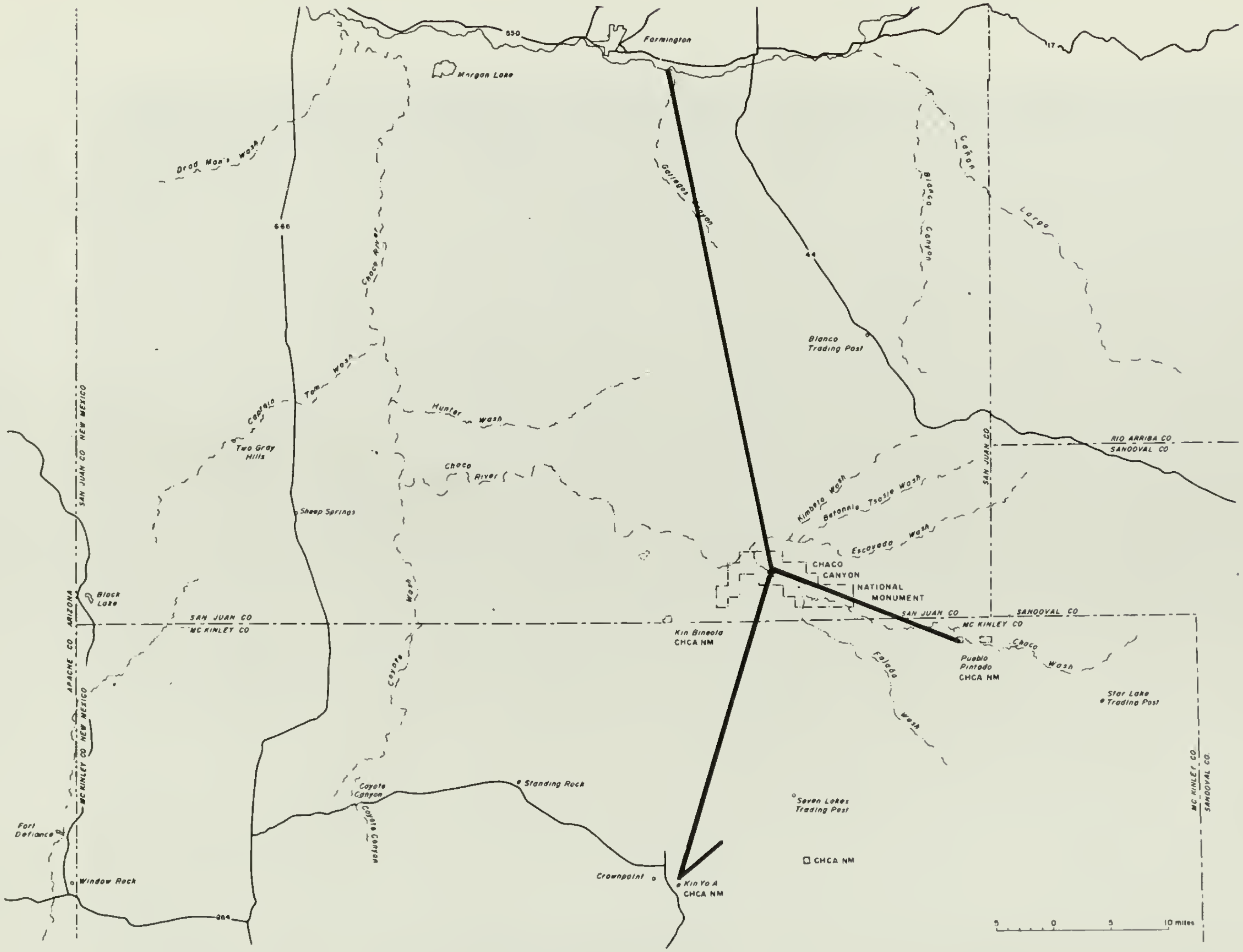


Figure 24 - Schematic map of the road system investigated by the Remote Sensing Project of the Chaco Center.

As Chief Archeologist of the National Park Service, John Corbett had funded the Remote Sensing Project of the Chaco Center for the purpose of experimentation with the applications of remote sensing to archeology. After Corbett's retirement, Robert Lister as Acting Chief Archeologist (in addition to his duties as Chief of the New Mexico Archeological Center), and then Douglas Scovill as Chief Archeologist continued the support of remote sensing in archeology that Corbett had begun. Scovill expanded the charter of the Remote Sensing Project to include experimentation on the applications of remote sensing to cultural resources management. With the apparent success of the 1973 roads project, Lyons felt that the roadway investigation was no longer experimental and the Remote Sensing Project began branching out into a number of new areas of investigation, many of which are reported in _Remote Sensing Experiments in Cultural Resource Studies_ (Lyons 1976) and _Remote Sensing and Non-Destructive Archeology_ (Lyons and Ebert 1978). The result of this change in direction has been that only about 50 additional miles of roadway were mapped between 1973 and 1977 when the author began photointerpretation for a Master of Arts thesis at the University of New Mexico. The thesis and maps will be published by the Chaco Center in a volume on Chacoan outliers.

Roadway-Related Investigations

The Remote Sensing Project of the Chaco Center, as the New Mexico Archeological Center was called after July, 1973, nevertheless did continue investigation of roadway-associated features in the summers of 1974, 1975, and 1976. In 1974 Richard W. Loose, a University of New Mexico graduate student, excavated several of these features, including the "blockhouse" in the north wall of Pueblo Alto. This wall was then mapped from photographs in an experiment on the use of the Whittlesey bipod as a photographic platform for mapping. (For more information on the bipod and its uses, see Klausner, this volume). Loose also sectioned several roadway segments at Penasco Blanco and Pueblo Alto.

In 1975, Lyons, Loose and Dwight L. Drager, also a University of New Mexico graduate student, began excavations at 29SJ1010, variously known as the "Curious Site" or "Poco." Drager continued this work in 1976. Located on one of the major branches of the Chacoan roadway system, the Chaco-Escavada road, the Curious Site had been discovered on the 1973 Road Survey and was so named because it resembles no other known Chacoan site. It consists of a number of low-walled masonry circles and possible roomblocks. The circles were at first thought to be kivas, but excavation subsequently disproved this supposition. None of the structures at Poco appear to have been over a meter in height and none appear to have been roofed. A striking feature of this site is its lack of cultural material. There is no trash mound, only 25 sherds and one projectile point were surface collected, and even fewer sherds resulted from excavation.

It was hoped that the direct association of the road with this anomalous site might mean that the function of the site was in some way related to the roadway and that something about the function of the roadway system could be learned through excavation of the Poco Site. However, it could not be determined by the excavation whether the site was built next to an existing roadway, the road constructed to reach the site, or both constructed contemporaneously (Drager and Lyons 1976:6). It is thought that Poco may have been part of a visual communications network linking sites in Chaco Canyon with outlying Chacoan sites (W. James Judge, personal communication, 1977). The relationship between the roadway system and the visual communications system still remains to be determined, although preliminary analysis seems to indicate that lines of sight coincide with road alignments in a number of locations (Drager 1976; Hayes and Windes 1975: 154-155).

Figure 25 - Drill hole roads of <u>one</u> natural gas company in the Farmington (northwestern New Mexico) area.

Roadway Research in Progress

Northwestern New Mexico is currently in a state of change, one of the major causes being the "energy crisis." The San Juan Basin may be poor in agricultural resources, but it is rich in energy resources. The Basin contains over 53% of the nation's known uranium reserves; it is known to contain 5.9 billion tons of strippable coal and 121.8 billion tons of minable coal; oil and gas are also important resources in the region (Grant 1975).

Exploration for these resources has had a massive effect on the landscape of the Basin, with large numbers of new vehicular roads criss-crossing the countryside; drill holes and camps are also changing the area (Fig. 25). As exploitable deposits are isolated the impact becomes somewhat more localized, but still has a far-reaching effect. Not only is the area immediately around a well or sub-surface mine entrance intensively utilized and modified, but the access roads, pipelines, and railroads connecting the mine with suppliers, housing areas, trans-shippers and consumers also have an impact. In surface mining for coal and uranium, not only are the same support networks necessary, but to their impact is also added the large-scale destruction of the surface caused by the mining.

In addition to impact directly related to energy exploration and production, the increase in population of the San Juan Basin as a result of these activities will produce its own pressures on cultural resources. The population is expected--at the least--to double over the next few years as energy production increases in response to growing energy demands. This means more off-road recreational travel, more vandalism, more pot-hunting and more unintentional destruction of cultural resources. Because of their visibility, architectural sites are likely to be most affected, but the increased activity will also obscure the Chacoan roadways, both on the ground and on future aerial imagery.

Because of the expected direct and indirect effects of current and future coal and uranium mining, there is renewed interest in the identification, preservation, and conservation of the cultural resources of the San Juan Basin. Much survey and salvage work directly connected with energy exploration and production is in progress, and more will be necessary. The Chaco Center has been working since 1976 on a "Chacoan Outliers Project" with Robert Powers, Stephen Leckson, William Gillespie, and James Judge as the main investigators. The purpose of this project is the identification of outlying Chacoan communities which are believed to have interacted as members of a complex regional system. One of the criteria for inclusion as an "outlier" is the presence of a Chacoan roadway. Richard Loose, now with the Public Service Company of New Mexico, is coordinating a road-outlier project. One of the main goals of this project is the identification of sites for nomination to the National Register of Historic Places (Marshall, Stein, Loose and Novotny 1979).

A number of federal agencies responsible for the administration of lands and resources in the San Juan Basin have banded together under the auspices of the Bureau of Indian Affairs to perform an inventory of the known cultural and natural resources of the Basin. Participating agencies included the National Park Service's Remote Sensing Division, U.S. Geological Survey, Bureau of Land Management, U.S. Fish and Wildlife Service, Bureau of Outdoor Recreation, and Bureau of Reclamation.

Even though the Chacoan roadway network could probably be mapped in the future from existing imagery such as the USGS and SCS photography, if the network is not mapped now it will be much more difficult, and in some cases impossible to field check the results in the future since a large part of the network will be destroyed or obscured in the next few years. Therefore, many of the projects mentioned above are incorporating Chacoan roadway investigations into their research designs. The author of this paper is working on this project as a University of New

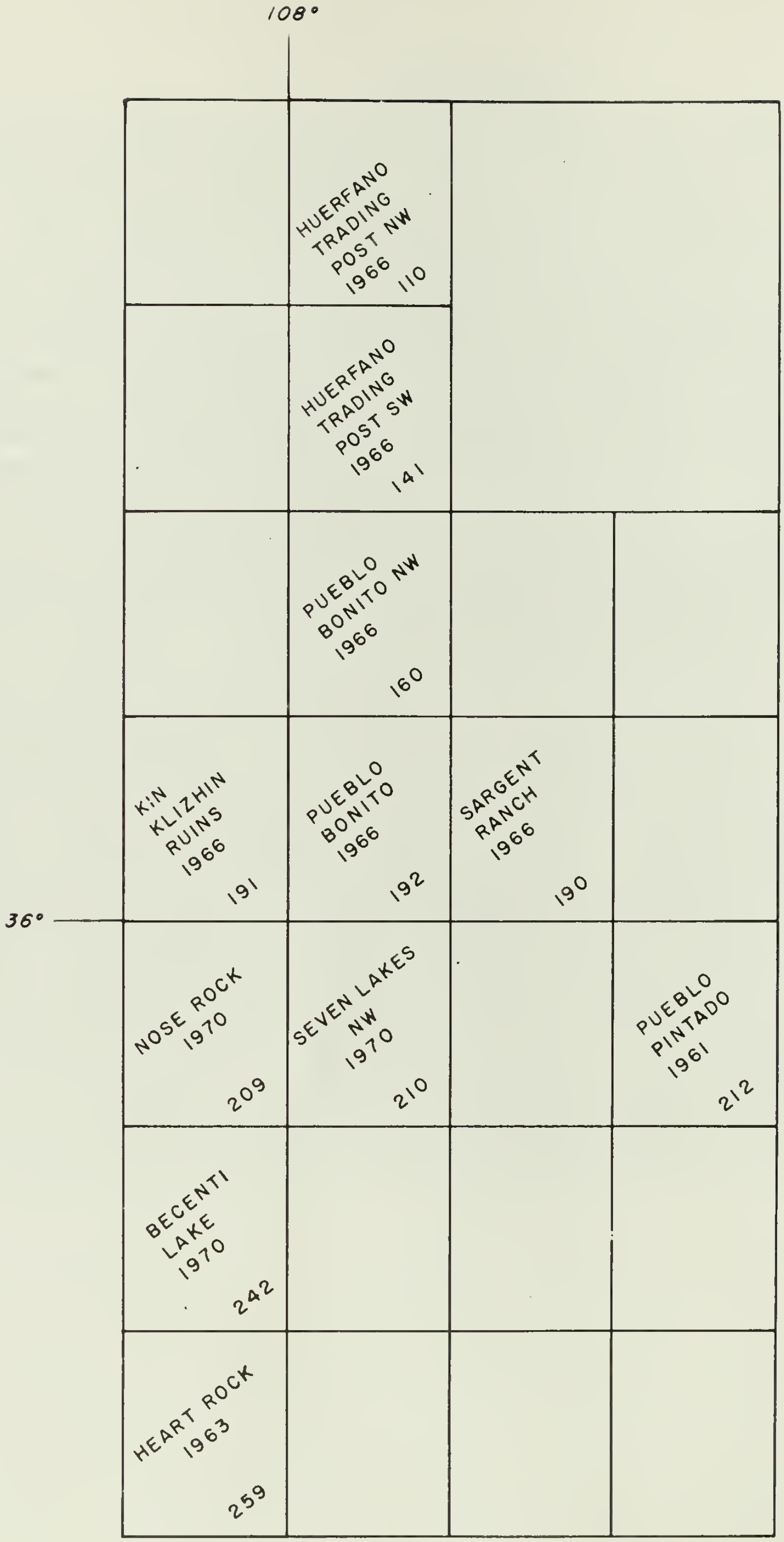
Mexico Master of Arts thesis, with the results to be published by the Chaco Center (Obenauf 1980).

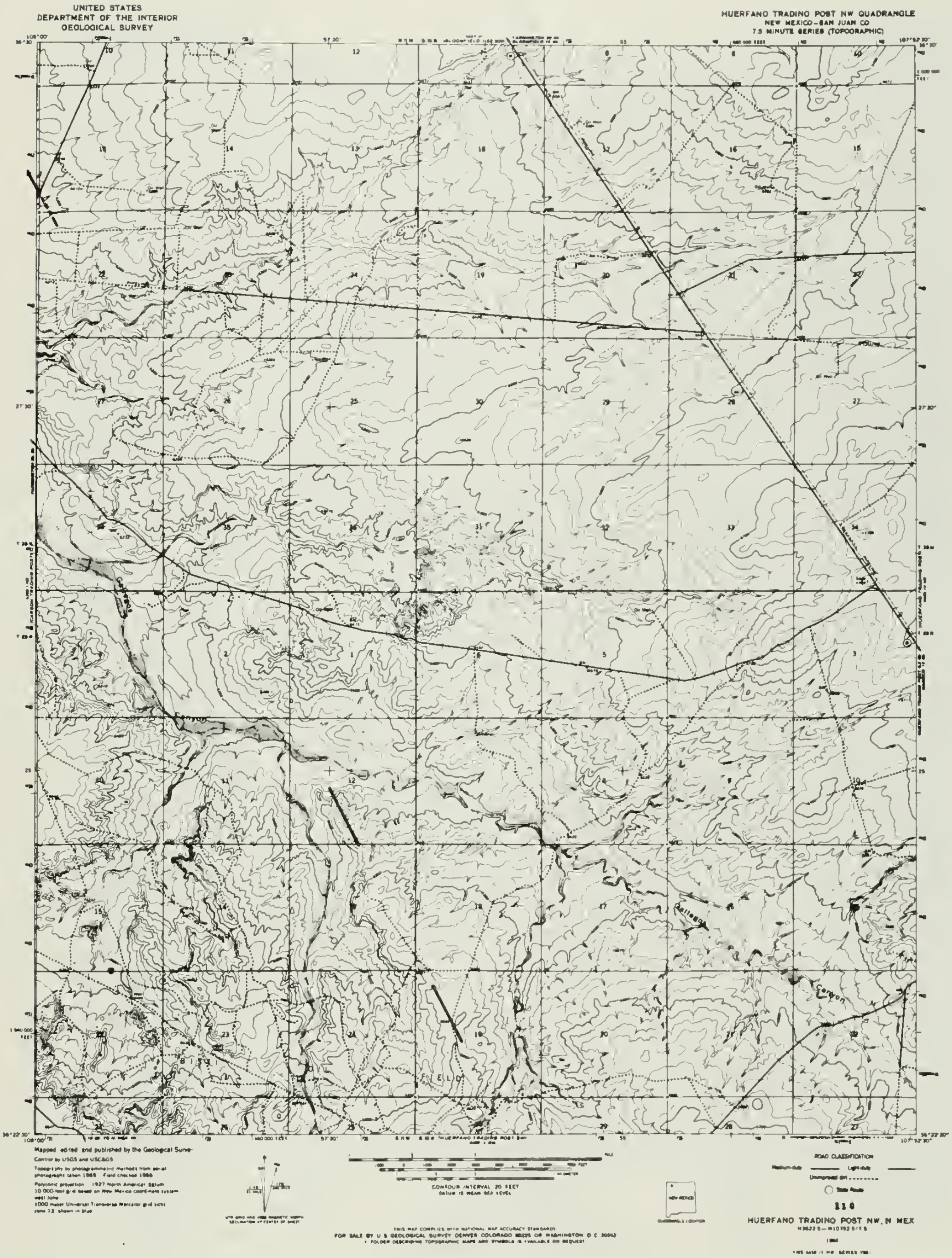
Conclusion

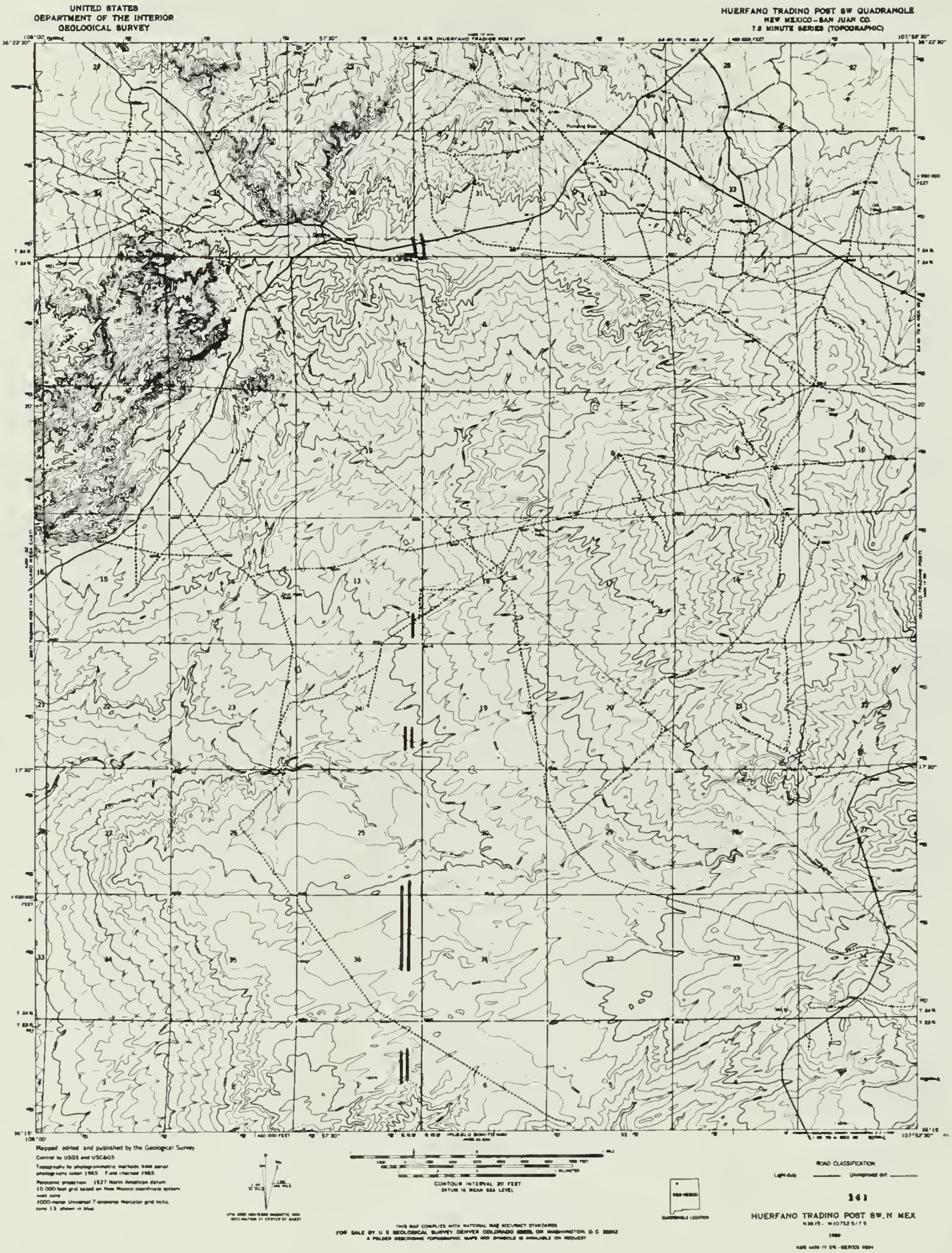
The discovery of an extensive system of prehistoric roadways in Northwest New Mexico has considerably changed archeologists' ideas about the Chacoan phenomenon. The engineered nature of the roadways, their width, the labor investment necessary for their construction, the extent of the system--all these aspects of the Chacoan roadway system have made archeologists question the accepted ideas about the Chacoan occupation of the San Juan Basin. The discovery of the roadway system has expanded our vision: we no longer see Chaco Canyon as isolated, but as part of a system which occupied the whole San Juan Basin. The roadway system also changed ideas about outlying Chacoan sites such as Aztec, Salmon, and Kin Ya'a. The existence of the roadway system linking outlying sites to Chaco Canyon and to each other suggested the possibility of the visual communications system. The vastness of the roadway system, with the Great North Road extending over 50 miles from Chaco Canyon to the San Juan River, and the South Road 40 miles between Kin Ya'a and the Canyon, has raised questions about the nature of the past economic system in the San Juan Basin. In response to all of these ideas suggested in part by the discovery of the roadway network, current research in the San Juan Basin is directed toward an understanding of the interaction between Chaco Canyon and outlying Chacoan sites.

APPENDIX I

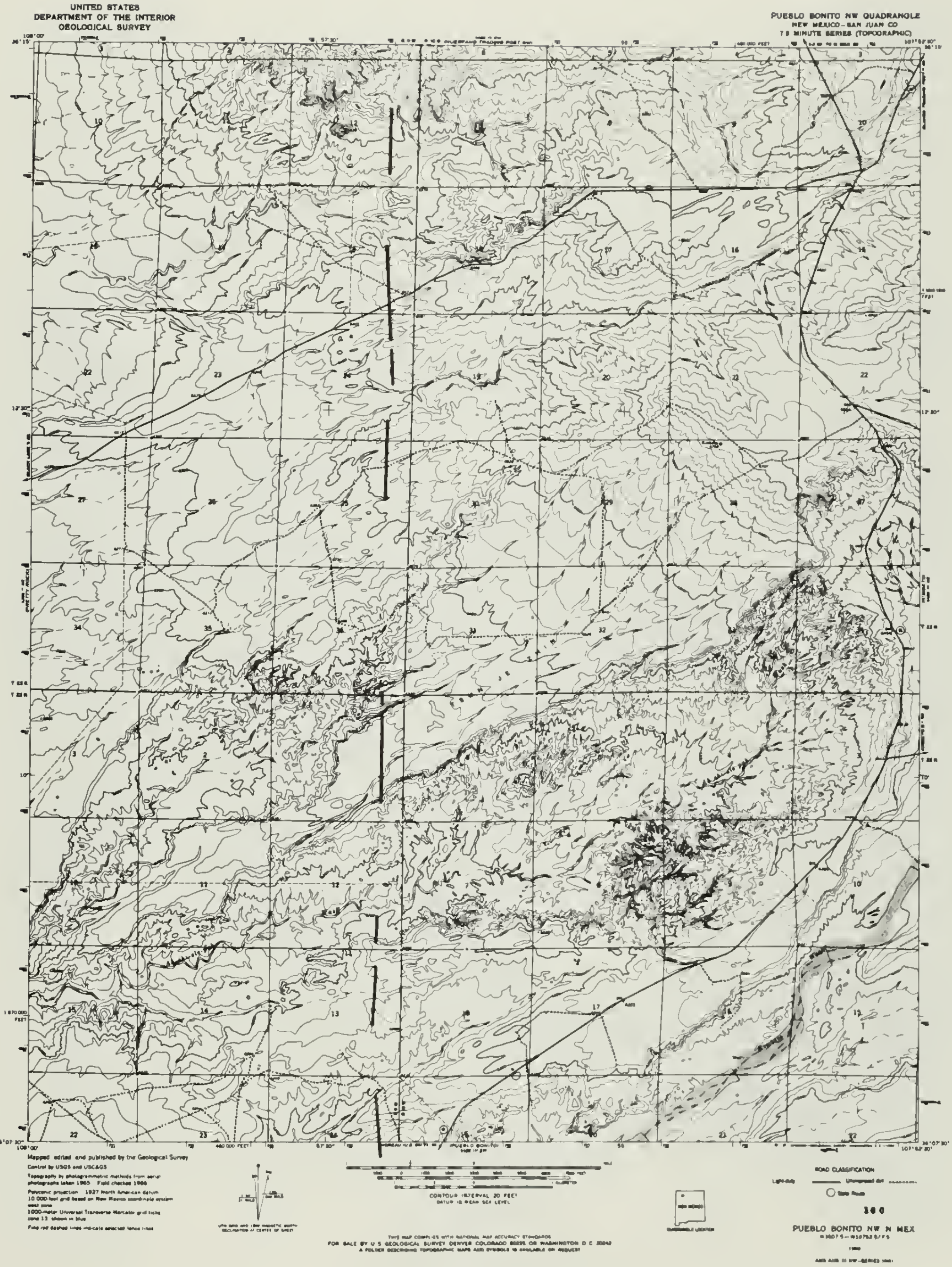
The following maps are reductions of 7½ minute USGS topographic maps. Steve Shure and Tom Lyons did the initial photointerpretation, mapping and field checking on these maps. Lyons, Jim Ebert and Bob Hitchcock continued with more intensive examination and mapping, and were later joined in field checking and mapping by Randy Morrison. Some of the alignments on the "Great North Road" (Pueblo Bonito NW, Huerfano Trading Post SW, Huerfano Trading Post NW) were mapped and field checked by Pierre Morenon. It should be noted that these maps prepared by the Remote Sensing Project were compiled prior to field check. Survey notes from the field check are on file at the Remote Sensing Division of the Southwest Cultural Resources Center.


108°
36°
HUERFANO TRADING POST NW 1966 110
HUERFANO TRADING POST SW 1966 141
PUEBLO BONITO NW 1966 160
KIN KLIZHIN RUINS 1966 191
PUEBLO BONITO 1966 192
SARGENT RANCH 1966 190
NOSE ROCK 1970 209
SEVEN LAKES NW 1970 210
PUEBLO PINTADO 1961 212
BECENTI LAKE 1970 242
HEART ROCK 1963 259


UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
HUERFANO TRADING POST NW QUADRANGLE
NEW MEXICO-SAN JUAN CO
7.5 MINUTE SERIES (TOPOGRAPHIC)
Canyon
Gallegos
FIELD
Mapped, edited, and published by the Geological Survey
Control by USGS and USC&GS
Topography by photogrammetric methods from aerial photographs taken 1965. Field checked 1966
Polyconic projection. 1927 North American datum
10,000-foot grid based on New Mexico coordinate system, west zone
1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue
CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL
THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
ROAD CLASSIFICATION
Medium-duty
Light-duty
Unimproved dirt
State Route
HUERFANO TRADING POST NW, N MEX
1966



UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
HUERFANO TRADING POST SW QUADRANGLE
NEW MEXICO–SAN JUAN CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)
Mapped, edited, and published by the Geological Survey
Control by USGS and USC&GS
Polyconic projection. 1927 North American datum
CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL
ROAD CLASSIFICATION
HUERFANO TRADING POST SW, N. MEX.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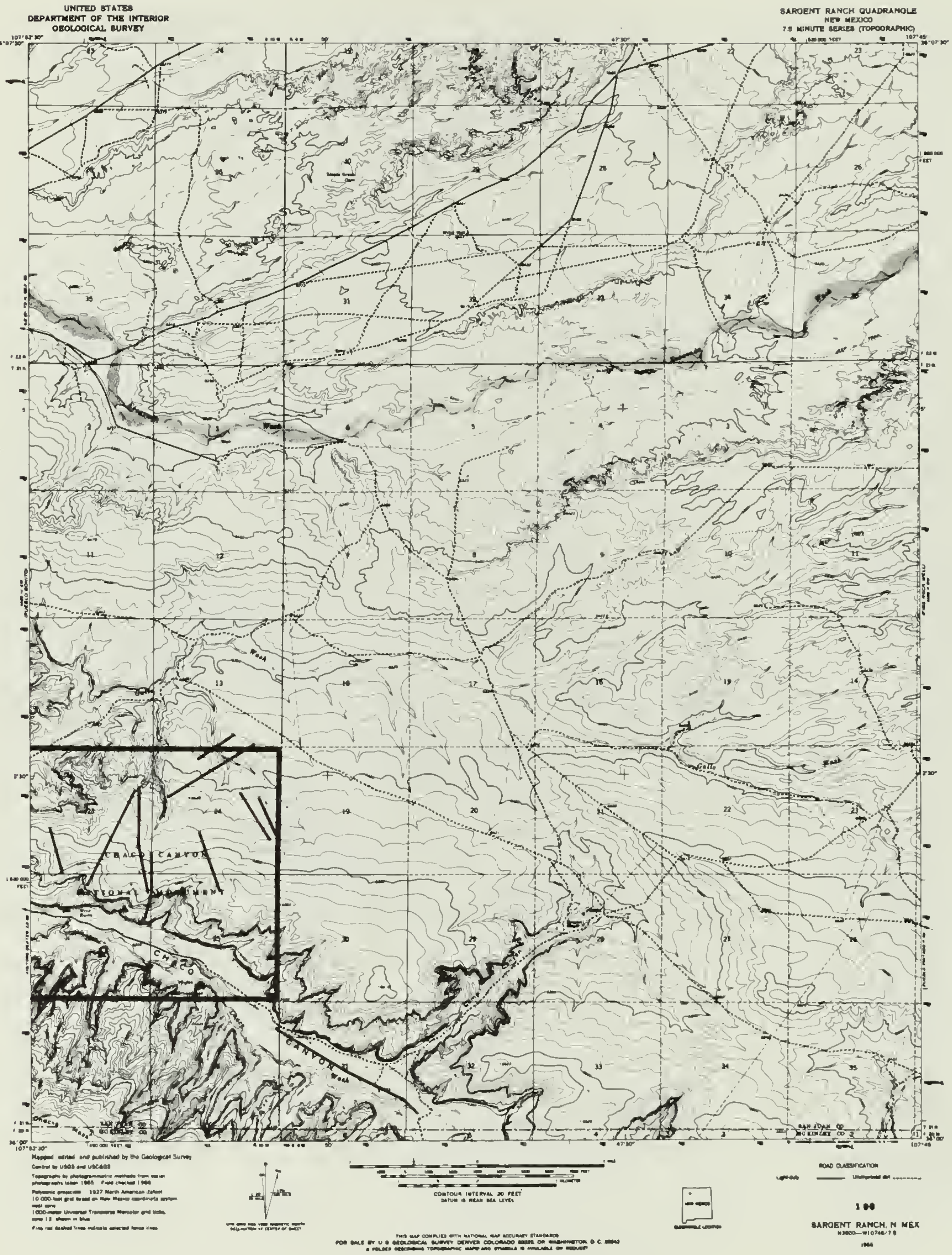
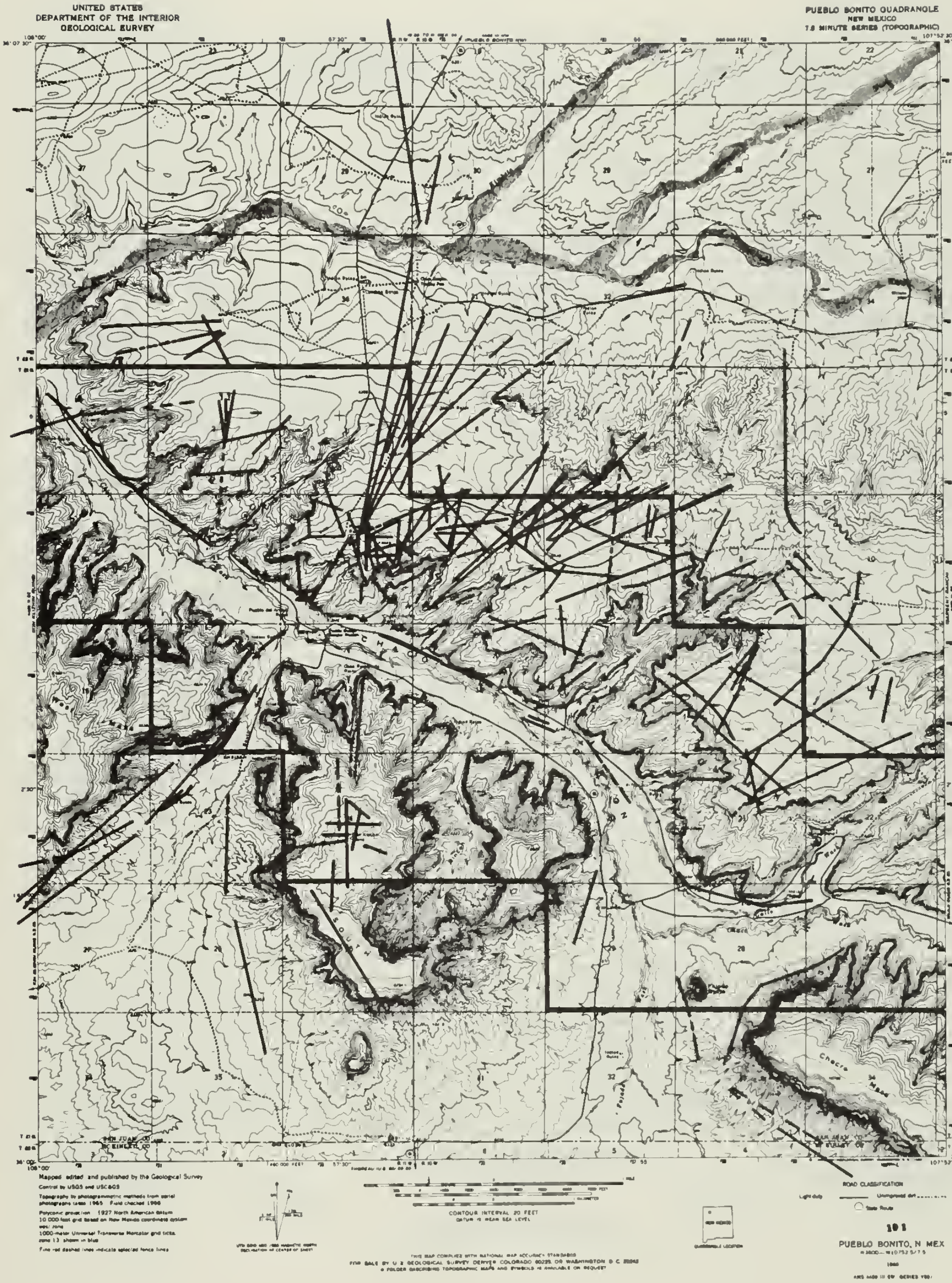
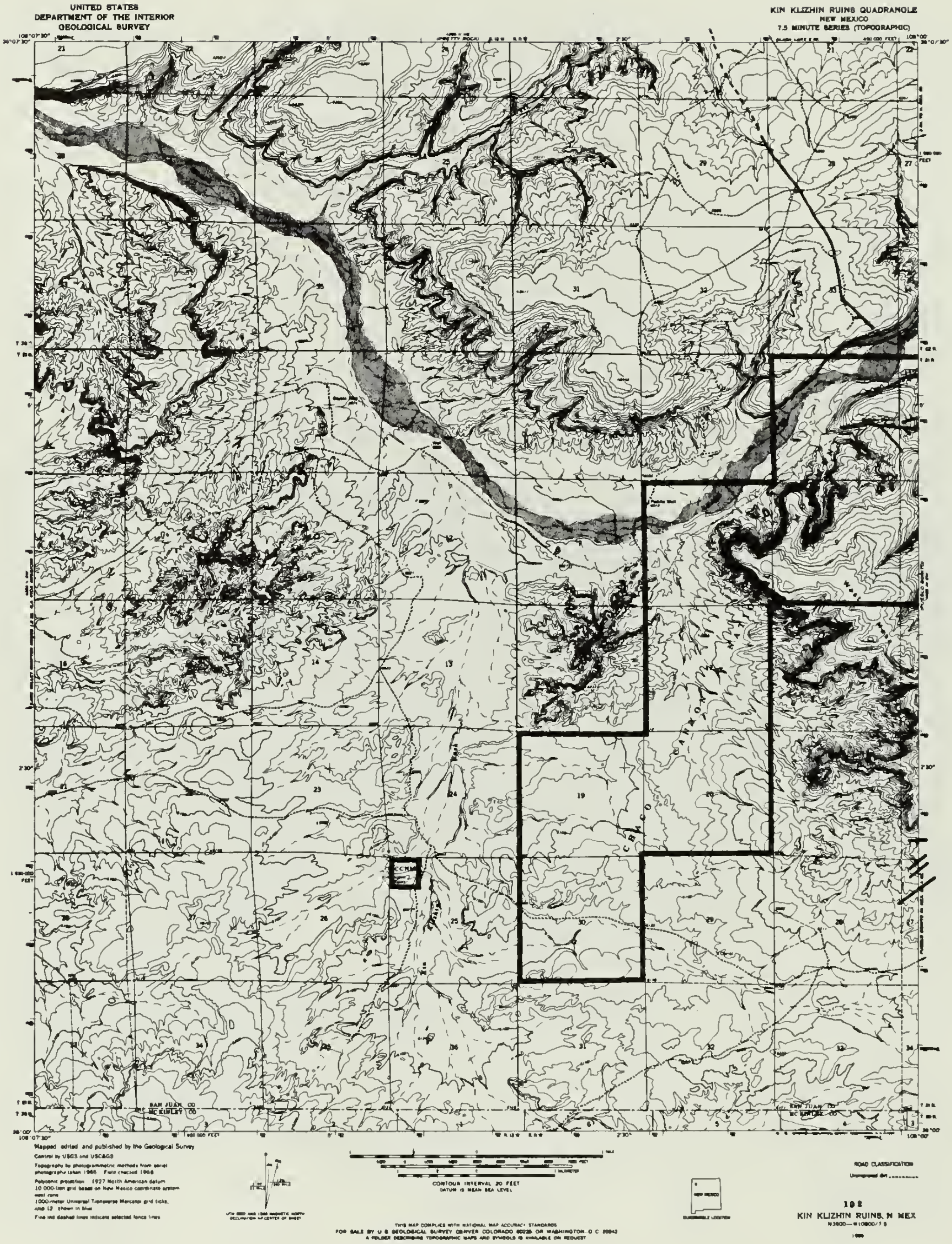
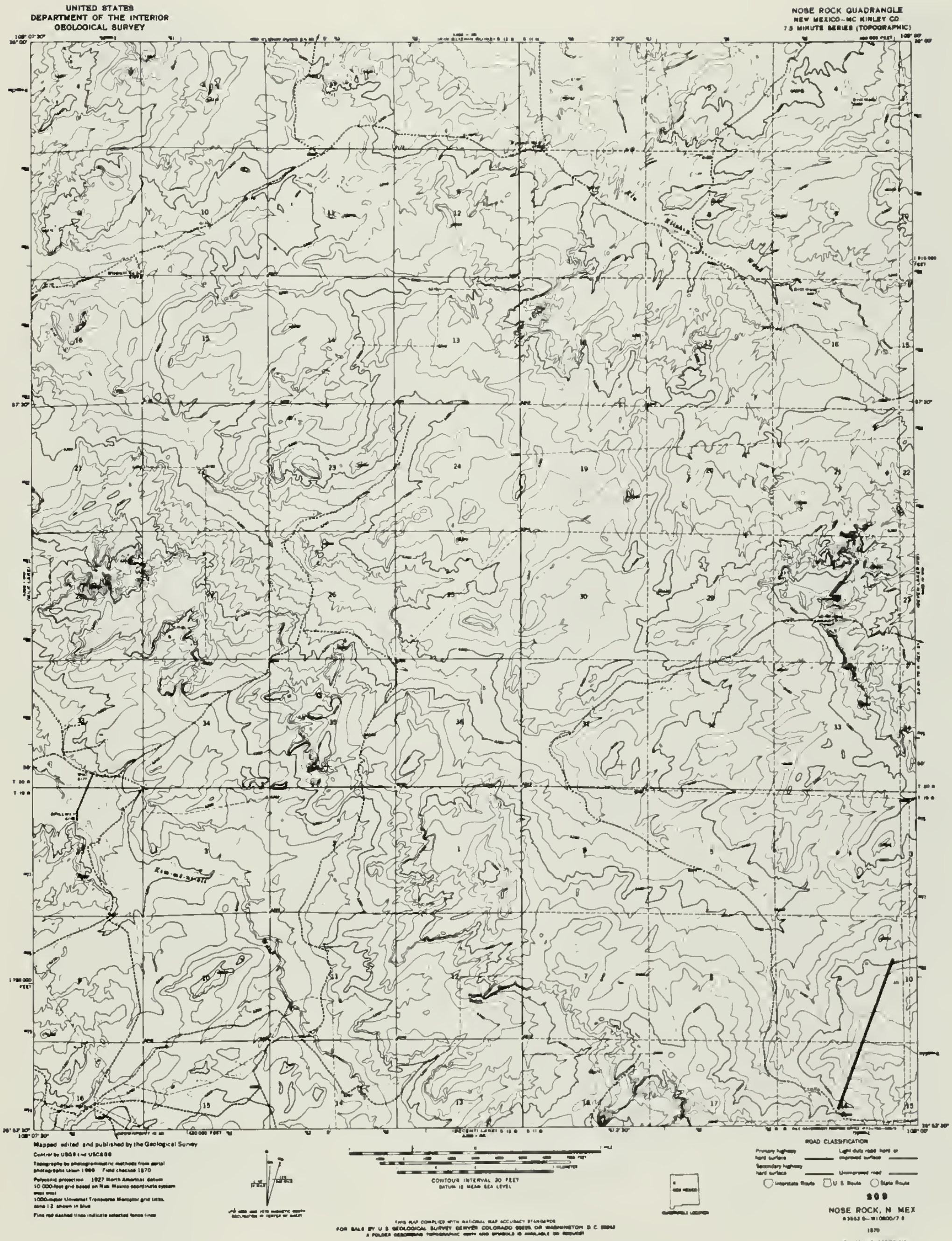
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
PUEBLO BONITO NW QUADRANGLE
NEW MEXICO - SAN JUAN CO
7.5 MINUTE SERIES (TOPOGRAPHIC)
Mapped, edited, and published by the Geological Survey
Control by USGS and USC&GS
Topography by photogrammetric methods from aerial photographs taken 1965. Field checked 1966
Polyconic projection. 1927 North American datum
CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL
ROAD CLASSIFICATION
PUEBLO BONITO NW, N. MEX.

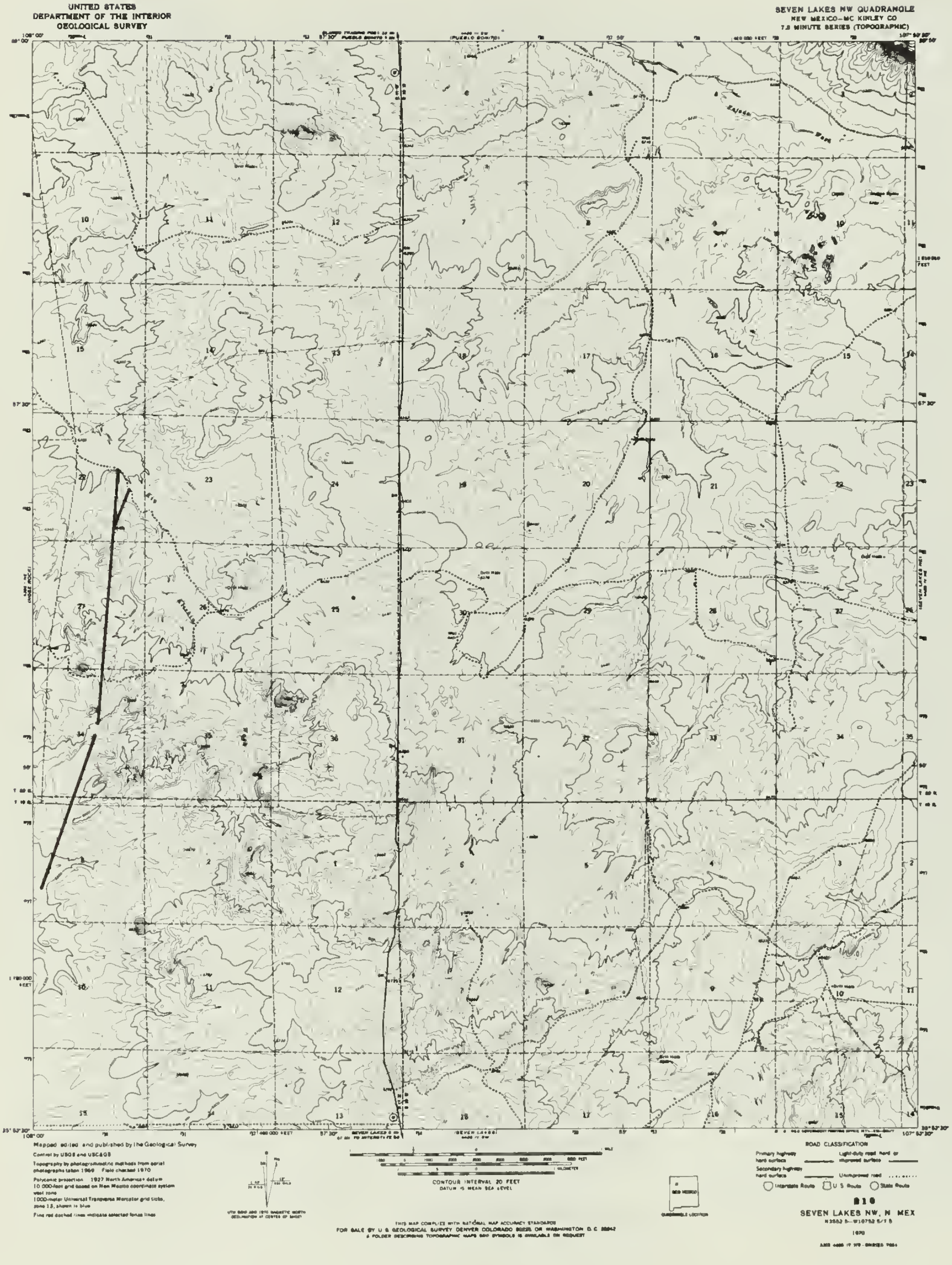

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
SARGENT RANCH QUADRANGLE
NEW MEXICO
7.5 MINUTE SERIES (TOPOGRAPHIC)
CHACO CANYON
NATIONAL MONUMENT
CHACO
CANYON
Wash
Gallo
SAN JUAN CO
McKINLEY CO
Mapped, edited, and published by the Geological Survey
Control by USGS and USC&GS
Topography by photogrammetric methods from aerial photographs taken 1965. Field checked 1966
Polyconic projection. 1927 North American datum
10,000-foot grid based on New Mexico coordinate system, west zone
1000-meter Universal Transverse Mercator grid ticks, zone 13, shown in blue
Fine red dashed lines indicate selected fence lines
CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL
THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U S GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR WASHINGTON, D C 20242
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST
ROAD CLASSIFICATION
Light-duty
Unimproved dirt
NEW MEXICO
QUADRANGLE LOCATION
SARGENT RANCH, N. MEX.
1966

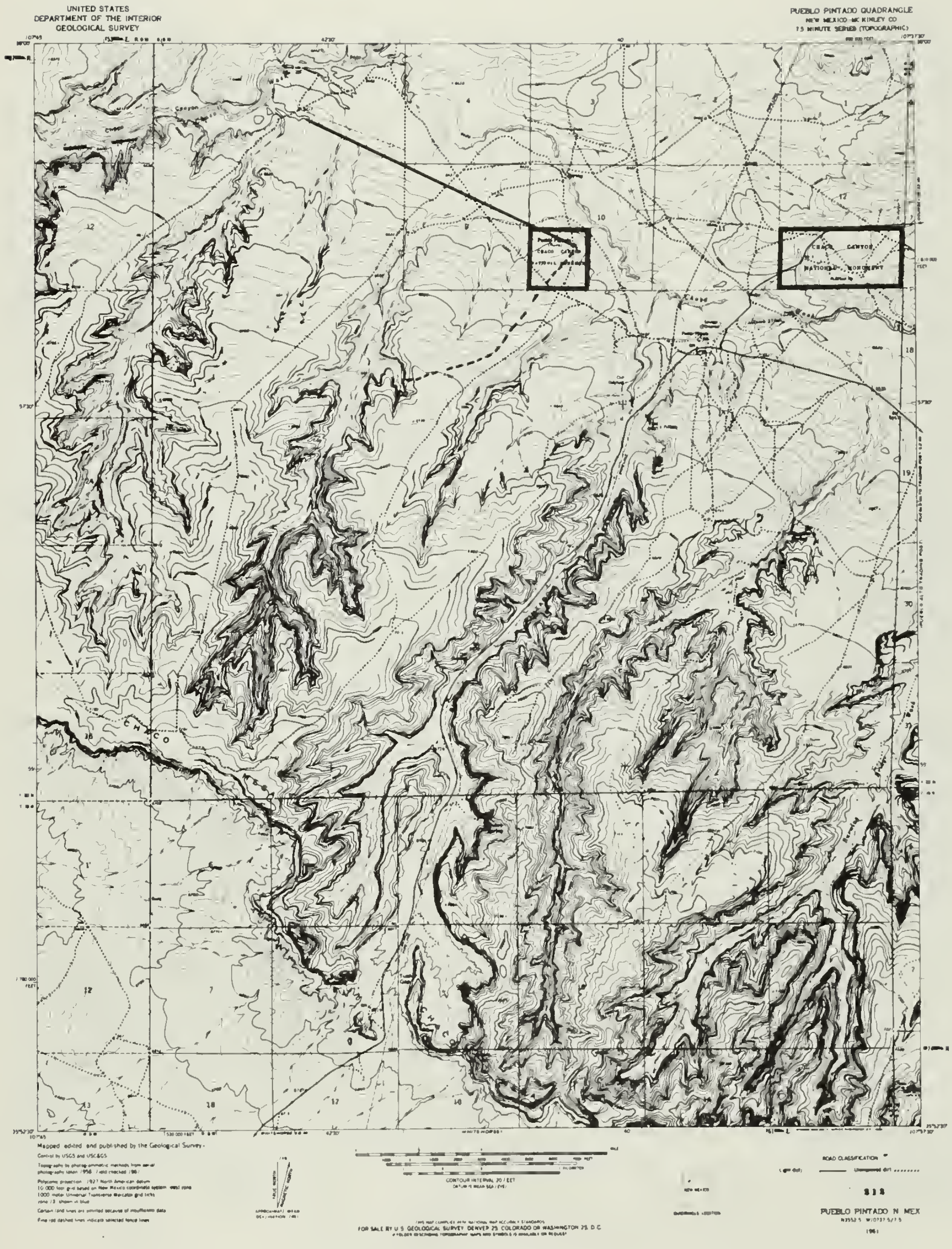


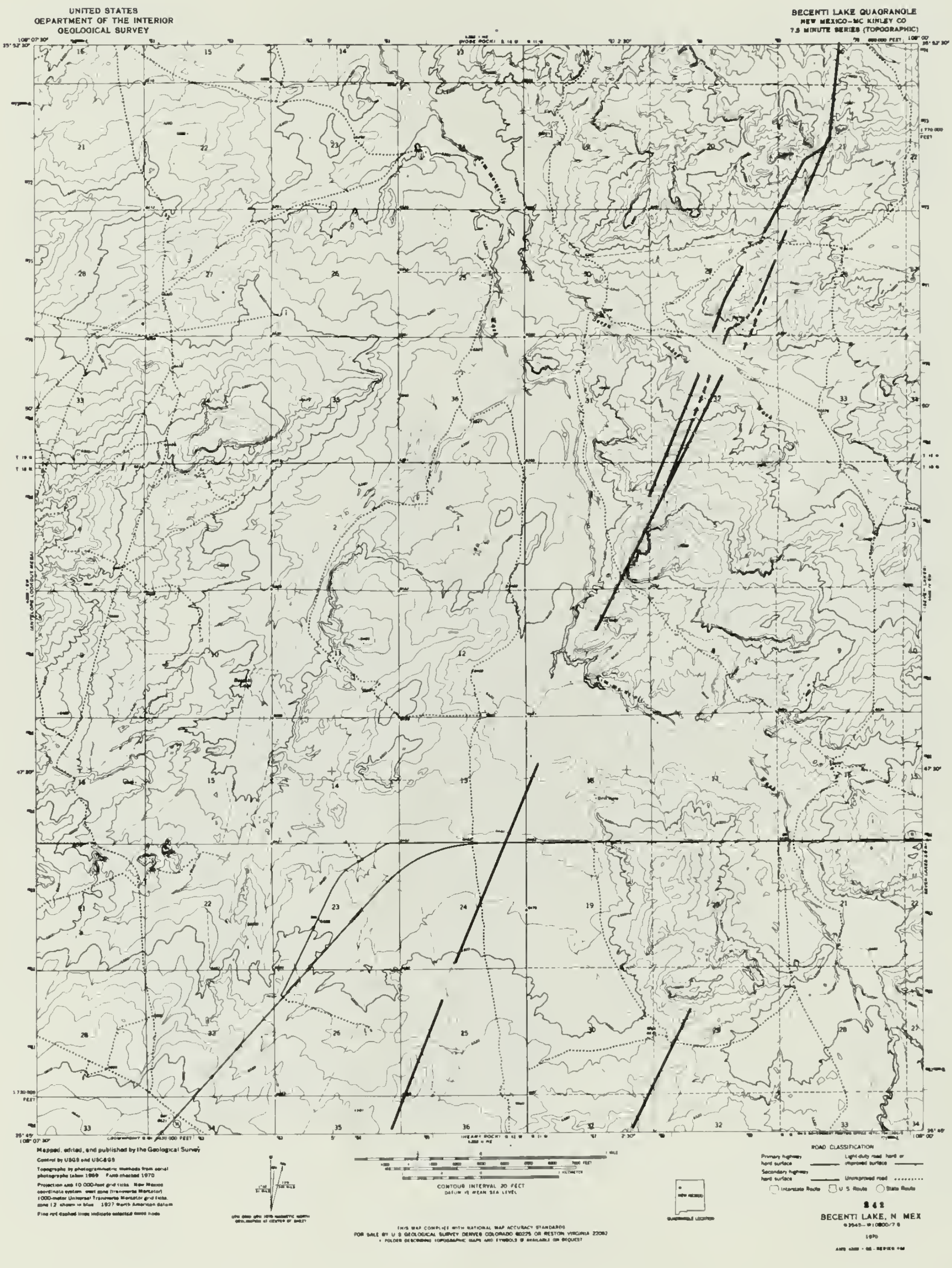
UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
PUEBLO BONITO QUADRANGLE
NEW MEXICO
7.5 MINUTE SERIES (TOPOGRAPHIC)
Mapped, edited, and published by the Geological Survey
CONTOUR INTERVAL 20 FEET
ROAD CLASSIFICATION
PUEBLO BONITO, N. MEX.


UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
KIN KLIZHIN RUINS QUADRANGLE
NEW MEXICO
7.5 MINUTE SERIES (TOPOGRAPHIC)
SAN JUAN CO
MC KINLEY CO
Mapped, edited, and published by the Geological Survey
Control by USGS and USC&GS
CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL
ROAD CLASSIFICATION
KIN KLIZHIN RUINS, N MEX


UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
NOSE ROCK QUADRANGLE
NEW MEXICO–MC KINLEY CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)
Mapped, edited and published by the Geological Survey
CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL
ROAD CLASSIFICATION
NOSE ROCK, N. MEX.
1970


UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
SEVEN LAKES NW QUADRANGLE
NEW MEXICO—MC KINLEY CO
7.5 MINUTE SERIES (TOPOGRAPHIC)
Mapped, edited, and published by the Geological Survey
Control by USGS and USC&GS
Topography by photogrammetric methods from aerial photographs taken 1969. Field checked 1970
Polyconic projection. 1927 North American datum
10,000-foot grid based on New Mexico coordinate system, west zone
1000-meter Universal Transverse Mercator grid ticks, zone 13, shown in blue
Fine red dashed lines indicate selected fence lines
CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL
THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U S GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR WASHINGTON, D C 20242
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST
ROAD CLASSIFICATION
Primary highway, hard surface
Light-duty road, hard or improved surface
Secondary highway, hard surface
Unimproved road
Interstate Route
U S Route
State Route
SEVEN LAKES NW, N MEX
1970


UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
PUEBLO PINTADO QUADRANGLE
7.5 MINUTE SERIES (TOPOGRAPHIC)
CHACO CANYON
NATIONAL MONUMENT
CHACO
Mapped, edited, and published by the Geological Survey
CONTOUR INTERVAL 20 FEET
FOR SALE BY U.S. GEOLOGICAL SURVEY DENVER 25, COLORADO OR WASHINGTON 25, D.C.
ROAD CLASSIFICATION
PUEBLO PINTADO, N. MEX.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DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
BECENTI LAKE QUADRANGLE
NEW MEXICO–MC KINLEY CO
7.5 MINUTE SERIES (TOPOGRAPHIC)
Mapped, edited, and published by the Geological Survey
Control by USGS and USC&GS
Topography by photogrammetric methods from aerial photographs taken 1969. Field checked 1970
CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL
THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U S GEOLOGICAL SURVEY DENVER COLORADO 80225 OR RESTON VIRGINIA 22092
ROAD CLASSIFICATION
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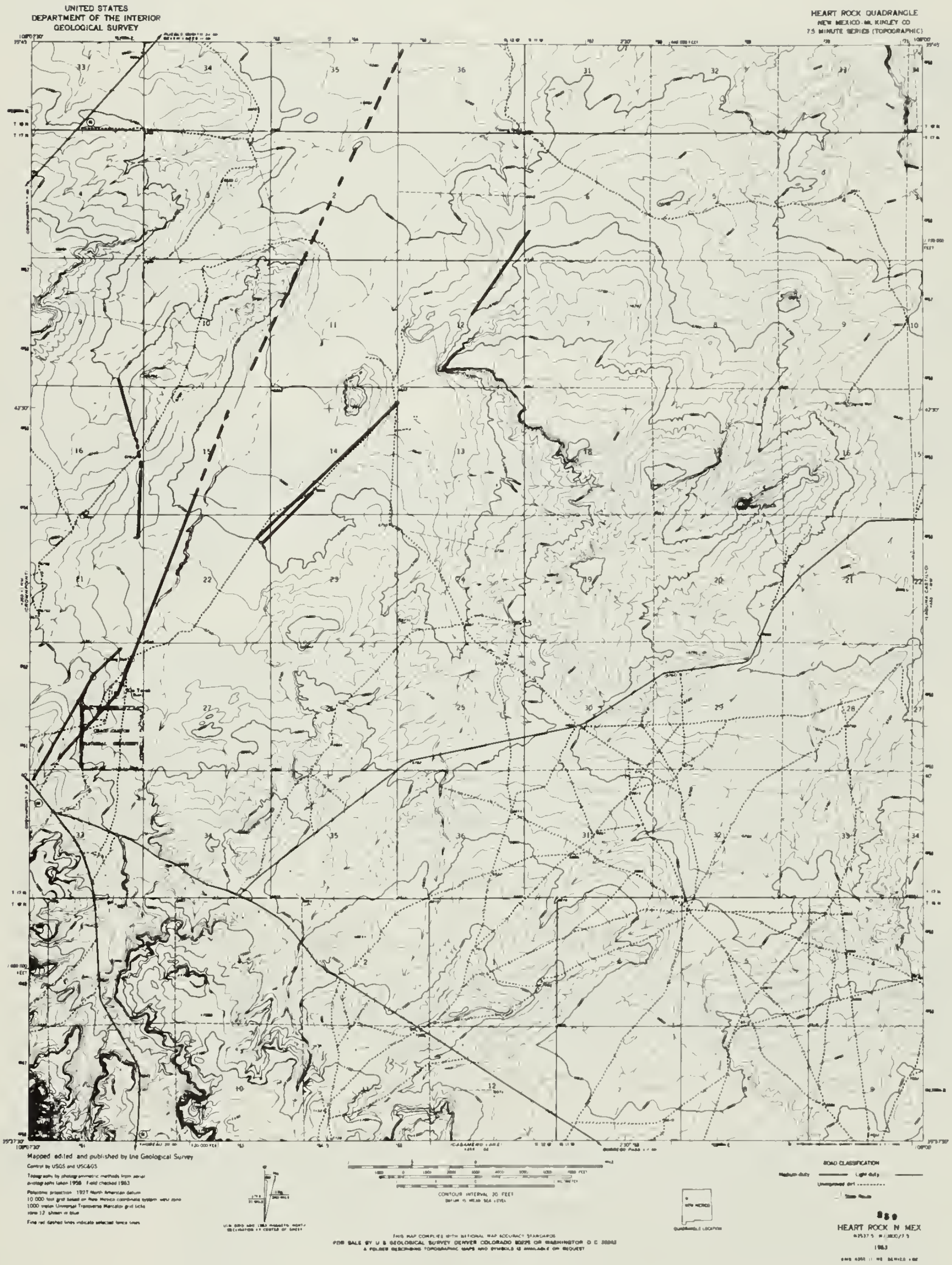
Light-duty road, hard or improved surface
Secondary highway hard surface
Unimproved road
Interstate Route
U S Route
State Route
BECENTI LAKE, N. MEX.
1970


UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
HEART ROCK QUADRANGLE
NEW MEXICO-MC KINLEY CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)
Mapped, edited, and published by the Geological Survey
Control by USGS and USC&GS
Topography by photogrammetric methods from aerial photographs taken 1958. Field checked 1963
CONTOUR INTERVAL 20 FEET
ROAD CLASSIFICATION
NEW MEXICO
QUADRANGLE LOCATION
HEART ROCK, N. MEX.
1963

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LOCATIONAL MODELLING IN THE ANALYSIS OF THE PREHISTORIC ROADWAY SYSTEM AT AND AROUND CHACO CANYON, NEW MEXICO

by

James I. Ebert
Robert K. Hitchcock

Of all the possible subjects for archeological study, perhaps the most interesting to modern urban man are ancient complex societies. These groups existed in a milieu similar in economic, political, and ideological intricacy to our own. Such societies, more importantly, were immersed in and in some cases overcome by problems and shortages similar to those facing the world today; if solutions lie in an examination of the past, the most immediate lessons are to be found in the rubble of such cities as Ur, Mohenjo-Daro, and Teotihuacan. Since anthropologists are unable to fathom the depths of present-day industrial nations--which are, it would seem, "totally accessible"--it would be foolhardy to expect better results from the apprehension of complicated prehistoric situations.

While not disputing the relevance of the study of complex societies to both academic and human survival, we would contradict the archeologist who hesitates at such an enterprise. The difficulty in reaching an explanation of any cultural phenomenon lies not in inaccessibility, but in reaching an inductive basis for its examination. It will be suggested that models and measures employed by geographers can be helpful in the delineation of problems, the identification of appropriate variables, and the determination of efficient sampling and testing procedures in confronting complex societies.

In support of this position is the examination of an extensive prehistoric transportation network at Chaco Canyon in northwestern New Mexico. This network, discovered and mapped recently with the aid of aerial remote sensing techniques, poses complex archeological and economic questions. Previous archeological investigation in this area does not provide a basis for posing either processual or economic queries; nor does it present data suitable in themselves for testing such hypotheses. Geographic models appropriate for the study of transportation and communication networks will be examined in the light of the Chaco Canyon data.

Historical Background of Complex Societies Archeology

The history of archeological investigation of complex societies can perhaps best be viewed in terms of the kinds of questions asked and the kinds of strategies employed in gathering data to answer those questions. Archeology, at its inception, was largely an individualistic undertaking concerned primarily with the amplification of written history. The work done by Schliemann at Hissarlik (Troy) in western Turkey, at Mycenae and Tiryns in Greece, and by Carter in the tombs of Egypt are examples of this kind of orientation, as is much of the early work of Biblical archeologists in Palestine. Another major concern of early archeologists was the acquisition of valuable and educational objects for individuals and museums. This led to the excavation of such sites as Pompeii and Herculaneum, as well as the looting of many rich sites in Egypt. In essence, archeological sites were regarded in the early days as vast mines that could be tapped at will; selection of sites to be excavated was based on which sites were believed to hold the greatest number of valuable objects. There was no actual archeological strategy for their investigation; sites were simply stripped or tunnelled into, whichever was the fastest way of getting at the "goodies." This approach was not without its positive aspects, however; it led to the discovery of many so-called lost civilizations and it awakened the world to the glories of the past.

As archeology developed, interest was focused increasingly on the sequence of occupation of various areas. This interest in establishing cultural sequences was felt to be the endpoint of research and, indeed, still is in many places. In order to establish the culture sequence for an area, stratified sites were selected and deep trenches cut into them, revealing a series of layers containing objects that varied stylistically through time. As before, single sites, considered to be representative of the occupational history of a region, were selected for investigation.

In the 1940's the Oriental Institute of the University of Chicago, under the direction of Robert Braidwood, began excavations at Qalat Jarmo, a site in the Kurdish foothills of Iraq (Braidwood and Howe 1960). This excavation was part of a project conceived of, not as a simple site excavation, but as an attack on a particular research problem using data from a number of different sites. The problem under investigation was the origins of domestication. Because of the nature of this problem, work could not be carried out by archeologists alone; other specialists were needed. It is to Braidwood, then, that we can attribute the rise of multidisciplinary research in archeology. At about the same time Braidwood was working at Jarmo, two other excavations of early Neolithic sites were begun, one at the Biblical city of Jericho by Kathleen Kenyon and the other at Catal Hüyük, Turkey by James Mellaart.

In a few short years the New World too saw the instigation of multidisciplinary research, and on a much grander scale than had heretofore been attempted. Again the problem was the origins of agriculture. The Tehuacan Archaeological-Botanical Project, headed by Richard S. MacNeish, concentrated its efforts on the valley of Tehuacan, a dry highland valley in Puebla, Mexico (MacNeish 1964; Byers 1967). Botanists, geologists, ecologists, geneticists, and geographers, as well as archeologists, were involved in this massive project. Their efforts were rewarded with the discovery of the oldest corn in the New World, and with the establishment of a 12,000 year sequence of prehistory, with adaptations ranging from primitive hunting and gathering to highly complex civilization. A similar project, again headed by MacNeish, was carried out in the Ayacucho Valley of highland Peru (MacNeish 1969).

This concentration on a single problem had tremendous effects on archeological research. First of all, it necessitated the close collaboration of a diverse group of scientists, all of whom were working toward the same goal. Secondly, it forced archeologists to look beyond the confines of a single site to a whole series of sites. With this shift to a problem orientation, then, there was a shift in archeological research strategy. New excavation techniques had to be employed, and new kinds of data had to be gathered.

A more recent multidisciplinary study was carried out in the Deh Luran Plain area of Iran (Hole, Flannery, and Neely 1969). In their report, Hole, Flannery, and Neely point out that sites relevant to questions about the beginnings of agriculture and settled life could not be found in a single ecological zone, as thought by Braidwood, but must instead be sought in a whole series of diverse ecological zones. To them, a regional approach was the most logical one if archeologists were to learn about processes of organizational change in cultural systems.

Multidisciplinary studies were not the only stimulus to regional studies in archeological research. Settlement pattern studies, pioneered by Gordon Willey in his study of prehistory in the Viru Valley of Peru (Willey 1953), were receiving increasing attention. Understanding relationships between sites was now deemed to be an important goal. Strategies were again changing; there was more and more dependence on archeological survey in addition to excavation.

Legacy of the Past--or Legacy of the Past Archeologist?

Unfortunately, despite the advances of the last century, we still have only a fragmentary understanding of complex social systems. This is due partly to the methods employed in the study of complex societies and partly to the nature of complex societies themselves.

Many of the problems encountered in specific research projects spring from improper or incomplete research design. Improperly phrased problems may be impossible to answer. Even plausible projects can go astray if research biases are incompletely considered. Most of our ideas about complex societies are only inferential since they are based predominantly on information gathered during the excavation of a single, large, complex site. Archeologists have assumed these sites to be representative of the system as a whole; consequently, they have tended to ignore other, smaller, sites that were also part of that system. This tendency has resulted in what Adams and Nissen (1972) refer to as a "city-centered view" of complex social systems.

There has been a proclivity on the part of investigators to concentrate not only on particular kinds of sites but also on certain kinds of information from within those sites. There has been a fascination with the excavation of temples and palaces at the expense of less spectacular structures. Because of the emphasis on chronological sequences, excavation strategies have been largely geared toward the use of narrow, deep trenches rather than broad horizontal excavations that would give us some idea on intra-site spatial variability. Finally, a lack of understanding of the techniques of probability sampling has resulted in the acquisition of incomplete and unrepresentative data, for which the degrees of bias and precision cannot be estimated.

Because of these methodological approaches, there are gaps in our understanding of complex social systems. Archeologists have very little insight into the organization of complex systems since nearly all of our data comes from cities, and cities constitute only a small portion of a complex system. Cities never existed independently of their hinterlands, and it is to the hinterlands that we must look if we are to better understand complex societies.

Spatial Modelling: One Approach to Complex Societies Archeology

Complex societies, by their very nature, impose extreme demands on the resources and capabilities of the archeologist. Cities, the most distinctive feature of complex social systems, are characteristically large and heterogeneous. The excavation of a city, therefore, is a tremendously complicated matter.

Cities, however, are only part of a complex system. One must also take into account all the other sites that compose the system, whether they be large primary centers or simply small areas where a single activity was carried out.

A fruitful approach to complex societies, then, is regional in scope. The processes of formation and maintenance of such societies involve not only centrally located population clusters, but also the interrelations between these settlements and others like them or with an outlying hinterland, a fact realized only recently in archeology. A regional scope argues for spatial inspection prior to costly and time-consuming excavation; in large field projects, in fact, excavation may soon of necessity become only a test strategy.

For almost 50 years, geographers have offered models and measures for the apprehension of spatial distributions. What is more, some notion now exists of the connection between these measures and economic, political, and other social reality obtaining during the development of the patterns measured. Geographical measures can aid in modelling past as well as present relationships, and such models are the best available inductive devices at the regional archeologist's disposal. In addition to offering insight during the inductive phase of the scientific process, these models can also aid in establishing data-linking assumptions by suggesting the locus and form of appropriate test data.

There has been a recent upsurge of interest in the use of geographic models and techniques in archeological research (e.g., Clarke 1972; Ucko, Tringham and Dimbleby 1972). Peter Haggett's Locational Analysis in Human Geography (1965) has proved a "spatial handbook" to archeologists, suggesting a multitude of ways of approaching data more profitably. One archeologist was so impressed, in fact, that he suggested that Haggett's book could just as easily been entitled Locational Analysis in Pre-historic Archaeology (Renfrew 1969:74). Other archeologists, however, have not been quite so effusive; Albert Spaulding, in a review of David Clarke's Models in Archaeology, commented that "Surely there is less to locational analysis than meets the eye" (Spaulding 1973:934). Archeologists are divided over the question of the utility of geographical techniques in archeological research. Hesitancy to uncritically borrow techniques from other disciplines is understandable, of course; caution must be exercised to assure the compatibility of assumptions linking any stage in the logical process to a final endpoint, and the assumptions of one science may not be applied in another. Admittedly, archeologists are dealing with systems of a very different nature from the modern, highly industrialized, market exchange systems from which geographers have extracted their models.

Notwithstanding seeming incompatibilities, a number of archeologists have attempted to use techniques pioneered by geography in their research. Perhaps the most successful of these attempts has been made in the study of spatial relationships between settlements in Roman Britain (Hodder and Hassal 1971; Hodder 1972). Through the application of nearest neighbor analysis it was shown that the spacing of the settlements was nonrandom. A central place model was then proposed; it was noted that the settlement distribution best conformed to Christaller's (1966) transport subtype. Hodder and Hassal concluded that transport considerations affected site location. It was found also that the model was of value in predicting a) that two centers were primary and b) the location of lower-order centers, two facts later confirmed archeologically. Hodder and Hassal's research had important implications for geography, too, in that it discussed some of the spacing considerations important in the location of rural periodic markets.

The prediction of site location was an important result of the application of geographic techniques to data on pre-Hittite towns in Anatolia (Tobler and Wineburg 1971). A gravity model (which assumes most interaction with the closest neighboring settlements) was applied to the mention of town names on cuneiform tablets and it was possible to arrive at the relative locations of 33 sites.

Geographic techniques have figured, also, in the isolation of variables relevant to site location in British Honduras (Green 1973). In her analysis, Green was able to show not only that such variables as soil type and distance to nearest navigable water affected decisions concerning the location of Maya settlements, but she was also able to rank the importance of those variables. Another examination of Maya sites in British Honduras, this time using connectivity and accessibility indices, resulted in the determination of possible functions of plazas within sites (Hammond 1972).

Central place theory has been applied to archeological settlement data in Iraq. An analysis of Early Dynastic settlement distribution in the Diyala Plains area of Iraq was attempted by Johnson (1972), and it was found that the distribution conformed to a rhomboidal variant of Christaller's classic central place model. Johnson also found that a combination of the marketing and transport principles of Christaller affected site location. Adams (1972; Adams and Nissen 1972) applied central place theory to settlement configurations in southern Iraq and found that his data did not conform to the classic model; he concluded that this was because assumptions basic to central place theory had been violated.

Although we do not wish to deny Adams his research prerogatives, we feel that perfunctorily discarding an entire class of model configurations at this point may be hasty. After all, a model is a useful and ideal abstraction and nothing more; no idealized blanket concept can cover all real situations. We would suggest, however, that this increases rather than obviates the value of a model. Through the comparison of ideal constructs with the real world, surprising nonconformity with prior expectations is unveiled. It is just such nonconformity that begs for explanation, and is the basis of all inductive thought.

Geographic techniques are methods for enabling us to look at static distributions of things. These distributions, in turn, raise questions about how and why they came to be that way. Distributions in themselves explain nothing. Rather than being the endpoint of our research, then, they are the take-off point for further analysis.

Transportation Models

Although perhaps one of the more undeveloped areas of spatial analysis, contemporary transportation has been the subject of numerous studies directed at determining relationships between measures of network configuration and other aspects of the social and physical landscape. Most of these studies are predicated on the application of graph theory, in which transport routes are represented as lines, and settlements as nodes or points, on a two-dimensional plane. Various geometric and arithmetic operations can be performed on a network so represented, the resulting measures being assumed to be relevant to certain factors or sets of characteristics under which specific transportation networks evolved. Garrison (1960) points out the advantages of a graph theoretical approach to transport networks, advantages that include the fact that whole systems or their parts can be observed with equal ease. In addition, graph theory measures are independent of gross network size and are thus of great generality and inductive breadth.

Economic geographers rarely feel constrained in the literature to formally construct hypotheses and seek independent test data; most transportation studies, at least, culminate with a demonstration of a particular model's utility in illustrating present processes and presumably in directing similar processes in the future. This, we feel, stems from the immediate and practical nature of economic geography. Whereas the archeologist must meticulously establish the validity of his logical processes, the proof of the geographer's science lies in successfully placed railroads and shopping centers. In any event, application of present-day geographic models to prehistoric social systems requires a re-examination of assumptions linking the two. Although the assumptions examined here pertain specifically to transport models, some apply generally to all propositions of economic behavior.

A first assumption basic to all causal models holds that humans--at least when observed collectively--are economic beings whose actions are governed in large part by the physical necessities and material exchanges that go on about them. Thus, one economic action results from another; most or all organized behavior, such as that often called social, political, ideological, or religious, is also the result of economic pressures. This assumption is fully compatible with the archeological paradigm.

Another basic assumption is that the spatial configuration of a network system visible to the scientist is the result of selective forces that channel the system into the ideal for its particular needs (Garrison _et al_. 1959). A restatement of this is Kansky's suggestion that network structure shifts from an "improbable" state early in its development to a "more probable" state later--clearly a case of evolution through selection (Kansky 1963). A slow evolutionary process may account for some road networks today, but is is probable that some early systems, such as that at Chaco Canyon, were carefully planned, laid out, and constructed even before selection could act upon them. Peterson (1950) asserts that many of the roadways of prehistory were probably among the first non-public facilities; such private works may have arisen for the use of entrepreneurial traders and specialists who transported goods or services in a laissez-faire manner beyond the regulation of the state. Our belief that the Chaco Canyon roads may have been non-public facilities will be discussed and supported later. Far from negating the validity of the evolutionary assumption, such planning eases the job of the prehistorian by relieving him of the task of sorting out "fossil" parts of systems that came into use but proved impractical and were selected against.

Another assumption forwarded by Kansky is that of the "tempering effect" of different transport modes. By this he means that the practicalities of different types of vehicle (automobiles and trains in this example) cause networks designed for their use to take slightly different forms. Although this assumption might be useful to the archeologist concerned with multiple transportation networks (e.g., pedestrian and llama traffic in the Andes), it is irrelevant to the Chaco Canyon problem. In any event, the network at Chaco Canyon seems untempered by anything; roads there often take a course directly into a 100-foot cliff, mount the obstacle by means of a precarious line of footholds hewn in the rock face, and continue on at the same bearing atop the bench.

Several models and applications of models pertaining to transportation networks and their relation to the social and physical landscape as a whole will now be examined. We will consider only those studies that promise to be useful in the Chaco Canyon problem. Thus, for instance, Nystuen and Dacey (1961), though concerned with systems of internodal communication, rely entirely upon data on flows rather than observable network shape; such data are inapplicable to the inductive phase of present Chaco research. It is, however, conceivable that other transport models will prove useful in later phases of the examination of the Chaco region.

Kansky (1963), in perhaps the most comprehensive treatment of network configuration, suggested that the structure of any network at any time could be estimated by a set of complementary measures. Although the direct relation between these measures and economic variables is not succinctly stated, correlations are found to exist in at least two cases; armed with a knowledge of these correlations and a set of independent variables, Kansky holds, one is able to postulate typical basic developmental changes in transport networks in axiomatic form. Development in Kansky's terms consists of a process of centralization--more developed networks have more vertices, shorter edges, more terminals, and fewer circuits. (Kansky balks at long definitions of terms, leaving it up to the reader to intuit them. We shall do the same.) Although his argument is based upon the appearance of modern industrial-state networks, such a view is congruent as well with a discussion of developing labor and trade specialization within prehistoric (and possibly non-market) systems.

The dependent variables--represented by graph theory measures--used by Kansky in his correlations are presented in Table 5 . Independent variables were chosen to mirror magnitude of economic activity, size of region, variability of physical relief within a region, and the shape of the region. These variables are listed in Table 6 . All variables were subjected to simple and multiple regression analysis, the results of which are summarized in Table 7 .

Knowledge of the relationships, expressed in correlational form, between these dependent and independent variables, holds Kansky, allows the quantification of functional relationships between such variables in any area. With the additional effort of delimiting the regional area and defining "exogenous" (non-economic) factors, Kansky reconstructs the railroad network in Sicily in 1909 with amazing accuracy.

Although the connection between predictability of railroad networks and predictability of prehistoric

Table 5.

DEPENDENT VARIABLES (Kansky 1963)

Index	Derivation	Significance
NON-RATIO MEASURES 1. Cyclomatic or First Betti Number μ	$\mu = e - v + p$ e = number of edges or routes v = number of vertices or nodes p = number of non-connected sub-grapbs within study area	The cyclomatic number of a linear graph is equal to the maximum number of independent cycles per graph.
2. Diameter δ	$\delta (G) = {}_{x}\max_{y}\, d(x,x)$ d = topological length, the number of edges in a path	Diameter is the maximum associated number of a graph--the length of the longest path in the network.
RATIO MEASURES 3. α (alpha)	$\alpha = \frac{e - v + p}{\frac{v(v-1)}{2} - (v-1)}$	Ratio between the observed number of circuits and the maximum possible circuits--a measure of connectivity. Value ranges from 0 to 1.
4. β (beta)	$\beta = \frac{e}{v}$	Another connectivity measure. Trees, disconnected graphs: $\beta < 1.00$. Networks with one circuit: $\beta = 1.00$. Higher values with more complicated networks: $\beta > 1.00$.
5. γ (gamma)	$\gamma = \frac{e}{\frac{v(v-1)}{2}}$ modified for planar graphs: $\gamma = \frac{e}{3(v-2)}$	Ratio between the edges and vertices of network in a form slightly different from α and β indices.
6. η (eta)	$\eta = \frac{M}{e}$ M = total network mileage	Expresses the relationship between tbe transport network as a whole and its routes as individual elements of network--the ratio of the sum of all edges and all vertices to tbe observed number of edges in a network.
7. π (pi)	$\pi = \frac{c}{d}$ c = the total mileage of a given network d = total number of miles in a network's diameter	Measure of the relationsbip between the network as a whole and specific edges of that network; the simplest network will have a π value of 1.
8. θ (tbeta)	$\theta = \frac{T}{v}$ or $\frac{M}{v}$ T = total traffic flow or volume of freight	Ratio of the network as a whole to its vertices.
9. ι (iota)	$\iota = \frac{M}{w}$ w = observed number of vertices weighted by their function	Ratio between the network as a whole and its weighted vertices--designed for use where no traffic-flow data are available.

Some of tbe indexes listed above were adjusted to correct for the effects of systems extending past regional (or political) boundaries for use in Kansky's correlational analysis:

β becomes β' :	$\beta' = \frac{e}{v + v_e}$ v_e = number of edges crossing a boundary	
η becomes η' :	$\eta' = \frac{M + M_e}{e}$ M_e = the total mileage of all routes going abroad between the boundary and the closest vertex on a given route	
ι becomes ι' :	$\iota' = \frac{M}{w + w_e}$ w_e = total number of weigbted vertices located abroad directly on routes crossing boundary line	

Table 6.

INDEPENDENT VARIABLES (Kansky 1963)

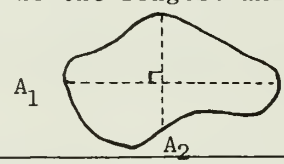
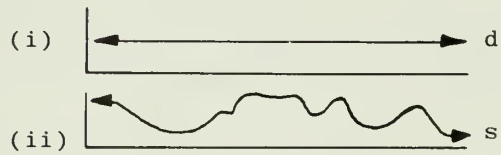
Variable	Derivation or Source
1. Technological Scale	After Berry (1961). Technological scale is a measure of general degree of development, a combination of 43 orthodox economic measures.
2. Demographic Scale	Index of population growth, birth and death rates, and other demographic quantities similar to the above variable (Berry 1961).
3. Size of Study Area	In square miles.
4. Shape of Study Area	An arbitrary index: $S = \frac{A_1}{A_2}$ where A_1 is the longest axis. 
5. Relief Index	Another arbitrary measure in which three random axes are located across the study area (i) and a cross-section is constructed along each axis (ii).  then, $\text{Relief } (\underline{S}) = \frac{\sum_{i=1}^{i=3} (s - d)}{3}$

Table 7.

CUMULATIVE MULTIPLE CORRELATION COEFFICIENTS (R)
AND MULTIPLE COEFFICIENTS OF DETERMINATION (R^2)
FOR SOME OF KANSKY'S VARIABLES[1]

Y		Technological Scale X_1	Size X_2	Relief X_3	Shape X_4
1. β'RR	R	83	83	83	83
	R^2	.69	69	69	.69
2. η RR	R	.65	.77	82	82
	R^2	42	59	.68	.68
3. η'RR	R	.69	.80	.83	83
	R^2	47	.65	69	.70
4 ι RR	R	.73	80	83	84
	R^2	.53	64	69	.71
5. ι'RR	R	.71	.80	.81	.84
	R^2	.50	.64	.65	.70
6. η HWY	R	66	79	79	.79
	R^2	44	63	63	63
7. η'HWY	R	.76	85	85	85
	R^2	.58	.72	73	.73
8. ι HWY	R	83	89	89	.89
	R^2	.70	.79	80	.80
9. ι'HWY	R	80	88	88	88
	R^2	64	77	.78	78
		Gross Energy Consumption X_1	Size X_2	Relief X_3	Shape X_4
1'. β'RR	R	80	80	.80	81
	R^2	.64	.64	65	.66
3'. η' RR	R	.66	.80	84	.84
	R^2	44	.64	.71	.71
5'. ι' RR	R	.65	77	.79	84
	R^2	.43	.60	62	.71
7'. η' HWY	R	.68	.80	80	.80
	R^2	.47	.64	64	.64
9'. ι' RWY	R	70	82	82	.82
	R^2	49	.67	.67	.68
		Imports per Capita X_1	Size X_2	Relief X_3	Shape X_4
3". η'RR	R	.60	.75	.82	.82
	R^2	.36	.56	.88	68
5". ι'RR	R	.81	.74	.77	.81
	R^2	.38	.55	.80	.85

[1] From Kansky, K. J. The Structure of Transportation Networks, Department of Geography, Studies in Geography, Research Paper no. 84, University of Chicago, Chicago 1963 p. 68

footways may be tenuous, the correlational trends listed above suggest models that might be applicable to archeological situations.

Contemporary utilizations of parts of Kansky's and other models and measures also suggest archeological applications. William Garrison (1960), whose goal was examining shifts in location caused by the new concept and use of the Interstate Highway System in the United States, cites the usefulness of a measure of "Degree of Connectivity,"

Degree of Connectivity = L*/observed number of routes

L* = m(m-1)/2 where L*: maximum number of routes that could exist between nodes of network under study, taken as a value of 1.

m: # of places in network

This measure bears a relationship to the balance between over-the-road costs and the cost of constructing transportation facilities. If unit over-the-road cost is low and investment cost in facilities is high, Garrison points out, a network will be little-connected or "underdeveloped." Conversely, if investment cost is low and over-the-road cost is great, the system will exhibit a higher connectivity. Subjective support of the truth of this assessment is available in the contrast between present-day rural roads (investment low, small scale transport costs high--high connectivity) and superhighways (investment high, over-the-road costs low--relatively unconnected). Garrison also shows that connectivity empirically scales with general economic development in a sample of 23 countries for which data are available. This simple model, feels Garrison, allows the comparative analysis of one regional subsystem with another as well as the contrasting of one regional subgraph with an ideal theoretical construct. Gould (1960) and Taaffee, Morrill, and Gould (1963) find relationships similar to those of Garrison between network connectivity and economic development.

The Problem: The Roads of Chaco Canyon

Although some attention has been paid by archeologists to the analysis of spatial distributions of settlements, practically no attention whatsoever has been paid to the analysis of connections (i.e., roads) between those settlements or what those connections may imply. The balance of this paper is devoted to the application of geographic measures to the analysis of a prehistoric road system in northwestern New Mexico in an attempt to illustrate their utility in solving problems of an archeological nature.

Chaco Canyon, an erosionally incised feature 20 mi. long and 1/2 to 3/4 mi. wide located in the semi-arid San Juan Basin of northwestern New Mexico, was the scene 1000 years ago of one of the most complex cultural developments in the American Southwest. At its cultural height, around A.D. 1050, Chaco Canyon hosted a sedentary population of 5000 to 10,000 people, living in a dozen multi-storied pueblos of several hundred rooms as well as in literally hundreds of smaller settlements. Especially significant in terms of the kinds of analysis we wish to pursue in this paper is the presence of an extensive network of roads connecting all of the major pueblos within the canyon with one another as well as with outlying pueblos.

There has been some disagreement among Chaco researchers over the form of the social organization extant in Chaco Canyon at the time of the peak Pueblo period (ca. A.D. 1000-1150). One view, that of Dutton (1938), holds that the two settlement types in Chaco (large, well-planned multi-story pueblos and small, architecturally inferior pueblos, distinguished by Vivian [1970a, 1970b] as "towns" and "villages"), are representative of a single homogeneous culture. Hawley (1937) agrees with Dutton, except that she says that the two kinds of sites represent conservative and progressive attitudes on the part of an otherwise homogeneous population. Kluckhohn (in Kluckhohn *et al*. 1939) attributed the smaller of the two settlement types to a migrant population who he said had the same cultural background of the inhabitants of the larger sites but were not as complex. Vivian (1970a, 1970b) feels that the two settlement types are representative of two completely different social systems with contrasting social organization living side by side in Chaco Canyon. Grebinger (1973) feels that a ranked society was developing under pristine conditions in Chaco. Thus, there is little agreement over the form of the social system(s) in Chaco Canyon. One of the intended purposes of this analysis is to gain further insight into the problem of Chaco regional social structure.

The occurrence of scattered roadway segments, often in association with features such as rock-cut stairways, has periodically been noted in Chaco Canyon since 1900. Despite repeated references to the roads by various occupants of the canyon, including the Navajos (Judd 1954), little attention was paid to them until 1970 when Vivian and Buettner tested some roads as an adjunct project to a study of water control features (Vivian 1972; Vivian and Buettner 1973). Part of the reason for this lack of attention is undoubtedly the fact that the roadways are almost impossible to see on the ground. Erosion has reduced topographic variation, which may have been slight during the time these facilities were utilized, to the point where present-day traces of the roads are practically indistinguishable even to a trained observer.

From the air, however, a complex network of roads, some of which extend far beyond the canyon, appears. For this reason, recent investigations of the roads have employed sophisticated techniques of aerial remote sensing (Lyons and Hitchcock 1977). Stereoscopic examination of black-and-white, color, and color infrared aerial photographs has resulted in the isolation of various kinds of cultural features, including prehistoric roads. In addition, electronic image enhancement equipment (such as an I^{2}S Digicol density analyzer and a color additive viewer) have been employed, permitting the display of many features that could not be detected during visual scanning of the photographs. Aerial photography has been used in the past largely as an exploratory tool for the discovery of unknown archeological sites, but to our knowledge has never served as an empirical data base. The comparative use of remotely sensed data, we feel, holds tremendous promise for future archeological investigations. Electronic image enhancement and manipulation methods, ignored until now by archeologists, can certainly be helpful in both inductive and deductive phases of social research.

After all of the identified features had been transferred to topographic maps, a crew was dispatched to the field with both the maps and the photographs to confirm or refute the mapped features and to record the existence of any features associated with the roads. In many cases the roads were difficult to discern on the ground, especially on the mesa tops where they had been largely obliterated by wind erosion and in the canyon bottom where a great deal of alluviation has occurred. Often the only way to observe the roads on the ground was by shadow marks at certain times of the day such as in the early morning or late afternoon when the sun is low on the horizon (Ware and Gumerman 1977). Occasionally, lines of vegetation mark their course, probably as a result of increased moisture in the road beds. Usually, though, there was little evidence on the ground other than an occasional potsherd.

Aerial and ground truth investigations in Chaco Canyon have led to the confirmation of some 200 mi. of roadway, and we suspect that many more miles of roads will eventually be found. The vast majority of these roads are wide and are sometimes bordered by low walls. They serve to connect all of the major pueblos in Chaco Canyon with one another and with some outlying settlements as far as 65 mi. away. Also, numerous smaller sites are distributed along the roads. One of the most striking characteristics of the roads is their linearity; they are straight regardless of what topographic obstacles may stand in their way. The roads simply go up and over cliffs by means of ramps and stairways, or, as in the case of low hills or trash mounds, cut through them (Lyons and Hitchcock 1977).

It appears that the Chaco road system was not formally engineered--in the sense of being "constructed" or "built"--in its entirety but was instead the result of "navigational" routes that facilitated foot travel between points of population aggregation. These routes in some cases ran in the direction of topographic landmarks that were known by the inhabitants of Chaco to lie near desired locations. This might account for the surprising linearity of the roadways through the region's uneven terrain.

The Chaco Canyon road survey permitted the gathering of data on the roads such as measurements, nodes to which they lead, and kinds of features associated with them. However, these data in themselves cannot explain the roads. To accomplish this we must have independent kinds of test data.

One of the problems that had to be faced in the archeological investigation of Chaco Canyon is the lack of data relevant to either processual or economic questions. The history of archeological research carried out in the canyon over the past 75 years reflects to a very great extent the evolution of archeological approaches to the study of complex societies discussed earlier. The earliest work in Chaco Canyon, carried out by the Hyde Exploring Expedition from 1896 to 1899, was done in Pueblo Bonito, the massive 800-room pueblo that is the largest ruin in the Chaco region. The same settlement was investigated by the National Geographic Society, under the direction of Neil Judd, from 1921 to 1927 (Judd 1954). Later work by researchers such as Roberts and Hawley was directed toward elucidating the cultural chronology of the canyon. In many ways, ceramics and architecture have taken precedence over other kinds of data. Only recently has there been any kind of concern with problem-oriented research in the Chaco region. In 1969 the Chaco Center, a joint research project of the National Park Service and the University of New Mexico, was established. The purpose of this project is to oversee multidisciplinary research in Chaco Canyon and to conduct archeological surveys and excavations of selected sites. Only now are data starting to be accumulated that will aid in solving problems of a processual nature.

The Chaco Transport Network Idealized

Data on the prehistoric transportation network are fragmentary, and probably will always remain so. It was decided, however, that for non-testing purposes the Chaco network map (Fig. 26) could be idealized on the basis of several preservational criteria. First, due to the fact that the slope of geological strata at Chaco is south-to-north, lineations on such an alignment would be accentuated by erosional processes in the 500 years they have lain unused; many east-west alignments would be obliterated. In addition, alluviation in the canyon bottom itself would erase all trace of paths not mounting the mesas and benches. Thus, both east-west and canyon bottom network edges have been assumed where there is reason to believe they existed. Where only fragments of identifiable roadway were located, these were interpolated and in the case of probable outlying centers, extrapolated as well (Fig.27). This idealized Chaco Canyon network data, it is stressed, is as appropriate a subject for inductive modeling as any other. A model is not a verifiable or critically examinable construct, but an abstraction against which expectations are compared and with which more stringent deductive statements can be framed.

Garrison (1960) holds that his connectivity measure and similar indices facilitate the comparison of one regional subsystem with another and of one regional system with an ideal construct. It is suggested that the latter application is most appropriate with the Chaco data, since we have as yet

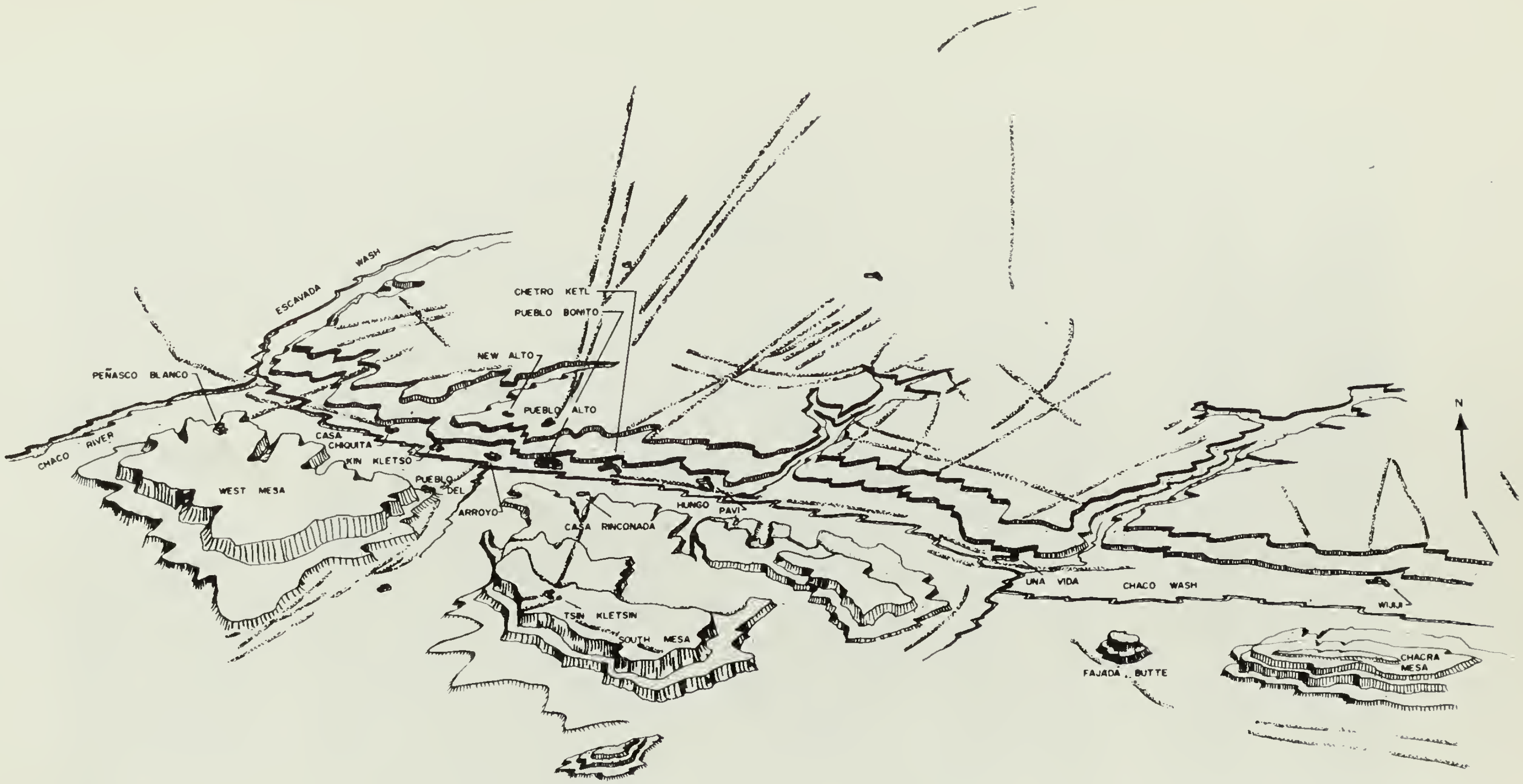


Figure 26 - Perspective map of the general appearance of the Chaco roadway system in and around Chaco Canyon National Monument. This figure is an artist's drawing of the Canyon and the landform features surrounding it. Roadway segments are represented by shaded lines which appear to extend from the central canyon at diagonal angles. The segments illustrated here, and many others drafted on a field map after interpolation from aerial photographs, were verified on the ground and constitute the basis of the idealized network map in Figure 2. For a more detailed map of actual ground-checked roadway segments, see Obenauf (this volume).

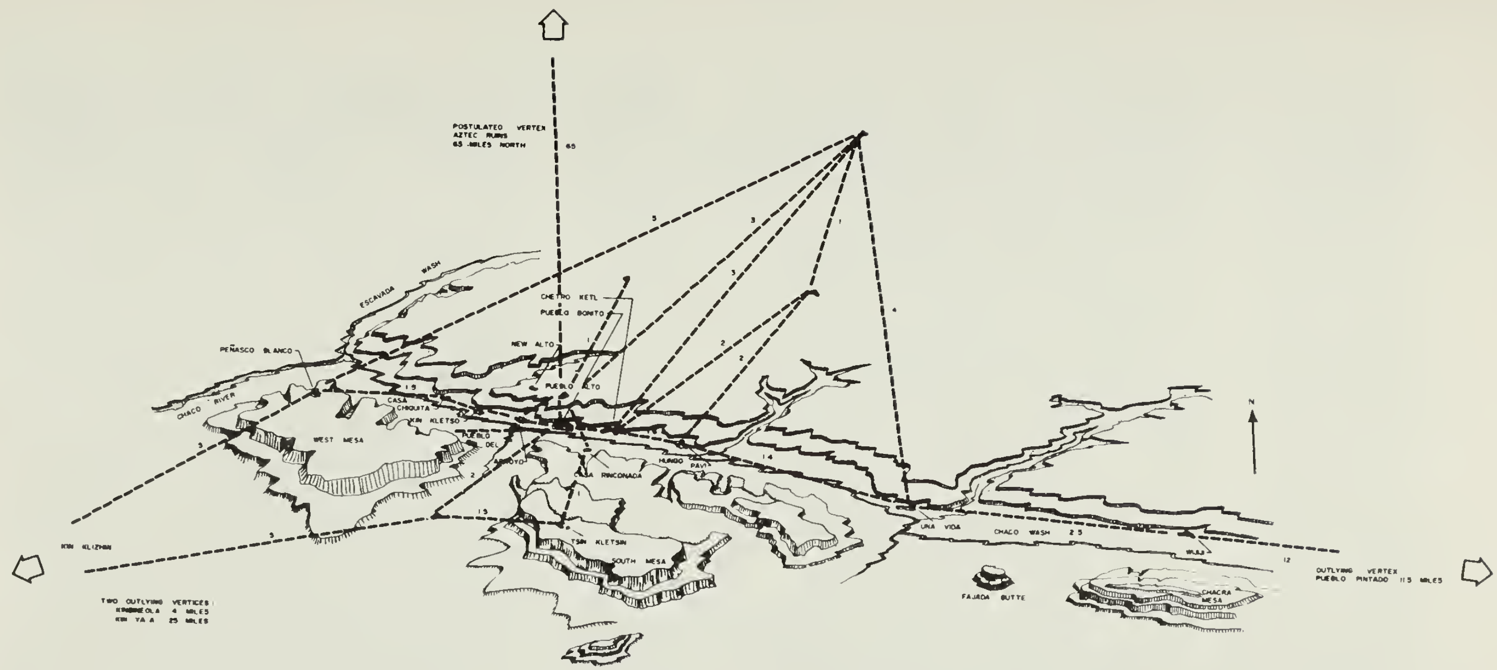


Figure 27 - Schematic, "3-dimensional" artist's concept of the idealized, reconstructed Chaco roadway network. Edges, or routes, are represented by dotted lines; vertices are those places where routes meet or which are judged to be final route destinations. Contemplation of the landform which comprises the Chaco Canyon area shows that routes are little influenced by cliffs and difficult terrain.

no data on the contemporaneity of the various network parts nor boundaries between subregional parts of the system. In addition to this, the configuration of the presently known Chaco network, at any rate, does not suggest a simple division into marketing or service polygons.

Using Garrison's method of connectivity determination, the Chaco data scales at a value of 0.1645 within a possible range of 0 to 1. This suggests a situation in which over-the-road costs were relatively low and investment in facilities high. It is interesting, in passing, to note the straight-line similarity of the Chaco roadways and modern superhighways. Such a configuration holds in cases where transport facilities convey high volumes of traffic or large amounts of bulked goods. Although Garrison's relationships between network connectivity and over-the-road vs. facilitative costs were postulated on the basis of observation of networks in the modern world, where unconnected systems are often the locus of export/import bulking, we assume little interregional trade at Chaco. Bulked goods at Chaco may well have been household and utilitarian materials, such as building and firewood, food, and raw materials for the manufacture of everyday articles.

A connectivity value of 0.1645 ranks low on Garrison's tabulation of 23 modern countries ranked from economically underdeveloped to developed, subjective extremes correlated to some extent with the magnitude of connectivity measures. Kansky's (1963) beta and eta measures also correlate positively with both Perry's technological scale and gross energy consumption, as can be seen by inspection of Table 3. The beta-prime value calculated for the Chaco network is 1.58 in a possible range of from 0 to 12.17 (which would obtain if the Chaco nodes were maximally connected). The beta value for the idealized Chaco network is 5.21; this index should approach zero when nodes are maximally clustered and infinity when nodes are separated farther. By such criteria, the Chaco region seems to tend toward the underdevelopment extreme of the continuum of economic integration.

E. A. J. Johnson's (1970) observations on the problem of economic development, though phrased in a social-engineering context that may be antithetical to predictive science, suggest a scenario for the Chaco area. Johnson notes that underdevelopment is coincident with a "poor utilization of space" in the sense of nonadherence to a regular hexagonal market lattice. Characterizing such a poor spatial arrangement is a dendritic exchange and transport network in which major connections and hence flows take place between only the highest-order centers, each of which in turn captivates smaller centers in its general vicinity at the exclusion of the other centers. Some of the economic conditions that go hand-in-hand with dendritic transport networks--and which, compounded, are the source of much international inequality in the modern world--are unregulated and exploitive traders, and the lack of price-setting markets. Monopolies hold immense power vertically through a dendritic system, and horizontal enterprise is of too small a scale to flourish through economies of scale.

The foregoing models strongly suggest similarities between the Chaco situation and underdeveloped, dendritic "ideals." The Chaco network is little-connected, edges passing between only larger centers and totally bypassing literally thousands of small, outlying sites in the immediate Canyon area. Roadways have, however, been traced with certainty to several large population centers distant from the canyon, presumably each with their own outlying midgets. Such a configuration is congruent not with Löschian spacing, but with the dendritic model suggested above. Perhaps the Chaco pueblos were great bureaucratic centers administering the labor organization of a largely undifferentiated population of urban residents and nearby villagers engaged in intensive livelihood of a similar nature. Roadways were obviously not feeder routes from population centers to immediately outlying smaller sites; instead, they connected major pueblos and/or large population centers within the San Juan Basin. They were not constructed or laid out for the purpose of "pleasing politically," or serving immediate hinterlands, nor do they seem to have evolved in a slow or capricious way.

Two possible theoretical organizational causes for such a system of transport are brought forth here. First, the roadways may have been an aspect of a super-regional system extending over much of the American Southwest. Alternatively, the Chaco Canyon network may reflect a smaller regional development of bureaucratic centers serviced by non-regulated and private entrepreneurs who planned and constructed or laid out the roadways for monopolistic exploitation of urban populations.

From Geography to Archeology

A transition has taken place between geographic and archeological models. Whereas observations of a spatial nature have served to incite "surprise" at nonconformity of the Chaco transport network to an ideally integrated economy, the outgrowth of this surprise is a model capable of yielding archeologically testable expectations. The necessity for this transition does not emphasize real differences between the fields of geography and anthropology--we believe that these differences are almost wholly cultural--but the fact that models are problem-specific inductive devices. A model cannot be tested, nor is it conventional for hypotheses drawn from a model to be tested with the data by which they were suggested.

What implications might be derived from the model of non-pervasive, entrepreneurial bureaucracy outlined briefly above? If the roadway network did evolve or was planned to accomodate economic needs--rather than being simply capriciously laid out for no physical reason at all (which has been suggested, by the way, by otherwise rational anthropologists)--then the form and nature of the network should be reconcilable with other aspects of the social and economic lives of the Chaco people. These organizational expectations should, in turn, be testable through an examination of the observable archeological record in the San Juan Basin.

A proper research strategy will include the suggestion of aspects of Chaco Canyon life that support initial beliefs about the nature of reality at that locus in time and space. Following this, expectations about the nature of the archeological record that would co-occur with the previously suggested organizational configurations are deduced. Such a framework both assures stringent assumption making and narrows the scope of test data being sought to practical dimensions. Traditional archeologists, armed only with vague and often formally unstated inductive models, often rely upon total excavation techniques, spending years "getting all the data." It should be obvious, however, that one can never get <u>all</u> the data--and that one tends to overlook data <u>not</u> consciously looked for. Informed sampling techniques and the application of statistical examination are finding an ever-widening place in archeology due to this realization, with resulting savings in the field. Perhaps more important than economy, however, sampling techniques permit a statement at the level of error in estimations of population parameters, allowing the scientist to speak in terms of deductive probabilities rather than a series of inductive value-judgements (see Judge, Ebert and Hitchcock 1975 for a more detailed discussion of sampling in archeology). In fact, by coupling sophisticated methods of data-collection and organization with a deductive sampling-statistical approach, archeology may soon proceed from problem to answer far more quickly and surely than at present, conceivably without recourse to excavation at all in some cases!

Some Archeological Expectations

In the present paper we do not intend to follow the logical research framework presented above to its culmination. The fieldwork from which the Chaco Canyon bureaucratic-center model inductively grows is only an exploratory base. Unfortunately, much of the archeological work already done in the canyon has been directed toward goals so removed from those presented here as to render past data largely useless in testing our assumptions. Further fieldwork, especially focusing on small outlying ruins, will be necessary. At this time we will state only a few of our expectations about Chaco organizational forms and derive test implications for them.

Our belief was stated earlier that Chaco social and economic organization during the period that produced the roadways was of the form of an administrative bureaucracy that regulated intensive agricultural forces in and around densely populated urban centers. Tied economically to these centers was an outlying and more dispersed population of dry agriculturalists, hunters, gatherers and resource suppliers integrated with larger centers not by market or kinship ties but rather through the entrepreneurial efforts of "businessmen" operating outside the regulatory bonds of administrative power. That administrators and entrepreneurs were the same people, as seems to be the case today, is not discounted. The dendritic transport network first suggested that the goods moved at Chaco Canyon were largely low-cost bulk materials, and it is reasonable to believe that urban centers of the size common at Chaco were in vital need of subsistence goods from external sources almost from their inception.

The social organization of a labor-intensive, relatively classless system is qualitatively different from that of a stratified society, differing primarily in the ascription of status positions and means of acquiring status. Stratified systems are characterized by successional rules; status is passed from one individual to another according to strictly prescribed customary regulations. Non-stratified systems, on the other hand, do not have these kinds of rules. Status attainment is instead based largely on the manipulative abilities of the individual. In stratified social systems status is ascribed; in non-stratified systems status has to be achieved.

One of the major areas in which differences might be expected between these two kinds of social systems in the archeological record is in mortuary practices.

Archeologists are becoming increasingly aware of the fact that burials offer excellent opportunities for reconstruction of prehistoric social relations. Differential mortuary treatment provides us with a means of determining how the individuals so treated were viewed in life. Status symbols in stratified systems are kept in the ongoing social system upon the death of an individual who occupied a certain status. In non-stratified systems, however, status symbols are not transferable and are frequently found in mortuary contexts as a result. It would be likely, then, to see differences in the kinds and quantities of goods associated with members of the two different kinds of systems. Differences in the age and sex composition of the burial populations of the two kinds of systems would be expected as well. Children, for example, would not be expected to compose a very high proportion of the burial population in a system in which status must be achieved, since children would not have had time to rise in status. By an examination of characteristics of the burial populations in Chaco Canyon it would be possible to determine whether the social system there was stratified or not.

The idea that at least the Chaco bureaucracy was based upon a labor-intensive rather than expedient organization of labor has already been advanced. Under such a regime, which removes the emphasis from the "expert" individual producer, increases in population are profitable and can be expected to occur as a result of increasing birth rates. This would have the effect of both increasing the numbers of the population as a whole, and reducing the mean age of the population. Population increase may be reflected in increasing room size or greater volume of storage to living-space over time. In addition, variation in demographic rates may lead to different accretional rates and forms in masonry architecture. This variation might be easily studied in the large pueblos, some of which slowly grew around a nuclear structure rather than being constructed as a unit; such an investigation could easily be undertaken entirely with aerial remote data, and is presently being considered.

A bottom-heavy population triangle is feasible under a labor-intensive regime, for even young children or those in charge of babies can work alongside other laborers. Small-sized children's work implements or carrying containers, as well as material and skeletal evidence of infant-carrying equipment, would evidence such a strategy.

Economic organization and the resulting material remains might be expected to take on certain characteristics under a labor-intensive regime and entrepreneurial trade, as well. Little central storage of goods would be expected, for a bureaucratic administrative center serves not as a redistributive but a directing force, combating stochastically determined material shortages by the "on paper" redirection of only small quantities of resources. Certain resources are more amenable to the practice of intensive labor than are others, and might be sought in the record. Irrigation agriculture, incorporating vigorous water distribution and expansive facilities, have been discovered in the canyon itself; in outlying areas, other alternatives would have been practiced, but still in a more or less intensive manner. The large-scale gathering of vegetable materials--much consigned for transport to urban centers--might have been practiced. Recent excavations on Chacra Mesa, several miles south of Chaco Canyon, indicate that intensive rabbit drives were conducted, and a kiva literally filled with rabbit remains points to the possibility that these too were being collected for "export."

The distinction made in the previous paragraph between a bureaucratic, entrepreneurially operated administration versus a redistributive system suggests a number of architectural differences that might be expected between these two systems. In a redistributive system, goods from an entire region are collected at one place before they are magnanimously redistributed by a chief or king. One ever-present characteristic of redistributive systems is bulk storage facilities at a central place; these are often located within the residence or palace of the head of government, where they can be guarded and controlled. Such storage facilities are often of a "silo" type, in which very large quantities of bulk goods are stored, rather than compartmented. On the other hand, storage facilities within a system organized on bureaucratic, entrepreneurial principles would be expected to be more numerous, to hold fewer goods per facility, and to be dispersed throughout an area in a number of buildings rather than at a central spot. The architecture of Chaco Canyon and outlying Anasazi pueblos served by the roadway system offers no evidence of palaces, huge bulk storage facilities, or any other trappings of a "redistributive" system in the sense in which anthropologists have used the term.

Finally, allowance for the wastage of the spoils of perhaps unscrupulous trade and the corruption that necessarily accompanies the marriage of administration and business must be made. A simple measure of affluence (reminiscent of modern geographic measures!) might be made through a comparison of trashmound volume accretion entirely by aerial photogrammetric methods. It would be expected that waste disposal at larger pueblos, where enterprising traders would have been based, would increase while that of the smaller outlying ruins would remain more constant. As entrepreneurial activity ramified itself, large accumulations of wealth would be expected to become more common and more evenly distributed.

These suggestions are necessarily brief and are based upon many nonstated assumptions of linking relevance. Testing of their implications is only touched upon, and would be requisite upon devising of appropriate taxonomic or measuring devices for gauging of covariance in objective terms. Our exposition is incomplete, as well, in not going far enough inductively: many additional questions are brought to mind dealing with the origin, stresses, and breakdown of a social and economic milieu based upon precariously-balanced public/private spheres.

Conclusion

In the preceding pages we have attempted to show the utility of interdisciplinary modeling in the social sciences. It must be stressed that a model is simply an inductive scenario, totally removed from inductive testing; nonetheless, in the Chaco Canyon situation a spatial model has suggested an anthropological model, which in turn yields expectations of prehistoric organizational behavior that have archeological test implications. Geographic models, perhaps better than those of other disciplines, provide ideal inductive material for anthropologists, especially in the study of sedentary complex societies in which distinctive spatial patterning betrays much about economic and social structure. The application of such models to prehistoric situations is increasingly facilitated by a shift to the sampling concepts and regional outlook of current archeology on one hand, and by new tools such as the aerial techniques mentioned here on the other.

Finally, although the foregoing has perhaps seemed "one way" in favor of the archeologist, we feel that mutual benefit is to be gained in almost all cases of interdisciplinary modeling. The cascading nature of inductive feedback, which we see happening today between geography and anthropology, is capable of producing insights that are overlooked within more familiar confines. Affirmation of hypothetical validity reflects upon all of the processes involved in the reasoning process, allowing an assessment of the appropriateness of broad problem orientations, the accuracy of central assumptions, and the applicability of the argument at hand to that array of theory and generalization that will eventually be a true science of man.

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PREHISTORIC IRRIGATION CANALS IDENTIFIED FROM SKYLAB III AND LANDSAT IMAGERY IN PHOENIX, ARIZONA

by

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Some seven or eight centuries ago the dry river valleys of southern Arizona were inhabited by a group of agriculturalists who interacted with local hunter-gatherers as well as with more civilized peoples to the north and south. Today called the Hohokam ("the dead ones" in the language of the Pima who later lived in the area), these people built both large, communal pueblos and more dispersed sedentary villages. Considerable attention has been given by modern archeologists to Hohokam pottery and ceremonial art with the object of tracing ideological connections with other complex societies in Mexico, Arizona, and New Mexico; there is anthropological evidence to suggest that contemporary societies in similar developmental stages tend to interact in such ways on a regular basis, and that the transmission of ceremonial or traditional objects and ideas may often link geographically diverse groups.

Some of the most interesting data available on the Hohokam, however, may pertain more directly to their life and subsistence. Mormon settlers in the Salt River drainage--the site of Phoenix today--in the early 1860's reported the existence of "a system of regular ways leading in a generally westward direction..." (Turney 1929). These lineal depressions were utilized by settlers first as wagon roads; later, it was realized that they must constitute an ancient canal system. Early records of this network were compiled by Gen. J.R. Rushing and William H. Pierce in 1867, by H.R. Patrick in 1903, and by Omar A. Turney during his service as Phoenix city engineer in the 1920's (Schroeder 1943). More recent and intensive excavation of Hohokam canals was undertaken near Snaketown, a prehistoric site near Phoenix, by Emil Haury (Haury 1976).

The canals were found in some cases to measure as much as 75 ft. from bank to bank and 10 ft. in depth; at least 135 mi. of these features could be traced on the ground at one time or another. Some canal segments were lined with rock or fired adobe, further enhancing their visibility (Hodge 1893). It is estimated that the system may have supplied water to at least 20,000 acres of farmland, serving a prehistoric population of 25,000-50,000. Turney (1929) calculated that the construction of a single major feeder canal, undertaken with primitive digging tools and manual material transport, may have required the moving of 7,000,000 cu. yds. of dirt! These canals may be the most intensive system of prehistoric irrigation presently known in North America.

The Rio Salado, which fed the canals, runs only seasonally today and it is probable that this was the case during Hohokam times as well. During rains, however, the canals would fill and supply the single watering necessary for the growth of the Hohokam peoples' drought-resistant corn (Castetter and Bell 1942). The Hohokam planted two crops, one in the spring and one in the fall, and if these failed they could be supplemented by saguaro in July and mesquite and mescrew beans in the fall (Borher 1970).

The Hohokam canals were "built into" the Phoenix landscape in a number of ways. At first, during historic times, they hosted wagon and horse traffic; later, farmers settling in the Salt River lowlands reopened almost all of the ditches for modern irrigation use. When land was sold or transferred, the cost of acreage occupied by prehistoric canals was sometimes deducted because the cost of filling and grading would have been more than the selling price. As land increased in value many of the canals were leveled, but field boundaries and roads often still conformed to their courses.

It is interesting to note that while in the 1920's several miles of canals could still be clearly traced on the ground, O.A. Turney lamented the lack of an aerial platform for their examination: "...if a balloon had passed over the valley, the ancient canals would have been as conspicuous as the (modern) highway roads" (1929:53). In 1930, Neil M. Judd, a pioneer in Southwestern archeology and, apparently, cultural resources remote sensing, led a joint Smithsonian Institution-Army Air Corps mission illustrating that Turney was right. Flying at an altitude of 10,000 ft. above the Salt River Valley, first up one side and then down the other, Judd's crew photographed a number of the prehistoric canal segments, but also commented on the rate at which the features were being destroyed by farming and land modification (Judd 1930, 1931).

Interpretive experiments carried out at the Remote Sensing Division of the National Park Service in Albuquerque illustrate that all traces of the canals have not vanished, and suggest that some parts of the system may be interpreted and mapped using photographic and even low-resolution digital data derived from satellite platforms. Visual interpretation and electronic enhancement of portions of Skylab III and Landsat space imagery permitted the identification of nearly 50 mi. of Hohokam canals visible primarily because of their effects on the configuration of land-use in present-day Phoenix. While the indications interpreted from the space imagery are usually not the canals themselves, but rather "canal traces" apparent because of the shapes of fields and the courses of modern roads and canals, many land-use features seen on remote sensor imagery are of this nature. Traces or not, these reflections of ancient canals built almost a millenium ago, seen from the perspective of Skylab and Landsat, not only confirm Turney's 1929 map but at times allow its correction.

Initial interpretation was accomplished with Skylab imagery, a choice made largely because of the higher resolution of this photographic medium. To facilitate interpretation, the central portion of the original imagery (Frame SL3-86-011, 5-in. format color Ektachrome, illustrated in Fig. 28) was enlarged and printed at a size of 11 by 17 in. on semi-matte paper. Although this enlargement process resulted in considerable image degradation, it was reasoned that this would not measurably reduce the detectability of linear features on the ground, which are visible because of the patterns produced rather than because of the resolution of the features themselves (Fischer 1962). Interpretation was for the most part visual, aided at times by a pocket comparator and hand

Figure 28 - The study area: Phoenix, Arizona, and vicinity enlarged from Skylab true-color image, Frame SL3-86-011.

lens. Although the interpreters had past experience in interpreting linear features--prehistoric roadways at Chaco Canyon, in northwestern New Mexico--a recognition pattern could easily have been arrived at by untrained interpreters in a few hours. When features had been tentatively identified, the print was overlain with a mylar sheet and the canals traced with the aid of a light table.

Turney's (1929) map (Fig. 29)served as an invaluable guide during the interpretation, allowing the tracing of distinctive shapes and the location of lineations that might otherwise not be identified as part of the canal system. The overlay of canals traced from Skylab imagery reveals some 50 mi. of straight, curved, and branching features that coincide with Turney's canals (Fig.30). The canals that were discovered from the Skylab imagery, as compared with the extent of Turney's network plot, is shown in Fig.31. Canal segments that pass through cultivated areas appear generally as lighter streaks, probably caused by bare earth exposure; those in the urban areas of Phoenix are indicated by textural patterning, most likely the result of the placement of roads and buildings.

It should be noted that the printing methods available for this publication do not allow the extremely high-quality reproduction of the Skylab or Landsat imagery necessary for the reader in most cases to recognize all of the canal segments illustrated in the overlays. Both Skylab and Landsat imagery can be obtained at reasonable prices from the EROS Data Center, User Services Unit, Sioux Falls, SD 57198.

A second stage in the Phoenix canals experiment was the inspection of Landsat imagery. Landsat data, collected by a four-band multispectral scanner (MSS) and telemetered to Earth from an altitude of approximately 530 mi., offers a visual ground resolution of about 60 by 60 m. after processing at Goddard Space Flight Center. This specification is often taken by prospective users as an indication of "low resolution," for, of course, it implies that only objects larger than 60 by 60 m. can be detected. Fortunately for anthropologists and archeologists, this is not the case. Although each picture element or pixel in a Landsat print represents the contri-

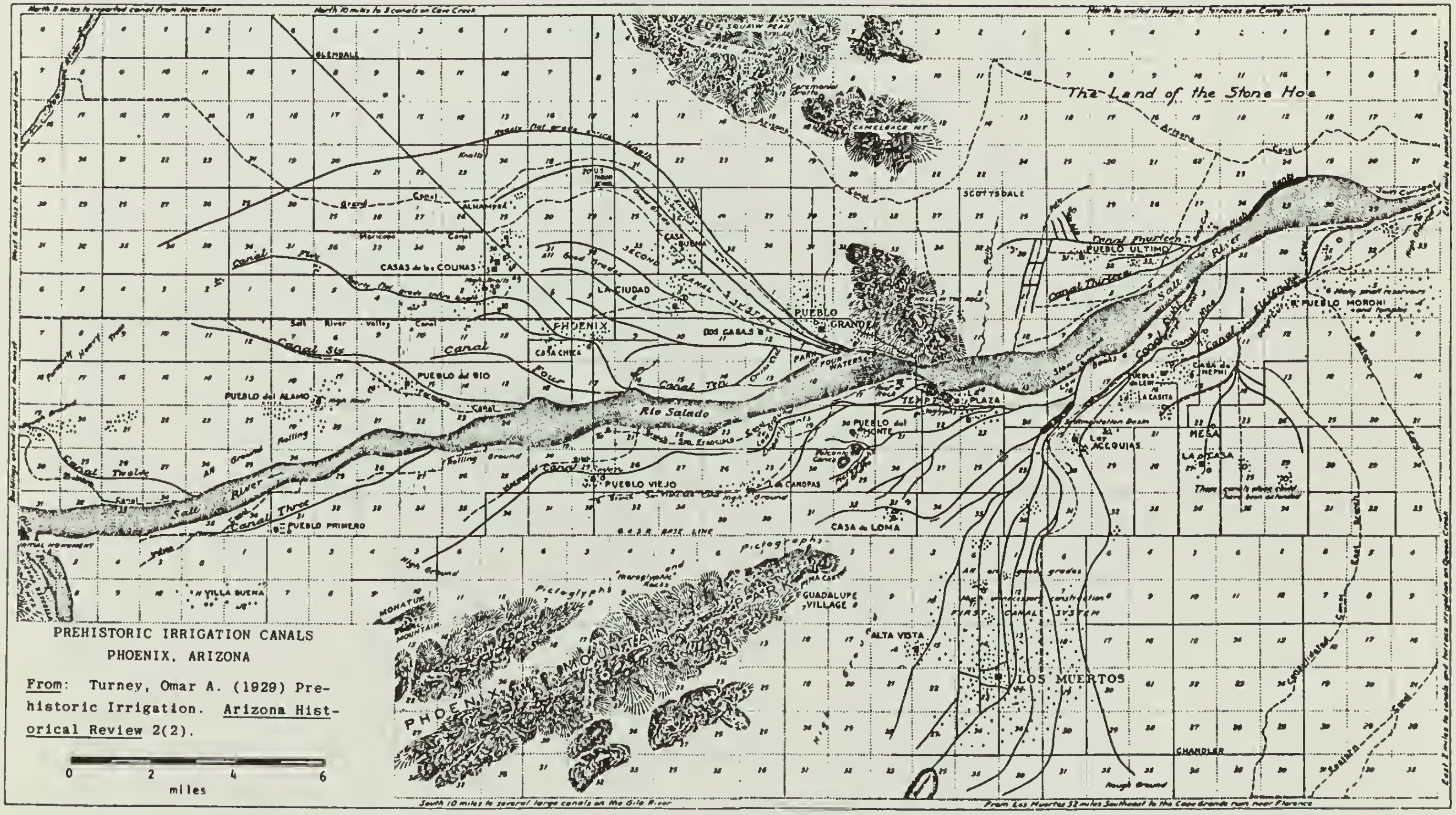


Figure 29 - Omar A. Turney's 1929 map of the prehistoric Hohokam canal system as detectable in the 1920's in the vicinity of Phoenix, Arizona. Extensive land-modification which preceeded intensive agriculture was rapidly obliterating the system at this time.

Figure 30 - Overlay of canal segments detectable on the Skylab imagery. Continuous lines represent canal segments interpreted with a high confidence level, while dotted lines indicate a somewhat lower level of confidence.

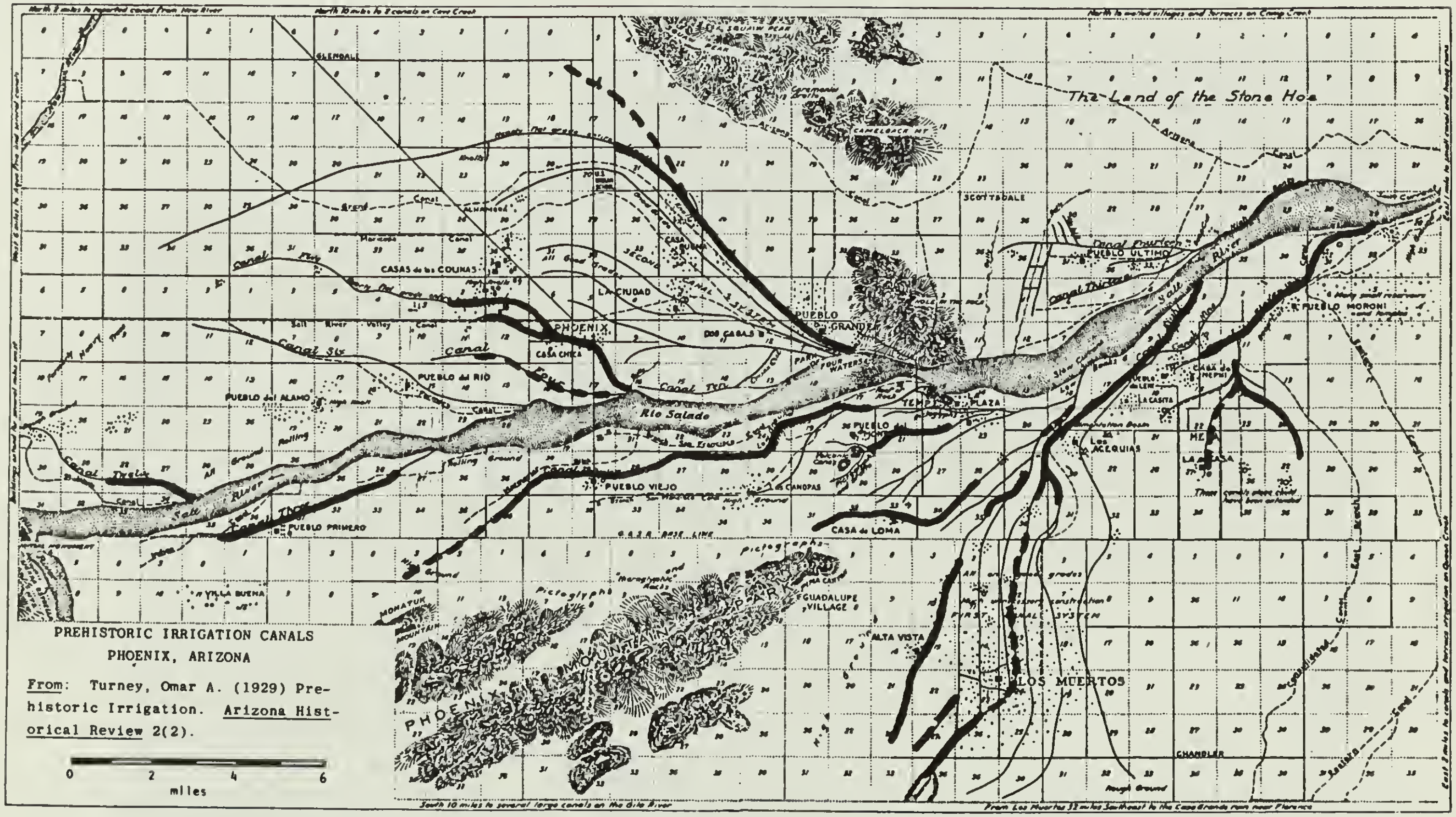
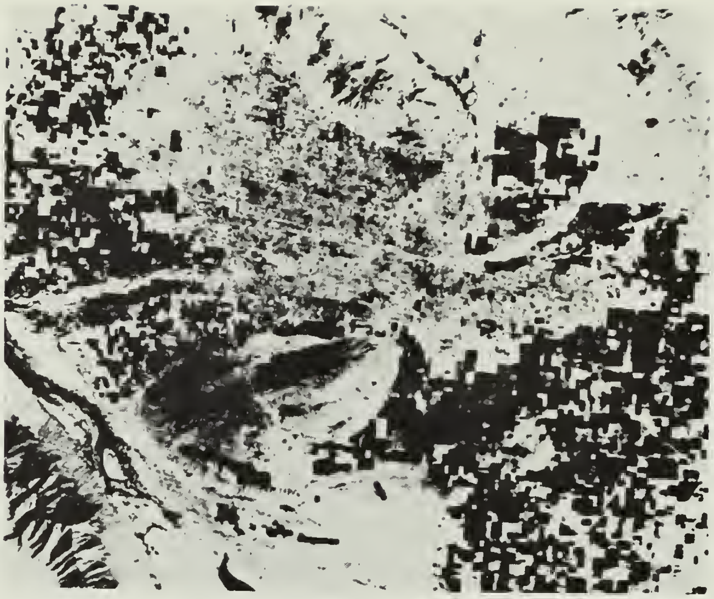


Figure 31 - Canal segments interpreted from Skylab imagery compared to those shown on Omar A. Turney's 1929 map of the Phoenix Hohokam canal system.

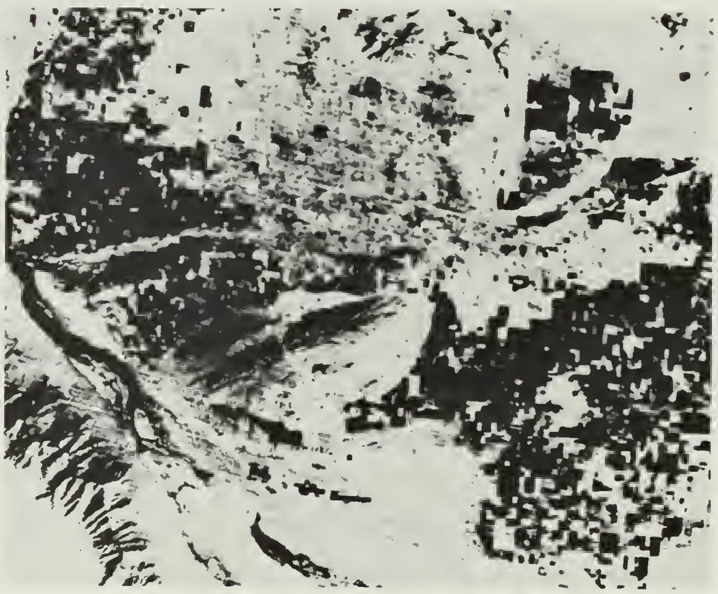
bution of a 3600 sq. m. area on the Earth's surface, that pixel is actually a combination of the contribution of all reflectance from the area pictured. Subtle patterning such as that caused by modern highways, ecological zone boundaries, fence lines, and (in this case) prehistoric canals, all of which are far less than 60 m. wide, can often be seen on Landsat imagery.

Landsat interpretation began with the interpretation of 1:1,000,000-scale black-and-white and color composite prints of Scene E-1985-17145 collected on April 4, 1975. It soon became apparent that the area of interest, which corresponded to the area covered by the Skylab enlargement, measuring about 4 by 5 c. on the 1:1,000,000 prints, was too small to be conveniently viewed. Using a macro lens, the study area itself was photocopied from each of the four black-and-white prints (bands 4, 5, 6 and 7) and the color composite print in 35 mm. negative format using Pan-X film. These negatives were then enlarged so that the study area covered almost 8 by 10 in. Again, this enlargement resulted in considerable image degradation. Imagery that has passed through at least eight generations since the collection of its digital data base (and at least 10 when seen in a printed publication) cannot be expected to possess the resolution of the original. Nonetheless, careful interpretation revealed that at least a few of the canal segments--one of which was not positively confirmed during the interpretation of Skylab imagery--can be detected. Turney's map and the Skylab overlay again served as guides in this process; often, the detection of vague or ephemeral patterns on any remote sensor imagery depends heavily upon knowing what to look for and where to look.

Each band of the Landsat imagery collects data on the intensity of reflected electromagnetic radiation within a different spectral region. Band 4 (500-600 nm) and Band 5 (600-700 nm) collect information at bands in which vegetative growth absorbs radiation and bare earth, rock, and urban areas reflect highly; the lighter areas on imagery from these bands represents nonvegetated or sparsely vegetated places on the ground (Fig. 32 and b). Band 6 (700-800 nm) records red light, and Band 7 (800-1000 nm) records near-infrared (IR). The near-IR band

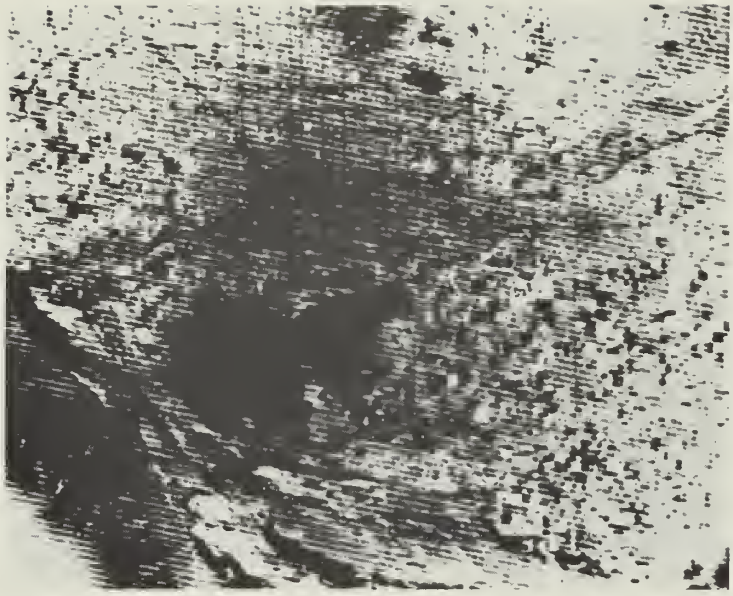


a

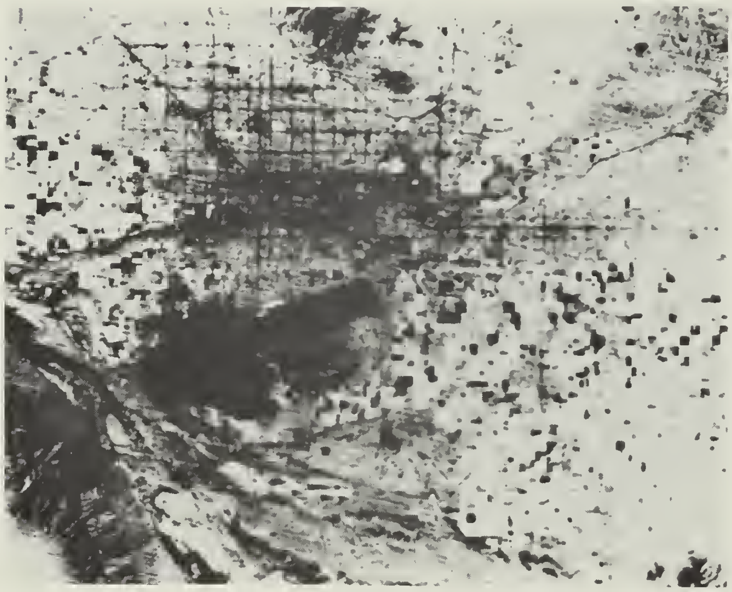


b

Figure 32 - Enlargements from Landsat multispectral scanner (MSS) four-band imagery of the study area. The first four photos are taken directly from the Landsat black-and-white prints for each band: band 4 (Fig. 32), band 5 (32), band

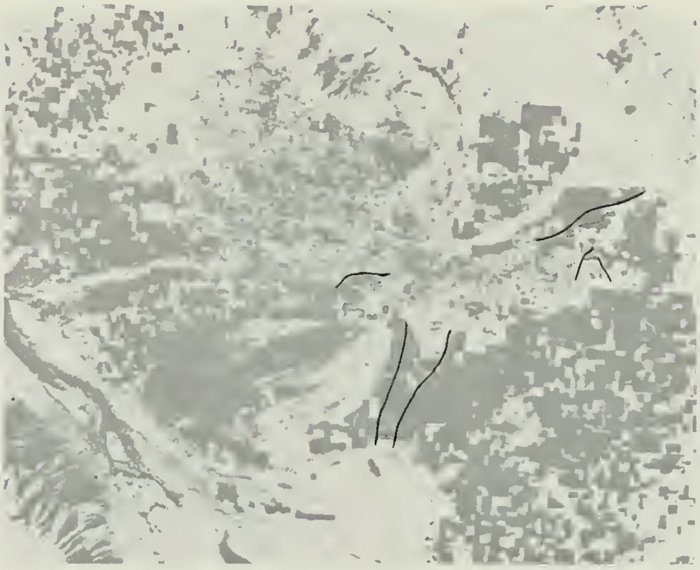


c

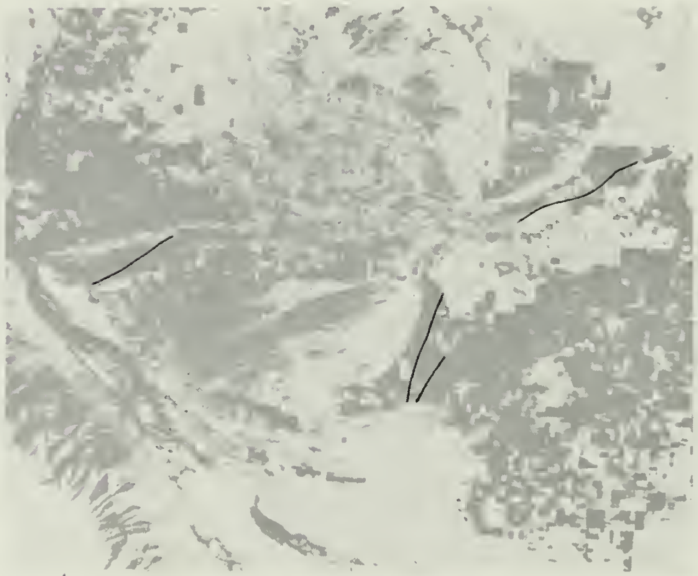


d

6 (32), and band 7 (32). In the next four frames, overlays of canal segments interpreted from each of the four bands have been added, bands 4, 5, 6 and 7 being shown in Figures 32e, 32f, 32g , and 32h respectively.

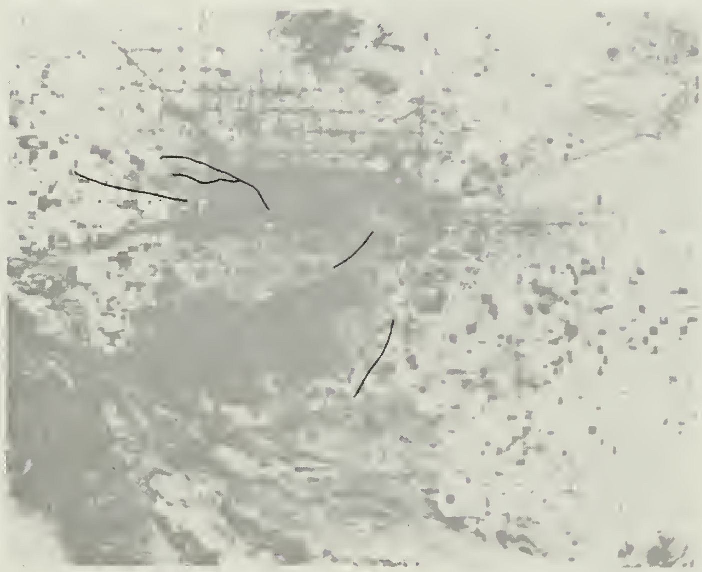


e

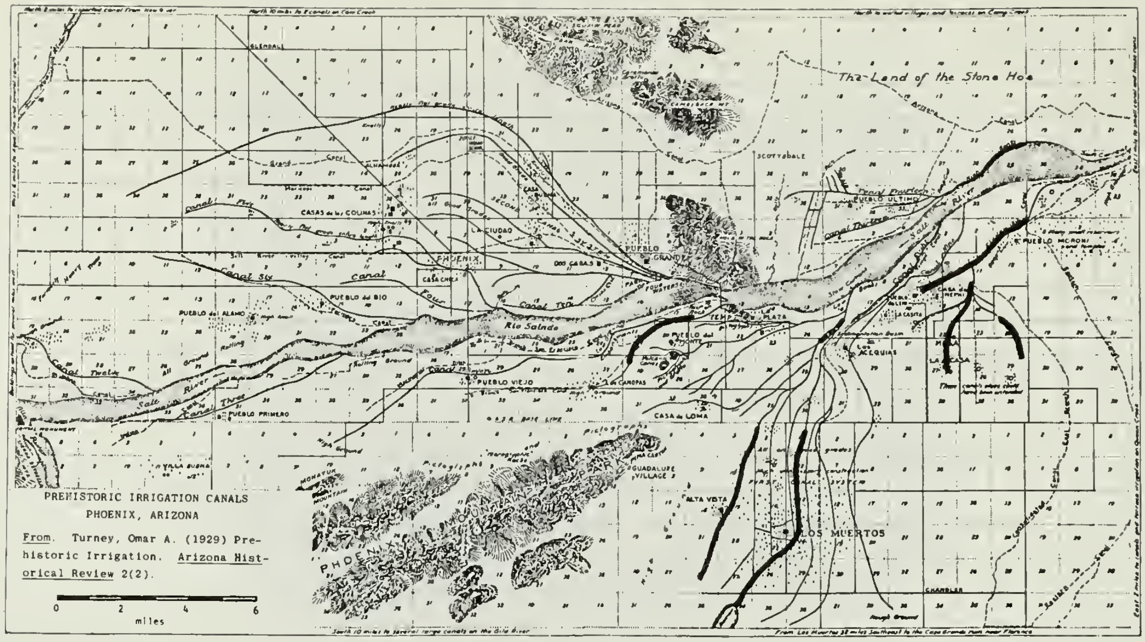


f

g



h



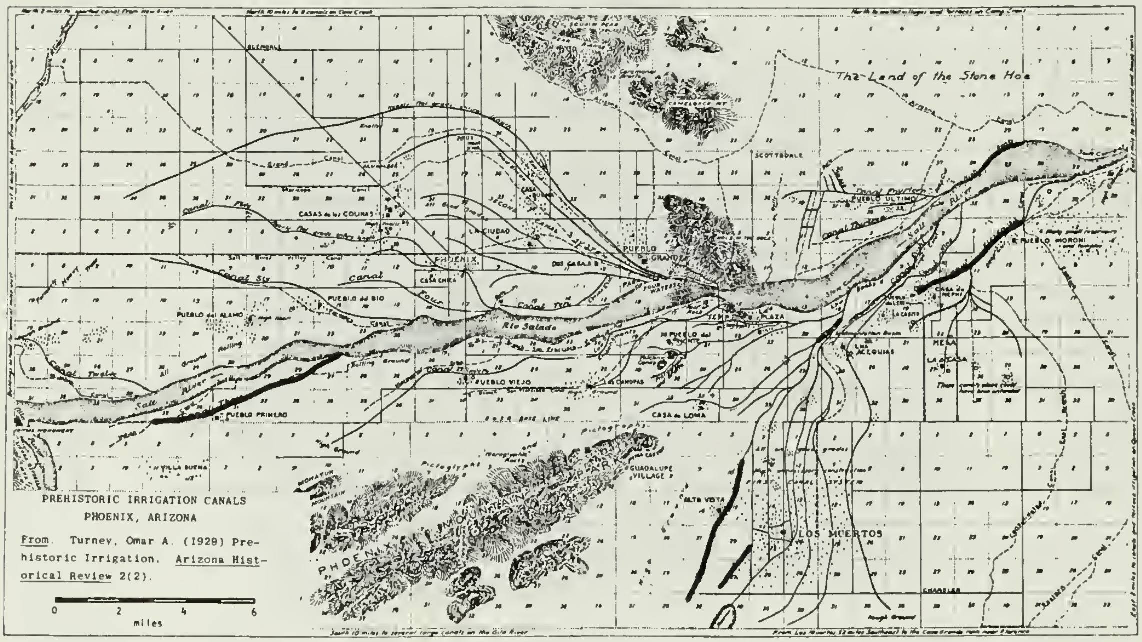
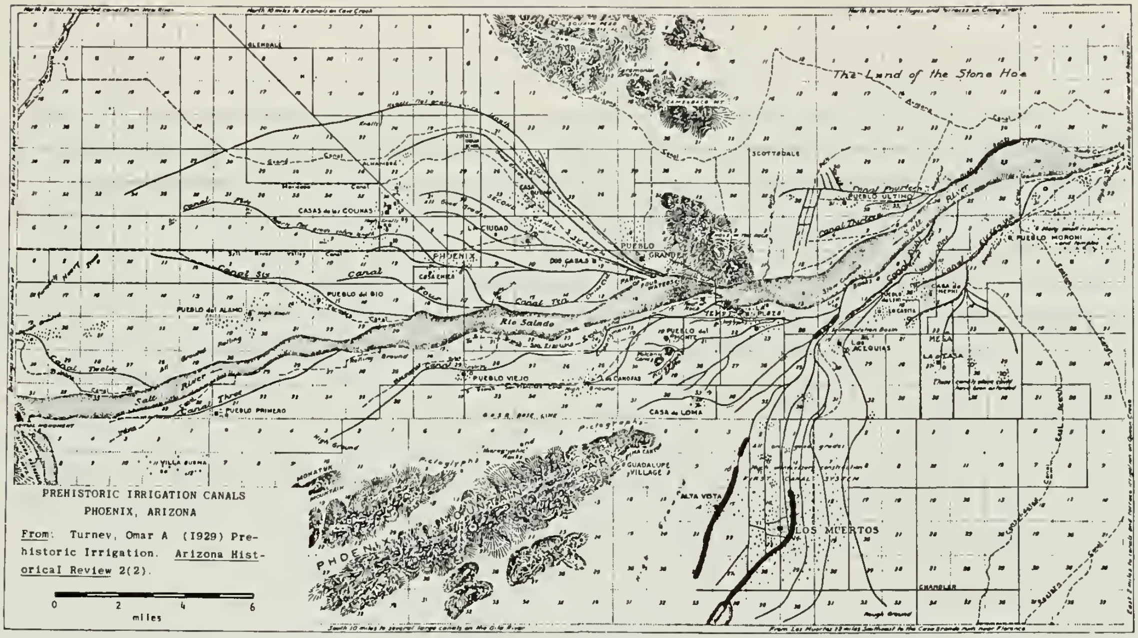
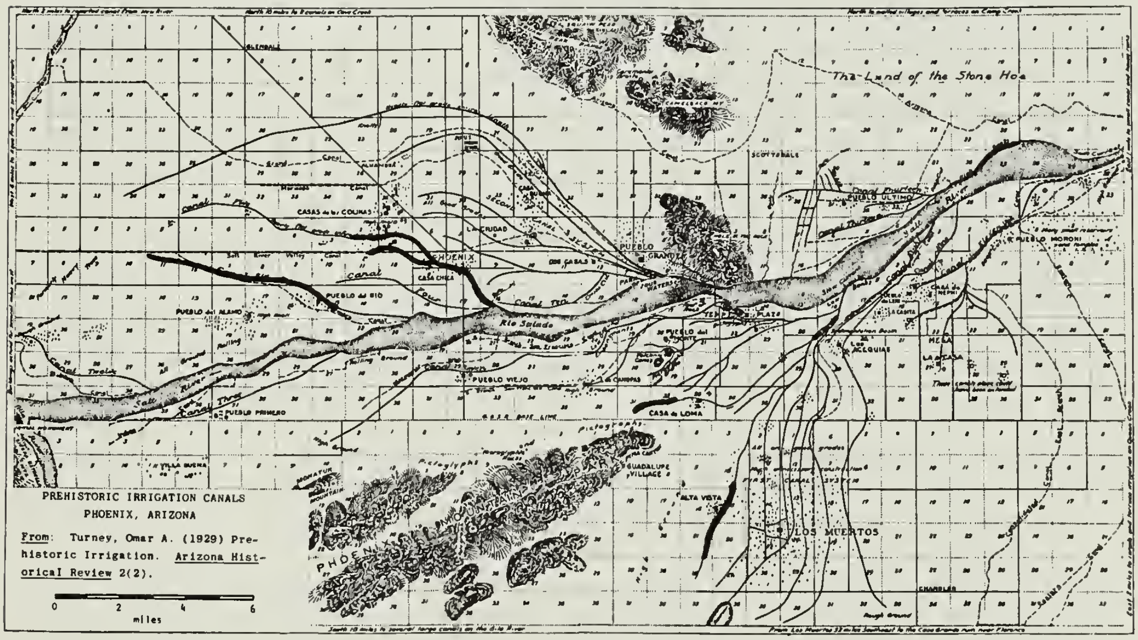


Figure 33 - Canal segments which were interpreted from each of the Landsat MSS bands. Note the differential success in identification of





canal segments in different sorts of land-use areas using each band. Segments interpreted from bands 4, 5, 6 and 7 appear in 33a, 33b, 33c, and 33d respectively.

is especially interesting because it reveals information not available from a true-color image such as the Skylab frame discussed above. Near-IR radiation is almost totally absorbed by water bodies on the ground, and reflected very efficiently by vigorously growing vegetation. The bright areas on Band 7 imagery are therefore representative of vegetated areas (and the brightest those plants that are cared for--cultivated varieties); darker areas are water or soil. Bands 6 and 7 images of the study area are shown in Fig.32 (c and d).

Landsat frames were overlain with mylar sheet and interpretation took place over a light table. Although frosted mylar sheet diffuses light and to some extent obscures detail, the patterning that results from linear features is not significantly affected. Landsat interpretation resulted in the discrimination of 10 segments of suspected canal traces, at least one of which was not detected on the Skylab imagery. These canal trace segments, identified according to the Landsat band on which they appeared, are illustrated in Fig. 33. Those segments passing through cultivated areas, and appearing as bare earth or road areas (lighter in tone) against the darker vegetation in fields, were detected most easily on Bands 4 and 5. Band 6, which in this image was of degraded quality even in digital form (apparently missing every second scan line), was not especially useful for the interpretation of canal traces. Band 7 revealed canal traces lying within urban areas. Canal traces lying parallel to the scan lines of the Landsat imagery were for the most part not visible, but those lying perpendicular to the scan lines were quite obvious. This is a general characteristic of Landsat or for that matter any scanner data--if lineations are to be discriminated, they should lie at a right angle, more or less, to the scan lines.

As a final "check," and in an attempt to extract more information from the Landsat imagery, portions of the study area were still further enlarged and edge-enhanced with an International Imaging Systems Digicol. This device is essentially a closed-circuit television system that views a frame of remote sensor data and then can be used to manipulate the grey-scale values within that frame in a number of ways. The most appropriate manipulation method in this case was edge-enhancement, in which a positive and a negative picture of the scene in question are superimposed and then offset electronically by a small increment. This results in the enhancement of linear contrast differences, and previously proved very useful in the discovery of prehistoric roadways at Chaco Canyon. In the case of the Phoenix canals, this procedure met with only partial success. Two canal trace segments, both of which are almost perpendicular with the Landsat scan lines, and both of which were very obvious in the Landsat frames, were easily enhanced (Fig. 34). Because of the complicated pattern of lines that image modern Phoenix, no additional canal traces could be identified with the Digicol.

CONCLUSIONS

The interpretation of traces of prehistoric Hohokam canals from Skylab and Landsat imagery discussed above illustrates that, even over urban areas that have been extensively altered in recent times, the reflections of land use in the distant past can be detected. Although space imagery has often been disregarded because of its "low resolution," this objection is irrelevant when certain sorts of features, especially linear features, are the object of interpretation. Resolution must be weighed against the spectral regions important in feature discrimination in different parts of a study area, which is illustrated by the fact that Landsat Band 7 imagery revealed at least one canal segment not visible on the higher-resolution Skylab data.

Most prehistoric sites are not visible on space imagery, and for this reason archeologists have tended to use such imagery as a source of data on non-cultural, but supportive, features such as environmental zonation, soil type, and landform. This study, however, points out that there are some classes of cultural features that can be discovered, mapped, and measured using currently available space imagery. Based on these results, we anticipate even more successful cultural analysis from space imagery when refined sensors such as the proposed Landsat thematic mapper and the Shuttle-borne Large Format Camera become operational.

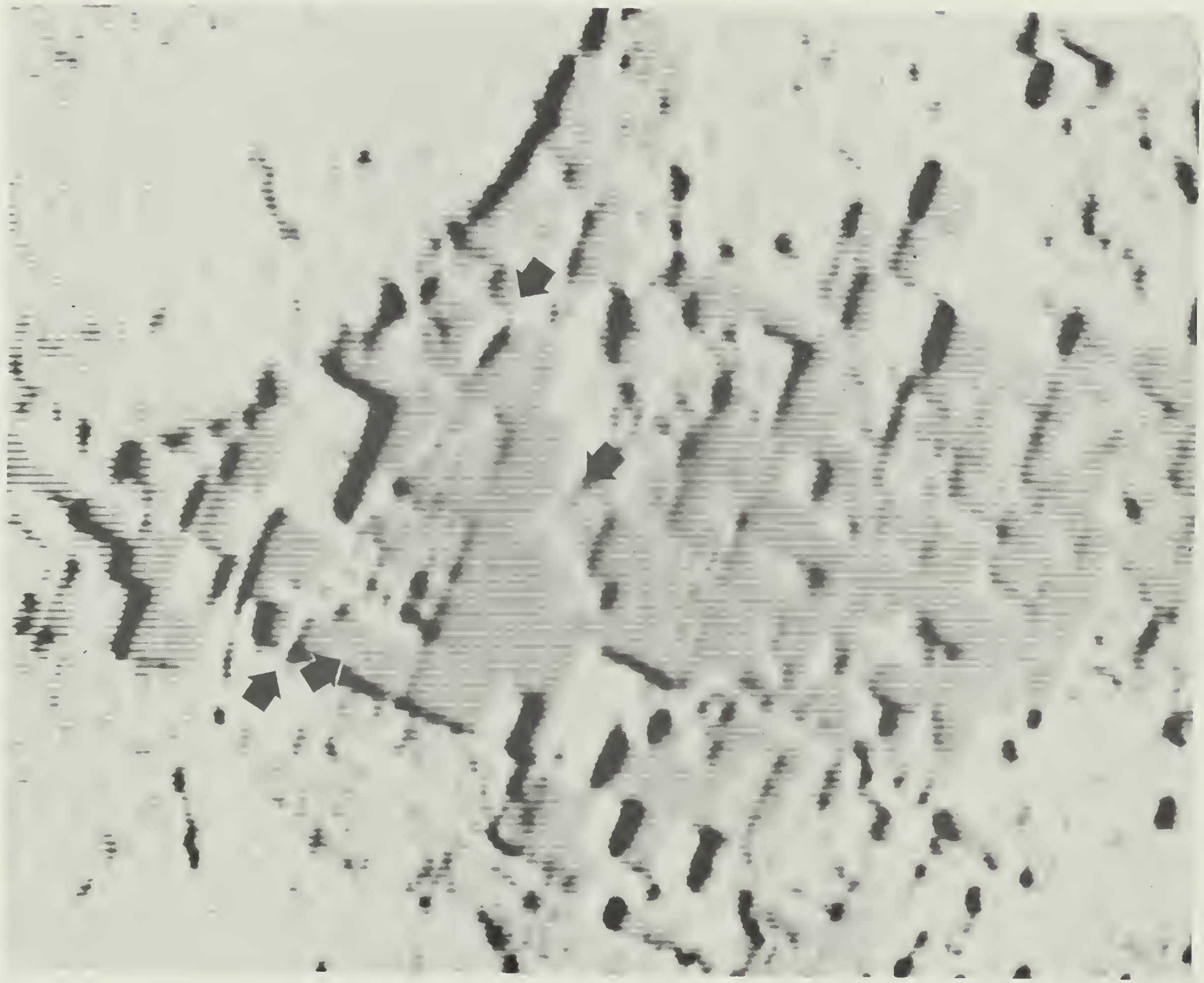


Figure 34 - Photograph of the Digicol screen showing two edge-enhanced canal segment traces (between the black arrows). Band 5 Landsat MSS imagery was used as the basis for this enhancement.

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NINETY SIX NATIONAL HISTORIC SITE SOUTH CAROLINA

by

Ellen B. Ehrenhard
W. H. Wills

Investigations conducted at Ninety Six National Historic Site were initiated in 1977 by the National Park Service in order to more precisely define the exact placement of General Nathanael Greene's Revolutionary War Camp (Cann, Rodeffer and Watson 1974; National Park Service 1975). The historical background, initial archeological investigations and soil analyses, and conclusions reached prior to an intensive study of aerial photography are documented by Ehrenhard (1977a, b; 1978). A summary of these are presented in Part I of this paper. More detailed analysis of the aerial photography was carried out as a separate and independent study in order not to prejudice the analysis in any way and is presented in Part II. One aspect of Part III was in part a ground check of the Remote Sensing interpretation and demonstrates the utilization of these intensive studies of the photography and the additional information that can be obtained using remote sensing techniques.

THE LOCATION OF GENERAL NATHANAEL GREENE'S REVOLUTIONARY WAR CAMP

NINETY SIX NATIONAL HISTORIC SITE SOUTH CAROLINA

by

Ellen B. Ehrenhard

Historical Background

Ninety Six National Historic Site consists of 468 acres of woodland, meadows, and fields. It is located in the South Carolina Piedmont, south of the Saluda River in Greenwood County (Fig. 35). The present boundaries encompass abundant cultural resources which represent many themes of American history, including the periods of Indian contact and trade, pioneer settlement, the French and Indian War, the Revolutionary War, and the growth of the frontier.

Ninety Six originated as a place name in 1730 when a settlement began at an intersection 96 mi. from Keowee on the Cherokee Path. Several land grants were made in the vicinity and by 1746 the Commons House of Assembly was encouraging settlement of the Carolina backcountry. Between the years 1750 and 1757 a registered Indian trader, Robert Gouedy, began a trading post that conducted a brisk business with both whites and Indians. Then in 1751 some white settlers stole deerskins from a Cherokee camp, eventually precipitating a frontier war. During this period of conflict many people took refuge at Ninety Six, adding to the already burgeoning population.

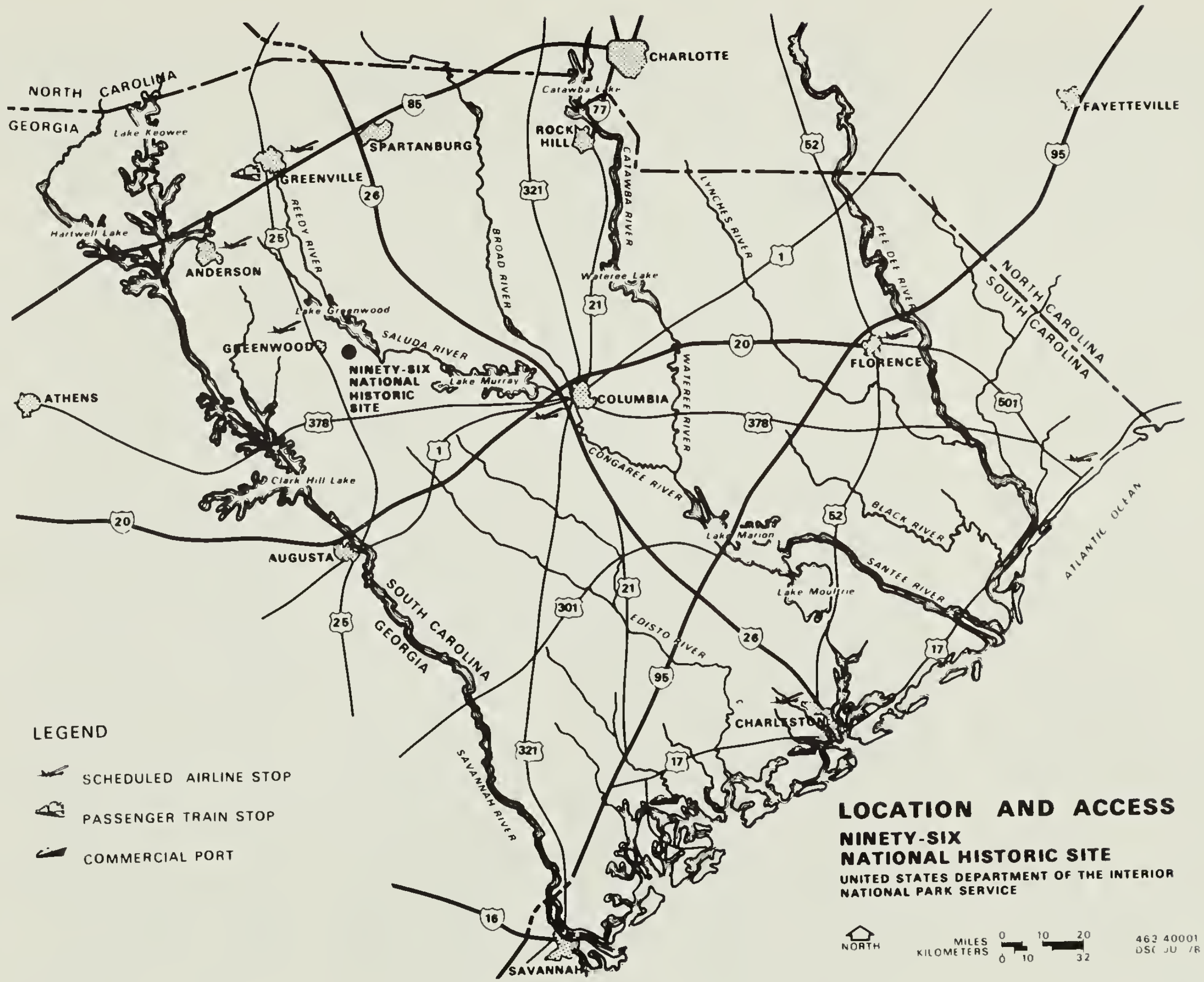

NORTH CAROLINA
GEORGIA
Lake Keowee
Hartwell Lake
ANDERSON
GREENVILLE
SPARTANBURG
CHARLOTTE
Catawba Lake
ROCK HILL
FAYETTEVILLE
REEDY RIVER
BROAD RIVER
CATAWBA RIVER
LYNCHES RIVER
PEE DEE RIVER
Wateree Lake
Lake Greenwood
GREENWOOD
SALUDA RIVER
NINETY-SIX NATIONAL HISTORIC SITE
Lake Murray
COLUMBIA
WATEREE RIVER
FLORENCE
NORTH CAROLINA
SOUTH CAROLINA
ATHENS
Clark Hill Lake
CONGAREE RIVER
Lake Marion
BLACK RIVER
ATLANTIC OCEAN
AUGUSTA
SOUTH CAROLINA
GEORGIA
Lake Moultrie
SANTEE RIVER
EDISTO RIVER
CHARLESTON
SAVANNAH RIVER
SAVANNAH
85
77
52
95
26
321
25
1
21
20
378
501
301
17
16
LEGEND
SCHEDULED AIRLINE STOP
PASSENGER TRAIN STOP
COMMERCIAL PORT
LOCATION AND ACCESS
NINETY-SIX
NATIONAL HISTORIC SITE
UNITED STATES DEPARTMENT OF THE INTERIOR
NATIONAL PARK SERVICE
NORTH
MILES 0 10 20
KILOMETERS 0 10 32

Figure 35

In 1759 Governor Lyttleton came through Ninety Six on his way to lead an expedition into Cherokee territory. While in this area, he stockaded Gouedy's barn to be used as a magazine and a safe place of retreat if necessary. Unfortunately, in the skirmishes to come all of Gouedy's buildings except this stockaded barn were destroyed by Indians, as were all of the other buildings, crops, and livestock at Ninety Six. In spite of this setback, Gouedy's business and the town of Ninety Six continued to thrive.

In 1769 laws were passed to establish courts, build jails, and appoint sheriffs inthe backcountry of Carolina. Judicial districts were established and a wooden courthouse and jail were constructed at Ninety Six. The population had reached 15,000 by 1772 and a more permanent brick jail replaced the wooden one in 1775. Ninety Six had become both the commercial center and the judicial seat.

This portion of South Carolina, the backcountry, was sympathetic to Britain in the days previous to the Revolution. These loyalist sentiments eventually led to the first land battle of the Revolutionary War in the south in 1775 between the patriots under Major Andrew Williamson and the loyalists under Captain Cunningham. The patriots ultimately gained control of Ninety Six and the frontier backcountry remained under their control until 1780 when Williamson surrendered to the loyalist Brown at Ninety Six. The courthouse at Ninety Six was garrisoned to use as a fort and Lt. Col. John Cruger assumed command. In this same year the command of the Southern patriot army went to General Nathanael Greene.

On May 22, 1781, General Greene and his army marched to Ninety Six and began the siege against the fortified town. With General Greene was his engineer, Colonel Thaddeus Kosciuszko. Their attack was focused against the Star Redoubt, which was defended by Lt. Col. Cruger and approximately 550 men. On June 9, Colonel Henry (Lighthorse Harry) Lee arrived at Ninety Six from his successful campaign at Augusta to reinforce Greene and begin siege against Holmes

Fort, which was defending the town's water supply. "Lighthorse Harry" was successful in his attack but Greene lifted his siege against the Star Redoubt when he received work that Lord Rawdon was on his way from Charleston with reinforcements for Cruger. Greene and his men retreated across the Saluda River with Rawdon in pursuit. Cruger was ordered to evacuate Ninety Six, but before he did, he demolished the Star Fort, destroyed the village, the courthouse, and the jail.

By 1783, a new village (Cambridge) was established near the old one on land that was confiscated from James Holmes, a loyalist. It consisted of 15 to 20 houses, seven stores, and three taverns in 1806; by 1850, however, the economy had failed.

In 1903 the first efforts were made to focus national attention on the historic events that occurred at Ninety Six. In 1969 Old Ninety Six and the Star Fort were listed on the National Register of Historic Places; in 1974 the Secretary of Interior officially designated Old Ninety Six and the Star Fort a National Historic Landmark.

Although public interest in the preservation of this site originated in the early years of the 20th century, it was not until January 1977 that the responsibility for the administration of this National Register site was transferred to the National Park Service.

During July and August of 1977, the National Park Service, Southeast Archeological Center (SEAC) in Tallahassee, Florida, conducted archeological investigations at Ninety Six in an attempt to locate and identify General Nathanael Greene's Revolutionary War field camp. This was part of a program to determine the amount of land acquisition necessary to include historic features to the north of the Star Redoubt.

ARCHEOLOGICAL RESEARCH

Archeological excavations at Ninety Six National Historic Site and at Yorktown (Colonial National Historical Park) indicate that both of these Revolutionary War sieges were conducted according to prescribed military strategies and tactics. The French military strategist, Vauban, was the source of the principles followed by the engineers of both General Washington at Yorktown and General Greene at Ninety Six when the siegeworks were constructed (J. A. Greene 1976:21; Holschlag and Rodeffer 1976:19). Although Vauban's manual was over a century old, no other work existed that so carefully dictated the gentlemanly art of siegecraft (Vauban 1968).

While Vauban's Manual of Siegecraft and Fortification deals with siegecraft in depth, it touches only briefly on aspects of castramentation (camp layout). There are little, if any, graphic directions for the procedure of laying out a camp or for the order and discipline of the soldiers. During the Revolutionary War this deficiency was recognized by General Washington and he solicited the compilation of a written system of order and discipline for his troops from Baron von Steuben in 1779. This book was to become the official military manual of the American Army and remain so until the War of 1812 (Riling 1976:19).

So, by 1779, the Continental troops and officers had available for their use a standardized handbook for military discipline and exercise. There is no reference to whether or not this handbook was utilized by General Greene's engineer, Thaddeus Kosciuszko, during the siege of the Star Redoubt at Ninety Six. In all likelihood he did, since at that time he held the office of Chief Engineer in the south, an official position and von Steuben's Regulations were officially accepted and ordered into use by the United States Congress.

General Greene and Lt. Colonel Kosciuszko arrived at Ninety Six on May 22, 1781, with an army of

427 Continentals from Maryland and Delaware, 421 Virginia militia, 66 North Carolina Continentals, and 60 men from Captain Kirkwood's Delaware scout company (Ward 1952:12). Kosciuszko focused his attack against the Star Redoubt because he felt that Greene's forces were not strong enough to seize both Holmes Fort and the Star simultaneously (Haiman 1943: 112).

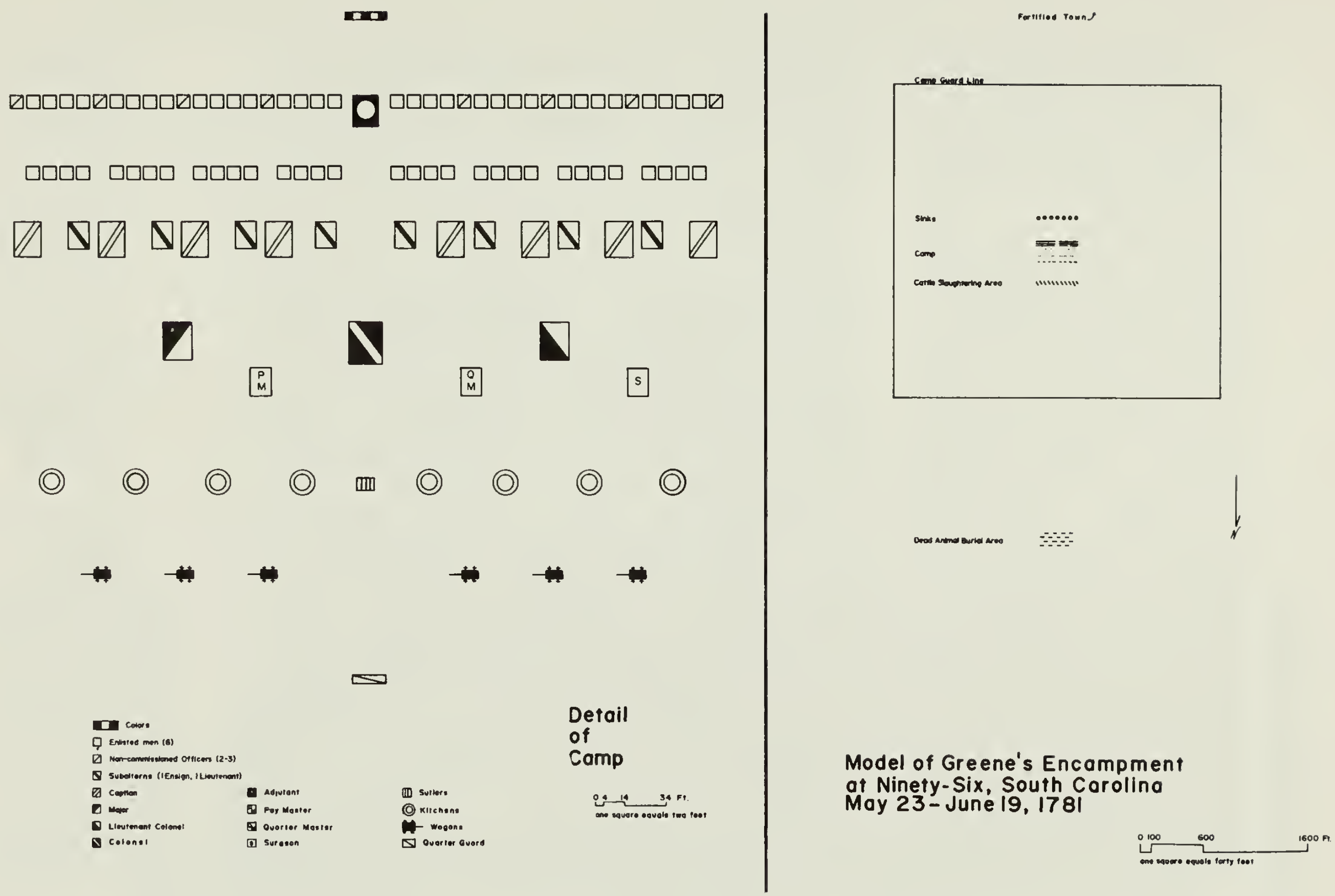
The 18th century earthworks constructed by Kosciuszko were excavated by Holschlag and Rodeffer in 1975 and subsequently restored (Fig. 36). Although the construction of the siegeworks varied from the recommendations specified in the military manuals, Holschlag and Rodeffer concluded that these variations could be explained as an adjustment made by Kosciuszko "commensurate with the objective and number of troops...." They also state that aside from these variations, "The placement and configuration of the parallels and approaches conform well to expectations based on the military manuals" (Holschlag and Rodeffer 1976:74).

Hypothesis

Based on Holschlag and Rodeffer's conclusions, it was our hypothesis that Greene's selection of the campsite and his layout of individual camp components for the siege of the Star Redoubt at Ninety Six also followed regulation procedures described in contemporary military manuals. That is, in order to test this hypothesis, a schematic model of the camp was formulated (Fig. 37). Military manuals, principally von Steuben's manual (Riling 1966) and Smith's (1968) military dictionary, and a reference to the number of men in Greene's army were the basis for this reconstruction. Once the size of the camp and the various elements were established, an attempt was made to place this model within the environment. This procedure was conducted with the aid of 7.5 minute quadrangle maps and aerial photographs of the site.

Map of siegeworks opposite Star Redoubt.

Figure 36



P M
Q M
S
Colors
Enlisted men (6)
Non-commissioned Officers (2-3)
Subalterns (1Ensign, 1Lieutenant)
Captian
Major
Lieutenant Colonel
Colonel
Adjutant
Pay Master
Quarter Master
Surgeon
Sutlers
Kitchens
Wagons
Quarter Guard
Detail
of
Camp
0 4 14 34 Ft.
one square equals two feet
Fortified Town
Camp Guard Line
Sinks
Camp
Cattle Slaughtering Area
Dead Animal Burial Area
Model of Greene's Encampment
at Ninety-Six, South Carolina
May 23-June 19, 1781
0 100 600 1600 Ft.
one square equals forty feet

Figure 37

Expected Camp Location

There are no known direct references to the location of Greene's Camp and no contemporary maps. Johnson's map of 1822 was drawn after the siege and shows four camps, the larger one being in the northeast corner on the inside of the bend in the Island Ford Road (Johnson 1822). The siege works were depicted incorrectly both in position and in form on his map. The Star Redoubt was illustrated as having 16 salients rather than the actual eight. The correct placement and form of both the Redoubt and the siegeworks (Fig. 36) are shown by the excavations of Holschlag and Rodeffer (1976).

There were, however, several indirect references to the camp's location, and a locational model based on information derived from such references is illustrated in Fig. 37 (Ehrenhard 1978:5-7). This model corresponds to all recommendations with one exception--that is, that there is a reference to the camp's being within cannon range. Vauban indicates that it is permissible for a camp to be placed within range if it is protected by a depression. The depression is interpreted in this case to refer to a reverse slope, a positional tactic still in use by the military. It can be seen from the topographic map that a reverse slope exists in the hypothesized area (Fig. 38). In order to demonstrate this more precisely, an exaggerated profile was prepared from the elevations taken at each stake along the meridian line that was established from the north salient of the Star Redoubt northward for a distance of 2590 ft. (Fig. 39). The essential purpose of placing a camp on this type of terrain would be for protection from enemy fire and observation.

Expected Camp Elements

As the hypothetical camp layout was constructed, the number of men listed as composing Greene's army was borne in mind. The assumption was made that the main body of the army, i.e., those responsible for

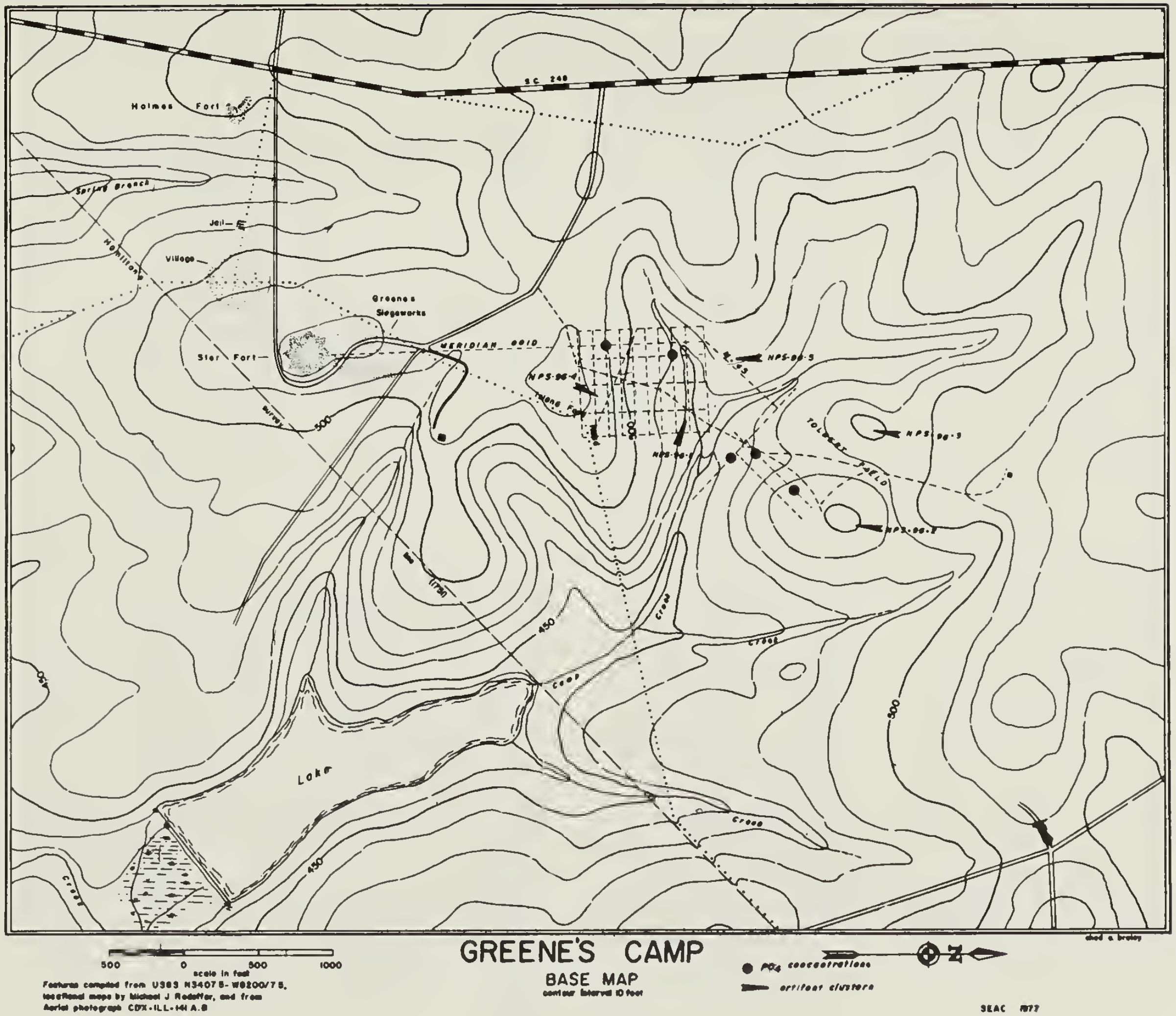
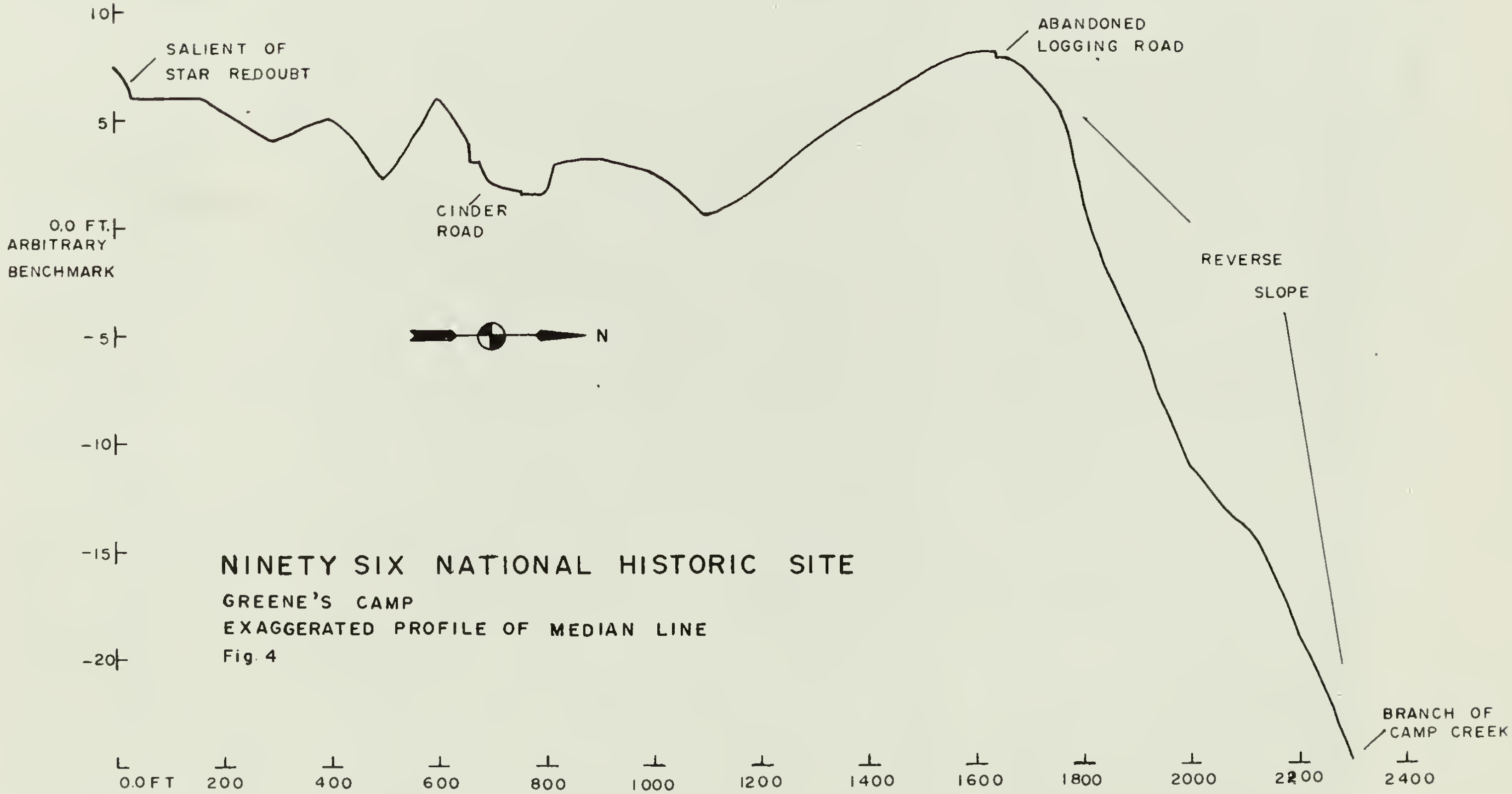

GREENE'S CAMP
BASE MAP
contour interval 10 feet
500 0 500 1000
scale in feet
Features compiled from USGS N3407.5-W8200/7.5, locational maps by Michael J Rodeffer, and from Aerial photograph CDX-1LL-141 A.8
PO4 concentrations
artifact clusters
SEAC 1977
S.C. 248
Holmes Fort
Spring Branch
Jail
Village
Hamiltons
Greenes Siegeworks
Star Fort
MERIDIAN GRID
Tolbert Field
Lake
Creek
Camp
500
450

Figure 38



10
SALIENT OF STAR REDOUBT
5
CINDER ROAD
0.0 FT. ARBITRARY BENCHMARK
-5
N
-10
-15
-20
ABANDONED LOGGING ROAD
REVERSE SLOPE
BRANCH OF CAMP CREEK
0.0 FT
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
NINETY SIX NATIONAL HISTORIC SITE
GREENE'S CAMP
EXAGGERATED PROFILE OF MEDIAN LINE
Fig. 4

Figure 39

the construction of the siegeworks and the actual siege, were the "two regiments of Maryland and Delaware Continentals--427 rank and file fit for duty--the Virginia brigade numbering 431..." (Ward 1952: 817). The remaining men, "a North Carolina battalion of 66, and Kirkwood's 60 light infantry" (Ward 1952: 817), probably constituted the guards and outposts and were presumably not quartered in the main camp. With these knowns and assumptions, the regiments and brigades were broken down into the actual numbers of enlisted men, non-commissioned officers and commissioned officers.

Maxims from von Steuben's Regulations were integrated to compile the model of Greene's camp represented in Fig. 3 (Ehrenhard 1978:7). Included in von Steuben (Riling 1966:76-80) are "Necessary Regulations for Preserving Order and Cleanliness in the Camp." These orders were of particular interest in that they contain additional information from which inferences can be made about subsurface features and the artifact inventory:

1. When a regiment enters a camp, the field officers take care...that the sinks (latrines) and kitchens are immediately dug in their proper places.

2. The utensils belonging to the tents are to be carried alternately by the men; and the noncommissioned officers of the squads are to be answerable that they are not lost or spoiled.

3. Whenever a regiment is to remain more than one night on the same ground, the soldiers must be obliged to cut a small trench round their tents, to carry off the rain; but great care must be taken not to throw dirt up against the tent.

4. Daily an officer inspects the tents to see that "no bones or other filth be in or near them."

5. Fire is to be made only in the kitchens and all "dirt" is immediately removed and burned or buried.

6. The quarter-master must be answerable that the parade and environs of the encampment of a regiment are kept clean; that the sinks are filled up, and new ones dug every four days, and oftener in warm weather; and if any horse or other animal dies near the regiment, he must cause it to be carried at least half a mile from camp and buried.

7. The place where the cattle are killed must be at least fifty paces in the rear of the wagons; and the entrails and other filth immediately buried.

There would be very few subsurface features resulting from this occupation of fewer than 1,000 men for such a short period (May 22, 1781--June 20, 1781) (N. Greene 1781). The features expected to survive would be latrines, kitchen hearths, trash pits, and animal slaughter and burial areas. In all probability the tent trenches would have been too shallow to have survived the succeeding cotton cultivation and plowing. There was no reference to the burial of men who died in camp as a result of wounds or disease, but their interment would undoubtedly be some distance away from the main body of the camp.

Expected Artifact Inventory

The artifact inventory expected would consist of military articles as well as personal and kitchen-related items. Stanley South and Randolph Widmer (1977:137) have compared the artifact pattern from Fort Johnson, South Carolina, a Confederate military fort captured by Federal forces, with the artifact pattern they found to be prevalent in 18th century frontier sites (Table 8). A positive correlation in percentage of artifact groups in both the Frontier Pattern and those from Fort Johnson was made. Their tables showing this correlation are presented in Tables 8 and 9 in this report. Based on these data, it would be reasonable to predict a similar artifact pattern for Greene's Camp, since the geographic location and period of occupation are the same for both sites.

TABLE 8 (South and Widmer, 1977:183)

Comparison of Fort Johnson with the Frontier Pattern

	Frontier Pattern		Fort Johnson	
Artifact group	Percentage	Range	Percentage	Count
Kitchen	27.6	22.7-34.5	33.6	142
Architecture	52.0	43.0-57.5	61.7	261
Furniture	.2	.1-3	0	0
Arms	5.4	1.4-8.4	4.0	17
Clothing	1.7	.3-3.8	0	0
Personal	.2	.1-4	.2	1
Tobacco Pipes	9.1	1.9-14.0	.5	2
Activities	3.7	.7-6.4	0	0
Totals	99.9		100.0	423

TABLE 9 (South and Widmer, 1977:138)

Comparison of Kitchen, Architecture, and Arms Group Artifacts from Other Sites (in Percentage of All Artifacts at Site)

Site	Kitchen	Architecture	Arms
Fort Ligonier, Pa. (1758-1766)	25.6	55.6	8.4
Fort Prince George, S.C. (1753-1769)	22.7	57.5	6.4
Fort Watson, S.C. (1781)	43.8	41.6	8.9
Fort Johnson, S.C. (1860's)	33.6	61.7	4.0
Fort Moultrie, S.C. (British) (1780-1782)	69.2	19.7	1.2
Fort Moultrie, S.C. (American) (1775-1794)	68.6	24.8	.6
Brunswick, N.C. (tailor shop) (1732-1776)	61.1	26.2	.1
Brunswick, N.C. (S10 dwelling) (1728-1776)	51.8	31.4	.3
Cambridge 96, S.C. (dwelling) (1800-1820)	64.6	25.2	.1
Camden, S.C. (town, 1.0% sample) (1758-1820)	71.4	22.0	.2
Spalding's Lower Store, Fla. (trading post) (1763-?)	34.5	43.0	1.4

Dates given are for the approximate documented range of occupation.

South and Widmer also drew correlations between behavior patterns of contemporary armies and the 19th century forces to explain the lower ceramic ratio at Fort Johnson. They suggest that 19th century soldiers traveled with tin cup and bowl--the equivalent of the 20th century mess kit (South and Widmer 1977: 143). Another comparison that might explain the lower numbers of lost or discarded objects on military sites can be interpreted from a probability that all military operations (in contrast to habitation sites) are carefully policed and the personal neatness of the troops is dictated. This concept of personal responsibility would considerably reduce the number of articles that were broken or misplaced through carelessness. In addition, replacement of lost or broken items would be difficult for an army on the march. It became obvious during the preparation of a research plan that artifacts would be few and features far between. Thus, traditional archeological exploratory techniques would not be sufficient to locate Greene's camp. Since the site had never been reported from surface artifact scatter and was not expected to be located by survey, it was apparent that some type of subsurface testing would be necessary to locate surviving features. It was not practical to propose the use of techniques that had proved so successful in previous investigations at Ninety Six, specifically the use of machinery to remove the plow zone and expose the original surface. Too much territory was involved in this case and the nature of the resource too fragile to risk this type of treatment. Slot trenching was considered, but, based on the assumed occurrence and relationship of features, it would be difficult to isolate an area into units for excavation. It was thus decided that the chemical analysis of soil samples to determine the presence of phosphates (PO_4) would result in the maximum amount of data with a minimum of disturbance to this National Register site and to private property.

Site Description

The area north of Camp Creek in Tolbert field encompassed the two knolls and the downslopes to Camp

Creek (Fig. 38) and was an area that fit the model described for a camp location. Most of this field is now in pasture, but in the past has been timbered and cultivated. Within the owner's lifetime, it has also been used by share croppers, and one house is still standing. An abandoned road, shown on the base map (Fig. 38), is still visible and appears to have linked at least three of these homes.

The ground cover is a grass interspersed with a variety of briars, sedges, wild plum, and large cedar trees. There are two stands of large hardwood trees downslope toward Camp Creek from the west and east knolls. These hardwood stands are separated by the old road. This tract was probably withheld from timbering in order to prevent the erosion characteristic of the soil type in the area.

Another possible camp area is located partially on National Park Service property and partially on private land. This tract differs in both topography and vegetative cover from the field first examined. It consists of pine and secondary growth hardwoods, plus a heavy understory of dogwood, sassafras, briars, Japanese honeysuckle, and poison ivy. The slope south to Camp Creek is much gentler and past erosion has been stabilized by a stand of large hardwoods. There is evidence to indicate that past erosional activity has been severe, particularly in the section adjacent to and north of the historic Island Ford Road where the road bends to the east. This erosion may have been precipitated by the road itself (since the roadbed in this particular place is eroded to a depth of as much as 15 ft. below present grade), but it is more likely that the erosion occurred during the era of cotton cultivation that succeeded the Civil War.

Several homesites are located in this area, particularly along the first terrace above the creek bottom. Old logging and wagon roads are still visible and in some places still passable. (An old brick yard of undetermined age is located to the northwest.)

Methodology

Prior to the initiation of field research, aerial photography of Ninety Six National Historic Site and environs (DCS 205-209, 12-7139; GS-VDBE 1-7 through 1-11, 3-5-72) was analyzed by Thomas Lyons of the National Park Service, Division of Remote Sensing, prior to any ground check. Black and white aerial photographs such as these can reveal information about archeological sites that might be overlooked during a surface survey. This is particularly the case when past cultural activity has altered the subsurface soil horizons so that moisture retention capability and fertility are altered. The results are seen as increased or vigorous plant growth or a deficiency of growth compared to the surrounding areas. The term "anomaly" has been utilized to describe these alterations, indicating that the interpretation is based on a deviation from what is considered the norm for a particular environment. Lyons tentatively identified the area of Greene's camp by delineating soil and vegetation anomalies that he felt were culturally induced (Figs. 40,41).

During standard survey in the field the anomalous areas were examined to determine whether they could be identified on the ground. The anomaly proved to be an area of inactive erosion that was probably the result of poor soil conservation methods during periods of cultivation and timbering. A smaller area was apparent on the 1939 photo than on the 1972 photo, possibly indicating that the erosion increased at some point after the 1939 photograph was taken. The erosion has been stabilized.

Other soil and vegetative anomalies indicated by Lyons were also examined and were identified as features associated with either the sharecroppers' homesites or past cultivation of the field.

During this initial survey, cultural material was collected, the areas of concentration given temporary NPS site numbers, and artifacts bagged according to location. These areas are located on the archeological base map (Fig. 38). The greater number

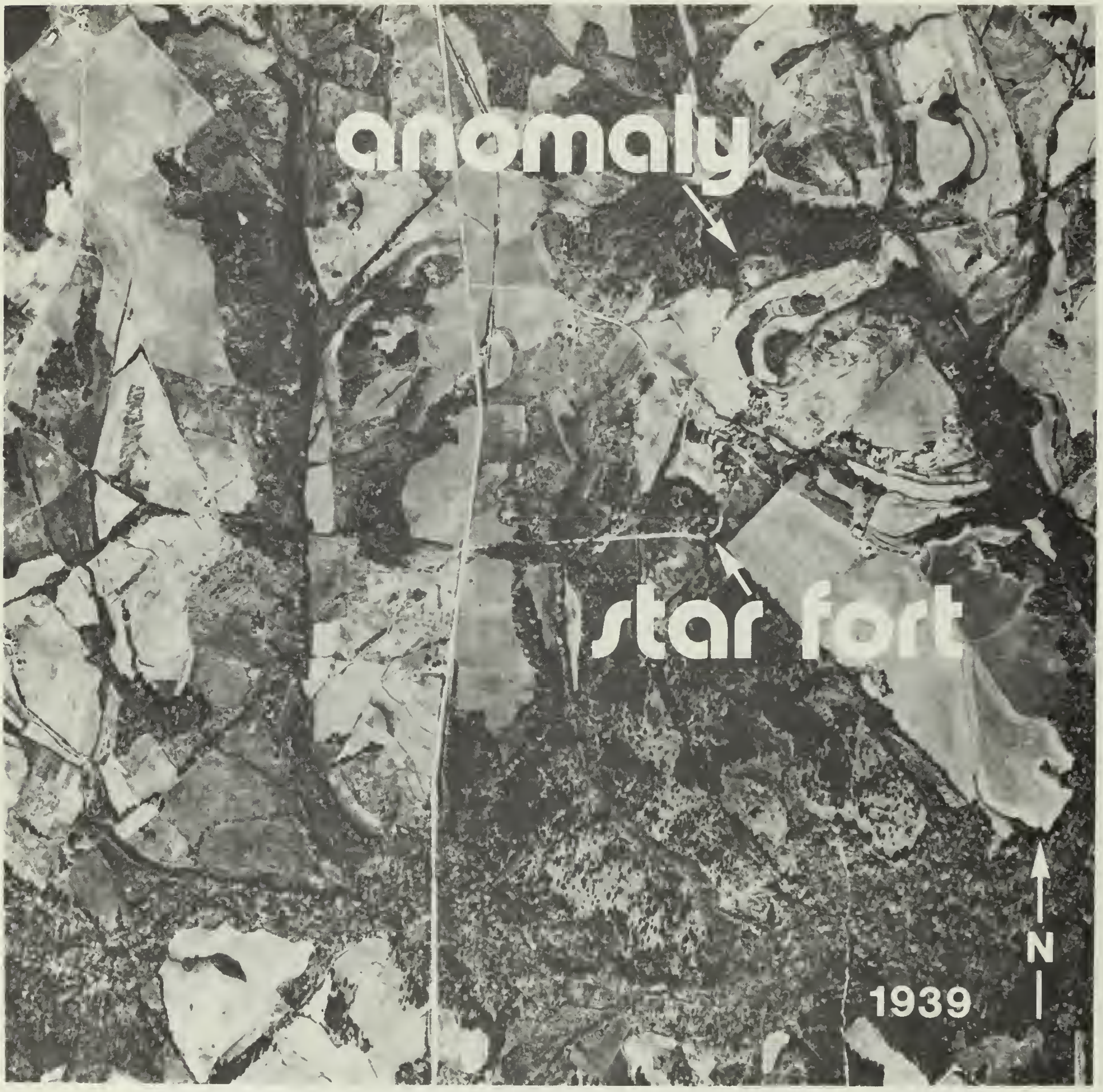


Figure 40 - Aerial photograph, 1939. Vegetative anomalies.

Figure 41 - Aerial photograph, 1972. Vegetative anomalies.

of lithic artifacts were found on the ridge above Camp Creek and on the knolls in Tolbert Field. Historic material recovered was associated with 19th and 20th century occupations; the prehistoric material was representative of early to middle Archaic (Fig.42).

When the surface survey failed to yield artifacts that could be attributed to a 19th century military occupation, a systematic soil chemistry investigation (phosphate analysis) was begun in the previously delineated areas. Phosphates occur naturally in the soil in minute amounts and are deposited slowly over time. Higher concentrations of phosphates are usually the direct result of cultural activity. Therefore, this procedure was used to locate past areas of cultural activity since it lends itself well to both qualitative and quantitative analysis for either a spot test in the field for site location or for a more detailed laboratory analysis. It is especially useful in areas where sites are fragile and more destructive techniques might not be advisable. Based on the data obtained, results were inconclusive. There were, however, close correlations between the camp location as defined by the aerial photography, the hypothetical model of the camp, and the higher phosphate values (Ehrenhard 1978:17-34).

CONCLUSIONS

Conclusive statements cannot be made about the camp's location in the absence of either artifacts and/or features; however, it was our recommendation that the camp location (shown on Fig. 36) be accepted primarily as a historical model and on the basis of the results of the soil analysis, which indicated cultural activity in the area. The hypothesis stated in the research design has been neither proven nor disproven. Resource management concerns have, however, been satisfied in that sufficient data and recommendations had been generated that will enable the National Park Service Land Acquisition Division to make judicious boundary extensions that will protect the historic fabric of Ninety Six National Historic Site.

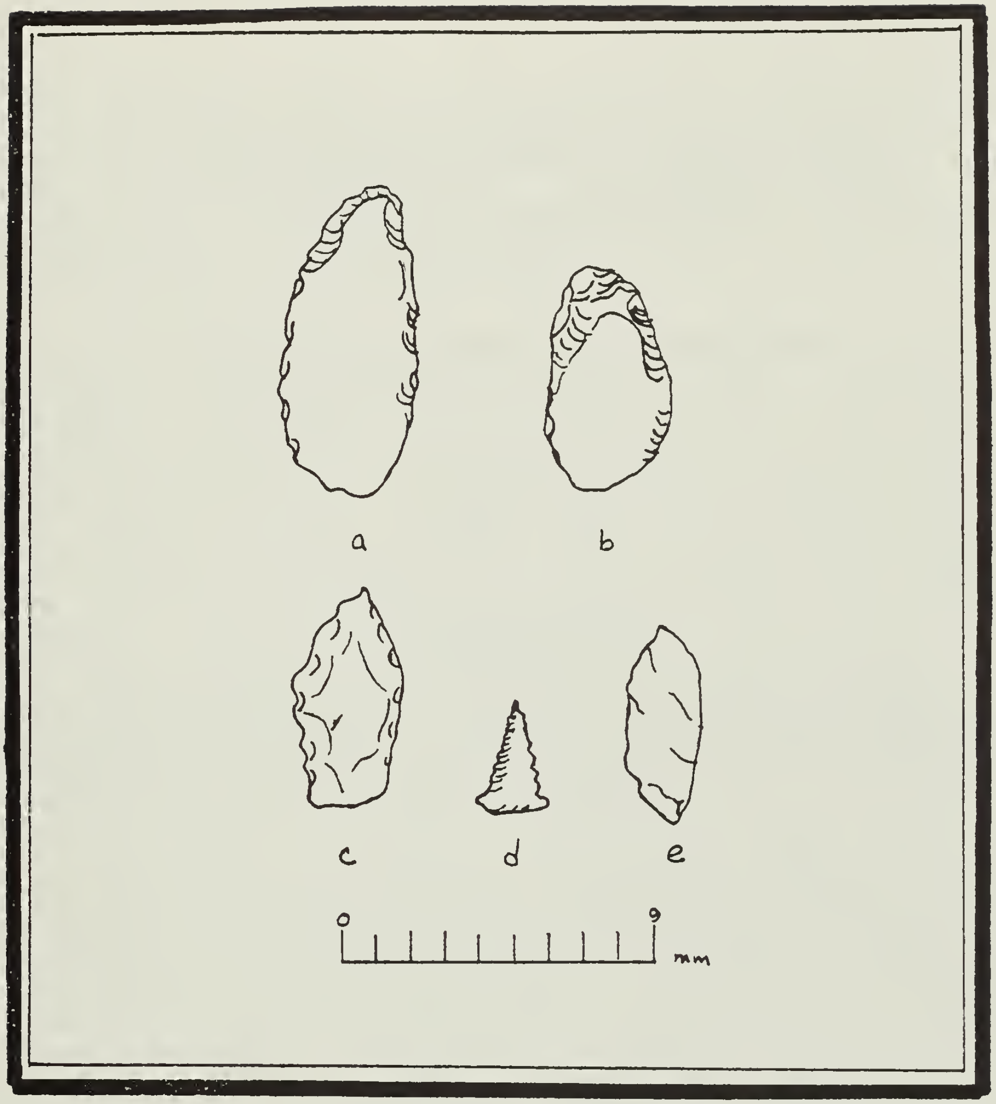


Figure 42 - Diagnostic lithics, Greene's Camp, Ninety Six, NHS.

a. Rhyolite bifacial blade
b. Rhyolite unifacial scraper
c. Morrow Mountain projectile point, quartzite
d. Decatur projectile point, quartzite
e. Guilford projectile point, quartzite.

THE LOCATION OF GREENE'S ENCAMPMENT:

A REMOTE SENSING ASSESSMENT

OF

NINETY SIX NATIONAL HISTORIC SITE

by

W. H. Wills

Introduction

Recent archeological research at Ninety Six National Historic Site in South Carolina has led to the discovery and delineation of numerous features associated with the 18th century town of Ninety Six and the fortifications built during the Revolutionary War (Holschlag and Rodeffer 1976, South 1972, South n.d.). During the period of May 22 to June 18, 1781, the British-occupied Star Redoubt was under siege by General Nathanael Greene of the Continental Army. This redoubt and the nearby siegeworks have been of particular interest to researchers and considerable study has been focused in this area. Among the results of these investigations has been the location of the trenches and mines that represent the colonials' attempt to breach the fort by sapping the walls. Most of these features have been accurately plotted and defined (Holschlag and Rodeffer 1976). Despite the wealth of information on the exact location of the conflict (Ehrenhard 1978; Holschlag and Rodeffer 1976; South 1974, n.d.), there has been no reliable means of determining where the American army was bivouacked. Soil testing procedures (Ehrenhard 1978) have not produced particularly convincing evidence of the camp location and historic accounts are vague at best. Numerous maps (South 1972) show a conjectured area just to the north of the Star Redoubt as the most probable site for the encampment. This general area has apparently been selected on the basis of several factors: historical accounts, direction of the siegeworks' approach to the redoubt, maximum range of 18th century artillery fire, and topography. Unfortunately, field checks have so far failed to substantiate this supposition.

Consequently, the following remote sensing assessment has been completed with the goal of providing a new perspective on the possible location of Greene's encampment. Remote sensor data have often proved valuable in revealing evidence of past occupations where none were previously definable from the ground (see Deuel 1969; Lyons and Hitchcock 1977). The situation at Ninety Six suggested that the application of such techniques might prove useful. Specifically, the fact that the siege was the longest American envelopment effort of the war (Cann, Rodeffer, and Watson 1974) and involved over 1,000 colonial troops may well have resulted in an impact substantial enough to have affected the immediate camp environment in a manner discernible today.

In order to facilitate the interpretation of the remote sensor data, it was useful to construct a model of the camp design and to consider what effects camp-specific activities might have had upon the environment. Ehrenhard (1978) had constructed a model that located many of the camp elements based on research of historic documents and military manuals. Her model was considered a first step; the model below will be more specific and will allow predictions that can guide the remote sensing study.

The Model

The following camp layout proposed by Baron von Steuben (1779) for the Continental Army has been taken as a basis for a working model. Fig. 43 presents a schematic illustration of von Steuben's directives (Riling 1966). This layout, ideally corresponding to the army's order of battle, provides rather specific

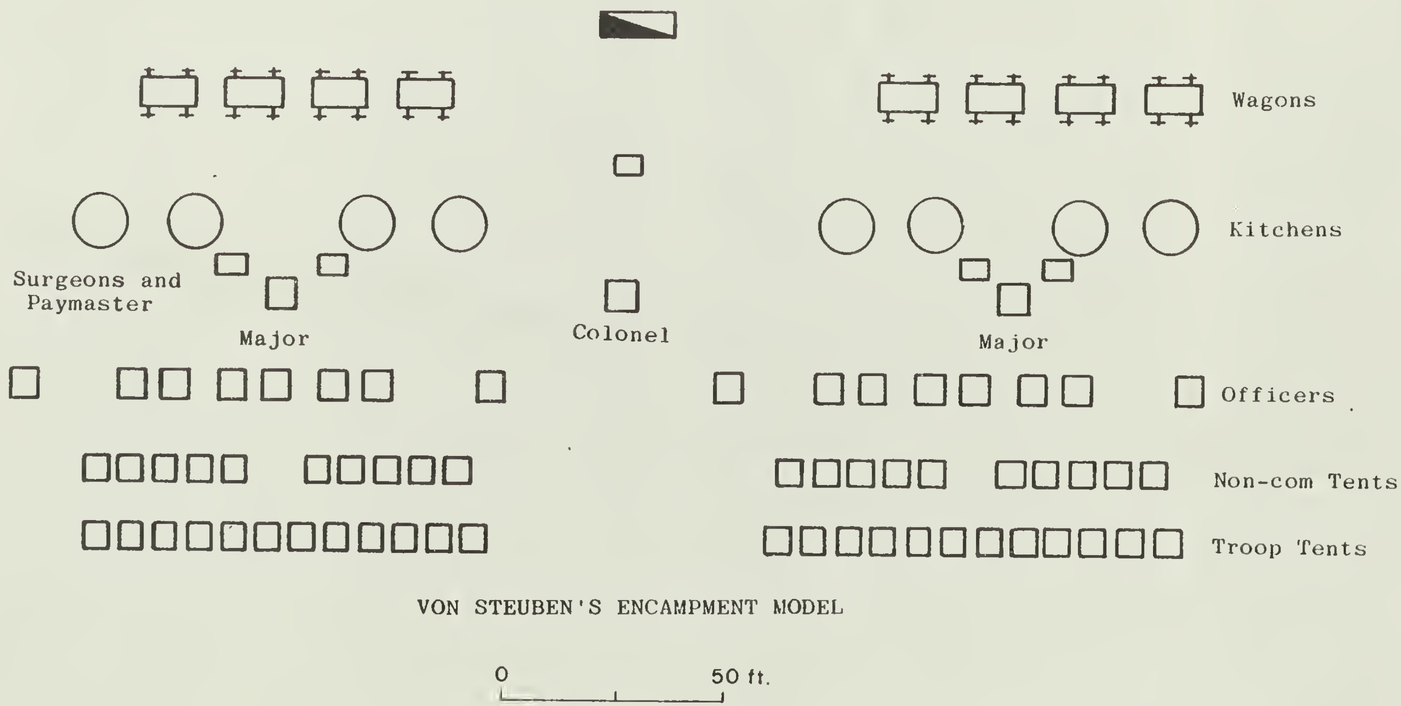

Wagons
Kitchens
Surgeons and
Paymaster
Major
Colonel
Major
Officers
Non-com Tents
Troop Tents
VON STEUBEN'S ENCAMPMENT MODEL
0
50 ft.

Figure 43

locational placement of individual camp elements. The following specifications provide an approximate guide to the amount of space utilized by a single regiment in bivouac:

1. Tents of privates and non-commissioned officers pitched in two ranks with an interval of 12 ft. between ranks.

2. The front of each tent requires 12 ft., excluding those of commissioned officers.

3. Captains and lieutenants in one line, 20 ft. from the rear of the troop tents.

4. Majors 30 ft. from captains and lieutenants, opposite the center of their squadrons.

5. The colonel is 20 ft. from the majors, opposite the center of the squadron as a whole.

6. The paymaster and surgeon in a single line, the fronts of their tents even with the rear of the colonel's.

7. Kitchens dug behind the center of each troop, 20 ft. from the rear of the colonel's tent.

8. Baggage wagons in a line 20 ft. from the rear of the kitchens.

The application of these specifications to the graphic model produces a rectangular area roughly 500 ft. by 230 ft. These figures apply to the illustration provided by von Steuben. That is, they are based on the above specifications and the exact number of tents and features shown in Fig. 43. However, using an average of 12 soldiers per tent and an average tent size of 12 feet on each side (both estimates derived from Greene's report on Yorktown 1976) the above size estimates should probably be revised upward since the given layout would accomodate only about 600 men.

This revision is suggested on the basis of Hogg and Batchelor's estimate that a company averaged about 82 "officers and men" (1976). Combining this figure with von Steuben's ideal specification of 10 companies per regiment, we might accept the number 820 as reasonably close to the size of any given American regiment. This leaves 220 men unaccounted for in our model.

In the above derivation of 600 men from von Steuben's model, approximately 71 officers and 528 troops can be assumed, on the basis of types of tents shown. This gives a ratio of about one officer per 7.5 men. Applying this proportion to the unaccounted-for 220 troops, we find that theoretically there should be 28 officers and 192 soldiers in that group, figures that in turn represent seven officers' tents and 16 troop tents. Sixteen more troop tents, when added to the tent ranks, increase the length of the camp, at minimum by 112 ft., and at maximum by 224 ft. Therefore, we might expect the camp boundaries to be at least 600 ft. by 230 ft.

This points out the importance of determining camp organization, as well as the number of men in camp, prior to defining expected camp characteristics. When discussing camp organization we refer to the arrangement of its elements into some sort of structure. Using the von Steuben model as a base, we must ascertain what correspondence or deviation Greene's encampment might have possessed in relation to the model. It has been noted that the camp boundaries should be larger than those of the model. We might also expect the internal arrangement of elements to differ from the "norm." For example, the numbers of tents, kitchens, etc., are probably directly proportionate to the number of men in camp. It is also possible that the relative sizes of such units as latrines, kitchens, and livestock enclosures are also dependent upon troop numbers. Therefore, in addition to our first expectation of a rectangular area of about 600 by 230 ft., we should also expect more and larger internal elements than shown in Fig. 43.

Several other predictions can also be derived from the given model. Within the boundaries of the camp these elements should be:

1. Rows of rectangular outlines (tents), each rectangle about 12 by 12 ft. sq. Von Steuben notes that for a camp of more than one night's duration, small trenches to carry off runoff should be dug around each tent.

2. The longest rows should be in the area of the camp that faces the enemy (order of battle).

3. Circular areas, probably depressed and containing hearths, should correspond to kitchen locations at the rear of the camp.

4. Linear features representing latrines should occur in front of the first row of tents.

5. Areas representing corrals, livestock pens and butchering areas should occur to the rear of the kitchens (see Ehrenhard 1978).

These elements would probably be evidenced today by vegetational anomalies and ground surface depressions. Soil discoloration and crop marks might also correspond to the camp location.

Target Locations

Having established some idea of what we are looking for, we might next ask <u>where</u> that entity should or could be located. Greene's account (1976: 139) of Washington's selection of a campsite prior to his arrival at Yorktown, on the basis of existing maps, suggests that concern with camp location was of more than passing interest. Several variables can intuitively be expected to have conditioned decisions about where to place the campsite. The more salient of these are:

1. Topography--An area would be needed that was relatively flat, open, and large enough to contain the occupying force. It would also need to be situated on a defensible high point.

2. Distance to the enemy--It might be reasonable to assume that the camp would be located out of artillery and sortie range, yet close enough to facilitate movement of troops and supplies to the conflict area.

3. Communication--The camp would probably be located on or close to some sort of roadway in order to increase the efficiency of information and supply flow.

4. Resource availability--In order to minimize the costs of transporting water, firewood, and other locally derived resources, we might anticipate that the camp would be located fairly close to springs, streams, forests, etc.

The reader may recognize the above variables as pertinent to a theory of site location strategy known as Mini-Max, the notion that site locale will be chosen to minimize energy costs and maximize return. For example, farming communities might be expected to locate close to agricultural plots in order to cut down on transportation costs. Although this concept has been most often applied to prehistoric archeology, it probably has value for predicting military camp loci. The individual variables may be weighted differently in response to different objectives (e.g. military vs. agricultural) but the impinging criteria are probably identical. That is, conditions relating to resource availability, topography, communication, etc., are relevant to any sort of site location but in different degrees of importance. In the present study, for instance, the variables concerning communication and transport were probably given utmost consideration because of the essential military need for quick, coordinated movements. Hence, we can expect Greene's headquarters/camp to be strategically placed to maximize communication and coordination of activities. Ideally, the location would be a high point near a road (and preferably a crossroads) that was a safe but relatively close distance from the fighting.

These assumptions may, quite naturally, be totally incorrect. Other factors, now unknown or unimagined, may have had precedence in the selection of the camp location. Then, too, there is no certainty that the Revolutionary forces were always cognizant of the proper conduct of warfare and associated needs. Nevertheless, the Mini-Max concept, as related to military necessity, would seem to provide a logical starting point in a site prediction scheme for Greene's encampment.

Given this bias, three areas have been subjectively selected as possible target locations for further investigation. These are the stipled areas on the accompanying Fig. 44.

Analysis of Black-and-White Stereopairs

The first methodological step in the remote sensing assessment involved a comprehensive survey of the entire area encompassed by the park boundaries, as well as surrounding areas, with the aid of black-and-white aerial photography. This imagery (Fig. 45) was taken January 1978 to facilitate the observance of ground features that might otherwise be obscured by tree foliage. All the photographs were taken along specified flight lines, which produced a series of overlapping individual frames. This procedure enables the photointerpreter to place consecutive photos under a stereoscope, producing in turn an exaggerated three-dimensional image (Avery 1977; Lyons and Avery 1977). The benefit of this process lies in the interpreter's ability to distinguish, through the optical effect of exaggeration, surficial variations that might otherwise have gone unnoticed.

Several black-and-white frames from flights taken in 1939 and 1972 were also examined. Only minor differences were noted, most likely due to the poor resolution of the earlier photography.

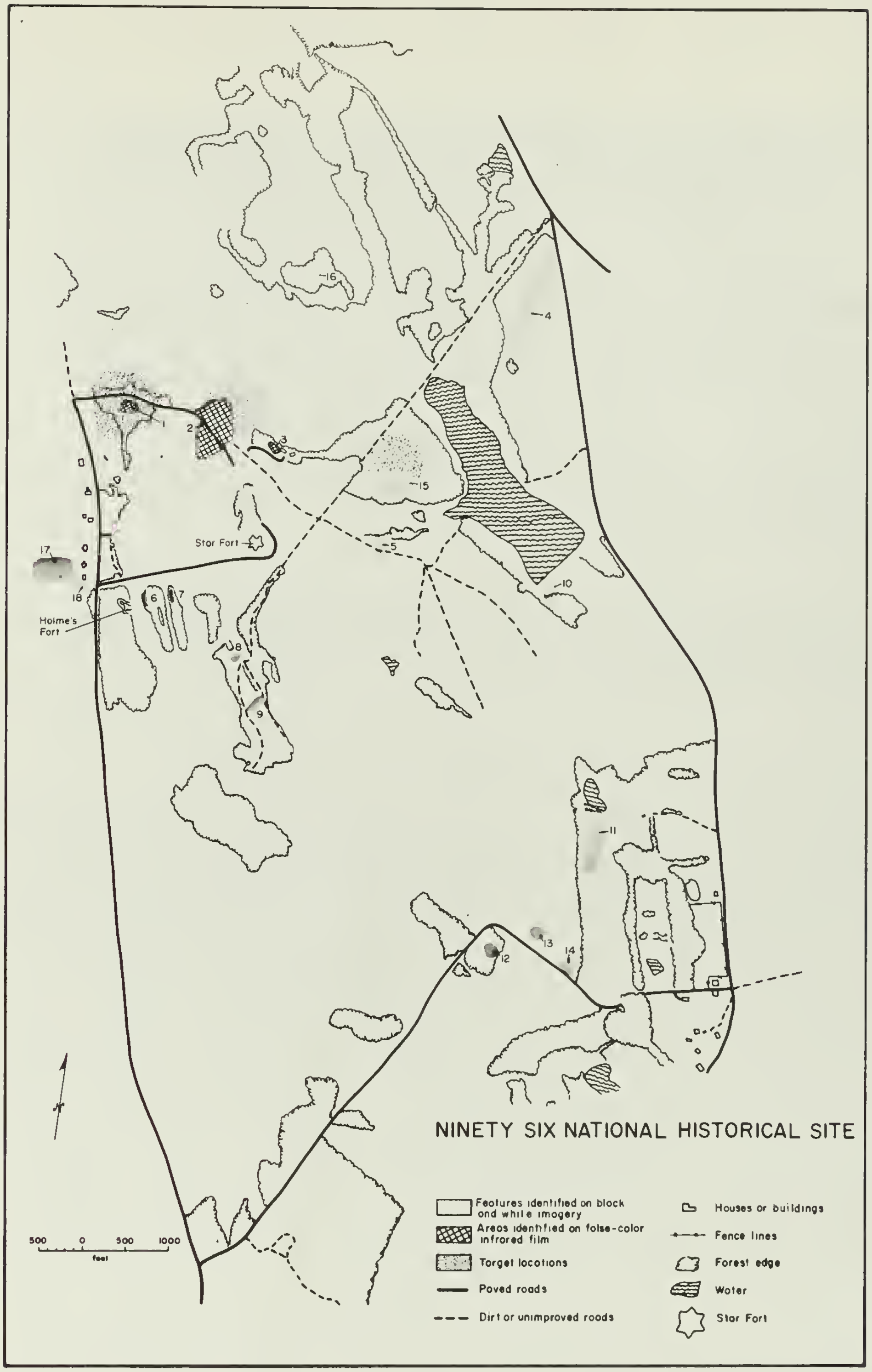


Figure 44 - Overlay map constructed from uncontrolled mosaic showing locations of identified anomalies.

Figure 45 - Uncontrolled mosaic of the Ninety Six area made from photography exposed 1-3-78.

Infrared False-Color Analysis

Imagery was also taken of the general Ninety Six area using false-color infrared film. This kind of product has proven excellent for determining changes in vegetation patterns and agricultural land use (Avery 1977:179-226). In this case the film was also viewed stereoscopically with the expectation that soil disturbances in the past might be observable today through variations in the vegetation growth within the affected area. Unfortunately, only two areas of interest were identified. These are noted in Appendix I along with the features identified on the black-and-white imagery.

The results of these two studies are presented in Appendix I. The list identifies various anomalies and features (A1-A18) that were not immediately recognizable as being the result of modern or recent activities, or that were thought to have some intrinsic interest. Features other than those that might be linked to the location of Greene's encampment are also included. The numbers correspond to the numbers on Fig. 44 . All of these should be field checked and the results compared to the interpretations suggested here. (Appendix I also includes comments made after further ground checking was undertaken. See Part III).

Recommendations

Feature 2 corresponds to minimal expectations regarding camp outline and size. The immediate area around Feature 1 may also meet these requirements. Consequently, special attention should be given to these areas. Feature 3 is of particular interest in that it occurs on the hillside just above the siegeworks. Features 8 and 9 are also of interest since no record has been found of them on excavation maps. These are the points that may prove the most rewarding to the problem orientation of this study, although all the noted anomalies should be field checked.

Project Summary and Evaluation

The identification and location of Greene's encampment through the application of remote sensing techniques constituted the initial problem orientation of this study. Examinations of black-and-white photography, as well as false-color infrared imagery, permitted identification of several anomalous features and/or areas. However, confirmation or negation of these anomalies as representative of elements of Greene's camp awaits ground checking. Nevertheless, the combination of expectations generated from von Steuben's model and information derived from photo-interpretation narrows down the possible locations, thereby increasing the probability that a solution will be found.

And the probability that the campsite can be identified is good, since the length of duration and the number of men present (including, no doubt, numerous camp followers--see Bolton 1964) argues that the evidence for the camp should be more than ephemeral. Specific activity areas such as kitchens, latrines, and corrals can reasonably be expected to have left some mark upon the environment. The question concerning preservation of that evidence in view of intensive cultivation involving contouring and plowing (see Ferguson, quoted in South, n.d.:55; and accompanying photographs from 1972 and 1939) is not really of vital importance. Rather, can remote sensing provide the information necessary to determine the extent of destruction and preservation? In that regard, the present study is an essential first step in the information gathering process. Once these data have been accepted or rejected as valid to the research problem, further remote sensing applications can be designed, if necessary, to accomodate the refined focus of interest. It is this ongoing process of evaluation and adjustment of research strategies in relation to problems such as the Ninety Six Site, that makes remote sensing an integral part of the non-destructive approach to archeology.

PHOTOINTERPRETATION AND GROUND TRUTHING

by

Ellen B. Ehrenhard

Methodology: Photointerpretations

The method of data extraction and site location during the Cultural Resource Inventory was considered critical; therefore, a research design was formulated to obtain an optimum amount of data with minimum disturbance to the site. Two remote sensor methods--aerial photointerpretation and photogrammetric mapping and proton magnetometry with subsequent ground truthing were considered sufficient to fulfill the criteria for an inventory of the archeological components at Ninety Six (E.B. Ehrenhard 1977a).

Black-and-white aerial photography has been utilized since the 1890's for obtaining a synoptic view of archeological sites. High quality black-and-white photography has been the most commonly used remote sensor technique as well as the most effective for acquiring archeological data. Natural color photography, though it does not reveal cultural features as well as black-and-white images, does provide excellent environmental data. Color infrared provides "differential reflection from various cultural and natural features," which produces distinct "false" colors. This is essentially the same tonal information provided by black-and-white images. These techniques can be used as exploratory as well as predictive devices and also provide testable hypotheses for site location information (Gumerman and Lyons 1971:126-134).

For the most part, photointerpretation techniques have been developed for and applied in sparsely vegetated or arid regions and climates (Lyons 1976, Lyons and Hitchcock 1977). Based on success in these areas, Lyons and Scovill (1978:6) advocated that at the discovery phase in archeological survey, neither excavation nor collecting is required if adequate remote sensing is conducted beforehand: "The use of collecting or excavating techniques should be considered when and only when the non-destructive procedures for data collection and analysis have been exhausted and then only if testable problems have been formulated and identified."

In order to test this hypothesis in the southeastern United States, Lyons was requested to conduct photogrammetric mapping and photointerpretation for the cultural resource inventory at Ninety Six. Problems in interpretation were anticipated because of the dense vegetation associated with this region. This problem was particularly pronounced at Ninety Six because of the presence of several introduced species of commensal plants, Japanese honeysuckle (*Lonicera japonica*) and kudzu (*Pueraria lobata*). Planted slash pine plantations and the accompanying understory of briars and dense high grass also prohibit ground visibility to such a degree that even standard survey techniques are inadequate. There are, however, numerous abandoned fields in various stages of succession as well as remnant oak/hickory hardwood forest providing a broad spectrum of ground cover in addition to the aforementioned types. This vegetative diversity permits the evaluation of remote sensor technology in numerous floral communities common to the southern Piedmont. Conducting a photoanalysis within Federal boundaries was seen as a way to provide information that would have region-wide applicability.

Very little information exists on the applications of photointerpretation in densely vegetated areas. Matheny (1962) found that certain types of growth associated with artificial mounds could be easily identified on black-and-white aerials of a coastal Campeche jungle test area. The particular vegetative patterns produced tonal variations indicating either changes in soil chemistry, topography, or vegetation--all three variables being interdependent in some cases. In addition, straight lines and angles not naturally occurring in nature could also be identified as both modern and prehistoric cultural activity.

More recently, W. Frank Miller (1974) proposed and tested three models for archeological site location utilizing photointerpretation in the vicinity of the Tombigee and Luxaphalila Rivers. Rather than base his model on vegetative indications alone, he included topographic and soil models as well. He based the three hypotheses on existing settlement/subsistence pattern data and the analysis of control data (previously located sites) collected during the initial phases of the project. The topographic model provided the greatest degree of accuracy, resulting in correct identification 71% of the time.

The Southeast Archeological Center of the National Park Service has routinely utilized aerial photography during cultural resource inventories and for more specific archeological projects. Most of these projects were concerned with coastal environments where the extreme ranges in tonal variation in both black-and-white and color infrared images allow easy recognition of site signatures. In addition to settlement models, photointerpretation has provided useful information on shoreline erosion, migration, and sea level changes, and the subsequent effect on site preservation and location (J. Ehrenhard 1976, 1977; Ehrenhard, Carr and Taylor 1978, 1979).

The methodology utilized at Ninety Six was multistaged. Three overlapping flightlines were first flown over the site in order to obtain stereopairs. Utilization of overlapping paired images produces a three-dimensional image under a stereoscope, facilitating the location of any anomalous topographic or vegetational features that might be culturally produced. Both black-and-white and infrared images were acquired using a mounted camera and a fixed-wing aircraft flying at a constant altitude. A 2-ft. contour-interval topographic map was then produced from these images to create the Cultural Resource Base Map for Ninety Six, a portion of which is illustrated in Fig. 46 .

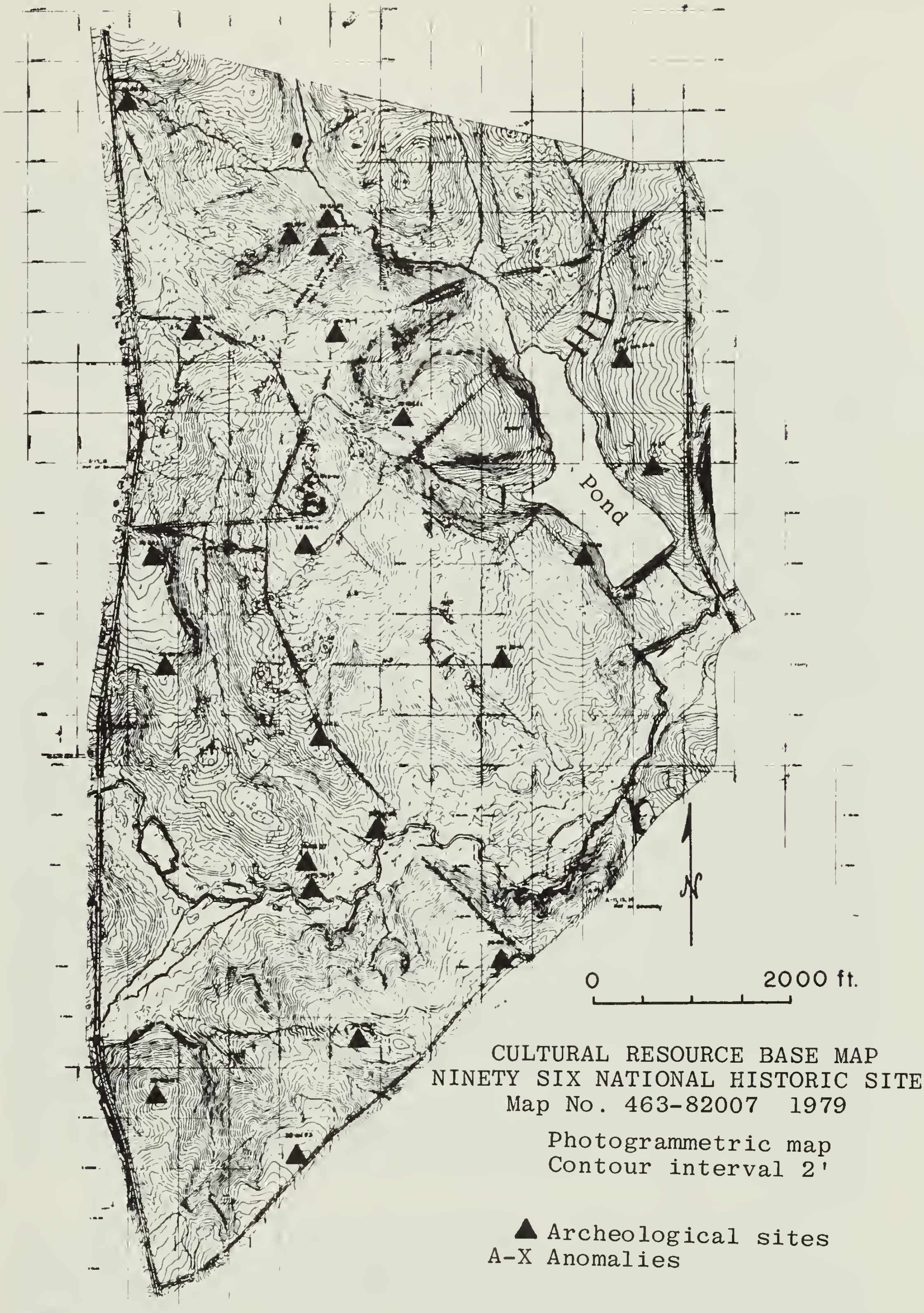

Pond
N
0
2000 ft.
CULTURAL RESOURCE BASE MAP
NINETY SIX NATIONAL HISTORIC SITE
Map No. 463-82007 1979
Photogrammetric map
Contour interval 2'
Archeological sites
A-X Anomalies

Figure 46

These images were also utilized by W. H. Wills for a remote sensing analysis sponsored by the Remote Sensing Division of the National Park Service for the location of General Nathanael Greene's camp during the 1781 siege of Ninety Six (Part II). Unfortunately, Wills' analysis was not available until after the 1977 survey conducted by the Southeast Archeological Center for the same purpose; however, his results were compatible with the results of the Center's phosphate (PO_4) analysis (E. B. Ehrenhard 1978).

During the course of Wills' aerial analysis, he compiled an annotated list of all anomalous features that he felt were culturally produced and were encompassed by park boundaries. He accompanied this list with a map drawn from an uncontrolled mosaic of the aerial photographs (Part II). Anomalies (identified by Wills [A1-A18] and others noted by Lyons [A19-29]) were plotted on this map and on the photogrammetric base map as well.

The next step in the remote sensing program was to contact people knowledgeable about the cultural resources base at Ninety Six and ask them about anomalies represented on the base map. After lengthly discussion, it became apparent that there were difficulties presented by the dense undergrowth and that a different approach was needed in order to demonstrate the validity of aerial reconnaissance in the Southeast. Many known features were so completely camouflaged that they were not detected by the Remote Sensing analysts on the aerial images. It was decided to reserve further comments on the application of the images until after the designated anomalies were ground truthed by the archeological team. "Ground truthing" is the term applied to the "procedure for establishing target references and measurements and/or for verification of image interpretation" (Lyons and Scovill 1978).

Ground truthing involved visually inspecting the anomaly and recording the probable cause. As a precaution, and to supply data sufficient for planning and management requirements, a systematic survey that included subsurface sampling was also conducted in portions of the Park. The annotated features list prepared by Wills and our comments following visual inspection are included in Appendix I. The corresponding anomaly is indicated as A-X on the Cultural Resource Base Map (Fig. 46) and the data is presented in tabular form on Table 10.

Results: Photointerpretation

The results are presented in Tables 10 and 11. Photointerpretation Analysis and Anomaly Descriptions and Site Prediction Statistics. Roughly 12% of the existing sites at Ninety Six National Historic Site were predicted during the photointerpretation exercises. The majority (55%) of the sites occur in cleared areas, followed by 27% in the densely vegetated portions, and 18% in the secondary or lightly vegetated areas. Correspondingly, 59% of the anomalies were predicted in open areas; however, only 14% were predicted for heavily vegetated areas and 28% for secondary and light growth--a reversal of the actual situation. Three of the four predictions for the heavily wooded areas, A-11, 22 and 27, were not visible or were not culturally produced features.

Ninety percent of the predictions were culturally produced (26 out of 29 predictions), which is extremely accurate although, as mentioned above, this figure represents only 32% of the total sites within the Park. A different approach may be needed at the analysis stage to provide control data for plotting already known sites and either eliminating these anomalies or utilizing the existing information as control data for establishing a site signature model to be applied to other sites in the area. This would also prevent skewing the statistical data as well.

Obviously, the most accurate predictions were obtained in the cleared areas and the least accurate in the heavily wooded sections. Again, a different methodology, such as that used by Miller (1974), could eliminate some of the inaccuracy. Another

Table 10. Photointerpretation Analysis and Anomaly Descriptions

PREDICTIONS		VEGETATION			CULTURE PERIOD				COMMENTS
Anomaly	Site No. & Description	Cleared	Light or Secondary Growth	Dense or Climax	Prehistoric	Historic	Recent Historic (Post 1865)	U.I.D	
A-1	NPS-96-11	X					X		On 1949 USGS
A-2	Greene's Camp Area		X			X			
A-3	38 GN 21	X			X		X		
A-4	Path or Swale	X						X	
A-5	Brick House		X				X		Greenwood Mills
A-6	38 GN 3 Ninety Six Village	X				X			
A-7	38 GN 3 Ninety Six Village	X				X			
A-8	38 GN 3 Ninety Six Village	X				X			
A-9	38 GN 3 Ninety Six Village	X				X			
A-10	Feature at Dam (SW Corner)	X					X		Greenwood Mills(?)
A-11	Erosional Ravine			X				X	
A-12	38 GN 22	X			X				
A-13	Sawdust Pile		X				X		
A-14	Standing Structure	X					X		
A-15	Unmowed vegetation	X					X		
A-16	House Site	X					X		On 1949 USGS, Not in Park
A-17	38 GN 2, Cambridge	X				X			Not in park
A-18	38 GN 2, Cambridge	X				X			Not in park
A-19	NPS-96-8	X					X		
A-20	Foundation?	X						X	Inaccessible
A-21	Foundation		X					X	Not visible on surface
A-22	Foundation			X				X	Not visible on surface
A-23	Car Bodies			X			X		Not visible on surface
A-24	Foundations		X			X			Sub-surface
A-25	38 GN 1 Foundations		X			X			Sub-surface
A-26	38 GN 1 Foundations		X			X			Sub-surface
A-27	Foundation			X				X	Not visible
A-28	Foundation		X					X	Inaccessible
A-29	NPS-96-10	X			X				
		17	8	4	3	10	10	7	
PERCENT OF TOTAL PREDICTIONS		59%	28%	14%	10%	34%	34%	24%	

Table 11. Site Prediction Statistics

Site No. & Description	PREDICTED Yes	PREDICTED No	CULTURE PERIOD Prehistoric	CULTURE PERIOD Historic	CULTURE PERIOD Recent Historic	VEGETATION Cleared	VEGETATION Light or Secondary Growth	VEGETATION Dense or Climax	COMMENTS	Reference
NPS-96-1		X			X			X		NPS-77
NPS-96-4		X	X					X	Occasional Clearings	NPS-77
NPS-96-5		X			X		X			NPS-77
NPS-96-6		X	X					X	Planted Pines	NPS-CRI-TRAN-SECT
NPS-96-8	A-19				X	X				NPS-CRI "
NPS-96-9		X	X					X		NPS-CRI "
NPS-96-10	A-29		X			X				NPS-CRI "
NPS-96-11	A-1				X	X				NPS-CRI "
38 GN1 Gouedy's		X		X		X				KNOWN
38 GN2 Cambridge	A-17&18			X		X				KNOWN
38 GN3 Star Redoubt		X		X			X			KNOWN
38 GN3-SW		X		X		X				KNOWN
38 GN3-DC		X		X			X			KNOWN
38 GN4-96 Village	A-6,8,25			X		X				KNOWN
38 GN4-J 96 Jail	A-7,9,28			X		X				KNOWN
38 GN21	A-3		X			X				KNOWN
38 GN26		X	X			X				KNOWN
38 GN27 Cemetery		X		X				X		KNOWN
38 GN28		X	X			X				KNOWN
38 GN54		X		X			X			KNOWN
38 GN58		X			X	X				KNOWN
38 GN59		X	X					X		KNOWN
	7	15	8	9	5	12	4	6		
PERCENT OF TOTAL SITES:	32%	68%	36%	41%	23%	55%	18%	27%		

solution might be to insure that archeologists conducting the photointerpretations are familiar with the physical and cultural environment under consideration.

Conclusions

The advantages of this remote sensor technique cannot be overemphasized due to the increased efficiency it provides during the field exercises and the quality of environmental and topographic data that can be obtained. The major contribution in terms of cost efficiency during this project was in the virtual elimination of time lost because of the inability to locate baselines and bench marks and crew disorientation when landmarks cannot be identified. All field exercises during systematic survey were conducted with a minimum of error and mislocation as a result of the opportunity to locate baselines and delineate survey areas prior to operations in the field. The follow-up exercises were similarly successful.

Until a regionally specific methodological refinement is attained that produces a greater predictive accuracy for dense vegetation, photointerpretation alone is not sufficient for locating and identifying sites at the discovery level in the southern Piedmont. This statement holds true only for the approach utilized in this project, and continued refinements in both technology and methodology will increase the predictive abilities for site specific locations. The formulation of a descriptive model based on control data and settlement/subsistence pattern information and subsequent targeting and model testing may provide the required level of accuracy.

APPENDIX I
Annotated Anomalies and Ground Check Comments

Ground Truthing

The following is the Annotated Features List from Wills, Part II with his comments based on the photo-interpretation and Southeast Archeological Center comments based on visual inspection.

1. Feature 1 is linear and forms a right angle. False color IR imagery shows a color change in this general area; green/brown as contrasted tc surrounding shades of red.

   Estimated length: 25 ft.

   Estimated width: 5 ft.

   Distinguishing characteristics: light coloration, shadows suggesting a depression.

   Orientation: N-E

   Comments

   Wills: May be a corner of some sort. The feature is not easily defined on any of the imagery and may be a product of the interpreter's enthusiasm.

   Southeast Archeological Center (SEAC): This is a late historic house site, probably a tenant. It is shown on the 1949 USGS quadrangle map for Ninety Six. There is some surface disturbance and mounding of bricks mixed with dirt, possibly the result of razing. Artifacts are spread about on the surface and were encountered during our subsurface sampling.

2. Feature 2 is a roughly rectangular area of anomalous vegetative growth. Specifically, the delineated area shows sparse and "stunted" growth

as compared to (Wills' emphasis) the surrounding area. This area also shows a rectangular outline of soil discoloration in the 1939 photography.

Estimated length: 500 ft.

Estimated width: 450 ft.

Distinguishing characteristics: sparse vegetation, rectangular outline.

Orientation: NW-SE

Comments

SEAC: In addition to Wills' description, this anomaly, particularly on the north side of the road is densely covered by Japanese honeysuckle. The eastern and northern edge of this anomaly is in the approximate location of the area designated in 1977 as the probable location of Greene's Camp (Ehrenhard, 1977). No artifacts were observed in this location. However, they were noted in the general vicinity on transects RP 34-38 between 1000 and 1500 ft. The soil on the western edges of this anomaly showed evidence of previous disturbance in that the A horizon appears to have been eroded. This could be the result of erosion caused by either cultivation associated with the habitation noted in feature 1 as well as the earlier military occupation.

3. Feature 3 consists of two parallel, curved lines following the contour of a hillside.

Estimated length: 100 ft.

Estimated width: 10 ft.

Distinguishing characteristics: light coloration on black-and-white photographs (1978). Extremely red in contrast to surrounding white on the IR false-color photography.

Orientation: E-W

Comments

SEAC: This feature is undoubtedly the drain field for the septic system of the mobile home also visible on the aerial photographs. Examination of the IR images indicates similar features at other observed houses within the flight frames.

4. Feature 4 is a linear depression.

Estimated length: 1500 ft.

Estimated width: 50 ft.

Distinguishing characteristics: light color, depressed aspect on the stereopair examination.

Orientation: NE-SW

Comments

Wills: This is probably the remains of a road that appears in the 1939 photography.

SEAC: This anomaly was traversed by one of the transects. The only unusual properties exhibited in the soil samples was an increase in the number of quartz pebbles. Directly SW of this anomaly is a recent historic house site located on RP 21, 600N. This was given the project designation NPS 96-8. The feature described is probably associated with this site.

5. Feature 5 is apparently a room block consisting of four to five rooms.

Estimated length: 50 ft.

Estimated width: 25 ft.

Distinguishing characteristics: distinct low walls, separate square and rectangular areas interpreted as rooms.

Orientation: NW-SE

Comments

Wills: 1972 black-and-white photos show a building at this location.

SEAC: Feature 5 is the ruin of a brick building that was built at the time the property was owned by Greenwood Mills. Because the structure was standing in 1972 and is therefore contemporary, it was not assigned a project site number.

6. Feature 6 is a linear trough.

   Estimated length: 225 ft.

   Estimated width: 10 ft.

   Distinguishing characteristics: light coloration, depressed aspect on the stereopair examination.

   Orientation: N-S

7. Feature 7 is actually a group of parallel linear features occurring along the contour of the slope just below the jailhouse/mound.

   Estimated length: 25 to 30 ft.

   Estimated width: 5 to 10 ft.

   Distinguishing characteristics: light coloration.

   Orientation: N-S

   Comments

   SEAC: These features (6 and 7) are located in the "historic zone" and are the results of earlier archeological investigations.

8. Feature 8 is a linear trough.

Estimated length: 100 ft.

Estimated width: 10 to 15 ft.

Distinguishing characteristics: light coloration, depressed aspect on the stereopair examination.

Orientation: NE-SW

9. Feature 9 is a linear trough.

Estimated length: 150 ft.

Estimated width: 5 to 10 ft.

Distinguishing characteristics: light coloration, depressed aspect on the stereopair examination.

Orientation: NE-SW

Comments

SEAC: These two anomalies (features 8 and 9) are situated just south of Hamilton's Survey Line directly below the Old Ninety Six Village Site. Transects RP 25 and 26 encountered obviously disturbed soil, charcoal, metal, peach pits, etc. Numerous depressions and small mounds not recorded by Wills' analysis, indicate past activity as do the presence of non-indigenous ornamental plants (genus *Lilium* or *Narcissus*). Personal communication with a local informant indicated that these bulbous plants become feral and have continued to bloom without cultivation for "at least 100 years." This property was formerly owned by Robert Gouedy. He reportedly subdivided and sold his property nearest the Survey Line during the occupation of the Ninety Six Village (Rodeffer 1975).

Michael Rodeffer, former site director, indicated the possibility that this area may have been utilized beyond the Cambridge period. However, there are no surviving documents for this occupation (Rodeffer, personal communication, 1977).

10. Feature 10 is a depression at the SW end of a dam showing numerous surface disconformities.

Estimated length: 150 ft.

Estimated width: 50 ft.

Distinguishing characteristics: rectangular outline and varied relief.

Orientation: E-W

Comments

Wills: Possibly related to dam construction or function.

SEAC: Surficial debris at the site of this anomaly included fragments of mortar or cement, several whiteware ceramic sherds and brick. No conclusion was reached on the identity of what appears to have been a small structure. It was possibly associated with the Greenwood Mills occupation.

11. Feature 11 is a linear trough.

Estimated length: 700 ft.

Estimated width: 25 ft.

Distinguishing characteristics: light color, depressed aspect on the stereopair examination.

Orientation: N-S

12. Feature 12 is a linear trough.

Estimated length: 225 ft.

Estimated width: 20 to 50 ft.

Distinguishing characteristics: light color, depressed aspect on the stereopair examination.

Orientation: NW-SE

13. Feature 13 is a mound.

Estimated length: No estimate possible

Estimated width: No estimate possible

Distinguishing characteristics: Rounded vertical protuberence.

Orientation: Unknown

14. Feature 14 is a house.

Comments

SEAC: Features 11-14 are not on property acquired by the National Park Service. However, some of these were accessible for inspection. Eleven was an area of erosion, now stabilized. Thirteen is a large mound of sawdust at the end of a dirt trail, and 14 is a house, no longer occupied. Number 12 is in a plowed field, however we were unable to detect any evidence of cultural activity on the surface. Archeological material was collected from this location by Michael Rodeffer and the site (38GN22) is recorded with South Carolina as a prehistoric site location.

15. Feature 15 is a rectangular outline which appears subdivided into at least two sections.

Estimated length: 300 ft.

Estimated width: 50 ft.

Distinguishing characteristics: dark outline, vegetation contrasting to the pasture in which it is located, rectangular morphology.

Orientation: E-W

Comments

SEAC: This anomaly appears to be a topographic feature. A thicket of blackberry and other thorny shrubs occur along a rather steep slope. The maintenance crew at the site state that this vegetation has been allowed to remain in this location because of mowing difficulty. This vegetation is the normal vegetative succession when fields or pastures are not cultivated for a length of time.

16. Feature 16 is a circular or elliptical outline contrasting to the lighter colored vegetation surrounding it.

Estimated length: 225 ft.

Estimated width: 125 ft.

Distinguishing characteristics: oval shape, dark outline

Orientation: N-S

Comments

Wills: the suspected feature is very difficult to define except on photograph 1-3-78, 663-5-7.

SEAC: This feature is identified as a structure on the 1949 USGS quadrangle map previously mentioned. Is not on National Park property.

17. Feature 17 is a rectangular outline bordered by a long, linear feature on the west side. It may be divided into two portions.

Estimated length: 250 to 275 ft.

Estimated width: 100 ft.

Distinguishing characteristics: Rectangular outline, light coloration.

Orientation: N-S

18. Feature 18 is a linear trough.

Estimated length: 125 ft.

Estimated width: 10 to 15 ft.

Distinguishing characteristics: light color, depressed aspect.

Orientation: E-W

Comments

SEAC: Features 17 and 18 are on private property and could not be investigated. They are, no doubt, associated with the town of Cambridge if they are historic features. These are the last features identified by Wills. The remainder were identified on the topographic map produced under the supervision of Dr. Thomas Lyons of the Chaco Center. These were not given numerical designations. Therefore, we have assigned consecutive numbers to the following features, beginning with number nineteen.

19. This anomaly is a rectilinear feature south of feature #4 and is a recent historic house site. The area was readily identifiable on the ground because of the presence of large hardwoods and

ornamental shrubbery (rose bushes). Building material was noticeable on the surface and soil samples revealed a greater humic content than was present in other samples on the transect. Several fragments of whiteware were also present in the subsurface samples. Other observations included tin roofing material and board siding. No foundation footings were recorded. Therefore, it is assumed that the building was placed on a field stone pier foundation. This is the typical construction used for tenant and small farm homes in the Piedmont and the assumption was therefore made that this was the cultural association rather than the more recent Greenwood Mills Occupation. The site was assigned the project number NPS 96-8.

20. This rectilinear feature is located on private property and was inaccessible. It is located just north of the Hamilton Survey Line, which was also utilized as our first baseline in the transect survey. On NPS property, just south of this anomaly, a stone-lined cistern was located. It was small, approximately 3 ft. in dia. and 4 ft. deep with a conchoidal profile. No features or artifacts were observed in the immediate vicinity. However, the photogrammetric map reveals a path that begins at the Survey Line approximately 175 ft. southwest of the rectilinear anomaly and follows the 480 ft. contour in a southerly direction for 600 ft. and ends abruptly at the cistern. This path was not visible to the archeological team on the ground, possibly because of waist-high vegetation. Although the function of this feature was not conclusively established, it is in all probability a component of the rectilinear feature identified as #20. Final analysis of this feature will depend on acquisition of the Williams' property by the National Park Service.

21. The archeological team was unable to identify a rectilinear feature in this location. This

slope has been subjected to erosion caused by what appears to be fairly recent timbering. Several denuded areas that correspond with the anomaly on the aerial photograph were observed. It is possible that timbered trees left on the ground could be interpreted as linear features on an aerial image.

22. This anomaly was intersected by RP 43 at a distance of 1200 ft. Although no artifacts were observed records indicate a change in soil properties in the area of this transect and the transects directly north and south. At 1000 ft. the soil changed from a brown red clay loam to a more plastic red clay at 1200 ft. What appeared to be a network of logging roads or erosional ravines was noted in this vicinity. A hundred feet farther east, the consistency of the soil became looser with a yellow clay and pebble inclusion. The soil profile returned to normal after this sample. This is the same disturbance that was noted on transect RP 44 at about 900 ft.

23. This feature proved to be two abandoned car bodies lying at right angles to each other. They are completely shrouded in honeysuckle vines, as is most of the terrain in this vicinity.

24. These two features are rectilinear anomalies approximately 200 ft. apart. The more westerly of the two is just north of the Survey Line and the larger one is bisected by the fence that marks the Line in this area. No surface evidence of habitation other than two clusters of bulbous plants (genus *Narcissus* or *Lilium*) were noted. There is, however, in this entire area, evidence of numerous archeological features.

25. This anomaly indicates the remains of a brick structure although its association is not known. Under a visual inspection the bricks appeared to be similar to those from the Ninety Six jail site. No artifacts were noted on the surface and because of the moundlike deposition of the bricks it is not likely that the brick mound marks the site of the subsurface features. The brick pile is possibly a secondary deposition or chimney fall rather than the actual structure. This feature was apparently connected by a path with the cluster of buildings on the west side of the Charleston Road. This linear feature (path) is indicated on the topographic map, but was not observed by the archeologists on the ground. This brick fall was previously identified by Michael Rodeffer as a chimney base and may mark the site of one of Gouedy's outbuildings.

26. This anomaly contains four linear outlines, one rather large L-shaped structure (approximately 60 ft. by 40 ft with a 20 ft. by 20 ft. ell attached). The other outlines measure 20 ft. by 40 ft.; 15 ft. by 15 ft., and 30 ft. by 50 ft. Rodeffer also recorded a chimney base in the same location of the 20 ft. by 40 ft. building on an undated site location map. At the present level of investigation it is not possible to determine either the functional or chronological relationship between these features. There is no surface evidence other than the previously reported chimney base and a porcelain toilet located during this survey. The entire area, however, shows evidence of intensive use--several iron artifacts were uncovered, and soil samples indicated large amounts of charcoal, a few peach pits, and generally disturbed soil. Numerous depressions were also noted but no ceramics were observed.

It is conjectured that this could be a hypothetical location for the plantation home of Robert Gouedy, the trader. Although his stockaded barn and a cellar were located some 600 ft.

southeast of these features by Stanley South (1970), the residence and other outbuildings have yet to be identified. Since these buildings were all burned during the Cherokee conflicts, surface evidence would not be expected. The maps produced from the magnetic survey indicate no additional subsurface features in the vicinity of Gouedy's trading post that could be interpreted as the residence location. This strengthens the assumption that this cluster of anomalies may prove to be the missing buildings.

27. The survey team did not observe any surface evidence of cultural activity or features in the location.

28. This feature is located on private property and was not investigated.

29. This anomaly is identified as a possible foundation on the photogrammetric map. It was not identified on the surface. However, numerous prehistoric lithic artifacts were recorded in this location. The cultural identification of this feature cannot be determined at this time.

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BIPOD PHOTOGRAPHY:

PROCEDURES FOR PHOTOGRAPHIC MAPPING

OF ARCHEOLOGICAL SITES

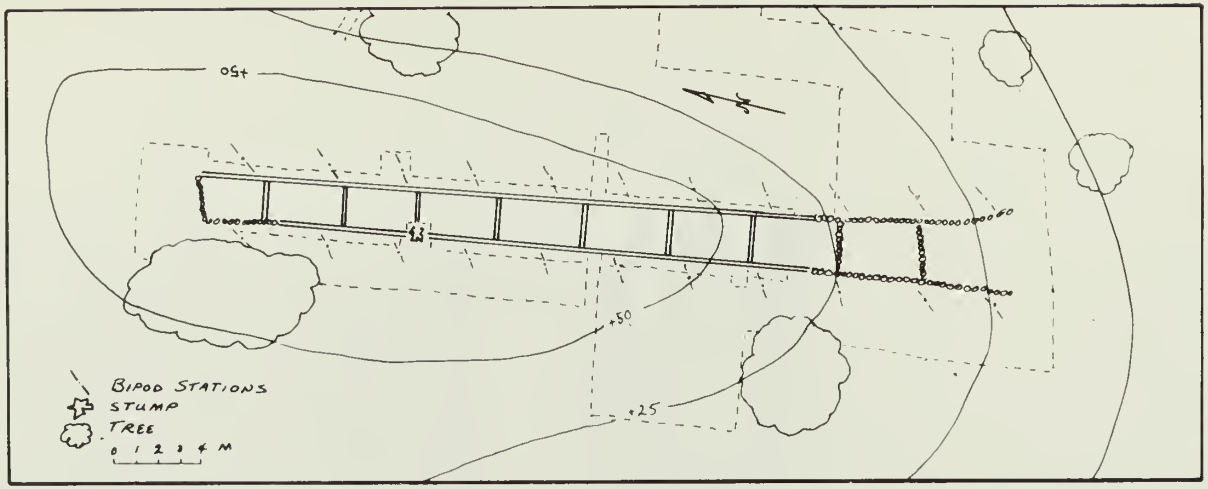
by

Stephanie Klausner

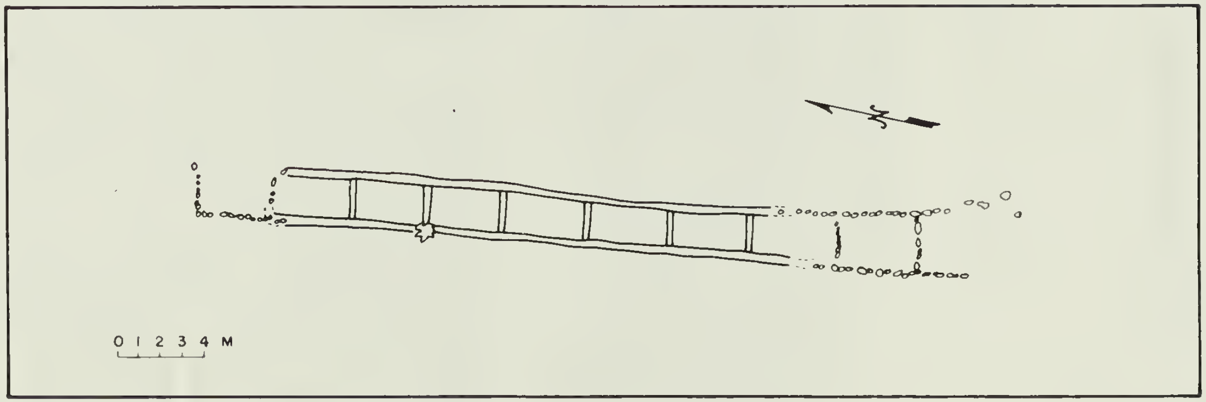
Introduction

The present concern with archeological remains as a limited and non-renewable resource has expanded the obligation of the archeologist in the area of data collection. Archeological context is, of course, basic to this concern. Because removal of an artifact from its context is a form of destruction, the perennial bane of the field archeologist has been the tedious and time-consuming task of mapping each phase of work.

There are two types of bias inherent in traditional archeological mapping. The first is visual--preconceived notions of form influence the archeologist's visual perception. Theoretically, working with an alidade and plane table, the archeologist must plot an infinite number of points to fully document the variations and irregularities of an architectural feature. The only solution within this framework is to plot points arbitrarily and interpolate between them. Resorting to more sophisticated surveying equipment does not help because the problem is substantially one of inability to predetermine which points are significant. Mapping from vertical photography, however, eliminates this bias. As an example, the alidade map of the roomblock shown in Fig. 47 was compiled from points taken at the wall abutments; the drawing completely eliminates all of the outer-wall irregularities that are clearly shown in the map drawn from a vertical photograph.



ALIDADE MAP



MAP DRAWN FROM VERTICAL PHOTOGRAPHY

Figure 47 - Maps of roomblock at LA 11830, showing the difference between an alidate map and a map drawn from vertical photography-

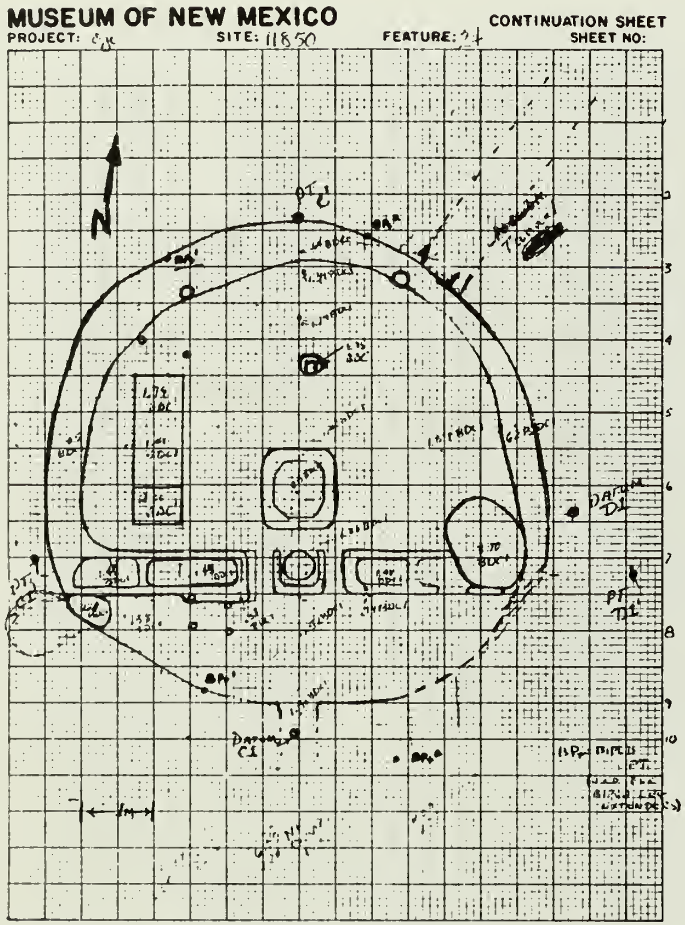
Although it seems a simple matter to select additional points for mapping, the difficulty is that irregularities are not always obvious from the ground. Fig. 48 demonstrates the case in point. The floor of the pithouse illustrated was more than 3m. below ground surface. The field map was drawn from points triangulated from the subdatum points--an acceptable procedure in archeological field work. A comparison of the photogrammetric map with the triangulated map shows that the error lay not in the plotting of the points but in the interpretation. In both cases, the photogrammetric maps are more accurate representations of the scenes than the traditional maps, which are misleading because of their inherent limitations.

The second limiting factor in traditional mapping is the archeological bias of the investigator. The archeologist records only what he considers relevant, a consideration that changes through time and from archeologist to archeologist. This bias has particularly serious implications for recording associations of artifacts. Recording decisions made in the field are irrevocable once a feature has been destroyed or an artifact assemblage collected. In contrast, controlled vertical photography produces a "photographic artifact." The print can be manipulated to suit the particular recording needs, but the negative remains intact for future research.

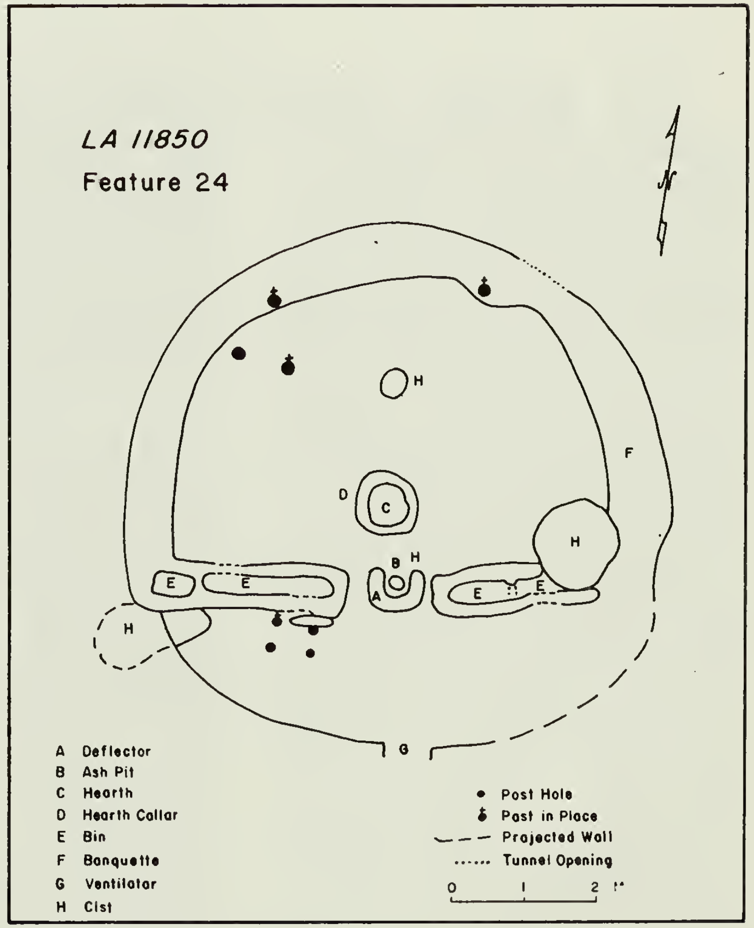
It can be seen that both of the biases inherent in traditional archeological mapping--visual bias and archeological bias--can be resolved, to a considerable degree, by applying photogrammetric mapping techniques.

Photogrammetric mapping is the method of creating maps or drawings of objects, not by measuring the objects themselves, but by measuring controlled photographs of the objects.

When large areas must be mapped, it is far more efficient to take measurements from photographs than it is to send field crews to take measurements at



FIELD MAP



PHOTOGRAMMETRIC MAP

Figure 48 - The field map and a photogrammetric map of a Gallina-phase pithouse at LA 11850, N.M.

the site itself. Machines called stereoplotters can precisely interpolate distances within a few known control points. Using three-dimensional stereoscopic images, the stereoplotter can plot not just the few points possible in most field mapping procedures, but can locate and measure any point in between. The accuracy obtained by this type of mapping far exceeds most current archeological mapping.

Photogrammetric mapping is most commonly undertaken using aerial photographs, and the large format and high degree of precision offered by aerial cameras make such an approach ideal for "one-time" mapping of structures and other features. The photography and measurement of site features during excavation, however, is somewhat more complex. Ideally, features should be photographed as they are uncovered, and this requires many exposures at different times; the cost of aerial overflights each time a feature is discovered would be prohibitive, as would the time delay required for contracting and arranging for an airplane and camera. Additionally, since the final accuracy of photogrammetry is relative to the scale of the imagery used for measurement, aerial photographs will generally be at too small a scale for the mapping of specific site features. The ideal platform for obtaining photogrammetric imagery during excavation is a camera suspended directly above the portion of the site in question.

Various ground-based camera platforms have been developed for and used by archeologists (Sterud and Pratt 1975). A photo turret (Fig. 49) developed in Sweden (Nylen 1964) has been utilized by Dennis Stanford of the Smithsonian Institution to produce photomosaics of bison bones at the Jones-Miller excavation in Colorado (Stanford, personal communication, 1977). In New Zealand, B.G. McFadgen (1971) has employed a photographic tower (Fig. 50) to obtain controlled stereopairs for photogrammetric plotting.

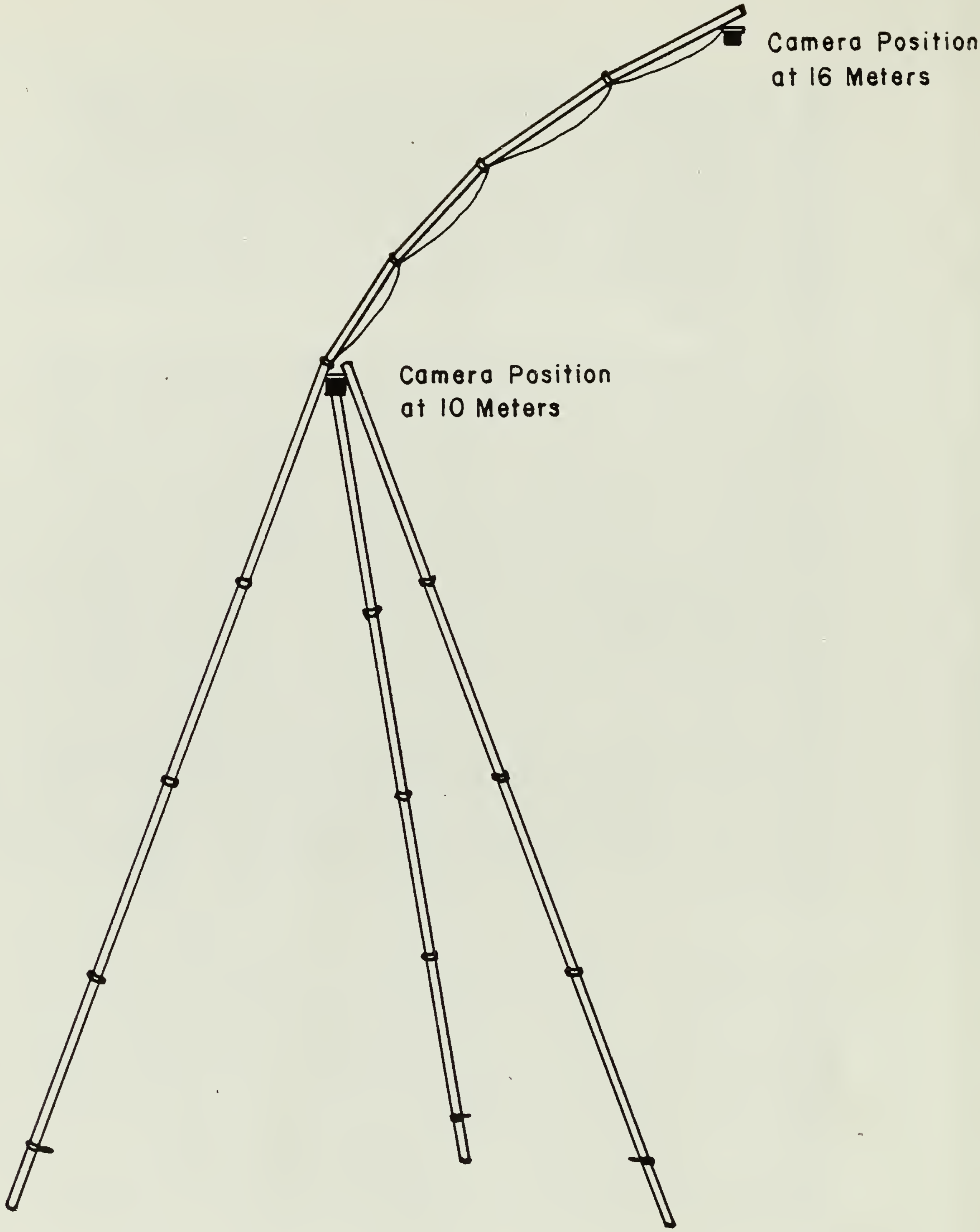


Figure 49 - The Nylen photo turret developed in Sweden.

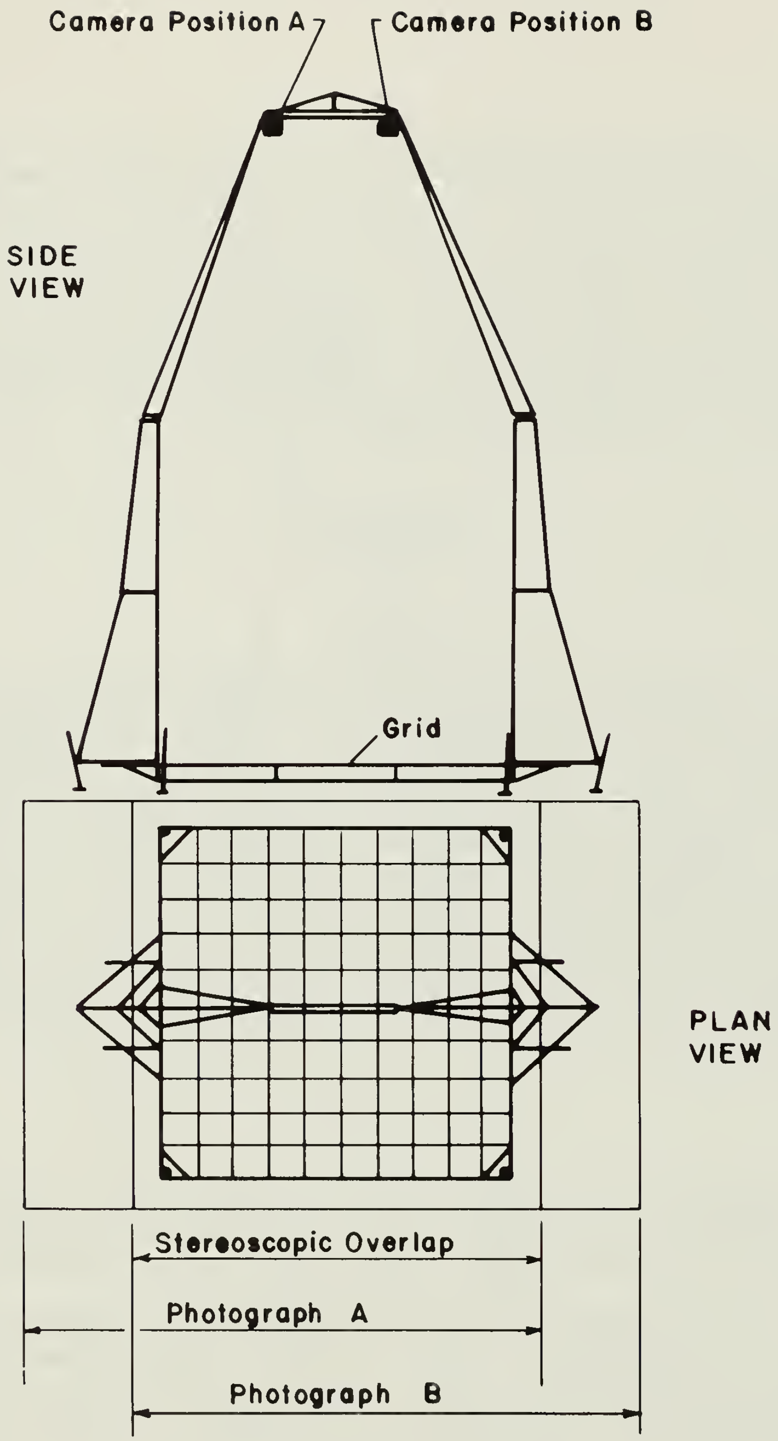


Figure 50- A photographic tower designed and utilized by B. G. McFadgen.

Since the function of a camera platform is to hold the camera directly above the area to be photographed at a fixed or readily calculable distance, any device that serves that purpose is usable. The techniques discussed in this report utilize the Bipod Camera Support System designed and built by J.H. Whittlesey (1966). The bipod (Fig.51) has some advantages over the other available platforms since it is less expensive, less complicated to operate, lighter, and more portable.

Equipment

The Bipod

A versatile piece of equipment made up of aluminum tubing, the bipod can be used in varying combinations of leg heights from 5 to 10 m. The tubes are laid out on the ground, assembled with screws and wing nuts, and lifted by means of guy lines. The camera is then hoisted into position at the apex. For a complete discussion of operational techniques and specifications, see Appendix I. More information about the bipod and its availability can be obtained from the Whittlesey Foundation, Inc., 122 East 65th Street, New York, New York 10021, which manufactures the devices at cost for use by archeologists.

Cameras

Any 35 mm. or 2¼ format camera can be used with the bipod. A pneumatic release should be used to fire the shutter when the camera is in position.

For maximum ground coverage, the standard lens/format combinations are: 35 mm. film-35 mm. lens and 120 film-50 mm. lens. Both combinations permit a moderately wide angle of coverage. Longer focal length lenses can be used for more detail. Lenses with shorter focal lengths will include the bipod legs in the photographs and could cause undesirable distortions.

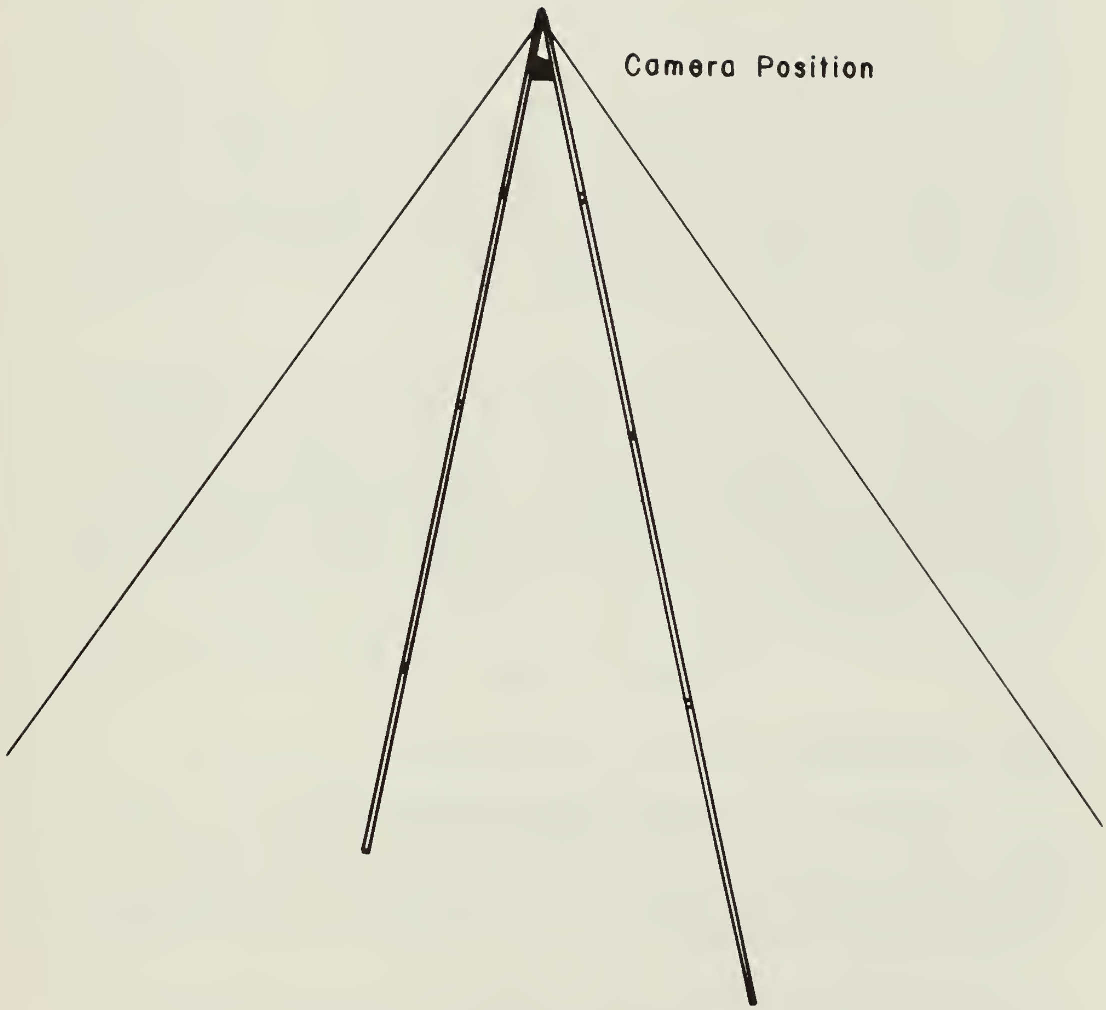


Figure 51 - The Whittlesey 30 foot (10 meter) portable bipod camera support.

Light Meters

There are two basic types of light meters: incident and reflectance. An incident-type light meter measures the intensity of light falling on the subject. The meter must be held facing the light source and in a light setting (e.g. full shadow) similar to that of the subject to be photographed. A reflectance-type meter measures the light reflected from a subject and therefore is influenced by variations in the reflective intensity of that subject. Light sand will result in a much higher reading than dark soil under exactly the same lighting conditions. All built-in light meters and many popular hand-held models are reflectance meters.

When a reflectance meter is used, it is advisable to take the meter reading from a Kodak Gray Card (18% reflectance), which reflectance meters are calibrated to read. The card should be placed on the subject or at an angle at which it will receive the same intensity of light. This allows for consistent exposure of the photograph regardless of the subject matter.

Films/filters

Black-and-White

Although any panchromatic black-and-white film can be used, the faster emulsions like TRI-X (ASA 400) offer the most versatility. In high winds, it is necessary to shoot at very high speeds to compensate for platform motion.

Fine grain developers should not be used for critical mapping since they tend to soften definition. Liquid developers allow fresh mixing of chemicals for consistent results. Recommended developers include:

RODINAL (Agfa)--very high dilution ratio and excellent tonal range.

HC-110 (Kodak)--very good results when the film ASA is cut in half with a corresponding decrease in development time.

Color

Color slide film offers inexpensive, color-balanced images for viewing. Internegatives can be made from the transparencies if prints are needed. If any color negative material is used, it is essential to include a gray card (18% reflectance) in the exposure to avoid incorrect color rendition in the prints.

Filters

The camera should never be hoisted up on the bipod without a protective filter over the lens. A skylight filter can be used to protect the lens without changing the exposure setting or the color rendition of the photograph. (For a discussion of the use of filters in archeological field photography see Simmons 1969).

Monoscopic Photographic Distortions and Photogrammetric Control

Control for photogrammetric purposes, also called ground control, consists of a set of points that are referred to a datum and to each other. They must also, of course, be positively identifiable in the photograph (Wolf 1974:218). The difference between "pretty" vertical photographs for publication and controlled vertical photography for mapping lies in the setting of ground control points, thereby changing the photographs from visual aids to quantifiable data.

Pre-set control points are useful in overcoming many of the problems associated with mapping from vertical, monoscopic bipod photography. It is important, therefore, to determine the specific mapping requirements for each project in order to plan the photogrammetric control: the exact number and optimum placement of the control points is determined by the use for which the photographs are intended (Wolf 1974:220).

Because measurements will be made from the photographs, rather than from the objects themselves, it is imperative that the same scale be maintained in all photographs to be used in compiling the same map. In practical terms, this means that in the case illustrated in Fig. 52, there are two separate levels of concern, the kiva floor (A) and the wall tops (B). These must be treated as discrete entities. Two bipod photographs would be required, each with its own set of control points. The relationship between any of the control points in A to any of the control points in B constitutes the completed plan map of the feature.

A major problem encountered when mapping from bipod photography is distortion. There are two sources of distortion or image displacement in vertical bipod photography: camera tilt and relief displacement.

One basic function of the control points in the photograph is to identify and permit correction for camera tilt. Tilt, which occurs when the film plane is not parallel to the ground, causes distortions of the photo scale (Fig. 53). These distortions are obvious in the case of regular or known shapes, as shown in the illustration. However, the irregularities of archeological features make it impossible to determine the distortions caused by tilt without additional, empirical, measurement.

The setting of three or more points of known horizontal separation, to form a right angle, allows for instant recognition of tilt distortions since a known shape (i.e., the right angle), which is readily identified and easily measured, has been added. The control points should be distributed to cover the

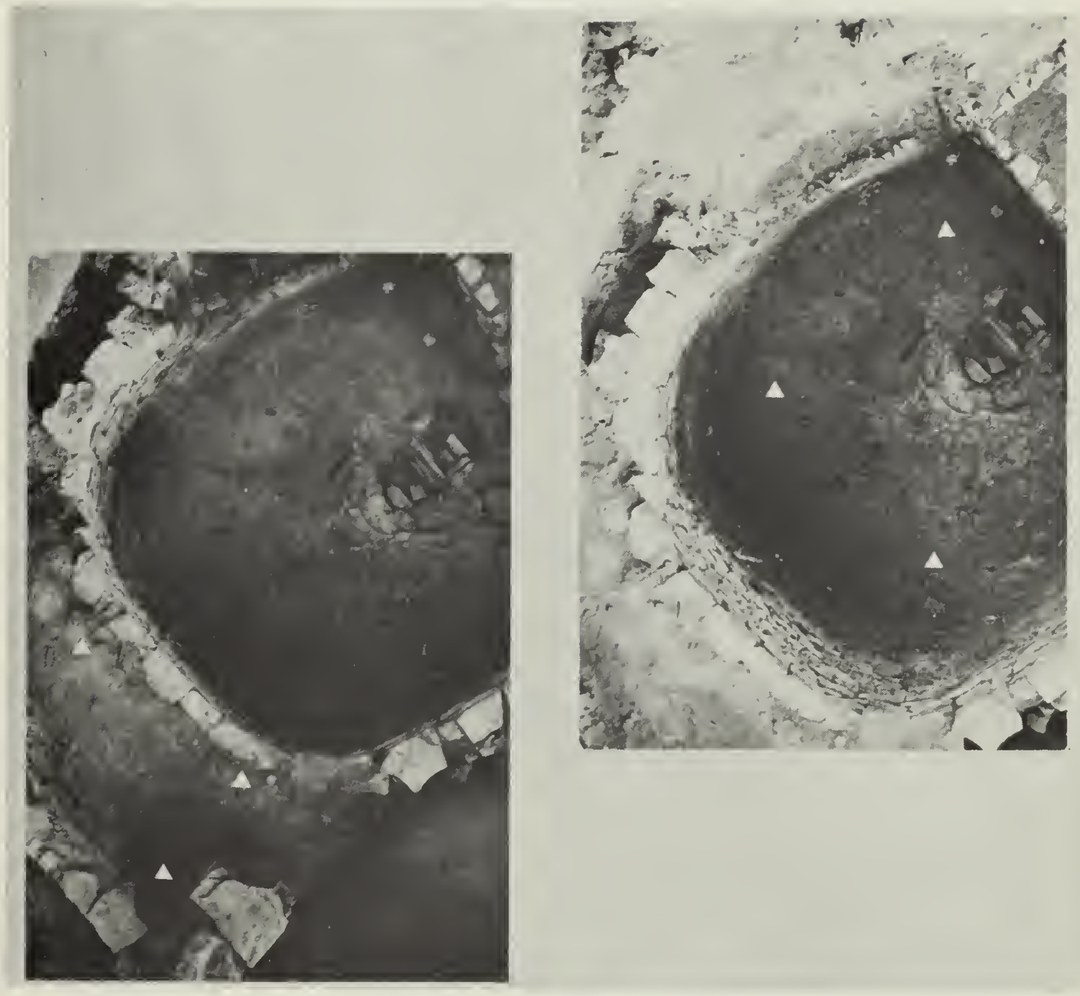


Figure - Relief displacement from two different camera positions.

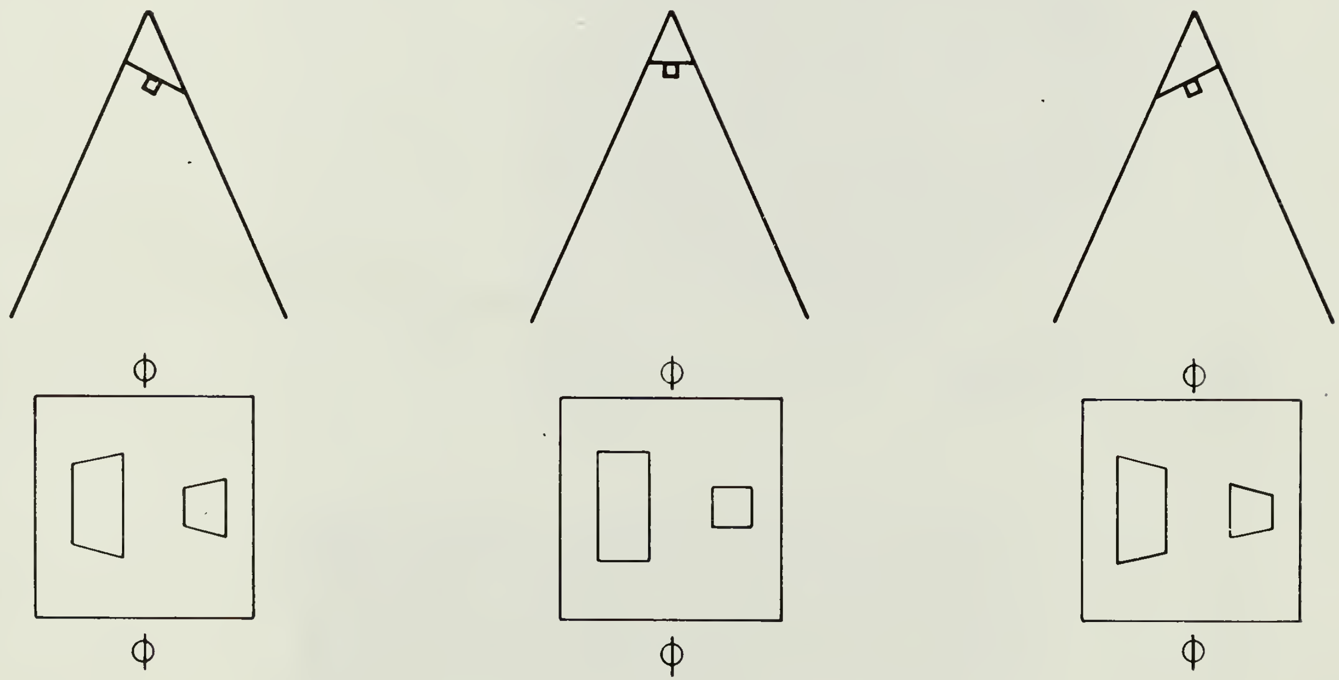


Figure 53 - Schematic drawing of tilt distortions caused by various camera angles.

area of maximum interest. In addition, these control points permit use of a simple procedure to correct the scale distortions--rectifying the photograph in the darkroom. Photo rectification is accomplished by placing scaled marks, in the same configuration as the original ground control, on a photographic easel used for enlargement and then tilting the easel until the projected control points match these marks.

The second factor to be controlled is the displacement caused by the three-dimensional relief of the feature being photographed. Relief displacement occurs when objects below a horizontal reference plane are displaced toward the center point, or nadir, of the photograph; objects above the reference plane, conversely, are displaced away from center (Wolf 1974:15). Displacement does not occur if an object is directly below the camera lens axis regardless of the relief, or if it is at the same elevation as the photo center point regardless of its horizontal position (Lyons and Avery 1977:18-19).

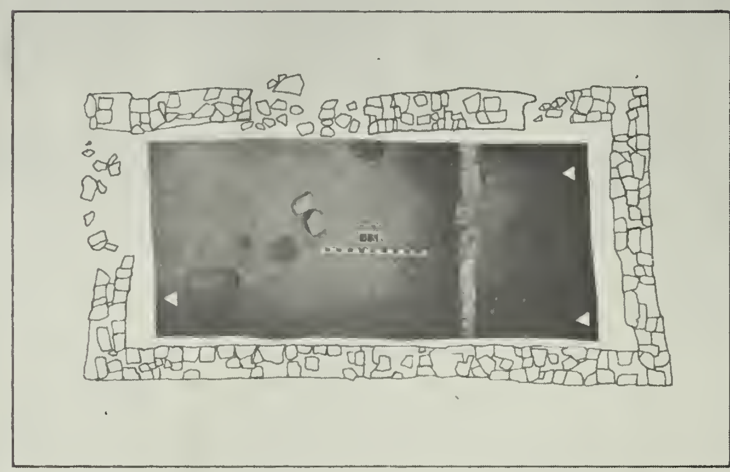
Applications

Sequential Photography

In sequential photography of progressing excavation for phase mapping, the control points serve to align the subsequent images, both in relation to one another and to the ground surface or wall tops. Fig. 54A & B shows scaled (1:25) bipod photographs of the first and last excavated levels of a room in Pueblo Alto, Chaco Canyon National Monument, New Mexico. The difference in elevation between the wall tops and the excavated floor is about 3 m. This difference in scale is illustrated in Fig. 54 . It should be noted that the four corner abutments in the photographs do not coincide. This difference in area created by the wall slope or by irregularities in construction can be mapped or computed from the two scaled photographs (Fig. 55).

WALLS

FLOOR



WALLS & FLOOR

Figure 54 - Scaled bipod photographs (A and B) showing two excavated levels of Room 103 at Pueblo Alto in Chaco Canyon, N.M. 8C shows difference in scale between the wall tops and the excavated floors.

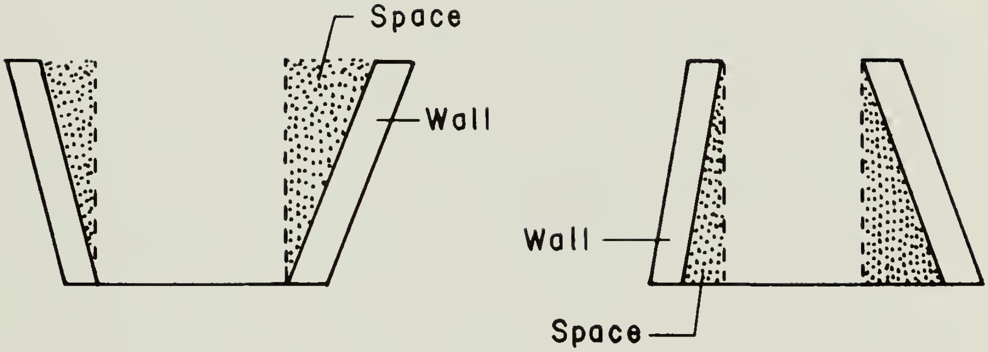


Figure 55 - An illustration of the space created by the irregularities in wall construction or wall slope.

Once the initial photogrammetric control for the first level has been established and the placement of the bipod decided upon, subsequent recording requires little time on the part of the excavator. The leg positions should be set and leveled so that the bipod can be repositioned quickly and exactly for succeeding photographs. To facilitate this, a section of 1-in. plumber's pipe can be driven into the ground for the feet of the bipod to rest upon.

A system must be employed for resetting the same control points at each succeeding level. One suggested method is the use of a plumb bob hung from a cross-stick and suspended from the wall tops as shown in Fig. 56. By lowering the plumb bob before photographing each level, the control points can be accurately transferred from their original positions. The two ends of the stick need not be level for this procedure, but the positions along the wall must be marked for duplication. A transit can be used to set the control points from datum if only a limited number of sequences are to be photographed.

For sequential photography of sites without architectural features or for pre-excavation records of sites, the excavation unit or grid corners can be used for limited ground control. The corners should be measured carefully and marked well so that they show clearly in the photograph. A meter stick or scaled arrow should be placed on the level being photographed for additional control in scaling. In order to switch from preexcavation grids to photography of architectural features and to insure the maintenance of continuity, control points should be reset from the primary site datum.

Site Plan Maps

Bipod photography of non-contiguous features for inclusion in a site plan map is a simple matter with preset ground control. Any two of the three

Figure 56 - A system for resetting control points for sequential photography.

control points set for tilt correction and sequence alignment can be mapped with transit or alidade onto the site contour map. This technique insures accurate placement of the feature on the site plan map without photographing the non-cultural areas of the site. An example of this is shown in Fig. 57 (Pithouse A).

Roomblocks or other contiguous archeological features can be treated as a single unit for the site plan map. It is necessary only to map several selected control points from the entire block. The optimal control should be chosen to cover the defining limits of the unit with at least one central pivot point, as illustrated in Fig. 57 (Roomblock). The three control points marked on the roomblock would be sufficient mapping control for this configuration of rooms.

Other Applications

There are many other applications of photographic mapping to field problems in archeology. Among these are the precise recording of soil color changes with color film. Changes in the composition of soils not visible to the human eye will often show up clearly on infrared films (see Buettner-Janusch, 1954). Wall abutments and important details of features, such as hearths, artifacts, burials, or fragile materials, can be photographed from a low bipod height, providing excellent backup for other maps.

Stereo Photography

Binocular or stereo vision is the ability of the human eyes to perceive depth or topographic relief. When an object is viewed alternately with each eye, its location seems to shift position with the point of observation. This phenomenon is called parallax. When an object is photographed from two separated points the resultant images can be viewed three-dimensionally or stereoscopically with the

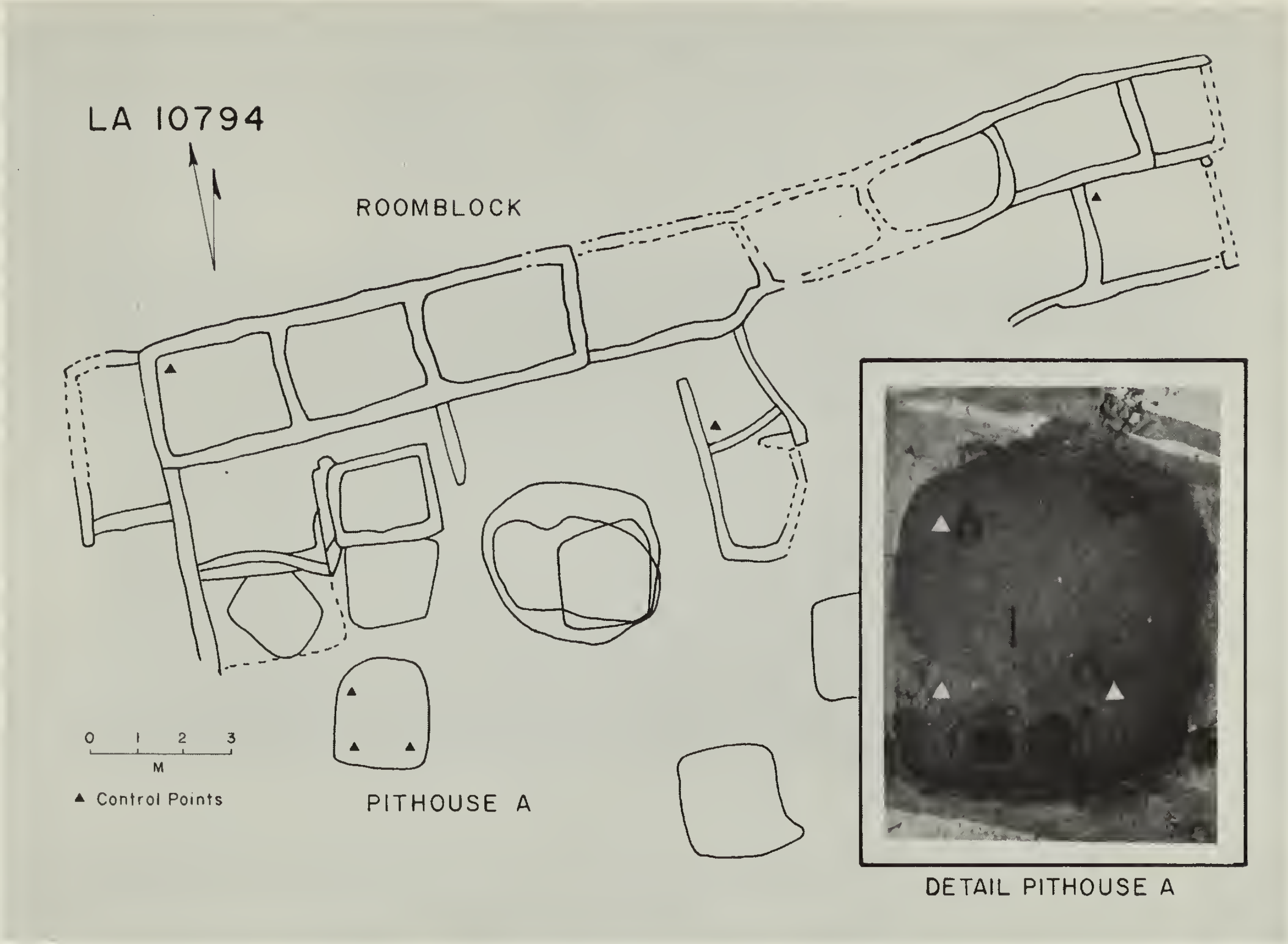


Figure 57 - Control point placement for site plans.

aid of a simple lens stereoscope (Lyons and Avery 1977:11). This simulates normal binocular vision by enabling the viewer to use one eye on each photograph of the pair.

It is possible to exaggerate the vertical displacement of objects in the scene by varying the distance between the camera points. The degree of vertical exaggeration is a function both of the focal length of the lens and of the separation between the two images of the stereo pair. Decreasing the focal length and/or increasing the distance between the camera stations increases exaggeration. The effect is the same as would be achieved by increasing one's eye separation: enhanced depth perception.

With this ability to manipulate the degree of three-dimensional exaggeration, stereo photography adds considerably to the archeologist's potential for photographic mapping and recording. Interesting or unusual archeological features can be restored to three-dimensional reality in the laboratory (Bevan 1973). Many low-relief artifact assemblages can be recorded and viewed among very small, similar entities. Traditional methods of measuring artifact placement are tedious, time consuming, and usually not very accurate. Photographic mapping of lithic assemblages poses a new set of problems: the inherent lack of contrast in the subject matter and the absence of topographic relief make it technically difficult to record lithic material with satisfactory results.

Stereo photography, however, can exaggerate the vertical relief, thus enabling the viewer to more readily distinguish one flake from another. When the photographs are viewed with the aid of even an inexpensive pocket stereoscope, the lithic material appears to stand out from the ground (Fig. 58). Any information required for mapping (i.e., artifact provenience, cluster concentrations, etc.) is easily recorded two-dimensionally on either an enlarged single print or on a mylar overlay tracing

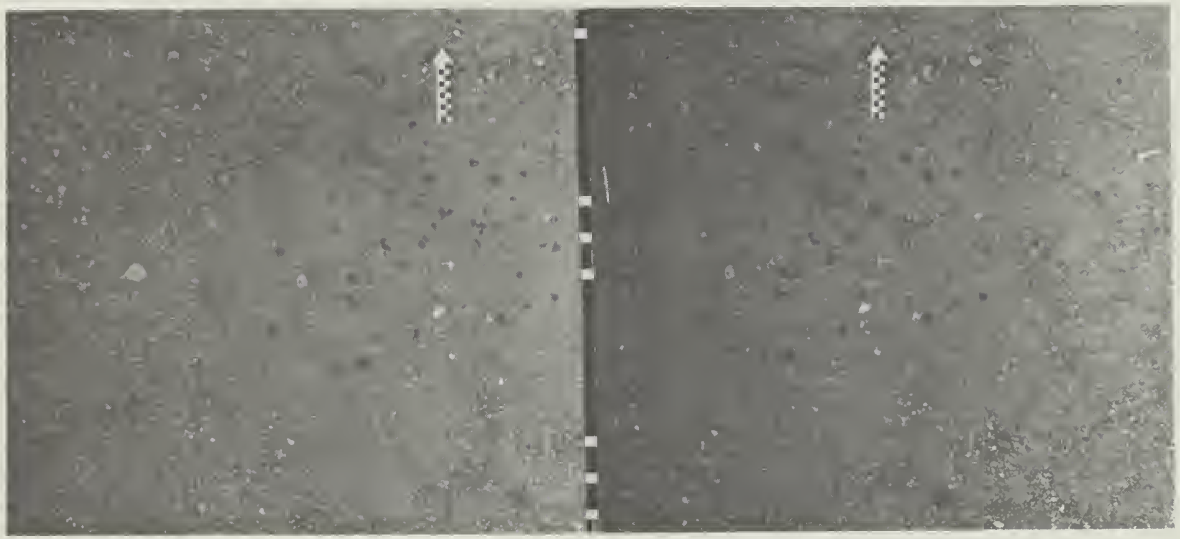


Figure 58 - A stereogram of a lithic scatter.

(Fig. 59). In addition, since the photographs are representations of the spatial associations of the assemblage, any number of different analytical biases can later be imposed on the data without altering their original context.

Three-Dimensional Point Plotting with Stereo Photos

Although parallax and radial displacement have been discussed as problems above, it is these very properties of photographs that allow stereoscopic viewing and the measurement of three-dimensional spatial data from a stereo pair. The possible advantages of stereo viewing for purposes of artifact identification and differentiation were discussed above. The metric properties of stereo photographs offer an even more useful tool in lithic studies, however.

Traditionally, and especially in the Southwest, archeologists have tended to use "natural" units of excavation such as rooms within structures (or quadrants of rooms) as provenience units for recording artifact placement. Where structures are not present, or not immediately obvious (as in much of the eastern and midwestern United States), arbitrary recording units are used; these usually vary between 5- and 10-ft. squares or 1- to 2-m. grids. Little contemplation is required to arrive at the conclusion that such spatial recording is far too inaccurate for the analysis of intra-site activities in many cases, especially in smaller sites. A recent experiment with Eskimo lithic data (Binford, personal communication 1977) suggests that the smallest acceptable grid unit applicable to modern clustering analyses is on the order of 20 cm. on a side. The ideal form for the spatial recording of artifact location, in fact, is for each artifact to be assigned its own three-dimensional coordinates. This has been referred to as piece-plotting.

Archeologists who have employed piece-plotting in the field know that this method can be time-consuming and frustrating. Piece-plotting, when

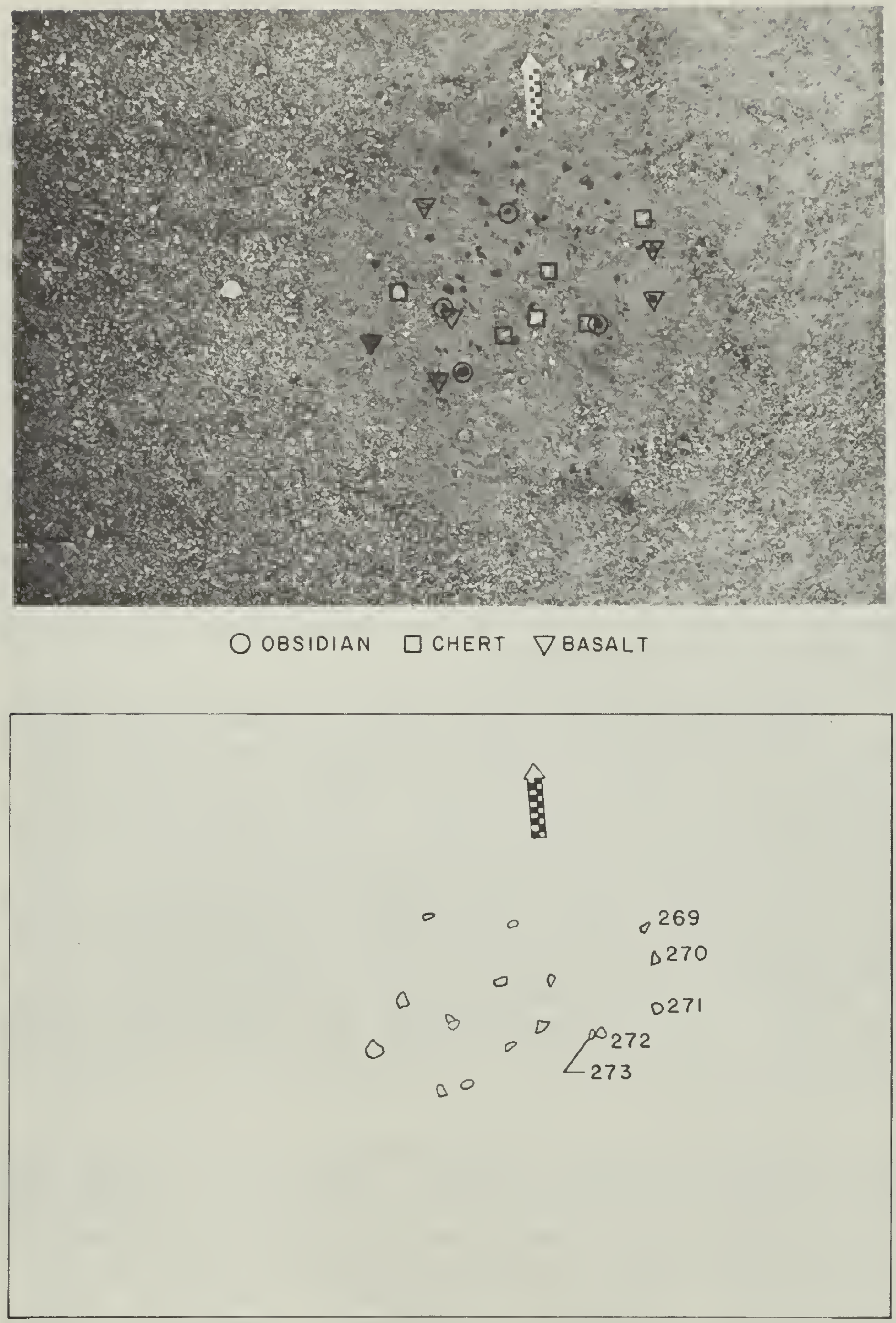


Figure 59 - Two examples of recording procedures on lithic scatter--material source and artifact provenience.

employed today, is accomplished in most cases by square measurement from the two sides of an excavation unit with tapes or strings that cross over the artifact being measured. Vertical or Z-axis measurements are made either by levelling the measurement lines and measuring downward from the crossing point, or by reference to a triangular datum marker that can be viewed from a level plane. In some instances transits or plane tables are used for this purpose.

An alternative method, and one that offers far greater accuracy and cost-effectiveness, would be the use of bipod stereo photography to facilitate piece-plotting of artifacts. Although the cameras used in bipod photography are not strictly metric cameras (as are aerial mapping cameras), the use of precision equipment such as Hasselblads at low bipod altitudes would provide sufficient accuracy. Three-dimensional locations are measured from stereo photographs through the use of two techniques, planimetric plotting and stereometry.

Planimetric plotting can be accomplished using very simple equipment--clear mylar sheet overlays, a ruler, and a pen--or with a number of different planimetric plotting devices. For introductory or small-project use, the radial line plotting method is probably more practical; it is described in detail in several available publications (Lattman and Ray 1965; Avery 1977; Wolf 1974). Planimetric plotting equipment such as the Kail Radial Plotter or the Bausch and Lomb Zoom Stereo Transfer Scope ranges from about $400 to over $9,000, but such costs could conceivably be justified in the case of large or ongoing projects.

Stereometry is the measurement of vertical height relationships between objects appearing in both images of a stereopair by reference to parallax displacement of the object as viewed from the two camera positions. A stereoscope and a parallax wedge or parallax bar are required for such measurement, which can be performed with a minimum of training. One of the best summaries of how parallax measurements are performed is provided by Wolf (1974).

The stereophotographs from which piece-plotting is to be done would be exposed at intervals from a bipod platform in much the same manner described earlier in this paper. Artifacts can be left on a pedestal of earth, if desired. It is important that the ground surface directly under the object be left unaltered. It would not be strictly necessary to remove the fill in the excavation unit evenly or in level layers; all that would be required is that when a number of artifacts are exposed, a stereo pair would be exposed. The artifacts could then be removed and the excavation would proceed.

APPENDIX I

MANUAL for

30 FOOT PORTABLE BIPOD CAMERA SUPPORT

PART I GENERAL INFORMATION

Background and History

This system designed and built by Whittlesey, issued by Whittlesey Foundation for archaeological work only, is protected by U.S. Patent 3371589.

The first model Bipod Camera Support, 12 meters long, was built for work at Sardis in 1965 and later patented. It subsequently worked in Greece, Tunisia and Sicily. The second of that model was built for research by U.S. Army in the Arctic Circle, later used for photogrammetric research at Ohio State University. It weighs 98 lbs., retracting to 10 feet. Coverage capacity over 1000 sq. ft.

The second Bipod, 6 meters long, was portable, weighing but 10 lbs. retracting to 4.5 ft. Issued to some 20 archaeologists, it has worked in U.S., Greece, Italy, Jugoslavia, Israel, Sicily, Holland, Afghanistan, France, Hudson's Bay and Labrador. Coverage capacity 190 sq. ft.

This third Bipod called "Thirty Footer," retracting to 6 feet, is also portable and offers capacities up to 635 sq. ft. In effect, it is three Bipods in one. Set up as the "Maxi" 30 ft. long, it weighs 20.5 lbs; set up as "Midi" 25 ft. long, it weighs 16 lbs; and as "Mini" 17 ft. long it weighs 11 lbs. The variations of leg extension run from 30 feet down to 15 ft. through eleven different combinations, according to one's choice. Complete tabulation of capacity according to leg extension and leg spread are provided in the Manual Parts II-A and II-B.

The Bipod is designed for 35 mm format with f 35 lens and 2¼ in. format with f 50 lens. Lifting platforms are provided for each. Other format/lens combinations are possible, although not recommended as utilizing the Bipod to its best advantage. Tabulations for Bipod posture and capacity for other format/lens combinations may be calculated from formulae provided in the Manual, Part II.

Availability

First issued in 1975-76 to U.S. National Park Service for use at Chaco Canyon, to Smithsonian Institution (2 Bipods) for use in Labrador, to Loyola University for use in Greece; more will be available to others.

Complete detailed working drawings, specifications and manuals are available to archaeologists through the Whittlesey Foundation. Considerable precision metal working is required to make the Bipod, a number of special parts being involved.

The Foundation maintains a research and development precision shop at Wilton, Connecticut for construction of balloons, bipods and other systems for use in field archaeology. Interested visitors may participate there.

The Whittlesey Bipod Camera Support systems have been widely published as in the *Journal of Photogrammetric Engineering*, *Archaeology*, *Journal of Field Archaeology*, *Photography in Archaeological Research*, University of New Mexico Press.

Care of Bipod

Bipod is shipped in strong wooden case, designed to hold each component firmly. The most delicate part is the hinged pair of tubes for the apex of the Bipod. The camera levelling brackets are accurately positioned on these tubes. These must be protected against any distortion. The hinged pair of tubes is tied together at interlocking blocks so as to protect the brackets during handling of the tubes and while not in use. The tie should not be removed until the entire Bipod is laid out assembled on the ground ready in the field for lifting. The tie at the interlocking blocks should be restored when the Bipod is put away.

Talcum powder is the best lubricant for nesting the aluminum tubes in storage, and will relieve sticking except in salt air climates. The Bipod tubes should not be left in contact during prolonged storage in or near salt air climate. Such climate induces aluminum oxide corrosion.

Utilization

DESIGN and CAPACITY Part II-A and B should be consulted to achieve best utilization of the Bipod to secure the desired photo coverage. The Bipod is designed for cameras having the formats and focal length lenses shown below:

24 x 35 mm format with f 35 lens
$2\frac{1}{4}$ x $2\frac{1}{4}$ in. format with f 50 lens

The above lenses are moderate wide angle. Photo coverage figures and control dimensions for Bipod posture are directly related to these formats and focal lengths. They do not apply to other formats or focal lengths. Use only those formats and focal lengths for which the Bipod is designed.

Consult capacity tables to decide what Leg Lengths are required to suit coverage needs. There is no need extending legs to 30 feet if lesser extension will suffice. Consult tube assembly drawing for tube layout and pinning to achieve any of the scheduled extensions from 15 feet up to 30. While 32 feet is possible, do not use it under any circumstances, or the Bipod will be endangered as will any camera. Note the limitations in relation to type of camera. For Hasselblads do not extend beyond 25 ft. in the case of the heavy 500 EL model, otherwise not beyond 27.5 ft.

Erecting

Part III provides illustrated text for step by step field procedure. 60 ft. camera lift line of #4 solid braid polyester is provided. Tethering line is not provided. 120 feet of good quality strong mason's cord will be needed; also 4 wooden stakes about 2 ft. long. Mason's line level is provided. Pinning screws and wing nuts are provided. Two of the pins are long enough to serve as line cleats. Pulley is provided at the apex hinge.

OPERATION Part IV. The illustrated text gives step by step procedure. The camera lift platform of ¼ in. acrylic plastic is cut out to receive the type of camera mounted on it. The platform for 35 mm cameras is exactly 7½" x 8-5/16" with cut out to receive the camera.

The dimensions of the camera platform are directly related to the film format and focal length. These in turn govern the angle of leg spread. Therefore, the above platform size will not suit the Bipod's wider posture for 2¼ in. sq. film format with f 50 lens. In that case the platform will be 8-3/8 x 11-¼. It must be neatly cut to receive the particular camera with its c. of g. at center of platform.

Pneumatic shutter release system, such as "ROWI" should be used. This is not provided with the Bipod.

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BIPOD PHOTOGRAMMETRY

by

W. Kent Boyer

Photogrammetry can be defined as "the science and art of obtaining reliable measurements by means of photography" (Thompson 1966:1). Ground-based vertical photogrammetry involves the use of a platform that rests on the ground and allows photographs to be taken straight down at some target area. The bipod, developed by Julian Whittlesey, is the platform this paper is chiefly concerned with, but the principles of vertical photogrammetry are not altered by the nature of the platform.

A basic difference exists between this kind of photogrammetry and aerial photogrammetry, as normally practiced, which makes it difficult to apply many of the methods and techniques used in aerial photogrammetry. This difference is in the quality and sophistication of the equipment used in aerial photogrammetry compared with equipment that is likely to be used for bipod photogrammetry. This is not to say that the same equipment could not be applied to this kind of vertical photogrammetry. However, it is the purpose of this paper to show persons who do not have access to photogrammetric cameras, stereoplotters, and related equipment how they can make measurements from photographs using simple and inexpensive equipment. A further aim is to indicate how the accuracy of these measurements can be determined.

It is felt that this subject will be of interest to professionals in archeology because it offers a means whereby they can more completely and economically record certain properties of cultural resources.

Although the following treatment will deal primarily with measurements taken from stereopairs, the kind and quality of measurements that can be taken from single images will also be dealt with.

Principles of Vertical Photogrammetry

The basic principle that allows the measurements of distances on the ground to be made from a photographic image is that, within the limitations of equipment and human skills, the spatial relationships of points on the ground are derivable from the spatial relationships of the corresponding images on a stereopair.

The primary differences between spatial relationships on the ground and spatial relationships on some corresponding photographic image are differences in the magnitude of metric measurements that can be made of the respective relationships. These differences are known as differences of scale. Although, for convenience, a photograph is usually treated as though it has a single uniform scale, this is true only under certain ideal circumstances. As we shall see, reality departs from these ideal circumstances in important ways. If we wish to know how accurately the measurements we make from photographs reflect the corresponding measurements on the ground, we must be able to quantify the effect (called distortion) circumstances, which cause the scale to vary within a single photograph.

First I will describe the ideal circumstances under which a photograph has only one scale, and the parameters and geometric principles that determine the scale. The area we are photographing will be treated as a horizontal plane. This is called the object plane. The photographic medium is ideally another horizontal plane, parallel to the object plane. This is called the image plane. The lense is treated as an infinitesimally small node through which all light rays from the object plane pass in straight lines to the image plane. This node is called the perspective center. The distance from the object plane to the perspective center is called the object distance (d), and corresponds to the height of the camera above some ground datum. The distance from the image plane to the perspective center is called the image distance (d') and corresponds to the focal length of the lense (Fig. 60). Since the image plane is where the light rays from the lense form the sharpest image, the image distance is determined by the physical properties of the lense. By

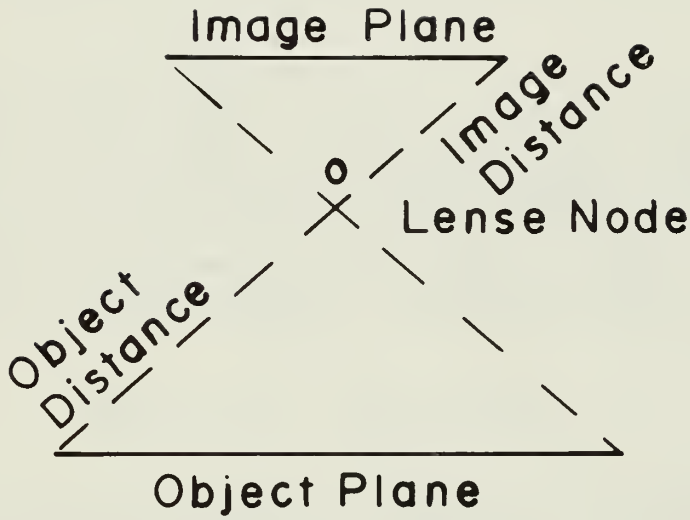

Figure 60- Geometry of a photograph.

similar triangles, the ratio of the image distance to the object distance is the same for all lines that pass through both planes and the lense. Because of the constant nature of this ratio (the importance of which we shall soon see), any image/object distance pair will allow us to determine the ratio. For convenience's sake, we use the height of the camera above the object as the object distance and the focal length as the image distance. The line that corresponds to these measurements passes through the perspective center and is perpendicular to both the image and object planes. This is called the lense axis.

Further reference to similar triangles allows us to prove that the ratio of the distance between any two of these object-node-image rays on the image plane to their corresponding separation on the object plane is the same ratio as the image/object distance ratio (Fig. 2). This convenient fact allows us to determine the distance between two points on the ground from their corresponding distance on the image and the image/object distance ratio:

$$\frac{a'b'}{ab} = \frac{d'}{d} \; ; \quad d = d' \frac{ab}{a'b'}$$

The image/object distance is therefore equal to the <u>scale</u> of the image. It is to be hoped that the above discussion will allow the reader to comprehend (and thereby intelligently use) the esoteric formula:

$$S = \frac{f}{H}$$

where S is the scale, f is the focal length, and H is the height of the camera.

A second basic optical formula: $1/d' - 1/d = 1/f$ informs us that we must be cautious in using the focal length (f) as the image distance (d'). Mathematically the equality $1/d' = 1/f$ only holds when $d = \infty$. Lim $[1/d' - 1/d] = 1/d'$.

The object distance beyond which the focal length can be used as the image distance is determined by the accuracy

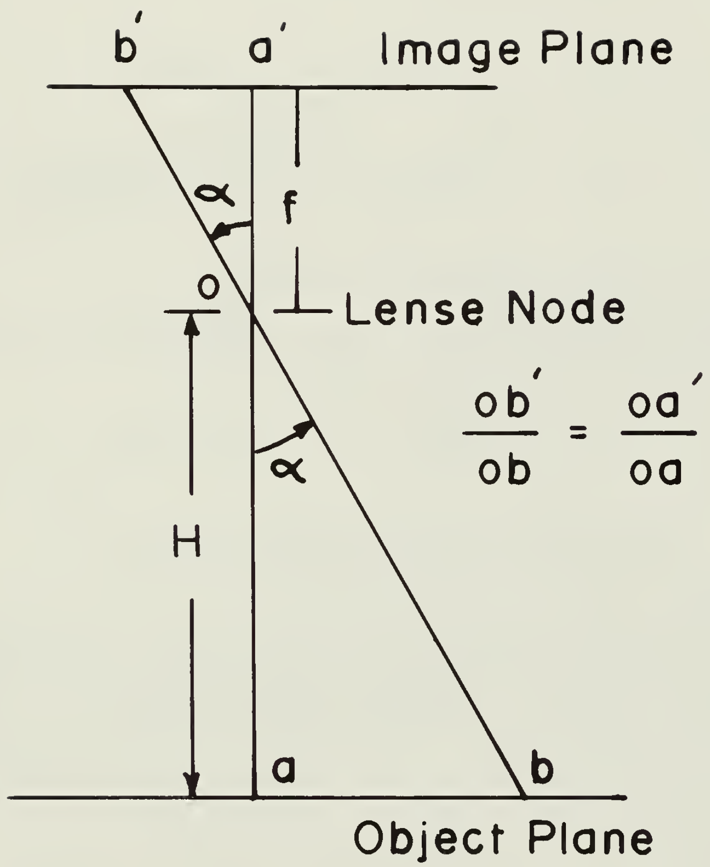

Figure 61 - Constancy of image distance-object distance ratio.

desired. If you desire 1% accuracy and your focal length is 50 mm., the object distance must exceed 5 m.

$$1/d' = 1/f + 1/d$$

$$d' = \frac{f \times d}{f + d}$$

$$d' = f + 1\% \times f \text{ (1\% error)}$$

$$d' = 50.5$$

$$50.5 = \frac{50 \times d}{50 + d}$$

$$d = 5050 \text{ mm.} = 5.05 \text{ m.}$$

At distances less than 5 m., the scale must be computed from a corrected image distance:

$$d' = \frac{f \times d}{f + d} \qquad S = \frac{d'}{H}$$

Sources of Image Displacement

Now that we have analyzed how to relate image measurements to ground distances under ideal circumstances, we can start accommodating our model to real circumstances. When a camera does not have a truly vertical orientation, it is said to have tilt. What this means, essentially, is that the lense axis is not normal (perpendicular) to the horizontal object plane. Consequently, the image plane is no longer parallel to the object plane, but lies at some angle, α , to the object plane (Fig. 62). Normally, α is composed of three angles perpendicular to one another (x, y, and z tilt). For purposes of explaining their displacement effect, however, we can treat them as a single angle. α is the camera tilt angle, and it has the effect of changing the magnitude of object distances relative to image distances (the ratio d'/d). Since scale is determined by the ratio d'/d, the scale of the distances on our image plane is no longer the same between all points. However, for every tilted photograph, there is an equivalent vertical photograph. This intersects the tilted photograph along the isometric parallel

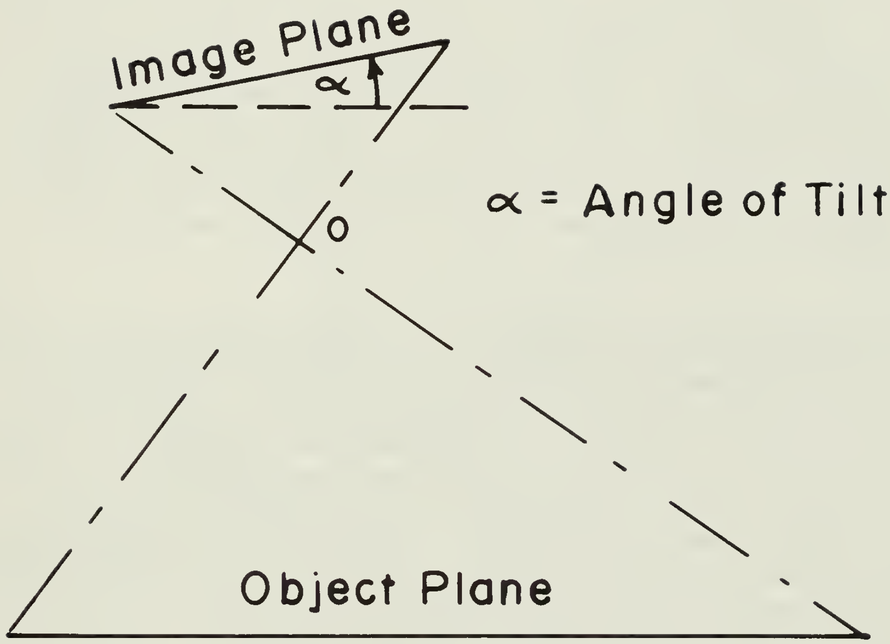

Figure 62 - Photographic tilt.

(Fig. 63). The isometric parallel bisects the line between the nadir point and the principal point and is perpendicular to it. The bisection point is the isocenter. Computation of tilt displacement requires locating the isocenter of the photograph, as it is the center of tilt distortion. This in turn depends on locating the nadir. This should be kept in mind when establishing control in the field. As the recommended means of dealing with tilt displacement is image rectification (which produces an equivalent vertical photograph), I will not go into the details of computing the displacement due to tilt. The interested reader can refer to Thompson (1966:25-27) or some other standard photogrammetry text. By providing compensation for camera tilt, we can insure that the rectified image is equivalent to a truly vertical photograph within a known margin of error.

Another aspect of reality we must deal with is that the area being photographed is a three-dimensional surface, not a two-dimensional plane. Since the scale of an image is inversely related to the object distance, objects that are closer to the camera will have a larger scale and objects farther from the camera will have a smaller scale. The resulting phenomena is known as terrain displacement (Fig. 64). This displacement occurs radially from the nadir. It is possible to determine the displacement due to differences in object distances (different elevations) of any point from its correct position on some horizontal reference plane. This displacement is found from the equation:

$$d = \frac{r \times h}{H}$$

where r is the radial distance from the principal point, H is the distance from the perspective center (lense) to a horizontal reference plane, and h is the vertical distance from the object to the reference plane. When measurements are being taken from a stereo-pair, h can be determined from parallax differences (see Thompson [1966: 23-24] for a simple method for measuring differences in elevation). H is arbitrary but usually corresponds to the vertical distance between the camera and some control datum. r can be measured directly from the photograph.

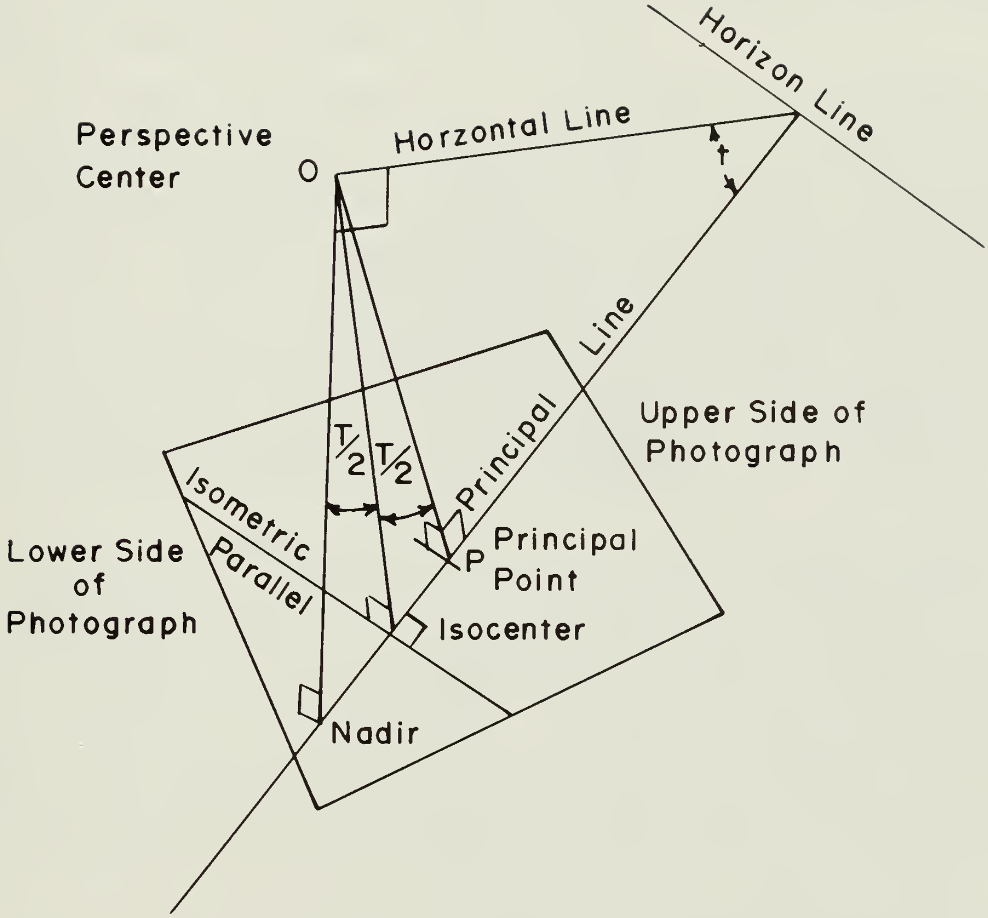

Figure 63 - Nomenclature for tilted photograph (adapted from Thompson, 1966).

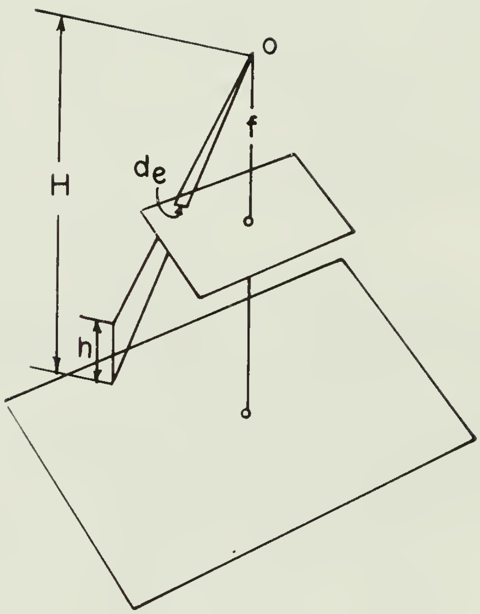

Figure 64 - Displacement of the photograph image due to the elevation of the object.

When the measurements are being taken from a single photograph, there is no way of measuring differences in elevation from the image. Consequently, the elevation of all data points must be measured in the field or else all data points must lie close enough to the horizontal reference plane that the resulting displacement is within some known margin of error. This is the severest limitation of photogrammetry based on single photographs.

The remaining assumption we must make to apply the principles of geometry to photogrammetry is that the recording medium lies in the image plane at all points. Photogrammetric cameras are specially equipped to ensure that this assumption is legitimate to a fairly high degree of accuracy. The workhorse of bipod photography, the Nikon F (or similar single lense reflex camera), has no such provisions. The magnitude of error due to the geometry of the film as it passes behind the lense is something that must be determined empirically. The resolution of the image will also affect the accuracy of measurements, but for reasonably good lenses and paper, this will be small relative to other sources of error.

There are other sources of image displacement the photogrammetrist should be aware of. One of these derives from the fact that the light from the object to its corresponding image is not a straight line passing through a node. Rather it goes through a lense, which changes the line's direction very slightly (Fig. 65). This change has two components, a radial and a tangential component. This same property holds for the lense of the enlarger. The amount of displacement should be known, at least within some margin of error, because it is a factor in locating control points for rectification of tilted photographs.

Once control points have been accurately located, the technique of radial line plotting corrects for the radial component of lense distortion. Tangential displacement is normally very small if the lense elements have not been displaced due to rough handling. The last source of image displacement comes from instabilities (shrinkage) in the film base and printing paper.

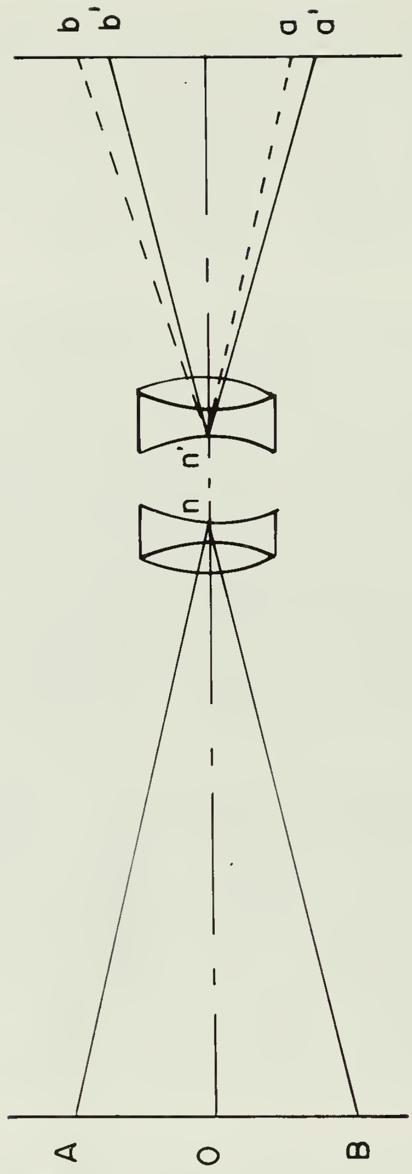

Figure 65 - Radial lense distortion.

Planning for Image Acquisition

The most important step in planning a strategy for vertical photogrammetric recording is to determine what degree of accuracy is meaningful and whether that degree of accuracy can feasibly be achieved within the constraints of budget and equipment. All too often, archeologists fail to ask the question: "In what sense will I improve my interpretation of archeological materials if I improve the accuracy of my measurements?" In the absence of a convincing answer to this question, the often considerable expense of a large improvement in accuracy is a dubious investment.

Once the allowable error has been determined, one has to plan a strategy for controlling the sources of error. It is important to note that in order to reliably assert that the maximum error in a measurement is within some stated limit, one must remember that the errors from independent sources have a cumulative effect. When deciding how much error to allow for from each source, we should consider the fact that some sources of error are cheaper (easier) to control for than others. We can borrow a concept from microeconomics to guide us in planning how we will control for error. This concept states that the most efficient allocation if inputs (error reducing measures) is achieved when the ratio of the value of the marginal product (the increase in accuracy) to the cost of the marginal product (cost of that increase in accuracy) is the same for all inputs (different error reduction techniques). This is not to suggest that one needs to engare in exacting cost/benefit analysis. It is simply intended as a conceptual guide to keep from losing perspective on the situation and overinvesting error reduction efforts in one source of error to the neglect of the others.

Once we have decided how much error we will allow from each source, we are ready to plan the actual steps involved in acquiring the imagery. The first step is to determine the area each image will cover. For stereopairs it is recommended that these areas overlap 55% in one direction and 30% in the perpendicular direction. For single shot coverage, a 10%-20% overlap in both directions should normally be adequate. If there are large elevation differences (approx. 3% of the camera height) from the datum plane in a single shot coverage, it may be desirable to reduce the image area to reduce the error from terrain displacement (this reduces the maximum value of r in the equation:

$$d = \frac{r \times h}{H} \quad).$$

At this stage of planning, it is useful to have a reasonably accurate scale drawing of the site perimeter. The camera stations should be marked off on this drawing in parallel transects so that the entire area is covered by a minimum number of images. If a bipod is to be the platform, the legs will rest on the lines that connect the camera stations (Fig.66). The leg stations should be coded to show their sequence, and their x and y coordinates with respect to some main site datum accurately scaled off and recorded in tabular form.

Example

Determine the camera stations and corresponding leg stations for a site that measures 20 x 30 m., using the 30 ft. bipod and a 24 x 35 mm. format camera.

The actual camera height will be 8.35 m. above the bipod base. The area covered in one frame will be 8.35 x 5.73 m. The short dimension is parallel to the legs. The flight lines will be parallel to the long dimension of the site and the bipod will be moved in this direction, with the legs making a line perpendicular to the direction of travel (Fig. 66).

The distance along the flight line between each camera station will be (8.35) x (1.00 - .55) = 3.8 m. This will require 30 ÷ 3.8 = 8 camera stations (always rounded up to next integer). If we want stereo coverage over the entire length, we need to overlap at each end, making 10 in all. The first station will lie 30/2 - 5 x 3.8 + 3.8/2 = -2.2 m. from the datum along the Y axis (Fig. 67). The 10th station will lie the same distance beyond the far perimeter of the site. The distance between flight lines will be 5.73 x (1.00 - .30) = 4 m. This will require 20 ÷ 4 = 5 inter-flight line intervals or six flight lines, with one

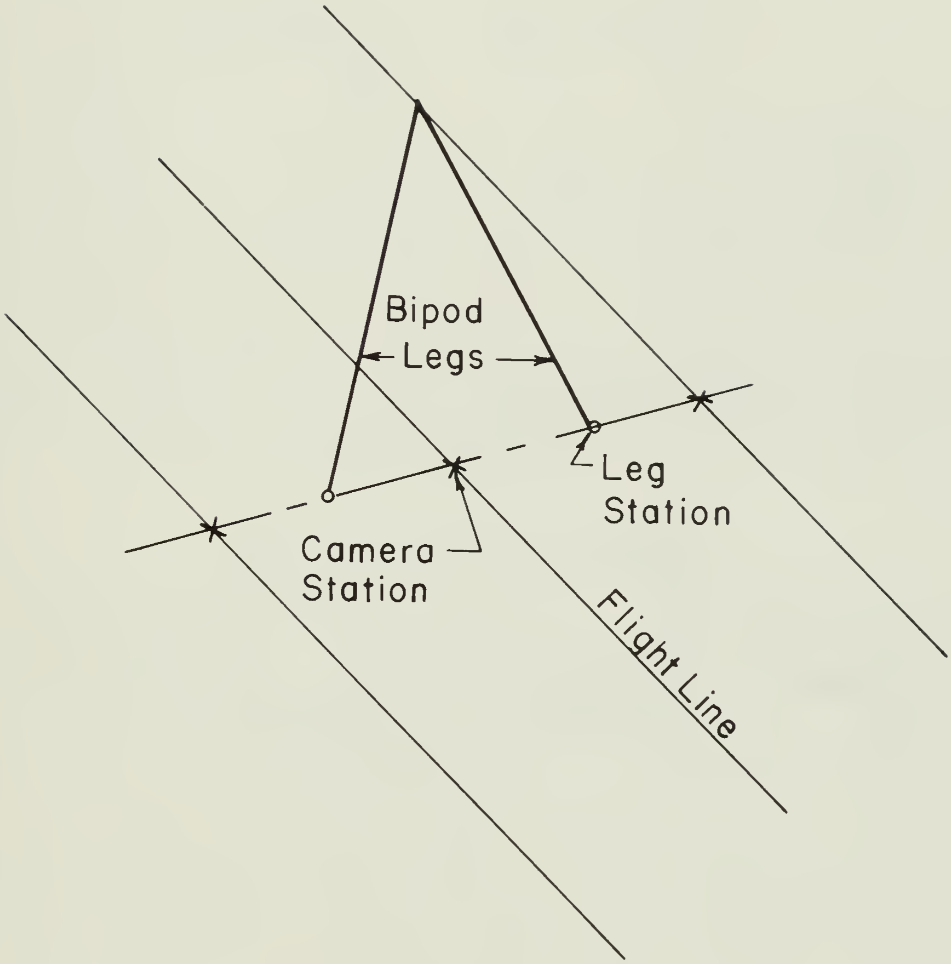

Figure 66 - Placement of bipod legs.

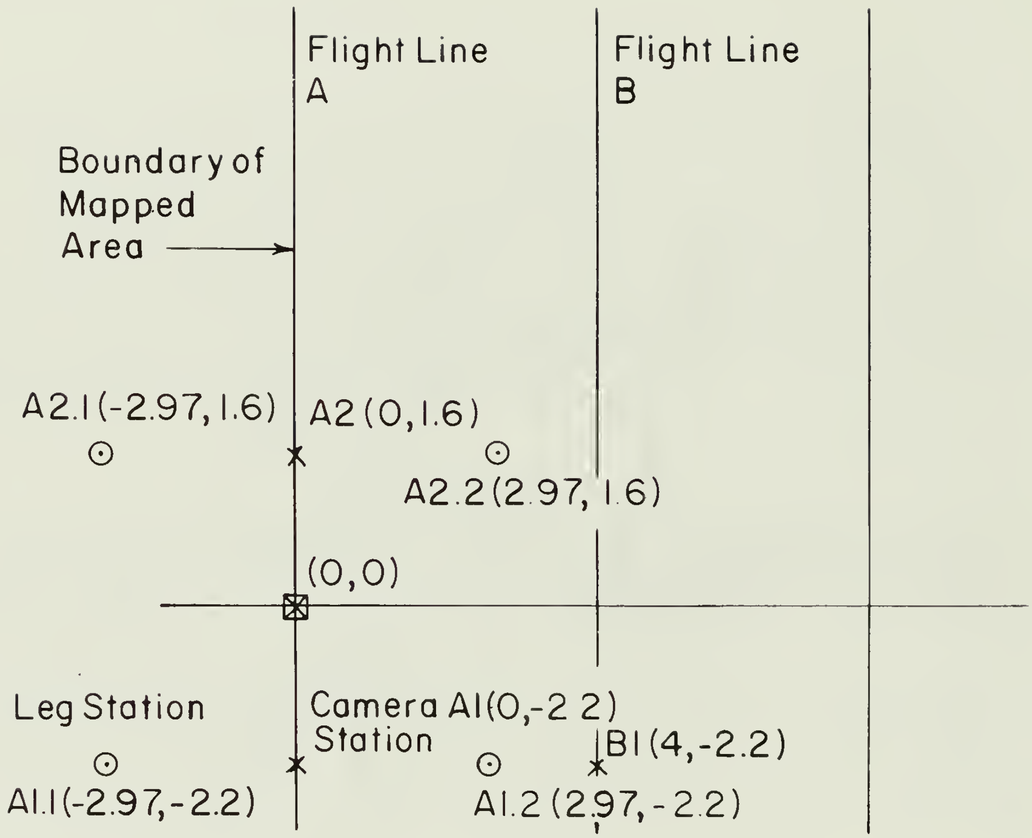

Figure 67 - Layout of leg and camera stations.

centered on each of the two long perimeters. The leg stations are a fixed distance apart (5.94 m.) and should be centered on the camera stations.

Let us suppose the datum we are going to use is in the southwest corner of the site. Camera station one will have an X (east) coordinate of 0 and a Y (north) coordinate of -2.2 m. (0, -2.2). This station will be A1 (flight line A, camera station 1). The corresponding leg stations will be A1.1 and A1.2. The coordinates of leg station A1.1 will be 0 - 5.94/2 = -2.97 (X coordinate), Y coordinate the same as the camera station (-2.2) or (-2.97, -2.2). Leg station A1.2 will be at (+2.97, -2.2). Stations A2.1 and A2.2 will have the same respective X coordinates but the Y coordinates will increase by the inter-camera station distance: (-2.97, +1.6) and (+2.97, +1.6) respectively. The remaining leg stations can be quickly computed in a similar manner. Once the pattern becomes familiar, the stations can be figured in the field with a hand calculator while they are being taped off.

Photogrammetric Controls

These are points for which locations in a three-dimensional reference system are found using standard field survey techniques. They serve as reference points that can be used in controlling for systematic sources of error, such as camera tilt and film instability. They can also serve as a check on camera elevation.

In order to rectify a photograph for tilt, it is necessary to have at least three control points whose X, Y, and Z coordinates are known. It is preferable to place them in the corners of the area to be imaged so they form a right triangle. As it is desirable that the photo images of the controls be sharp and in high contrast, a plywood or plastic panel, painted black on one side and white on the other is recommended. It is also useful for the camera station to be marked on the ground, as this is the nadir of the photo and can be of use in the process of tilt rectification. This point does not need to be measured in. It is found at the time of photographing by plumbing with the camera or plumb bob. The coordinates of the controls can be computed in the same manner as the leg stations.

Field Methods

The leg stations and photogrammetric controls should be located on the ground using standard field survey techniques. As the vagaries of terrain can make it difficult to erect the bipod at the appropriate leg stations, the operators must be equipped to provide an auxiliary leg stand that can be placed vertically over the leg station. Appreciable deviations from the base width specified for the bipod will interfere with its proper operation. Klausner (this volume) and Whittlesey (1976) both go into more detail on the actual operation of the bipod. I will restrict myself to mentioning that proper exposure of all areas to be mapped is important in ensuring adequate image resolution.

Laboratory Techniques

Rectification is a means for correcting the effects of tilt, and this is done when the film is printed. Image rectification in aerial photogrammetry uses sophisticated equipment and techniques which are not available to most archeologists. However, one can rectify an image by fairly simple procedures so that it will only have a small amount of residual tilt distortion. Thompson (1966:838-840) and Moffitt (1967:281-288) both give detailed instructions on rectification by empirical orientation. Basically, what it involves is tilting the easel and changing the magnification until the images of the control points lie over their correct positions on a template. The correct positions of the control points are determined analytically by considering the scale of print desired, the true horizontal separation of the control points and their image displacement due to terrain and lense distortion.

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TERRESTRIAL PHOTOGRAMMETRY OF CLIFF DWELLINGS IN THE CANYONS OF ARIZONA

by

Perry E. Borchers

In the summer of 1975 Chaco Center of the National Park Service contracted with Perry and Myra Borchers for terrestrial photogrammetry and survey controls en site and with The Ohio State University for photogrammetric plotting and drawing in the laboratory to record the two cliff dwellings of Mummy Cave in the Canyon del Muerto, Canyon de Chelly National Monument, and Keet Seel in Tsegi Canyon, Navajo National Monument. Both national monuments are within the Navajo Reservation in northeastern Arizona.

This was innovative use of photogrammetry. In sites less shielded from the air, archeological ruins in the American Southwest have been recorded by aerial photogrammetry. Terrestrial photogrammetry has not been used before in the recording and drawing of the cliff dwellings.

This report of the work is illustrated with some of the photography taken en site and with reproductions, at reduced scale, of the final drawings. It is intended to present, as concisely as possible, the advantages and limitations of photogrammetry and photogrammetric procedures to be followed under differing conditions.

Photogrammetric Equipment

Photogrammetry, the science of measuring by means of photography, is based on the geometry of central projection. Practical applications require: 1) detailed knowledge of the internal geometry of the cameras used or the ability to calculate this geometry, and 2) some combination of measurements of the camera's external orientation in space or in relation to a net of survey control measurements in the space recorded on the photographic image.

There is a wide range in the sophistication, degree of precision, and relative efficiency of the various photogrammetric instruments and procedures required in different situations and applications. Three photogrammetric instruments were used in recording and drawing Mummy Cave and Keet Seel.

The first, a Galileo-Santoni phototheodolite designed for architectural surveys, is in part a surveying instrument capable of turning angles between two tripods and the subject. A telescope attached to the phototheodolite on one tripod enables the photographer to plot a 90^{o} angle between the target on the second tripod and the subject. After the first photograph is taken, the phototheodolite and the target are shifted to the opposite tripods, a 90^{o} angle plotted, and a second photograph taken. Thus, in maintaining parallel photo axes, the phototheodolite produces the same results that photogrammetric stereocameras do, but uses only one camera. The theodolite is also capable of marking the camera horizon (the point at which the horizontal plane of the camera intersects the vertical plane of the survey control point) to permit establishment of the horizontal plane that will be required when the final drawing is plotted. Because the rigid camera mounted on the theodolite possesses a lens of adjustable focal length that can be increased or decreased by fixed increments, it is possible to focus from infinity to as close as 5.5 m. The focal length used is recorded on the photographic plate. The camera body contains fiducial markings that indicate the principal point of the image plane--also recorded on the photographic plates. Glass plates are used because of their dimensional stability. Photographs from this camera appear in Figures 68, 69, and 70.

A second camera, used in this project to take photographs within Mummy Cave and from the opposite side of the Canyon, is a Hasselblad Supreme Wide Angle camera, also calibrated, essentially distortion free, and equipped for accepting photographic glass plates. The stereopair in Fig. 71 was produced with this camera.

Figure 68 - Right photograph of photogrammetric stereopair of Mummy Cave from valley floor approximately 1000 feet forward of and 170 feet below Tower House. Taken with Galileo-Santoni phototheodolite, focal length 151.66 mm, 13 x 18 cm format. Base distance to left camera station 110.50 ft. Camera axis angled upwards 12°. Photograph by Borchers.

Figure 69 - Right photograph of photogrammetric stereopair within Keet Seel ruin. Taken with Galileo-Santoni phototheodolite, focal length elongated to 151.66 mm, 13 x 18 cm format. Base distance to left camera station 5.42 ft. Camera axis level. Left camera station is the basis for survey control horizon markings of tape. Photograph by Perry E. Borchers.

Figure 70 - Right photograph of photogrammetric stereopair of Keet Seel from valley floor approximately 650 ft. in front of cliff opening. Taken with Galileo-Santoni phototheodolite, focal length 151.66 mm, 13 x 18 cm format. Base distance to left camera station 57.21 ft. Camera axis angled upward 15°. Photograph by Perry E. Borchers.

Figure 71 - Film stereopair in western cove of Mummy Cave looking towards Tower House. Taken with Hasselblad Supreme Wide Angle Camera, focal length 38 mm, $2\frac{1}{4}$ x $2\frac{1}{4}$ in. format, no enlargement, approximately 24 in. base. Photograph by Myra Borchers.

The third instrument is Ohio State University's Wild A7 Autograph, in which the glass plate stereopairs taken at the sites were oriented and plotted. A first order universal plotting instrument of high precision, the Wild A7 Autograph is capable of accepting plates from many different cameras, has a wide range of plotting scales, and is adaptable to plotting either plans or vertical sections from aerial photography and either facades or plans from terrestrial photography. The re-creation of the site as an optical model within the A7 Autograph is the most impressive part of the entire photogrammetric process. Measuring marks in the two eyepieces are adjusted until they coincide. A further adjustment brings the two marks, now functioning as one, into contact with a point on the optical model contained in the stereopairs (i.e., the plane of the measuring mark within the plotter represents the plane of the point on the optical model). When the measuring mark is in "contact" with a surface, perspective distortion is eliminated from the orthographic projection of the surface traced by the pencil as it travels across the plotting table and duplicates the movements of the measuring mark. The plotter is provided with gears that can be adjusted to permit variations in scale of up to 24X. Digital readout of three coordinates (two horizontal, one vertical) in series can also be performed on the Wild A7 Autograph.

Photographic Coverage

In terrestrial photogrammetry the geometrical problem--which differs for every site--is to achieve an efficient photographic coverage, which also permits efficient photogrammetric plotting in the laboratory. The subject must be recorded on both photographs of overlapping stereopairs. The base between the successive camera stations must be sufficient to allow the photogrammetric technician good binocular judgement of depth perpendicular to the photographic image planes when the stereopair is oriented within a plotting instrument. At the same time, the loss of stereoscopic coverage in areas where the two photographs do not overlap must be minimized.

Because tall objects (whether plants, manmade structures, or natural features) are less likely to obscure large portions of the subject, photographs made from an angle nearly perpendicular to the image plane permit more precise detail in the drawings than do photographs taken at an oblique angle. Further, when irregularities of the ground prevent parallel-axis photography, the cost of terrestrial photogrammetry increases.

Photographic Position

Six general situations for photographing Mummy Cave and Keet Seel can be listed:

1. Terrestrial photography from the valley floor.

Photographic distances between 400 and 1000 ft.; base/distance ratios (camera to camera distance/camera to subject distance) from 1:9 to 1:12; camera axes inclined 12°-15° upward to record full stereopair height of the cliff faces. See Fig. 68, the right photograph of a stereopair of Mummy Cave, taken from the valley floor approximately 170 ft. below the base of the Tower House.

From this stereopair has been derived 90% of the detail appearing on Fig. 72, an elevation drawing of Mummy Cave prior to addition of the numerical contour designations. Terrestrial photography--from the valley floor, the opposite talus slope, or the opposite canyon rim--is the only practicable means of producing photographs that can be used for elevation drawings that combine cliffs, cliff dwellings, and talus slopes in a unified orthographic projection from which true width/height dimensions can be scaled and on which true depth dimensions can be expressed by contours representing equidistance vertical planes. In the optical model within the plotting instrument all pertinent detail can be plotted for incorporation in such elevation drawings. This includes geological data such as stains and fractures in the cliff faces, hand and footholds in the rock face, petroglyphs, painting on the cliff face that served as the back walls of now vanished rooms, beam-end bearing holes carved in the cliff, and all those stubs of walls--both at Mummy Cave and at Keet Seel--that suggest ancient structures rising from the cliff bottom to the level of the major building platforms under the cliff overhang.

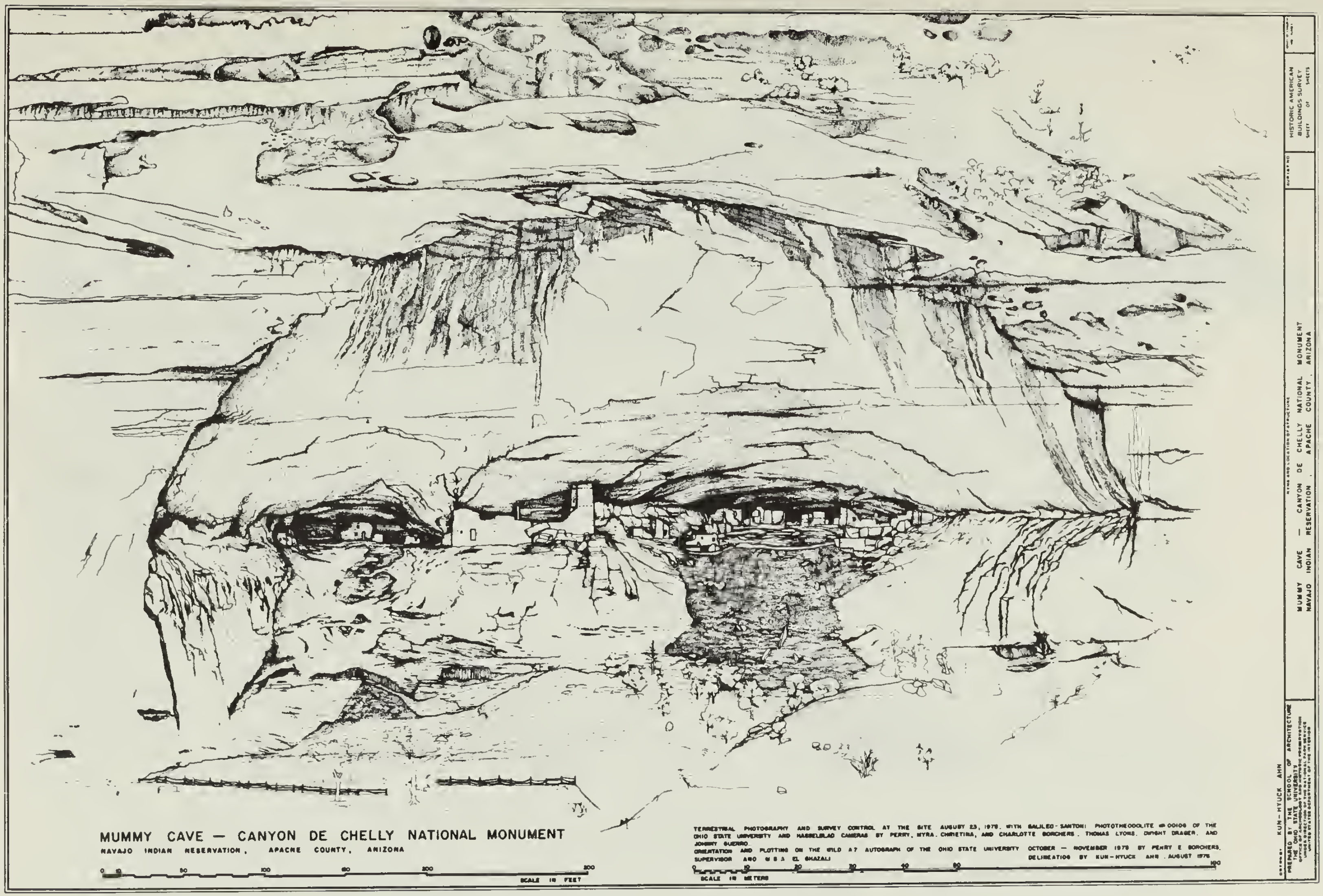

MUMMY CAVE — CANYON DE CHELLY NATIONAL MONUMENT
NAVAJO INDIAN RESERVATION, APACHE COUNTY, ARIZONA
SCALE IN FEET
SCALE IN METERS
DELINEATION BY KUN-HYUCK AHN . AUGUST 1978
HISTORIC AMERICAN BUILDINGS SURVEY
PREPARED BY THE SCHOOL OF ARCHITECTURE
THE OHIO STATE UNIVERSITY
KUN-HYUCK AHN

Figure 72

Photographic axes. The Wild A7 Autograph allows a laboratory correction of the common azimuth angle of a stereopair by somewhat more than 5^{o}. Accordingly, the axes of photography in the field must be within this 5^{o} latitude of the desired direction of the depth coordinate in the final plottings and drawings. The axis of photography selected at Mummy Cave was perpendicular to the imaginary arc connecting the outer extremities of the cave opening. At Keet Seel, however, where the opening was more irregular than at Mummy Cave, the axis of photography and that of the final elevation drawing was exactly from the southeast. This choice was somewhat arbitrary.

The alternative choice of a south-to-north axis of photography and plotting would facilitate studies of the orientation of the cliff dwellings to the penetration of sunlight. With a change of axis there is a change in the horizontal distribution of elements in the elevation drawings and a change in the whole pattern of vertical contours, since the optical model in the A7 Autograph appears in a different position for orthographic projection and for cutting by vertical contours.

Plotting scale. A change of gears in the Wild A7 Autograph allows a twenty-four-fold range in plotting scales. Through the selection of a smaller plotting scale the elevation drawings can be extended upward to the canyon rim. Alternatively, at a scale three times larger than that used in Fig. 72 the elevation drawing in Fig. 73 is concentrated on the Tower House. Intermediate contours are added, and broken-line on the underside of the cliff face shows how high the ruined walls could have risen before they reached the overhang. It should be noted in the photographs (Figs. 74, 75) that a whitish area of stain, paint or plaster on the cliff face, surprisingly higher than the present Tower House, lies within the area projected upward from the Tower House walls below.

Approximately 65% of the detail on the plan drawing of Mummy Cave in Fig. 76 was derived from photographs taken from the valley floor. This photography is particularly effective in determining the maximum overhang of the cliff face and the horizontal location of elements on the steep rock and talus slopes where accurate hand measurement would

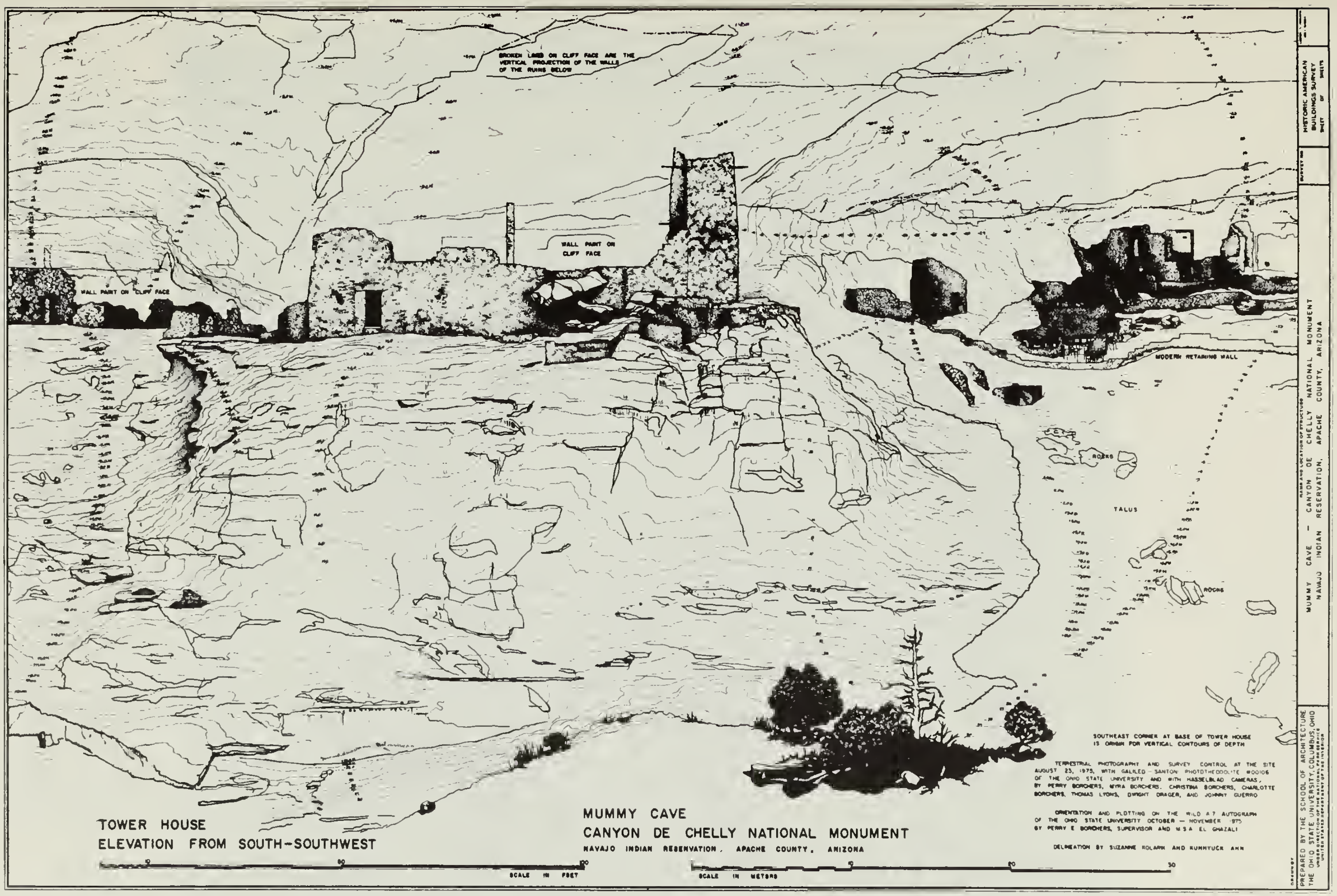

BROKEN LINES ON CLIFF FACE ARE THE VERTICAL PROJECTION OF THE WALLS OF THE RUINS BELOW
WALL PAINT ON CLIFF FACE
WALL PAINT ON CLIFF FACE
MODERN RETAINING WALL
ROCKS
TALUS
ROCKS
SOUTHEAST CORNER AT BASE OF TOWER HOUSE IS ORIGIN FOR VERTICAL CONTOURS OF DEPTH
TERRESTRIAL PHOTOGRAPHY AND SURVEY CONTROL AT THE SITE AUGUST 23, 1975, WITH GALILEO - SANTONI PHOTOTHEODOLITE #00106 OF THE OHIO STATE UNIVERSITY AND WITH HASSELBLAD CAMERAS, BY PERRY BORCHERS, MYRA BORCHERS, CHRISTINA BORCHERS, CHARLOTTE BORCHERS, THOMAS LYONS, DWIGHT DRAGER, AND JOHNNY GUERRO
ORIENTATION AND PLOTTING ON THE WILD A 7 AUTOGRAPH OF THE OHIO STATE UNIVERSITY OCTOBER — NOVEMBER 1975 BY PERRY E BORCHERS, SUPERVISOR AND M S A EL GHAZALI
DELINEATION BY SUZANNE ROLARK AND KUMMYUCK AHN
TOWER HOUSE
ELEVATION FROM SOUTH-SOUTHWEST
MUMMY CAVE
CANYON DE CHELLY NATIONAL MONUMENT
NAVAJO INDIAN RESERVATION, APACHE COUNTY, ARIZONA
SCALE IN FEET
SCALE IN METERS
MUMMY CAVE — CANYON DE CHELLY NATIONAL MONUMENT
NAVAJO INDIAN RESERVATION, APACHE COUNTY, ARIZONA
HISTORIC AMERICAN BUILDINGS SURVEY
PREPARED BY THE SCHOOL OF ARCHITECTURE
THE OHIO STATE UNIVERSITY, COLUMBUS, OHIO

Figure 73

Figure 74 - Mummy Cave as photographed from opposite talus slope of the Canyon del Muerto, at nearly the level of the Tower House, distance approximately 1650 ft. Taken with Hasselblad 500 C, 150 mm lens, with 2X enlargement of 2¼ x 2¼ in. format. Note whitish area in cliff face above the Tower House. Photograph by Myra Borchers.

Figure 75 - Photograph down from Mummy Cave overlook on opposite canyon rim of the Canyon del Muerto. Enlargement from Hasselblad 500 C, 150 mm lens, $2\frac{1}{4}$ x $2\frac{1}{4}$ in. format. Distance approximately 2000 ft. from Tower House. Photograph by Myra Borchers.

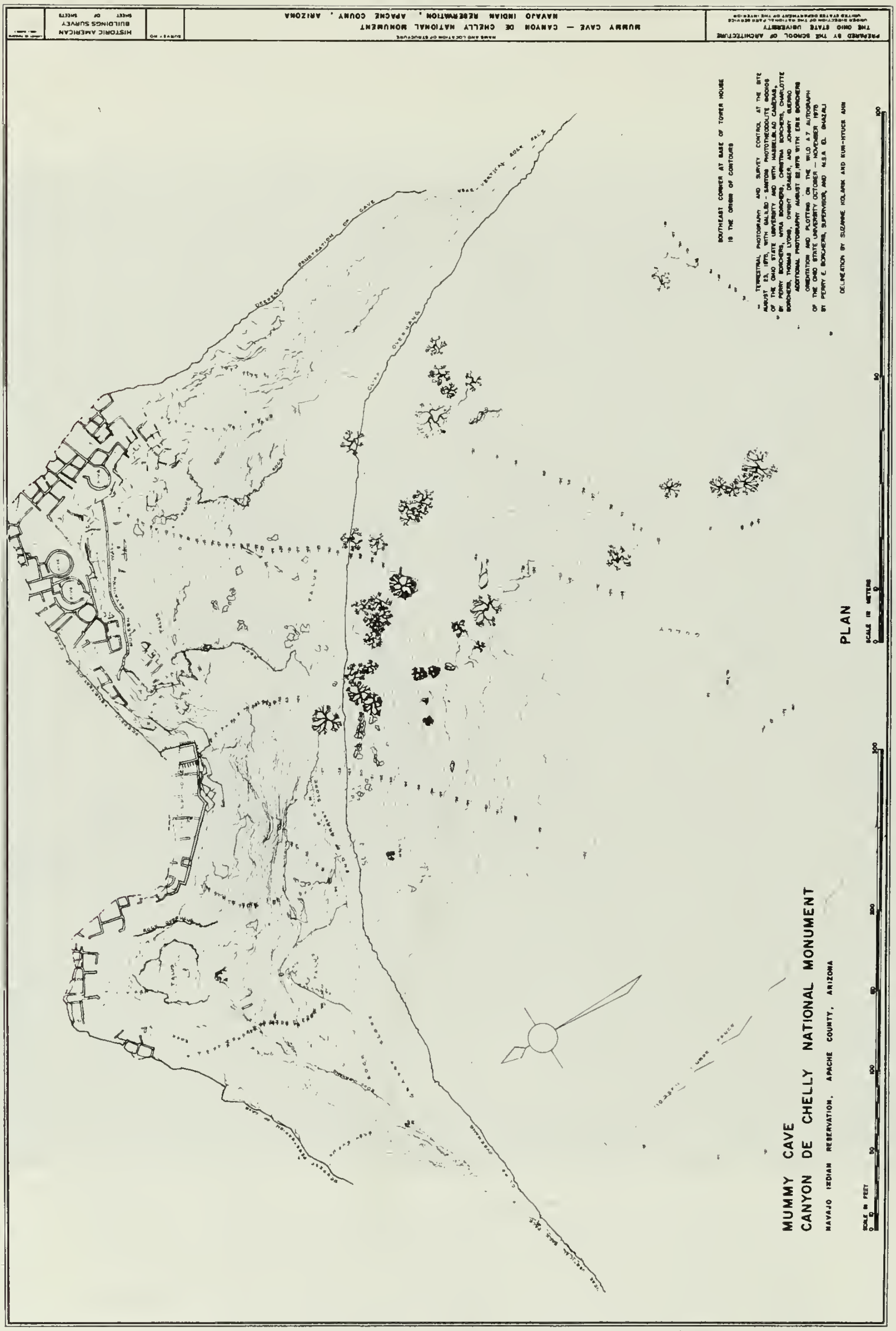

MUMMY CAVE
CANYON DE CHELLY NATIONAL MONUMENT
NAVAJO INDIAN RESERVATION, APACHE COUNTY, ARIZONA
PLAN
HISTORIC AMERICAN BUILDINGS SURVEY

Figure 76

be most difficult. The photograph fails in coverage where the near-horizontal main building platforms bend back our view, where stubs of walls are barely visible in the talus, and where standing walls conceal the depth of cliff opening behind them. It is in these areas, of course, that supplementary hand measurement could be carried out easily and accurately.

2. <u>Terrestrial photography from the opposite talus slope</u>

Some of the missing detail noted in the last paragraph was supplied by a strenuous climb up the opposite talus slope of the Canyon del Muerto which gained a position for photography at nearly the same level as the buildings deep in the two coves of Mummy Cave. Fig. 74 is an example of this photography. The scale of photography in the original $2\frac{1}{4}$ x $2\frac{1}{4}$ in. format is approximately the scale of low level aerial photography at this distance of nearly 1700 ft. Additional contours on the slopes leading up to Mummy Cave could be plotted from these photographs, since the slopes were no longer obscured by trees as they had been in the valley floor photographs.

3. <u>Terrestrial photography from the opposite canyon rim</u>

On returning to Canyon de Chelly in August 1976, we travelled the newly completed north rim road to the Mummy Cave overlook, where the enlarged photograph in Fig. 75 was taken. It is evident that terrestrial photographs made from the canyon rim could have been used effectively, the plotters' skills or orientation and adjustment in the universal first order Wild A7 Autograph being relied on to compensate for the highly unusual tilts and convergences of the photographic stereopairs necessitated by the twin requirements of coverage and safe positions for the phototheodolite and the operator on the canyon rim. If the necessary choice of camera stations and axes of photography are so far from ideal that the Wild A7 Autograph cannot reconcile them into effective stereophotogrammetry, it is still possible to resort to digital reading of points in separate photogrammetric images and to calculate the intersection of lines of sight by means of analytical photogrammetry.

4. <u>Terrestrial photography within the cliff dwellings</u>

In the recording of Keet Seel the first stereopair was taken from within the cliff dwelling itself from the northeastern end of the shelf, which is the main platform for the buildings. Fig. 69 is the right photograph of this stereopair.

The phototheodolite was used to establish survey control markings in a horizontal plane both for this stereopair and for later stereopairs taken from the valley floor. These are the prominent crosses that can be seen marked with tape on posts and walls in Fig. 69.

Terrestrial photography within the cliff dwellings is generally hampered by relatively short bases between pairs of camera positions and by foreground impediments that limit stereoscopic coverage. The third disadvantage--the large numbers of stereopairs required to piece together a major plan or elevation drawing--results from the first two difficulties.

However, such photography is efficient when the object is to make very large and detailed drawings of wall segments or to cut sections through both the cliff and cliff dwellings. Such drawings can express the character of the space under the cliff overhang and convey a sense of human involvement with that space in a way that the elevation drawings made from the perspective of the canyon floor cannot.

Fig. 70 is similar to Fig. 68 in being the right photograph of a stereopair from the valley floor in front of Keet Seel. The camera is inclined 15° upward to record the entire cliff face.

Approximately 85% of the detail in Fig. 77, an elevation drawing of Keet Seel, is derived from this stereopair. The remaining detail--as well as the detail of the deeper cliff dwellings in the plan drawing of Fig. 72 --comes from two unusual and difficult positions on the talus slope about 400 ft. forward and to the left of the cliff dwelling. The 27.5 ft. base between the camera positions was inclined approximately 33° on this slope, which made it a lengthly process to orient this stereopair within the A7 Autograph.


THE CLIFF DWELLING OF KEET SEEL
TSEGI CANYON, NAVAJO NATIONAL MONUMENT
NAVAJO INDIAN RESERVATION, NAVAJO COUNTY, ARIZONA
ELEVATION FROM SOUTHEAST
SCALE IN FEET
SCALE IN METERS
HISTORIC AMERICAN BUILDINGS SURVEY
THE CLIFF DWELLING OF KEET SEEL — TSEGI CANYON, NAVAJO NATIONAL MONUMENT
NAVAJO INDIAN RESERVATION, NAVAJO COUNTY, ARIZONA

Figure 77

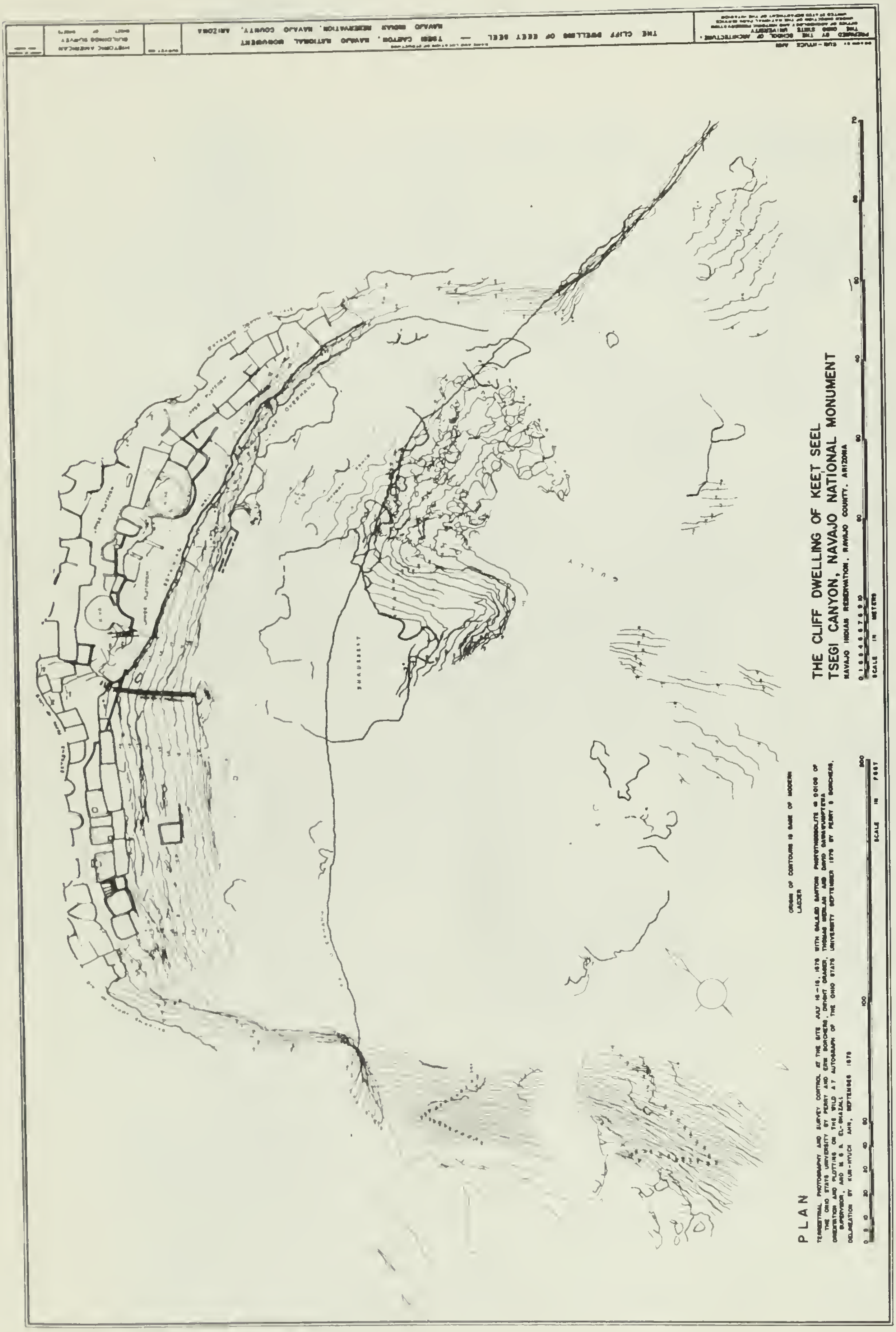

PLAN
THE CLIFF DWELLING OF KEET SEEL
TSEGI CANYON, NAVAJO NATIONAL MONUMENT
NAVAJO INDIAN RESERVATION, NAVAJO COUNTY, ARIZONA
SCALE IN METERS
SCALE IN FEET

Figure 78

A sand hill covered with small trees and shrubbery obscures the view of the immediate approaches to Keet Seel. This hill, and the concealed slopes in the arroyo draining away from the cliff, are responsible for the large blank areas in the plan drawing. An alternate site for photography, the talus slope on the opposite wall of the canyon, is distant and is not high enough above the sand hill. A position on the opposite canyon rim is more distant and extremely difficult of access. In this case the most efficient way to complete the plan drawing of Keet Seel would be from aerial photography--ideally when winter has stripped the foliage from the trees and shrubbery.

5. Aerial photography

Aerial photography has not been a part of the recording of Mummy Cave and Keet Seel, but it should be discussed.

Vertical aerial photography--terrain permitting--could be accomplished from a height 1500 ft. above the valley floor and from 500 to 1000 ft. above the canyon rim, on a flight line approximately 800 ft. forward of the cliff face. With the typical wide-angle aerial camera, the aerial view would penetrate about 30° under the cliff overhang. This is usually not enough to record the deepest areas of the cliff dwelling, nor does it match the penetration of view from the opposite canyon rim. In this case, however, detail gained would be substantial. The flight line should pass over some known benchmark, to permit a strip of aerial frames to connect the elevations and contours in the drawings to a global system of mapping rather than to such arbitrary origins as the southeast corner at the base of the Tower House or the base of the ladder leading up to Keet Seel.

Aerial photogrammetry requires ground survey control. There is sufficient plotting of ground forms and contours at Keet Seel from terrestrial photogrammetry to provide ground survey control for future aerial photography.

In future projects ground survey control targets could be set out at the time of terrestrial photography. Ground and aerial photography could then be coordinated and could proceed at the same time.

6. Film stereopairs

Fig. 71 is an example of a film stereopair taken within the western cove of Mummy Cave. It was taken with a fairly lightweight camera, the Hasselblad Supreme Wide Angle Camera of 2¼ x 2¼ in. format. Two tripods are used to permit the horizontal displacement necessary to produce stereopairs that effectively record additional detail within the net of major dimensions established by previous photography. On 5 x 7 in. mounts for viewing with a pocket stereoscope, film stereopairs can be used to give archeologists and craftsmen a three-dimensional view of the original form of structural elements that may have been dismantled for stabilization and reconstruction. Film stereopairs should also be substituted for the traditional single documentary photograph showing artifacts in site.

Hand Measurements

Photogrammetry does not eliminate the hand measurements used in traditional archeological recording. For example, in small dark rooms abutting the rear cliff face, handmeasurement is the only efficient means of recording interiors. When the inner surfaces of walls are not visible in the photographs, the thickness of the walls must be determined by hand measurement. Photogrammetry can be used to provide a net of measurements over highly irregular sites; hand measurements must sometimes fill out detail.

Some calculations of photogrammetric accuracy were carried out for the plotting of Keet Seel. For photography from approximately 650 ft. in front of the cliff opening with a stereoscopic base of 57.21 ft., the residual discrepancies in the locations of 10 control points within the cliff dwelling averaged ± 3 in. or ± 1/64 in. at the scale of 1:200 in the drawings. This is approximately the width of an inked line. Measurement of points that were not targeted would have somewhat greater error, influenced by the lean of walls and by partially fallen corners, which confuse the choice of surface for measurement and drawing. For large scale drawings, which would require a greater accuracy than drawing at 1:200, photography at closer range would be necessary.

Compared with systems of hand measurement, photogrammetry has a special advantage in accuracy. The advantage lies in the elimination of major blunders--misreading, incorrect recording, or incorrect transcription of major dimensions.

An example of a blunder in measurement occurs in a handsome architectural plan of the pueblo of Walpi, measured and drawn in the 1880's, in which one house cluster is displaced from the position it obviously occupies today to an unsupported position in empty space beyond the limits of the top of First Mesa.

Part of the orientation procedure in the photogrammetric plotting instrument is leveling and scaling the optical model at the survey control points on the basis of hand-measured dimensions between these points. When--as in the case of Keet Seel--one recorded dimension of 87.14 ft. is out of scale with all the other dimensions, but would be in good agreement if the dimension were 78.14 ft., we have a clear example of a blunder isolated and corrected. The errors in photogrammetry are not sudden or large. If systematic error is properly eliminated by the orientation procedure in the plotting instrument, there remains only residual error caused by small irregularities in photographic lenses, small variations from flatness of photographic plates and emulsions, and occasional differences of lighting and stereoscopic focus in the optical model. A standard error can be computed with a normal statistical distribution.

Photo Interpretation

There is greater chance for error in the interpretation of the photographs than in photogrammetric measurement. For example, the operator of the plotting instrument may not recognize--and, therefore, neither measure nor draw--what a specialist in the field would identify as significant detail. An architect would recognize the possibility that the original Tower House structure was a stunning altar-like building--if the whitish area on the cliff above it is actually paint or plaster--but he or she would not recognize geological detail in the rock face that might have equal geological significance.

Finally, there is the problem of selecting the type of delineation to use in the finished drawings after they are traced over the plottings from the Wild A7 Autograph. The delineation seen in Fig. 5 is preferred to that in Fig. 73. The cliff dwellings are generally smoother, less textured and lighter in tone than the surrounding rock and talus. Rock forms are more significant than bushes and trees.

Time on Site

For those not experienced in terrestrial photogrammetry, a breakdown of tasks and time on site would be of little value in estimating the costs of recording additional cliff dwellings. There are great differences in site conditions in the canyons. However, it can be noted that required time on site is relatively short.

Mummy Cave was reached by four wheel drive with the noteworthy Navajo driver and guide Johnny Guerro. A team of six spent four hours on the site on the first occasion; four worked for six hours on the site on a second trip.

The theodolite, camera, and loaded plateholders of the Galileo-Santoni phototheodolite were divided among three back packs for the hike to Keet Seel. The tripods traveled by Navajo horse pack. Working time spent on the site was about eight hours each for four persons, nearly the same as the walking time in each direction.

There had been a reconnaissance of both Mummy Cave and Keet Seel before the working trips. Much longer times were spent at the Wild A7 Autograph and the drafting tables at The Ohio State University than were spent on site.

If it is difficult to estimate comparative costs of terrestrial photogrammetry and other means of measurement in varying situations, it should not be difficult to recognize the usefulness of those drawings, including 1) contoured elevations of cliff dwellings, talus and entire cliff faces, and 2) contoured sections, perpendicular to the contoured elevations, through cliff dwellings, talus and cliff overhang, which are simply not attainable except by use of terrestrial photogrammetry.

Recommendations

Future photogrammetric recordings of the cliff dwellings should be more complete. They must be preceded by reconnaissance of the site and by careful planning of the work. Photographs should be tied into established benchmarks of known elevation and latitude and longitude and to true north lines. The work should include:

1. Terrestrial photography within the cliff dwelling with survey control established in the cliff dwelling.

2. Terrestrial photography from the valley floor with survey control established on the valley floor and targeted for either:
   (a) Aerial photography,
   (b) Terrestrial photography from the opposite talus slope, or--
   (c) Terrestrial photography from the opposite canyon rim.

3. Extensive film stereopairs within the cliff dwelling.

4. Hand measurement of rooms deep in the recesses of the cliff.

5. Terrestrial photography directed from the cliff dwelling outward, recording visual control over bottom lands and seeking elements in the outer landscape that might have served the inhabitants to mark the passage of the seasons and, in particular, the occurrence of the solstices.

Drawings should include:

1. Plan of cliff dwelling, at level of deepest penetration of the cliff overhang.

2. Elevation drawing, perpendicular to the arc between the extremities of the cliff overhang.

3. Elevation drawing, looking directly north.

4. Section through cliff dwellings and cliff overhang, perpendicular to the elevation drawing in (2).

5. Pertinent elements of the surrounding topography in topographic plan.

Possible additional studies include photogrammetric analyses of historic photographs--particularly those for which original glass plate negatives survive--for preparation of restoration drawings or for measurement of deterioration during a known period of time.

Additional terrestrial photogrammetry could follow any archeological clearing of talus slopes to determine--by the resulting differences in contours--the volume of structural material that could have been present on the slopes.

COST-EFFECTIVE MAPPING

by

Arthur K. Ireland

Introduction

One of the problems facing most archeologists today, once an archeological site has been discovered, is that of mapping it. Among the prime considerations of site mapping, particularly if the site is of considerable size or if there is more than one site to be mapped in the area, is the cost. A good, accurate map is necessary if the site is to be nominated to the National Register of Historic Places but the costs of such maps may be prohibitive at many sites.

This paper will detail the various common methods and costs of site mapping and then will outline an additional, cost-effective means of mapping a site.

Mapping Techniques

One of the most common methods of mapping an archeological site is that of the plane table and alidade. This method produces a relatively accurate map of a site but requires considerable time. Jorde and Bertram (1976:47) point out that even though the final drafting time of the map is reduced and the potential for interpretive sketching is present when the plane table and alidade are used, the map accuracy is limited, the utilization of the mapping procedure is subject to the weather, and points on the map must be digitized by hand.

Also common is the use of transits. This method has advantages over the plane table and alidade. The transit is more portable and can be used in most weather conditions. The data recorded can be digitized and fed into a computer for computer mapping, a procedure that drastically reduces the major disadvantage of transit mapping--the final drafting time. The use of theodolites or EDMs (Electronic Distance Measurements) can produce the same maps, and even more quickly than transits, but suffer the same drawback, i.e. final drafting time.

A third but less common method is photogrammetric mapping. In this technique, stereoscopic photographic coverage of the site must be obtained. This can be either oblique or vertical aerial photography obtained from any number of different aerial platforms such as ladders, bipods or tripods, balloons, or, most commonly, aircraft. Partially limited by weather, this problem is no more serious than in the case of the plane table and alidade. The accuracy of the mapping is generally better than that of the other methods and automatic digitization is possible.

Jorde and Bertram (1976) compared the costs of mapping a site using traditional ground mapping techniques (i.e. plane table and alidade or transit) versus photogrammetric mapping (using aerial photography acquired by an overflight of the same sites). They found that, especially for larger sites or multiple sites, the costs of ground mapping--either plane table and alidade or transit--far exceeded the cost of mapping the site or sites photogrammetrically; further, the maps resulting from the ground mapping techniques may not have been as accurate as the photogrammetric maps. Additionally, only one map (or map type) could be generated from the ground mapping techniques, but any number might be generated from the photographs since the data base is still available. Finally, aerial photographs themselves provide a record of all the observable details of the site and might provide future archeologists, armed with better interpretive techniques, new information.

Estimates of the costs of mapping sites based on present-day (1979) figures are shown in Tables 12 and 13. The costs of mapping a site using ground mapping techniques range from $3639 to $8231 for an "average" site. The "average" site here is considered to be a 175-room pueblo (the reasoning for this figure is discussed below). Based on Jorde and Bertram's (1976:48) figure of 1250 points mapped at Kin Bineola, the average number of points per room is taken to be 25, or 4375 points for a 175-room pueblo.

Per diem was estimated at $20 a day. Salaries were increased by 20% from the figures used by Jorde and Bertram (1976:54) to $6.00 per hour for the crew chief and $3.60 per hour for each of two crew members, or $106 per crew-day. Vehicle rental rates are based on current Albuquerque rates for a four-wheel drive Ford Bronco. The best rate, i.e. daily, weekly, monthly, etc., was used. Mileage costs were calculated only for the total number of sites to be mapped (125 sites, as will be explained below). Equipment rental rates were based upon the current rate schedule for the University of New Mexico's Civil Engineering Department, except for the EDM rental, which was based on figures received from a private rental firm. Mapping rates are based on current drafting rates.

The paneling and ground control of a site can be done in several different ways. First, and most expensive, is that a crew may be sent out by the photogrammetric engineering firm with whom the aerial photography acquisition and mapping was contracted. They will then lay out control panels and survey them in, tying them to existing U.S. Geological Survey bench marks, state grid systems, or other controls. A second option, similar to the first but somewhat cheaper, is for the photogrammetric engineering firm to send out their crew, not to tie the ground control to another known control point, but rather to set up an arbitrary control datum. The third, and cheapest, alternative is for the contracting archeologist to send out his own crew to set ground control panels and to survey them in. Based on the current rates in Albuquerque, the first option could cost $300 per control point, the second around $150 per control point, and the third about $100 for the entire site (usually about 4 or 5 control points). The costs, of course, could vary, depending on the number of points to be surveyed in, the location of the site, and the terrain at the site.

Flight costs, photography fees, and lab fees are based on a mission in which more than one site was flown. Jorde and Bertram (1976:45) point out that when large areas are flown, the costs go down. Also, if more than one target can be flown on the same mission, the costs will decrease. Naturally, if there is a great deal of urgency, the archeologist may have to foot the entire bill himself, but if the time element is not critical, thus allowing the contractor to wait for additional clients and schedule all targets for the same flight, the savings can be considerable.

The mapping costs are the most expensive part of photogrammetric mapping. The estimates here are based on several recent contracts performed for the Division of Remote Sensing, Southwest Cultural Resources Center, National Park Service, Department of the Interior.

A point to be noted is that two factors, bad weather and inflation, can cause costs to rise dramatically. They are more likely to affect the traditional methods than the photogrammetric methods.

The San Juan Basin Sites

The problem of mapping sites and the costs inherent therein have recently been pointed up in the San Juan Basin of northwestern New Mexico. Archeological research in this area has revealed the existence of a large number of Anasazi ruins, some of which are associated with a prehistoric road system that tied them to the centers at Chaco Canyon, now a National Monument. At present, some 75 sites have been recorded and it is suspected that the total number of such sites will approach 125 medium to large pueblo sites, of 25-300 rooms each (Drager 1976:3). It is imperative that all or most be nominated to the National Register of Historic Places, in order that they receive at least the minimal protection the nomination would confer on a site.

However, part of the nomination request must be a map of the site. To map all the Chacoan Outliers/San Juan Basin Communities would require over 14 years of non-stop work at a cost of $1,030,000 if a plane table and alidade were used. Use of a transit would still require over 10 years and would cost $724,000. Slightly less than eight years and over $653,000 would be needed if a theodolite were used and a little less than five years and over $456,000 would be needed if an EDM were used. Depending upon the options chosen, photogrammetric topographic mapping would cost between $88,000 and $226,000 and would take slightly over one year (Table 1).

Photo-Interpretive Mapping

There is yet another mapping alternative--photo-interpretive mapping. This is a type of mapping from aerial photographs that lacks the tight control of photogrammetric topographic mapping. The mapper works with a stereoscopic model which, unlike the model used in photogrammetric topographic mapping, has not been rectified or corrected for any tilt or distortion present in the photographs. Thus, some distortion is introduced into the map but, generally, the distortion will be minimal. The accuracy that can be achieved by this type of mapping may be as good as some of the ground mapping techniques, regardless of the distortions. The main disadvantage is that the map produced by this method is a map in plan, not a topographic map. However, topographic or physiographic features such as mesa top edges or arroyos or roads can be mapped fairly accurately. See Figs. 79 and 80 for examples of photo-interpretive mapping.

There are two options available in this type of mapping (Table 12). Crews can be sent to set ground control panels and survey them in, but for this type of mapping it is not necessary. The major difference is that the map resulting from the controlled option can be drawn to a more reasonably

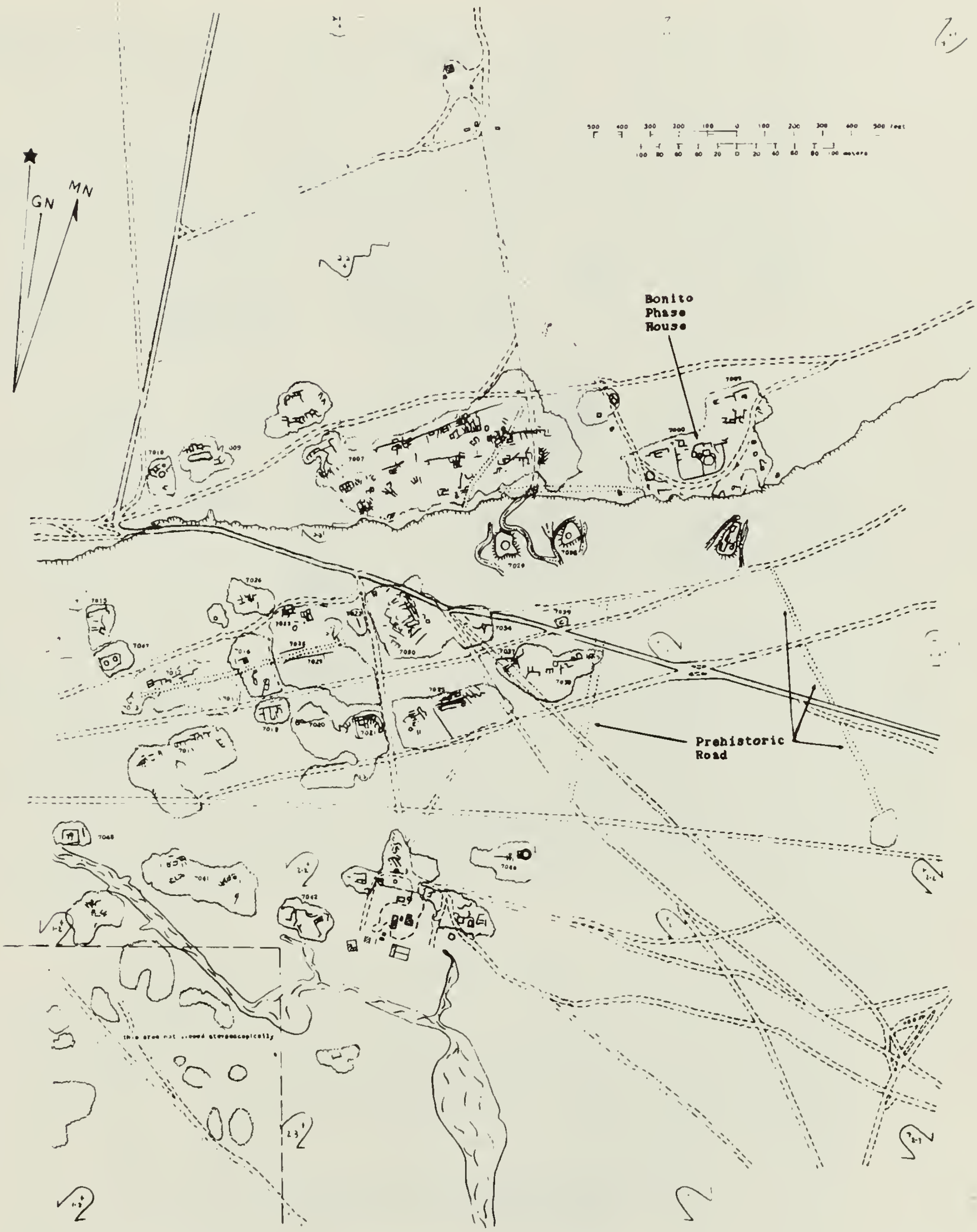
LEGEND

- Probable historic wagon road
- Light-duty road
- Unimproved road
- Suspected prehistoric roadway
- Mesa edge
- Arroyo with intermittent stream
- Buildings (dwellings, places of employment, etc.
- 000 Laboratory of Anthropology site number
- Buildings (barn, ramada, etc.)
- Suspected walls of prehistoric structure
- Extent of rubble mounds, possible roomblocks
- Probable roomblocks
- Aerial photography ground control panels
- Corner fiducial marks of individual photographs

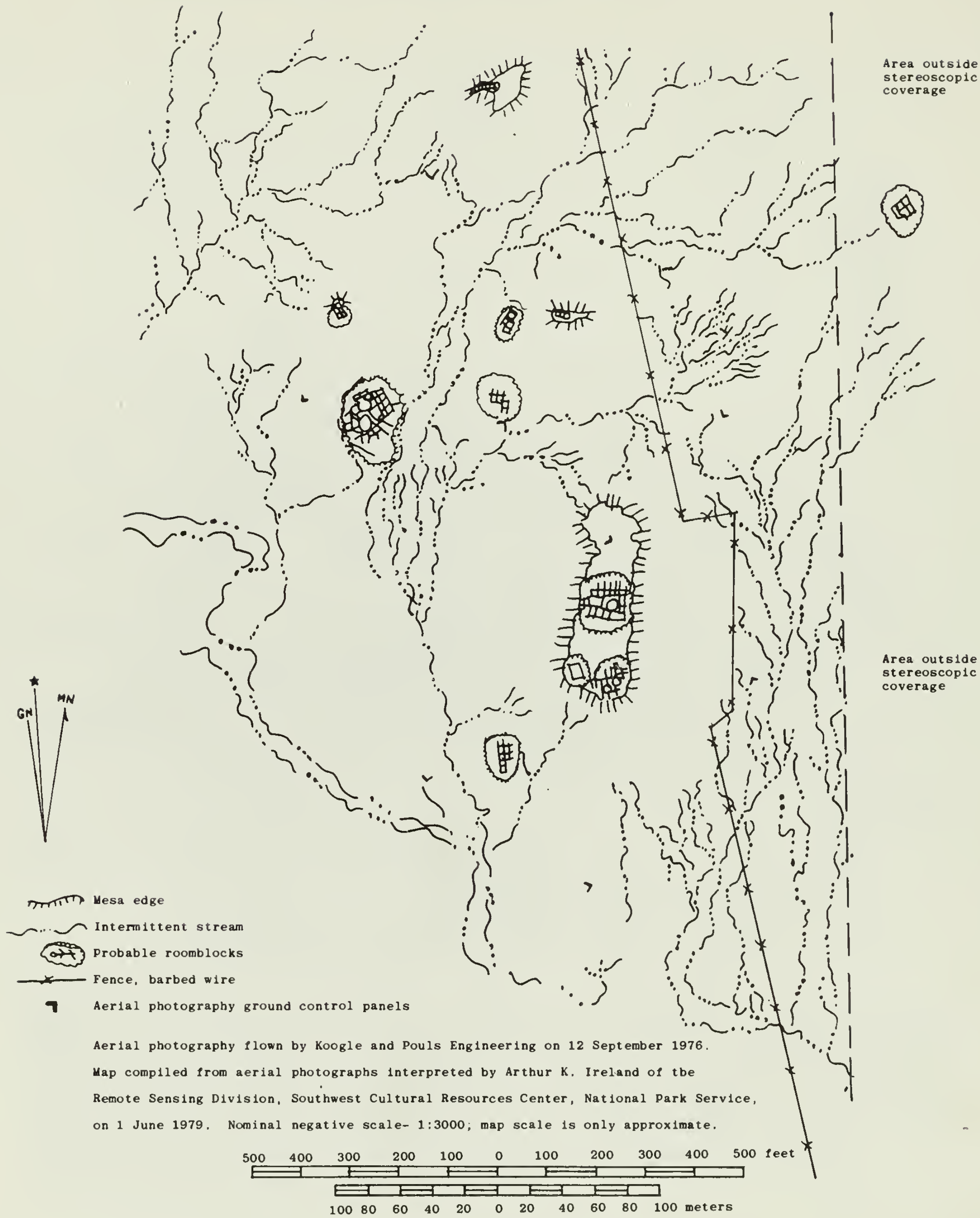
Aerial photography flown by Koogle and Pouls Engineering, Inc., at 4:05 P.M. on 4 October '78. Map compiled from aerial photographs interpreted by Arthur K. Ireland of the Remote Sensing Division, Southwest Cultural Resources Center, National Park Service, on 8 February 1979. Nominal negative scale - 1:3000; map scale is only approximate.

Figure 79

The Skunk Springs Site, New Mexico



Pierre's Site, New Mexico



Aerial photography flown by Koogle and Pouls Engineering on 12 September 1976. Map compiled from aerial photographs interpreted by Arthur K. Ireland of tbe Remote Sensing Division, Southwest Cultural Resources Center, National Park Service, on 1 June 1979. Nominal negative scale- 1:3000; map scale is only approximate.

Figure 80

exact scale; the scale of the map resulting from the uncontrolled option will depend on the nominal scale of the photographic negative. The latter is about half as expensive as the former due to cost of field crews and has been found acceptable for nominations to the National Register of Historic Places. Using the controlled photo-interpretive mapping method, the cost for mapping all 125 sites would be $27,250. The cost for uncontrolled photo-interpretive mapping would be $14,750. The time required for either option would be only slightly more than six months (Table 12).

The Division of Remote Sensing, Southwest Cultural Resources Center, National Park Service, Department of the Interior, has been experimenting with this method of mapping. Initially, ten sites were mapped and copies of these maps have been submitted to the New Mexico State Historic Preservation Officer for inclusion in the National Register of Historic Places nomination materials.

All these maps were created using uncontrolled (at the time) aerial photography, the nominal negative scale of which was 1:3000 (1" = 250'). A clear piece of plastic or mylar was placed over one half of the stereoscopic model and features seen in the photographs stereoscopically were traced onto the overlay. The overlay was then enlarged using an opaque projector called a C-55 Map-O-Graph and projected onto mapping paper, upon which it was copied.

Scales for the resulting paper maps were then calculated by comparing the distances between topographic and cultural features on the new maps with the distances of the same features on U.S. Geological Survey 7.5' topographic quadrangle maps (scale 1:24,000). Using these scales, it was possible to calculate the distances between ground control panels. These figures could then be compared to the actual ground measurements, which became available after the maps were made, to establish the relative degree of accuracy in the mapping (see Table 14 for complete figures).

Table 12.

MAPPING COSTS BASED ON THE "AVERAGE" SITE

Per site costs	Plane Table and Alidade	Transit	Theodolite	EDM	Photogrammetric				
					Topographic			Photo-interpretive	
					Option 1 a	Option 2 b	Option 3 c	Option 1 d	Option 2 e
Time required (in days)	42	31	24	14	4	4	4	1½	1½
Per diem	$2,520	$1,860	$1,440	$840					
Salaries	$4,452	$3,286	$2,544	$1,484					
Vehicle	$955*	$465*	$807**	$514**					
Equipment	$150*	$90*	$200**	$150***					
Mapping	$150	$225	$225	$225					
SUB-TOTAL	$8,227	$5,926	$5,216	$3,213					
Per site costs									
Ground control					$1,200	$600	$100	$100	$0
Flight, photography, lab fees					$43	$43	$43	$43	$43
Mapping					$563	$563	$563	$75	$75
SUB-TOTAL					$1,806	$1,206	$706	$218	$118
Times 125 sites	$1,028,375	$740,750	$652,000	$401,625	$225,750	$150,750	$88,250	$27,250	$14,750
Plus Mileage (8100 mi.)	$1,439	$1,439	$1,439	$1,439	N/A	N/A	N/A	N/A	N/A
TOTAL	$1,029,814	$742,189	$653,439	$403,064	$225,750	$150,750	$88,250	$27,250	$14,750

* Monthly rental rates applied
** Weekly rental rates applied
***Daily rental rates applied

a. Ground control tied to another known point by photogrammetric engineering firm.
b. Ground control not tied to another known point by photogrammetric engineering firm.
c. Ground control set by archeologist.
d. Ground control set by archeologist.
e. No ground control.

Table 13.

MAPPING COSTS SUMMARIZED

Per site	Plane Table	Transit	Theodolite	EDM	Photogrammetric Topographic Option 1	Option 2	Option 3	Photo-interpretive Option 1	Option 2
Data Acquisition	$8077	$5701	$4991	$2988	$1243	$643	$143	$143	$43
Mapping	$150	$225	$225	$225	$563	$563	$563	$75	$75
SUB-TOTAL	$8227	$5926	$5216	$3213	$1806	$1206	$706	$218	$118
Times 125 sites	$1,028,375	$740,750	$652,000	$401,625	$225,750	$150,750	$88,250	$27,250	$14,750
Plus mileage 8100 mi.	$1439	$1439	$1439	$1439	N/A	N/A	N/A	N/A	N/A
TOTAL	$1,029,814	$742,189	$653,439	$403,064	$225,750	$150,750	$88,250	$27,250	$14,750

Table 14.

MAPPING ACCURACIES

Site Name	Approximate Scale	Points	Map Distance	Measured Ground Distance	Map Distance/ Ground Distance Ratio	Average % Deviation
Crumbled House	1:1833	1-2	115.5 m	103.9 m	1.11	10
		2-3	118.2 m	107.2 m	1.10	
		3-1	68.7 m	63.2 m	1.09	
El Rito	1:1532	1-2	40.6 m	no data		
		2-3	93.4 m	no data		
		3-4	93.4 m	no data		
		4-1	60.5 m	no data		
Halfway House	1:1421	1-2	27.0 m	33.3 m	.81	19
		2-3	52.6 m	65.3 m	.81	
		3-4	33.4 m	38.6 m	.86	
		4-1	33.4 m	43.2 m	.77	
Las Ventanas	1:1739	1-2	70.4 m	69.2 m	1.02	1
		2-3	123.5 m	123.5 m	1.00	
		3-4	69.6 m	67.7 m	1.03	
		4-1	111.3 m	111.3 m	1.00	
Mesa Pueblo	1:1667	1-2	49.2 m	50.2 m	.98	2
		2-3	no data	63.6 m		
		3-1	no data	62.1 m		
Mesa Tierra	1:1728	1-2	122.7 m	117.0 m	1.05	2
		2-3	104.5 m	105.3 m	.99	
		3-4	103.7 m	101.8 m	1.02	
		4-1	73.4 m	71.2 m	1.03	
Newcomb	1:1934	1-2	73.8 m	70.8 m	1.04	8.5
		2-3	48.6 m	45.8 m	1.06	
		3-4	47.0 m	37.6 m	1.24	
		4-1	70.4 m	70.2 m	1.00	
Pierre's Site	1:1934	1-2	161.1 m	160.2 m	1.01	1.3
		2-3	233.3 m	231.6 m*	1.01	
		3-4	158.7 m	157.0 m*	1.01	
		4-5	247.1 m	247.5 m*	1.00	
		5-6	120.8 m	114.3 m*	1.06	
		6-1	162.1 m	163.4 m	.99	
Skunk Springs	1:1758	1-2	152.9 m	143.2 m	1.07	5.8
		2-3	74.7 m	69.5 m	1.08	
		3-4	175.8 m	168.2 m	1.04	
		4-1	97.7 m	93.8 m	1.04	
Yucca House	1:1836	1-2	232.3 m	219.1 m	1.06	4
		2-3	83.5 m	69.5 m	1.20	
		3-4	32.1 m	30.2 m	1.06	
		4-5	64.3 m	70.0 m	.92	
		5-6	90.9 m	93.1 m	.98	
		6-7	189.1 m	183.3 m	1.03	
		7-1	190.0 m	182.9 m	1.04	

* Figures are calculated, not measured

Of the ten sites mapped, control was obtained for nine, access to the tenth being barred. For four of the nine sites for which control data were obtained, the mapping had an average of 4% deviation from the actual distances measured. The average deviation from the actual measurement for seven of the nine sites was 8.5% or less. Average deviations for the remaining two maps were 10% and 19%. These maps presented problems because the detail on the U.S.G.S. 7.5' topographic quadrangle maps was inadequate to establish reliable scales for either map. If a more reliable scale could have been established for these maps, the average percentage of deviation would probably have been much lower.

The average percent deviation can be a measure of accuracy. For instance, the average deviation of the Newcomb map measurements from the actual ground measurements of the same points was 8.5%. This can be translated into a value of 91.5% accuracy.

As the mapping experiment progressed, actual measurements of the ground control points became available. It was then possible to proceed with the semi-controlled mapping of an additional thirty-four sites.

The initial procedure is the same as that of the uncontrolled mapping: one half of a stereoscopic pair of photographs is covered by a clear plastic overlay. The stereoscopically-viewed features in the photographs including the ground control panels, can then be drawn on the overlay.

The scale for the finished maps must be chosen next. Using the actual measurements of the distances between the control points, the finished map distances can be calculated and a model of the control points drawn to scale. The manner in which this model is constructed is relatively simple. First, a line which represents the distance between control point one and point two is drawn to the appropriate map length on a piece of paper. The clear plastic overlay is then placed on the line in such a manner as to have the first control point on the overlay directly over the corresponding end point on the line and the second control point also directly above the line. The angle from the first control point to the fourth (or third, if there are only three) control point can then be drawn by placing a ruler on these two points on the overlay and drawing another line to the appropriate length to represent the distance between points one and four.

The overlay is then moved to the other end of the first line such that the second control point on the overlay is directly over the corresponding end point on the line and the first point is also directly above the line. The angle between the second and the third control points can be drawn in the same manner as the angle between points one and four. A fourth line can then be drawn from point three to point four, thus completing construction of the scale model of the control points.

The overlay is then placed in the opaque projector (in this case, the C-55 Map-O-Graph), projected onto the scale model, and enlarged or reduced until the projected model coincides with the scale model. At this point, the overlay is being projected at the desired scale and the map can be drawn at that scale in the same manner as the uncontrolled maps.

Two points should be noted here. First, the mapping technique must be considered only semi-controlled, since the stereoscopic model has not been rectified. Secondly, not all the dimensions of the ground control model on the overlay will necessarily coincide exactly with those of the constructed model. The reasons for this are two-fold: the distortions of the unrectified stereoscopic model play a role and the distances on the overlay may vary from the actual if there are major differences in elevation on the ground between the control points. Generally, however, at least two, and usually three, of the dimensions of the models will coincide closely enough to consider the projected model to be at the proper scale. In the experiment, the overlays were at a nominal scale of 1:3000 and were enlarged to a projected scale of 1:1800 for the finished maps.

Conclusions

Traditional methods of site mapping are useful and cost-effective means of recording site information if the site is small. However, if the site is large and/or if there is more than one site to be mapped, the traditional mapping methods can become extremely expensive in terms of time and money. Especially in the energy-rich San Juan Basin of New Mexico, where coal, oil, gas, and uranium are found as well as large archeological ruins, time may be of the essence. In terms of both time and money, the traditional methods of mapping simply are not feasible for a mapping problem of this scope. Photogrammetric or photo-interpretive mapping are the only methods of mapping that can realistically be considered. The only other mapping possibility that exists is sketch maps, but the accuracy of photo-interpretive maps, to say nothing of photogrammetric maps, is so far superior to that of sketch maps as to preclude the use of sketch maps.

Even in the case of small sites, the versatility of aerial photography may make the extra cost worth the expense when compared to the traditional mapping methods products. The imagery can be used again and again to produce additional maps containing other types of information, such as environmental, about the site with only the additional cost of the new mapping. With traditional mapping techniques only one type of map can be generated. Other types of maps, such as environmental maps, would require acquisition of new data and remapping.

Many archeologists today are familiar with the traditional methods of site mapping. Because fewer are familiar with photogrammetric mapping techniques, most archeologists assume that photogrammetric mapping is far too expensive to be of any use to them. This paper has clearly demonstrated that photogrammetric mapping, especially photo-interpretive mapping, can be a cost-effective means of creating a site map.

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