Remote Sensing and Non-Destructive Archeology

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CONTENTS

INTRODUCTION by Thomas R. Lyons
and James I. Ebert 1

NON-DESTRUCTIVE ARCHEOLOGY AND REMOTE SENSING:
A CONCEPTUAL AND METHODOLOGICAL STANCE
by Thomas R. Lyons and Douglas H. Scovill 3

The concepts of a non-destructive approach to archeology, which will be of increasing import as cultural resources management responsibilities mount in this country, are outlined and their scientific credibility explored. While archeology has long relied on techniques which disturb and often obliterate prehistoric remains, research and applications of remote sensing have led to advances which make a non-destructive orientation both feasible and efficient. The converging professional, managerial and technological currents which influenced the development of this stance are defined, and the impact of its methodological concepts on the conduct of research and cultural resource management are identified.

REMOTE SENSING AND LARGE-SCALE CULTURAL RESOURCES
MANAGEMENT by James I. Ebert 21

Recent trends in cultural resources management, including increasingly large areas to be surveyed and ever-greater concern with reducing the destruction of cultural resources by archaeologists as well as the public, require that new methods of planning, assessment, monitoring and research be devised and applied nationwide. One domain of such methods is remote sensing, which can increase efficiency, speed and data extraction at all stages of archeological research. Remote sensing methods which will revolutionize cultural resources management in the near future will be discussed in the context of a National Park Service assessment of the 23-million acre National Petroleum Reserve in Alaska.

AUTOMATED DATA PROCESSING OF DIGITAL AERIAL IMAGERY IN CULTURAL RESOURCES SURVEY
by Dwight L. Drager 35

The advent of large area cultural resources surveys has demonstrated the impracticality of ground-based techniques for mapping environmental variables in preparation for archeological survey of sample units. This paper discusses photographic densitometry as it applies to image digitization and multi-spectral data. Factors that affect photo densities are pointed out as well as methods for acquiring data. Once obtained, digital data can be processed to aid cultural resource managers with such things as the formulation of sampling procedures, environmental mapping, site location, and other aspects of assessment and management.

ECOLOGICAL MAPPING FOR PURPOSES OF SAMPLE STRATIFICATION IN LARGE-SCALE CULTURAL RESOURCES ASSESSMENT: THE NATIONAL PETROLEUM RESERVE IN ALASKA by Galen N. Brown and James I. Ebert 53

Both Federal policy and archeological practice have often called for "inventory survey" as a viable first stage in cultural resources management efforts. As assessment and conservation efforts increase in number and especially in size, however, it becomes apparent that finding each site is impossible; nonetheless, some idea of the nature and distribution of sites is necessary for the planning of subsequent mitigation, conservation and research. This problem can be solved through the application of a multi-stage sampling design based on environmental stratification. Remote sensing methods, which provide an efficient means of such regional stratification, are discussed.

REMOTE SENSING MONITORING OF IMPACT ON CULTURAL RESOURCES by Cordelia Thomas Snow 64

A principal foucus of cultural resources management is the conservation of sites and materials, whenever possible, so that the data they contain may be available for future study. Although it has been obvious from the beginnings of archeological science that post-depositional cultural processes are to a great extent responsible for the preservation and form of prehistoric data when they are discovered, contemporary changes in the form and information content of cultural resources are often difficult to measure. Remote sensing techniques provide a means of monitoring subtle changes in cultural resources which may affect scientific conclusions drawn in the future; methods by which such monitoring can be efficiently applied over both short- and long-range time periods are outlined.

INTRODUCTION

Cultural resources management, while without question a legally and economically valid pursuit today, is still for the most part without a workable body of method. A methodology, the ways in which a discipline proceeds in the treatment of its subject matter, must grow from technology, and we believe that the foundations on which a viable cultural resources methodology can be based are to be found at least in part in remote sensing. Furthermore, the unique nature of remote sensing techniques -- their capability to measure without directly disturbing physical objects -- allows an additional step, beyond methodology, toward the formulation of a philosophy of non-destructive cultural resources management.

The Remote Sensing Division is a joint office of the National Park Service and the University of New Mexico, and one of its primary objectives is the development of remote sensing techniques to increase the accuracy, economy and efficiency of cultural resources data collection. This development research is carried out in conjunction with actual remote sensing applications to current National Park Service cultural resources management problems in close coordination with the Cultural Resources Management Division. Its ultimate goal, however, is to devise techniques with general, nationwide application. Discussions of specific National Park Service projects contained in this volume are included in such a context, and it should be noted that these papers detail Remote Sensing Division activities and opinions and not necessarily those of other National Park Service project personnel.

The development of new techniques and methods is useless if these are not communicated to cultural resources managers and the scientific community at large, and it is for this reason that the papers contained in this volume are being presented in a general session at the 43rd annual meeting of the Society for American Archaeology in Tucson, Arizona, as well as distributed in printed form.

NON-DESTRUCTIVE ARCHEOLOGY
AND
REMOTE SENSING:

A CONCEPTUAL AND METHODOLOGICAL STANCE

by

Thomas R. Lyons
and
Douglas H. Scovill

INTRODUCTION

Under the aegis of the National Park Service's internal Cultural Resources Management Program, we are in our ninth year of a systematic and progressively more sophisticated project concerned with applications of remote sensing methods and techniques to the exploration, discovery, recording, evaluation, investigation, monitoring and management of cultural resources. We are now at the point at which we have put forth some results of our collective labors (Lyons 1976; Lyons and Hitchcock 1977) and have developed a methodology of "Non-destructive Archeology."

The objectives of this paper are threefold:
First, to define and describe our concept of non-destructive archeology.

Second, to discuss the methods, procedures and techniques upon which it is based.

Third, to identify the impacts of the concept on the conduct of research and on the management of cultural resources.

Our thesis, in brief, rests on the following position. Archeology is a science of the human past. The history of its practice demonstrates a continuous effort in the development, application and refinement of the scientific tools of observing, measuring, recording, classifying, analyzing, testing, defining, theorizing and explaining. The existing limits in the capabilities of each of these scientific tools constrain our capacity and our effectiveness in research into the human past. One set of tools that currently limits us is the traditional methods and techniques of observing, measuring, recording, analyzing and testing the physical attributes of the archeological record and the natural milieu within which that record exists.

The basis of modern archeology has rested on a weak foundation for decades: that of its concepts, methods, and techniques of observing, collecting and recording its basic data. Consider the following (admittedly jingoistic) description of how we currently go about these tasks:

> Frequently, archeologists still in training and with varying degrees of professional accomplishment and observational prowess walk the ground on site surveys. They visually search for, discover and concurrently assess, sift and select a highly limited number of physical attributes deemed to be adequately descriptive and representative of rather obvious classes of archeological and natural phenomena. They record mentally massaged observations of these physical phenomena in summary fashion in logs, diaries and on printed forms, using imprecise terminology and syntax in an often undecipherable scrawl. They plot site locations with Brunton compass accuracy, a technique that often precludes rediscovery and positive identification of them at a future date. From this process comes a highly personalized statement about the archeology of an area and the natural environment, a statement that invariably concludes more surveying, more collecting and more excavating of the resources are required.

Moreover, it is our assumption that the process of tromping over hill and dale using the limited observational capacity of the human senses, progressively dulled by growing fatigue as the days and weeks wear on, results in the following:

1. A mixing of the raw data and interpretation of that data -- to the extent that one becomes substituted for and indistinguishable from the other.

2. The inability of subsequent investigators to replicate the observations of the original investigators with any level of confidence.

3. An imprecise, low quantity, low quality, often frustratingly incomplete, record of limited use to future investigators.

4. Because of the physical limits of human observational capabilities, the failure to discover and thus, to record, entire classes of archeologically-relevant data and data relationships, and the failure to accurately and adequately record synoptic observations of the site(s) or of the territory covered.

We believe that there is an alternative to the traditional approach to archeological exploration, discovery and investigation -- an alternative that does not rely primarily on the use of field survey parties and field excavation as tools for determining the content and data potential of sites or areas of study. And we hold that there are substantially better ways to document observations and to record data accurately. The alternative is non-destructive archeology; its major method is remote sensing. We now turn to a discussion of its basic elements.

NON-DESTRUCTIVE ARCHEOLOGY

The non-destructive approach to the exploration, discovery and investigation of cultural resources uses a wide variety of pre-fieldwork research techniques. These techniques include collection, evaluation and analysis of data, and the planning of the overall research project. The non-destructive approach emphasizes the acquisition and sophisticated analysis of a variety of remotely sensed imagery and data as the <u>primary</u> tools of exploration, discovery and recording. It uses fieldwork (survey, collecting and excavation) <u>primarily</u> as a method of verifying, validating and testing the results of the pre-fieldwork research. And finally, it demands sound logistical planning, based on the pre-fieldwork research, as a condition precedent to the initiation of field studies.

The objectives of the pre-fieldwork research are to develop a synoptic understanding of the biosphere, geosphere and archeosphere of the site(s) or area(s) under investigation as a basis for designing research and logistical plans. In developing the synoptic view, the traditional approach of literature and site records search and evaluation, analysis and evaluation of available biosphere and geosphere data is buttressed by a search, evaluation and analysis of available remote sensor data. From this process the gaps in available data necessary to obtain the synoptic understanding of natural and cultural resources of the area of interest are identified and a systematic plan to acquire the data is formulated and executed. An assumption borne out by our experience of nine years is that when data gaps exist, the most rapid and cost effective way to fill them in will be through the use of remote sensing methods and techniques.

A complete and thorough analysis of all pre-fieldwork data should be made, including the identification from imagery and other remote sensor data of cultural features as well as of all anomalies that might be cultural features. The analysis should be thorough enough to allow the articulation of the fieldwork research design, including accurate logistical planning, scheduling and coordinating of field parties. Field procedures should be specified, terminology and field records standardized, and project staff trained to execute the work as planned. The field research design at this point emphasizes the confirmation, modification or rejection of the pre-fieldwork analysis, but without the use of test excavations or the collection of artifacts. 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.

We hold that collecting and excavating are tools of testing and verification, not tools of discovery, identification, or site or area exploration. The non-destructive approach makes the maximum use of predictive and confirmative sampling strategies and techniques. It sets stringent, defined limits in field research designs on the collection of artifacts, on the conditions under which excavation will occur, and on the extent of the excavation.

In non-destructive archeology, the use of field survey, with its direct observing and recording of on-the-ground cultural and natural phenomena by the human senses, is recognized as an essential ingredient of data collection, but not as a primary means of collection. The field survey is judged as an unreliable, ineffective and inefficient tool of data collection if it is not preceded by and systematically integrated with the pre-fieldwork research and logistical planning approach described above. The function of fieldwork is to verify and validate the findings of the pre-fieldwork studies -- not to explore, discover and record the cultural and the natural resources of the study area. It uses the traditional techniques of artifact collection and excavation to resolve the real issues based on testable problems rather than as an assumed <u>sine qua non</u> of "standard" field method.

In summary, then, we see five significant differences between the non-destructive approach to data acquisition and research in archeology and the traditional approach:

1. Sophisticated use of remote sensing imagery and techniques as the primary tool of acquiring, recording and analyzing data.

2. Rejection of collecting surveys and excavating as <u>sine qua non</u> tools of exploration, discovery and investigation of cultural resources.

3. Emphasis on fieldwork as being primarily the verifying, validating and testing phases of the project.

4. Acquisition of a synoptic data base as an essential ingredient to the development of specific research designs to resolve testable problems and as the basis for completion of the logistical planning, scheduling and coordinating of fieldwork.

5. Use of processed remote sensor imagery as the basic archival record of the cultural and natural phenomena, the "human" sensed data being only a supplementary record.

METHODOLOGY OF NON-DESTRUCTIVE ARCHEOLOGY

Instrumentation

From the standpoint of instrumentation (that is, data recording devices) advances in remote sensing are comparable to developments in optical physics. They provide a new perspective -- the synoptic as contrasted with the atomic view, the synergistic as well as the particularistic view of site-specific investigations. The potential of remote sensing for discovery and analysis is now as great as that of the new eyes on the universe provided by the optics of the telescope and the microscope.

Multidisciplinary Applications

Remote sensing has broad multidisciplinary applications to geology, geomorphology, biology, pedology, hydrology and climatology, as well as to anthropology. Coupled with the concept of non-destructive archeology, it provides a perspective that is indispensible in today's study of mankind, our past, our spread through time and space, and human cultural behavior and development. It has the capability for quantification of the human cultural activities and historic manifestations so intimately related to the geosphere and biosphere. The remote sensing perspective provides not only the synoptic overview otherwise unobtainable, but more importantly, a synergistic grasp of observed physical and cultural phenomena (Lyons and Avery 1977:53). This perspective is becoming more and more essential in the formulation of evaluation and monitoring schemes for the research into and administration of cultural as well as natural resources.

Aerial Imagery and Data

Many of the techniques of remote sensing are now operative, some are in the process of development, others are still on the drawing board. Photography and other types of imagery recorded from aircraft and spacecraft platforms are among the best understood and most useful products of remote sensing. Multispectral scanning systems ultimately hold the greatest promise for quantitative data handling and widespread use in anthropology as well as in other disciplines. Another technique to be studied further and made fully operational is automated data processing of digitized multiband photography and multispectral scanner signal output.

With the aid of data derived from spacecraft, aircraft, balloon and bipod platforms regional and site-specific analyses can be made. Obviously, regional overviews and studies of cultural resource areas can be undertaken with small scale imagery (Ebert et al. 1977; Schalk and Lyons 1976). This would include mapping and analysis of the environmental setting; that is, the differentiation of vegetative zones, physiographic regions, gross soil changes, etc. Using this base and armed with an understanding of the type and distribution of sites within a target area, the investigator can formulate predictive models for site and site cluster locations.

A most important remote sensing technique is the interpretation of multispectral scanner and photographic data and imagery. One of the most widespread applications of interpretation lies in reconnaissance. With minimal training, field crews can employ stereo pairs or models to determine the location of sites during ground survey (Loose and Lyons 1976). Even the locations of sites that are not themselves visible on the imagery can be identified as long as the crew is capable of reading topography, identifying its own location on the photos and marking its relationship to the discovered site. This identification of sites is not the only value of image interpretation, however. For further discussion see Lyons and Avery 1977:62-65. Another type of aerial photo useful in field surveys is the orthophoto, an aerial image derived from stereo models in which all elements in the physical environment are in corrent horizontal relationship to one another (Lyons and Avery 1977). Such orthophotographs can be of considerable use in both small and large areas, within sites and between sites and site clusters. Such imagery is also of great value in transferring site locational data and environmental information to base maps (Morris and Manire 1976). Standard base maps of the USGS topographic quadrangle type contain a minimal amount of vegetative and drainage data compared to what is observable in an aerial photograph. Much of this kind of information is readily observed on imagery and easily transferred to the standard quadrangle or other base maps.

Aerial photography and space imagery are excellent tools in the preparation of sampling and stratifying procedures. The identification of the region of interest and the determination of its general physiographic, vegetative cover and site type characteristics provide a base map for the development of a sampling technique and for stratifying procedures. For many years, workers in other disciplines have mapped vegetative cover with the aid of aerial photography. Recently, vegetative cover maps of portions of the Alaskan North Slope and the arid Southwest have provided the environmental information necessary in cultural resource identification and location, evaluation and monitoring (Schalk and Lyons 1976; Brown and Ebert, this volume). Vegetative communities are often identifiable on color or color infrared aerial photographs of proper scale. Gross vegetative cover can be identified and mapped from high altitude or space imagery. It is also possible, of course, to monitor vegetative change both seasonally and annually with the proper type of aircraft or spacecraft imagery (Drager 1977; Ebert 1977). Some regions lend themselves particularly well to soil mapping. The Southwest is one of these. Different soils frequently manifest themselves in the types of vegetation they support, in the color they present, and in the manner in which they erode. Consequently, soil studies can be made when the objectives are identified and specifications for the data gathering determined. Both low altitude photographs, and spacecraft and higher altitude aircraft imagery can be employed to this end. It should be remembered, however, that the objectives of the mapping effort are the determining factors in the selection of instruments, scale, format and film emulsion type. When vegetative cover studies have been completed, soil maps derived, and archeological survey information compiled, a foundation is provided for paleoenvironmental reconstruction. In addition, evidence of geomorphological features, such as dry lake beds, lake terraces, ocean strandlines, extant and fossil stream patterns, living and fossil springs and glacial features can be acquired. For this purpose various types of aerial imagery provide some of the best investigative tools.

Photogrammetry

Aerial and terrestrial photogrammetry are excellent measurement tools for documenting all types of historic and prehistoric sites with great detail and accuracy. Using aerial stereo models of sites (produced with preset horizontal and vertical controls), planimetric and topographic maps of a wide variety of scales and contour intervals can be constructed (Pouls, Lyons, and Ebert 1976). As a practical example, a scale of 1 in. to 30 ft. and a 6 in. contour interval were specified for Hidatsa village sites along the Knife River in North Dakota. A great deal of archeological information was derived, not only from examination of the villages, but also from interpretation of the topographic configuration of the photogrammetric contour map. Such maps are useful in pre-excavation evaluation of sites, in recording excavated features and in post-excavation analysis (Obenauf 1978).

Another capability of aerial photogrammetry used in studies of Anasazi ruins in the Southwest is the digitization of site features. Digitization consists of obtaining the x, y and z coordinates, that is, the horizontal and vertical relationships of the junctions and vertical breaks along walls in ruins, and punching the data onto computer cards for printouts and evaluation. With the aid of existing computer software this quantitative base can then be employed in developing floor plans, three-dimensional perspectives, reproductions, and cross-sections or profiles (Pouls, Lyons and Ebert 1976).

Currently, there is an experiment underway in which we are attempting to combine such data with field-derived data from the excavation of Pueblo Alto in Chaco Canyon National Monument, New Mexico. The field information consists of the calculations of the volume of fall rock from the excavation of this masonry structure. With this quantified data base (that is, the measured volume of fallen construction material and the digitized information on standing walls), together with complementary information acquired on site by the excavators, it is possible to make a perspective drawing of the structure. Utilizing computer graphic techniques permits greater accuracy and a higher level of confidence in the interpretation and restoration of sites than has been possible in the past using the "artist's conception" approach. In all these cases, it must be remembered that ground coordinate control is essential (Lyons and Avery 1977).

The principles and theory of terrestrial or ground-based photogrammetry and aerial photogrammetry are for practical purposes identical (Wolf 1974; Lyons and Avery 1977). Planimetry and horizontal or vertical plane topography of a target can be mapped using controlled ground-based photography. For instance, floor plans and architectural elevations of Anasazi ruins hidden within rock overhangs and caves have been successfully mapped (Borchers 1977).

Structure type and details, e.g. masonry, doors, windows, vigas, are easily identified and recorded. More detailed information, such as elaborate artistic design, can also be recorded.

It is apparent, then, that an individual trained in both archeology and in the theory and applications of aerial and terrestrial photogrammetry can gather relevant field data and furnish to the photogrammetrist (who operates the plotting instrument) the properly controlled photography for the development of elevations and maps specifically oriented to archeological and architectural interpretations.

Subsurface Probes

A set of instruments used in non-destructive remote sensing investigations, but not always recognized as remote sensors, are those involved in subsurface probing and exploration. These include ground-penetrating radar, resistivity measuring devices, seismographs and magnetometers. By and large these instruments are used for the detection of structures and incinerated clays buried in soil. The densities, residual magnetism, electrical resistivity and energy conductivity of the buried cultural elements in contrast with the ambient soil produces identifiable anomalies. With the exception of the seismograph, however, these instruments are not capable of great depth penetration.

Ground Truth

An essential and never-to-be-omitted element of remote sensing procedures is known as ground truth. Ground truth is often used as a generic term including: 1) the prearrangement of the on-the-ground data gathering devices or procedures that operate during instrumental overflights, 2) ground level horizontal and vertical engineering control and 3) ground checking of interpretations of acquired imagery. As used in anthropology, the term refers primarily to the latter two activities. Another way of expressing this in terms of archeological and cultural resource interests is that ground truthing is a procedure for establishing target references and measurements and/or for verification of image interpretation.

Standard Non-Destructive Techniques

In the minds of many, archeologists and non-archeologists alike, excavation is virtually synonomous with archeology. Some few standard methods and procedures of archeology are essentially non-destructive: in non-collection surveys, computer analysis, cartographic work, some dating techniques and archival or literature research. Obviously, much of what has been established in archeological methodology to date can be used in conjunction with the non-destructive methodology of remote sensing to provide a scientific approach to archeological problems. Combined procedures currently being employed to some degree in non-destructive analysis of historic and prehistoric cultural resources include non-collecting blanket and spot surveys, site location mapping with the aid of aerial photography in the field, sampling designs created with the help of imagery of the target area, and the analysis and mapping from imagery of the environmental setting (vegetative cover, drainage patterns, soils, slope, etc.).

Cultural Resource Management and Non-Destructive Archeology

The remote sensing procedures and techniques briefly described above have many applications, both to continuing research in anthropology and to the needs of cultural resource management.

Applications research in remote sensing is continuing in the Division of Remote Sensing of the National Park Service and in a number of anthropology departments across the nation. The ongoing work consists of investigations into the applications of different film emulsions in different physiographic settings containing different cultural manifestations, multispectral scanning studies, and photogrammetric documentation and reconstructions. From these efforts, technical, interpretative and applied publications have been and are continuing to be prepared for distribution to the profession. However, much remains to be done in formulating guidelines for the future directions of remote sensing research and for its application in non-destructive archeology.

A most practical application of the concepts of remote sensing in non-destructive archeology is in the administration and management of our cultural resources. The data and information derived from the techniques described provide managers with substantial input to their working data base to be used for planning, development and administration of cultural resources, particularly for those agencies -- civic, federal and private -- in control of large landholdings.

A vital extension of remote sensing and standard methods of non-destructive archeology is in the planning and setting up of monitoring programs for assessing impact on our cultural and related natural resources (Snow, this volume). As we are all aware, there is currently a tremendous impact on our historical heritage arising out of the needs and activities of an expanding population. In addition, natural forces, such as wind, water, chemical reaction and fire, have a destructive effect on these resources.

We must come to grips with the human factor. Not only is the visitor in a national or state park an agent affecting deterioration of the natural and cultural resources, but the administrator himself in his planning of walkways, roads, access trails, housing sites, and work areas is also often a major element in damaging or destroying resources. The industrial impact of the extractive industries, mining and petroleum companies, on natural or cultural resources is often profound.

It must also be acknowledged that one of the most destructive of all agents is the archeologist. When a site is pothunted archeologists understandably raise their voices in protest. At the same time there is a considerable variability in the skills of the professionals. It is painfully apparent that there are those who excavate a site, take only sparse field notes and do not fully record or adequately report the results of their efforts. Further, there are many available techniques of data recording that could be, but are not, employed. Two such techniques are the mapping of sites from vertical photographs taken from a bipod platform (Klausner 1977) and mapping from vertical aerial photographs (Pouls, Lyons and Ebert 1976). A very important consideration here is the historic value of these records. A wealth of data is captured in most site photography; if controls are set, measurements can be derived by other archeologists who may wish to reevaluate a site when the site itself no longer exists.

Another important aspect of non-destructive archeology through remote sensing is that of economics. The applications of the procedures of remote sensing and non-destructive archeology are not usually dollar-generating activities but rather dollar-saving and dollar-extension procedures. For both the archeologist and the manager this is an important factor in budgeting for the investigation, preservation and stabilization of resources.

IMPACT ON RESEARCH AND MANAGEMENT

There are few standard archeological techniques that are non-destructive in execution, and until now no explicit statement on the nature and implementation of a non-destructive methodology in archeological research has been set forth. Remote sensing techniques as applied to archeology provide a major component of such a methodology and constitute a viable scientific approach fitted to today's conservation and preservation requirements. In addition, remote sensing in non-destructive archeology is equally applicable to American archeology with its emphasis on human behavior, to classical prehistory and to ecclesiastical archeology. It is a source of vast amounts of data for studies in whatever theoretical or philosophical persuasion an investigator labors.

The non-destructive archeological approach, as defined and outlined here, is presented as an operational model or formula. It is a methodological stance formulated out of standard established techniques, resource management requirements and advances in remote sensing and other technologies. Its application to archeological research is truly interdisciplinary, requiring of its practitioners some functional knowledge of a number of complementary disciplines.

The remote sensing procedures of non-destructive archeology briefly listed above (and more fully explained in the cited literature) are techniques that obviate many of the problems encountered in recording ephemeral archeological data, whether data are environmental, excavational or artifactual. The value of these methods of recording regional and site-specific data lies in the facts that 1) the subjective bias of the human observer and recorder is reduced, 2) quantifiable and digital data in greater quantities than previous techniques produced are permanently registered, 3) archives of retrievable archeological data are produced and 4) the opportunities for re-studying, re-evaluating and re-testing are provided future generations of scholars.

In our view, given the products and advantages of the non-destructive approach, collecting surveys and excavation take their rightful place as techniques for testing hypotheses, and <u>not</u> for exploration and discovery.

Not only is it imperative that collecting surveys and excavation be undertaken only as testing procedures but it is vitally important as well to assess the probability of successfully accomplishing the research objectives prior to mining the archeological record. This assessment, so rarely made and so seldom explicitly stated, can be formulated on the basis of a non-destructive evaluation of the physical parameters of the task and on the basis of the experience and knowledge of the investigator. If intellectual honesty prevails, many resources will be saved from premature disturbance for future and more advanced removal methods that will yield greater returns in data.

Further, it seems incredible that the finite, fragile and diminishing data source of our discipline should be physically manipulated by untrained school children and dabbling amateurs. In the past there may have been some economic rationalization for this but there is no scientific justification for employing the methodology of dilettantism in data gathering and analysis of the perishable archeological record. The academic community has the responsibility to reassess its obligation to produce properly trained professionals and scholars and de-emphasize its role in summer session babysitting of undergraduates who often have only a casual and unsustained interest in anthropology.

As is emphasized in this volume, technology provides a greater quantity, high quality and wider variety of relevant data than can be acquired by any other approach. While the initial capital outlay may appear to be high, the use of remote sensing is cost-effective because it provides not only significant increases in the quantity, variety, and quality of data, but also because it produces an archival record. This record not only captures the state of the resources at a given time but also is amenable to a wide range of analyses in the future with no additional data acquisition costs. In many instances, it allows study of the resource base at an overall lower net outlay and without physically disturbance as would be the case in traditional archeological practices involving exploratory excavations. That is, it is non-destructive in its application. It provides the heretofore missing synoptic view so critical not only to research but also to the planning of visitor use facilities and conservation of resources. Additionally, it enhances the possibility of discovering resources such as old springs, fields, battle lines, and roads that were undiscoverable by prior methods and techniques. The overall result is the ability to make critical planning decisions concerning the development, protection, and use of resources based on hard data and real knowledge of the locations, characteristics, potential significance and relationships of a study area's cultural and related natural resources.

The ability to monitor the state of the health of the resources over time is acquired. This is particularly important to the effective management of cultural resources. Resources do not deteriorate overnight; rather, deterioration is a slow, inexorable process. The human senses, in combination with the limits of the human memory, even memory augmented by written record, simply do not detect what is happening to resources until problems are well advanced. This is particularly true of such impacts as changes in land use practices, heavy visitor use, coastal erosion, vibrations, and sonic booms. However, through the use of archival imagery as a kind of long-term time-lapse photography, problems of resource deterioration can be detected and strategies for correcting adverse situations devised.

And finally, there is the real world consideration of what share of the citizens' tax dollars our society is both willing and capable of devoting to cultural resources management. We can no longer use the standard techniques of the past such as the measured drawings of buildings, of transit or plane table surveys, or of scores of archeologists trooping over the ground to explore for archeological sites. Using the slow field methods of the past as our primary strategy will doom us to failure for we will be unable to make significant progress on the massive problems confronting the conservation and management of cultural resources.

Remote sensing is not a panacea. But it is a sophisticated set of tools which can be efficient and cost-effective when applied to inventorying evaluating, planning, managing, and conserving cultural resources. The application of remote sensing techniques is, in our judgement, a *sine qua non* of both research and management.

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REMOTE SENSING AND LARGE-SCALE CULTURAL RESOURCES MANAGEMENT

J.I. Ebert
2 March 1978

CULTURAL RESOURCES AND FEDERAL LAW

Cultural resource management means many things to many people. Some of us derive our livelihood from archeological investigations and research carried out under programs of resource management; at the same time, the concept is deplored as being mercenary, encouraging only cursory, businesslike treatment of the archeological record, or limiting the scope of research. Perhaps it is best, in the midst of such controversy, to view cultural resource management in a more practical light -- as springing from a long series of well-meant legislation designed to provide a rationale for preserving and dealing with prehistoric and historic remains.

Early in the history of American cultural resource legislation, which began with the Antiquities Act of 1906, material remains from the past were recognized as being somehow valuable, a notion that may have been a function of the classificatory focus of American archeology during the 19th and early 20th centuries (Willey and Sabloff 1974). The collection and viewing of artifacts was held as a goal in and of itself. Later legislation and policy rationalize cultural resources as worthy of protection on the basis of the "public interest" (U.S. Government 1960), the fact that they are <u>not</u> being preserved (U.S. Government 1974), or because "...they are potentially applicable to the investigation of research problems" (U.S. Government, Code of Federal Regulations 36 CFR 66). The thrust of Federal legislation is twofold: it is worded to protect and in addition to <u>organize and enable the support of the treatment</u> of cultural resources. This latter thrust, often not understood by archeologists, is apparent from the onset of American historical properties legislation; the 1906 Act requires permits, which are available only to qualified institutions, for excavations or destruction of cultural resources. The implication -- as important today as it was in the past -- is that prehistoric and historic properties and data are worthy of protection from archeologists as well as against other destructive forces. Subsequent legislation and policy formulations by those responsible for cultural resources have reinforced this stance, and the philosophy of non-destructive archeology (detailed by Lyons and Scovill, this volume) makes it explicit.

Stages of Cultural Resource Treatment

The imposition of organization -- a methodology -- upon archeological treatment of cultural materials has evolved along with the acceleration of industrial and extractive development that threatens material evidence in the ground, with increasing Federal management and development of land for recreational and other purposes, and with the expansion of archeology itself. The existing body of cultural resources law and policy prescribes three basic sets of physical steps or "stages" through which management must proceed:

1) Assessment of the cultural resource base;
2) Assessment of impacts on cultural resources; and
3) Assessment of the significance of cultural resources.

These three stages of cultural resources management might seem both simplistic and contrary to the aims of scholarship, but they are not inconsistent with research archeology. In addition, such a sequential ordering is the only logical means by which efficient treatment of cultural materials can proceed in today's world. Although it would be ideal if all research could proceed deductively, the exploitation and development of vast areas of archeologically unexplored lands in the western United States and Alaska makes an inductive structure necessary. We must proceed from assessment of data base to problem-solving if cultural resources are to be both studied and protected or otherwise exploited.

It is the contention of the papers presented in this volume that both protection and legitimate exploitations can be insured through proper planning aided by the application of appropriate technology, particularly remote sensing methods and techniques. In the course of this paper, the role of remote sensing in each of the stages of cultural resource management outlined above will be discussed in the context of the ongoing National Park Service survey of the National Petroleum Reserve in Alaska (NPRA).

NPRA AND THE PROBLEMS OF LARGE-AREA SURVEYS

NPRA, which covers some 23,000,000 acres south of Barrow at Alaska's extreme northern point, is undergoing cultural resources assessment by the National Park Service because the area will be opened to petroleum exploration in 1980. Both because the area is in the Arctic and because it is one of the largest areas ever archeologically surveyed, it presents certain unique problems to the archeologist. Other aspects of survey there are much the same as they are in any assessment situation. Particular difficulties in the NPRA survey include an extremely short summer field season, impossibility of access except by foot or helicopter, and relative lack of prior archeological knowledge of the area. NPRA's great size, however, also enhances its value for illustrating the application of new cultural resources management techniques, for some assumptions archeologists make as a matter of course in small-area surveys fall apart when considered in the light of a vast and inaccessible region. One of these assumptions, central to almost every cultural resources survey, is that a "total inventory sample" -- a listing of all cultural resources in any parcel of land -- can be achieved. In reality, of course, any archeologist who has performed field survey realizes that a total inventory is an impossibility -- for with a bit more care and effort, another site or artifact can always be found. Any inventory of items within an area is always a sample, an understanding of which is important from the start; through proper sampling procedures, estimates of confidence limits and possible error can at least be calculated. In the case of the NPRA survey because no realistic possibility of covering <u>all</u> of the area ever existed, it was decided at the outset that the initial assessment of cultural resources would begin with a feedback sampling strategy.

ASSESSMENT OF THE CULTURAL RESOURCE BASE

When the question, "What cultural resources are there?" is asked, certain general suppositions may safely be made -- even if an area has never been explored. One of these is that cultural resources, being the material expression of adaptive responses of people in a variety of circumstances, will not be homogeneously distributed across any area. If the distribution of sites were uniform, of course, only a very restricted portion of a survey area would have to be inspected to arrive at an assessment of the resource base. Since uniform distribution never occurs in reality a dispersed sample must be taken. In the assessment stage of cultural resources management, which requires the location of physical items within a bounded area and in which the population is (at least at the outset) unknown, the spatial universe must be divided into smaller sub-units or strata, which in turn serve as the basis of partial sampling.

Stratification in Sampling

Several methods by which a study area can be divided into strata have been suggested in the archeological literature. Perhaps the simplest scheme is that of random sampling (Hill 1967); other authors have suggested various types of stratified or systematic samples (Binford 1964; Redman 1973; Rootenberg 1964). It must be pointed out that the term "stratified" is used by these authors in the sense of Berry and Baker (1968): as a method of dividing an area to be cluster-sampled into a number of arbitrary super-units, from which are drawn lesser units. The object of such an exercise is to insure the even dispersal of sample units across a study area, a distribution that does not necessarily result from random cluster sampling.

Such sampling strategies have been used with some success in cultural resources efforts, and are advantageous in "inventory surveys," since they are oriented toward the realistic goal of inspecting only a part of the total variability within a large area and projecting from such data to a picture of the whole. There are problems with such stratification schemes, however. A problem that is frequently discussed is determination of the proper sampling fraction -- the proportion of the total area that must be surveyed in order to accurately model the total population. In practice and in the literature, sampling fractions ranging from 10% to 50% or more have been invoked, in no instance with much logical justification. Unfortunately, for neither random samples nor for the sorts of stratified samples discussed above, can a "proper" sampling fraction be determined, because there is nothing against which the adequacy of a sample can be tested. Although several archeologists have attempted to test a post-inventory sample against total-area site lists (Plog 1968; Judge, Ebert and Hitchcock 1975), purely inductive samples cannot be tested.

There is, however, another sort of stratification that deserves the attention of the cultural resources manager -- stratification in which a parameter, some variable, is held to be relevant to the significance of the resource base (Holmes 1967). This type, known as informed stratification, is intended to identify a group of cultural units that possess the same degree of diversity as the universe from which they are drawn (Wood 1955). In furtherance of this, the universe must be stratified into units each of which is less variable than the whole; whether a sample meets this requirement can be determined statistically. To achieve maximum sample precision, strata must be chosen so that their sampled averages are as different as possible, and their variances as small as possible. Clusters within strata, on the other hand, should be as internally heterogeneous as possible (within-cluster variances as high as possible, and between-cluster variances as low) (Stuart 1962).

Informed Ecological Stratification in NPRA

Given this, however, where is the archeologist to start? How is his universe to be stratified prior to statistical testing? Of course, any number of random or arbitrarily dispersed samples could be drawn and tested against one another, but this is inefficient and unnecessary. Much of the material record left behind by past people results from adaptations to environmental necessities, which clearly differ from place to place. Remote sensing provides the techniques for dividing a study area into ecological zones, i.e. for stratifying it in an informed way prior to the first sampling stage.

Environmental stratification for sampling is often avoided by archeologists, usually for one of two reasons. The first of these is that the archeologist feels uncomfortable with the subject matter of the biologist -- the bewildering array of Latin plant names, species/association/community distinctions, etc. These things need not concern the archeologist, at least at the inductive levels of assessment. It is necessary only to divide the study area into areas that are different in some way to approach an informed preliminary stratification. Another often-expressed fear is that environmental zones distinguishable in the present may not be the same as they were in the past. Although it is likely that the specific composition of each zone varied under different climatic conditions in the archeological past, the underlying determinants of zones and boundaries -- drainage regimes, altitude and landform will have remained constant. Specific adaptations within each zone may be very different than they would be if hunter-gatherers lived there today, but zones and their boundaries in many cases were the same, and can be differentiated using contemporary aerial and space imagery.

Stratification within the NPRA survey area proceeded with these assumptions in mind. As is described in more detail by Brown and Ebert (this volume), Landsat black-and-white bands 5 and 7 imagery served as the basis for preliminary delineation of ecologic/cover-type zones which appeared to differ from one another to the interpreters. Once plotted on a 1:500,000 scale base map, these zones were checked against Landsat EDIES (EROS Digital Image Enhancement System) color composite (false-color infrared) satellite imagery flown over NPRA during the summer of 1977. The concurrence of interpretations between space and aerial imagery was impressive.

In a "normal" survey, this stratification would serve as the basis for the first stage of field survey -- the fraction of each ecologic zone surveyed would correspond to the sampling fraction determined for the study area as a whole. It should be noted that, under a system of informed stratification such as that discussed here, the acceptable sampling fraction can be far smaller than is necessary for random or arbitrary stratification. This would, of course, also be necessitated by the extremely large size of the area and the limited field time allotted, constraints present in all large-area surveys. A sampling fraction of .001% was suggested during the planning of the initial NPRA sample on the basis of field time and funding estimates.

Unfortunately, there were complications in the NPRA survey which may teach a lesson for all large-area resource managers. Final notification of Park Service involvement in the project was not received until slightly more than a month before the beginning of field operations, and remote sensing activities were launched only a few weeks prior to field deployment. A sad fact of life that should be remembered by those wishing to employ remote sensor imagery in their survey work is that turn-around time, from ordering of imagery to its receipt, whether from EROS Data Center or from other sources, will not be less than several weeks and may be as much as three months. By the time the Remote Sensing Division in Albuquerque was able to establish a firm ecologic/cover-type stratification of NPRA, the field crew had nearly completed summer 1977 fieldwork and snow was beginning to fall on the North Slope.

The value of ecologic stratification and fieldwork prior to acquisition of remote sensing data are not thereby negated, however. As long as survey has been conducted within each of the ecological strata, the acutual physical areas covered within each stratum are known, can be divided between strata, and the actual sampling fractions for each part of the total universe can be determined. If, for instance, the number of sites were to be estimated for two strata, in one of which 1% of the area had been surveyed or the other of which 50% had been surveyed, the number of sites in the first stratum would be multiplied by 100 and that in the second by 2 to reach a preliminary estimate.

Such a projections from a first sampling stage are, of course, only preliminary, and must be tested for validity and acceptability. Sample variances within and between strata and clusters can be compared for various parameters (or values of parameters, such as different site types), and the results of one sample, such as that drawn during the summer of 1977 in NPRA, tested against another sample from different parts of the same area. Comparison between two samples may point to the necessity of revising stratum boundaries and definitions, increasing the number of strata, or lumping two or more strata that yield identical sample results. In all cases, it is the stratification that is being tested and manipulated, not the samples themselves. Followed to its logical extreme, this sort of multistage, "feedback" sampling strategy approaches the basis for explanation of past site and activity patterning.

Logistics and Mapping in Data Base Assessment

Although in the more technical sense, stratification for sampling purposes is the focus of remote sensing's contribution to the assessment phase of cultural resources management, there are numerous other ways in which remote sensor imagery can aid large-scale survey (Aikens et al 1977). One of the most straightforward of these is logistics planning -- aerial and even space imagery can be used to determine camp placement, supply-pickup locations, and transport routes without requiring prior field reconnaissance. Such considerations may also be extremely important in the placing of sample units or clusters within strata. Cultural resources, once located on the ground, must be recorded and their locations plotted for future reference or relocation. For most of the NPRA survey area, no topographic maps of scale larger than 1:250,000 were available; plotted on these maps, all of the sites found in a day's survey might be spaced closer together than the area covered by pencil mark. This problem can be alleviated by marking or pinpricking location on larger scale aerial photos (Loose and Lyons 1976), a procedure which will be followed during 1978 NPRA field activities. In addition, field crews often find it easier to orient themselves using aerial photos, which provide a very real picture not only of topography but also of specific vegetative features and landmarks.

ASSESSMENT OF IMPACTS ON CULTURAL RESOURCES

One of the aims of cultural resources legislation and policy is the protection of our record of the past, which requires not only identifying the resources, but also determining past, present, and future impacts upon them. There is a tendency, especially in cultural resources activities funded in view of impending industrial disturbances such as mining, dam building and construction, to see impacts as specific one-time occurrences. In actuality, the formation of the archeological record is the result of a continuous series of natural and cultural impacts. The initial "impact" in all cases was the discard, loss or adandonment of material evidence of cultural activities; this evidence and its initial location are affected in a number of ways by subsequent natural forces and human manipulation. Some natural forces can disturb materials to such an extent that their status as cultural resources is either totally negated (e.g.,a site erodes completely away) or diminshed (e.g., a site is covered with earth or vegetation). Cultural processes that result in impact upon sites include industrial and extractive activities, farming, ranching, real estate development, and archeology.

Remote sensor imagery can be employed by the cultural resources manager to assess the possibilities of all types of future impact on archeological materials, or delineate some of the past impacts on these data, and to monitor impacts through time (described in more detail by Snow, this volume). One example of past impacts that affect the usefulness of cultural resources in the NPRA project is offered by a consideration of site visibility. As any field archeologist knows, what one sees and what is actually present in a survey situation is skewed by factors that make sites and materials either more or less evident to the eye. In large part such factors are cultural, a result of such things as differential curation of artifacts, locale of tool discard or replacement, and manner of disposal exercised by the people who lived at the site. Other factors are natural, such as depth of overlying earth or density of vegetation. The latter natural "impact" on cultural materials proved very significant in the tundra-covered NPRA. In some areas, thick tussock meadow or brush cover prevents seeing anything but obvious structural sites; in dry, wind-blown, areas that host only sparse vegetation, even small flake scatters can be easily identified by survey parties. In the interpretation of Landsat and aerial color infrared imagery currently being performed at the Remote Sensing Division laboratories in Albuquerque distribution of plant cover is expected to serve as a valuable guide both in determining which areas will be fruitful during survey and in identifying biases injected into survey data as a result of plant cover.

Remote sensor imagery is also expected to aid in determining which areas of NPRA will sustain the greatest future impacts from petroleum exploration. Because the transport routes that served prehistoric people in the Arctic are also favored by travelers today, long continuous ridges and drainages are used extensively for tractor trails in the winter. Since it can be predicted that sites located along such routes -- which can be mapped using aerial and space imagery -- will be under maximum threat of impact in the years to come, steps should be taken now to legally and physically insure that sites will be avoided or at least mitigated in these areas first.

One very significant area of impact upon cultural resources often ignored by the archeologist is the process of archeology itself, which obliterates the data content of cultural resources in direct proportion to its intensiveness. Remote sensor imagery can be of use not only in assessing the probability of such impacts but also in diminishing their effects. Aerial photos constitute documentary evidence of site extent, configuration, and local environmental conditions prior to disturbance by excavation or collection; techniques of phased site mapping utilizing stereo bipod photography, currently being developed at the Remote Sensing Division, can provide accurate photogrammetric maps and three-dimensional point locations of artifacts discovered during excavation. Excavation can also be guided by a number of non-imaging remote sensing techniques such as magnetometry, below-ground radar, and seismic metering (Lyons and Avery 1977:40-45).

ASSESSMENT OF THE SIGNIFICANCE OF CULTURAL RESOURCES

The concept of the differential significance of cultural resources was introduced into Federal legislation with the advent of the Historic Preservation Act of 1966, and has caused cultural resource managers and public archeologists difficulty ever since. The origin of the legislated concept of significance seems to stem from the use of the term "resources" and what it implies -- that material cultural remains are valuable in much the same way as are veins of coal or pools of oil, and that the use of part of these resources diminishes our total cultural resource inventory by a proportionate amount; this view is perpetuated in later legislation that insists on total inventory survey as a final assessment stage in areas to be impacted by federally financed or backed construction or disturbance. Given the modern scientific basis of archeology, of course, this view of the value of our record of the past is misleading. The ultimate value of cultural resources stems from the fact that, through their study and analysis, knowledge of past human behavior can be reached. The gross number of items is immaterial in this quest. Simply because there are very few examples of a certain ("unique") site type or object -- or, conversely -- because there are many examples of one sort of cultural evidence, one cannot be said to be more "significant" than another.

It is not unreasonable, however, that those who finance preservation of and research on archeological materials demand justification of the utility of the archeologist's product. Given limited financial resources, limited time, and accelerated national needs for energy expansion, archeology as a profession must meet the question of significance with acceptable answers. There is, of course, a legitimate reason for granting high significance to unique and interesting examples of prehistoric material culture, for millions of citizens visit National Parks and Monuments and other maintained sites, gaining first hand experience and a "feeling" for their national heritage. Ultimately, however, the most valid motive for protecting and studying cultural resources may lie in comprehending the problems faced by past inhabitants of North America and the successful or unsuccessful solutions they devised to alleviate these problems. Fortunately, there is a trend in present practice and policy to include assessments of research potential in the measure of significance.

The research potential of a site or region is, of course, dictated by the problem orientation of those doing research. It is not within the scope or intent of this paper to suggest research orientations, but it should be remarked that, at every stage of cultural resource management, consideration must be given to problems that (1) can be answered with the data at hand, and (2) will yield useful results for the public at large, rather than only for archeologists. As illustrated in this paper, remote sensing methods can play a useful part in the first of these considerations in that remote sensing can permit accurate assessment of the nature of the data available in an area, and, to a certain extent, the physical means that will be required to preserve and sensibly exploit those data. The question of the ultimate public value of knowledge gained through the study of archeological materials is more difficult; this will rest in the final analysis with the imagination and abilities of scientists to apply their data to social and environmental problems facing us today. The regional, composite picture presented by remote sensor imagery lends itself to this sort of constructive thinking, and has and will continue to serve as the abstract basis for problem formulation in archeology.

CONCLUSION

It is the thesis of this paper, and of the other contributions in this volume, that remote sensing provides the ideal vantage from which to assess the nature of archeological data, determine the extent of past, present and possible future impacts on material cultural evidence, and ultimately to make the pursuit of knowledge of the past justifiable in economic and social terms. At all stages of large-scale cultural resources management projects, space and aerial imagery and measurements derived from these sources can increase the efficiency and completeness of logistics, research, and administration. Going beyond the simple physical treatment of cultural resources, the study of remote sensor data may also be the most direct path toward the justification of archeological science. Remote sensor imagery records not only archeological data, but also constitutes, frame by frame, a lasting document of situations on the ground at a particular instant, including the location and patterning of cultural resources, landforms, geology, climatic conditions, and probably a host of data not even imagined at present. Modern data collection techniques such as that represented by high quality Landsat imagery offer a regional perspective, far more useful in crossing disciplinary boundaries than the narrow focus of traditional archeological methods, and also afford an economical and periodic means of recording information necessary for monitoring the changing condition of cultural resources and the environment.

The application of remote sensor data in the NPRA project is only in the preliminary stages, but can serve as an example of some directions that the justification of cultural resource management and research might take. The circumpolar Arctic, subject to severe and easily measurable climatic change, offers an ideal "laboratory" for the observation of fluctuations and periodicities in global circulation patterns that affect the climate of lower latitudes as well. Whereas our instrumental record of meteorological conditions spans only slightly more than a century and geological indications of past conditions often suffer from lack of resolution, the dating of alternating cultural adaptations in the Arctic may be the key to revealing the nature of climatic cycles with greater discrimination. Landsat and other remote sensor imagery are presently being used as the basis for planning investigations of Early Man in the NPRA area with this in mind, and we hope to be able to report on this aspect of studies there in more detail in the near future.

Finally, and perhaps most importantly, remote sensing methods may occupy a significant place in the philosophical pursuit of archeology -- in the determination of problem orientations which can offer solutions of benefit to mankind in the future. There is a tendency within archeology, as in any science, for the practitioner to become so involved with his data base that he allows inquiry to stop there -- imagining, for instance, a tool type or pottery style "developing" or evolving from another, or dwelling on the day-by-day reconstruction of events at a specific site. Such pursuits are fun, and can be "sold" as intriguing even to non-archeologists, but in the end are unproductive and insupportable in and of themselves. Aided by the broad, interdisciplinary scope injected by remote sensor data, archeology may in the near future transcend its traditional narrow focus. This may, in fact, be one of the best justifications for a public, and publically funded, archeology: that it will, in the end, arrive at useful knowledge derived from past material remains or perish in the attempt.

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AUTOMATED DATA PROCESSING
OF
DIGITAL AERIAL IMAGERY
IN
CULTURAL RESOURCES SURVEY

by

Dwight L. Drager

INTRODUCTION

Because of increased activity in such fields as dam building, mining, oil well drilling, road building, and the like, archeologists are more frequently finding themselves faced with the problem of assessing the cultural resources contained on extremely large pieces of land. The largest archeological survey ever undertaken, some 23 million acres, is currently underway in the National Petroleum Reserve in Alaska (Ebert 1977). Though this may be an extreme case, and few archeologists may ever find themselves faced with the problems created by a survey of this magnitude, many will be working with areas of land much larger than can be dealt with by ground survey technques within the time constraints imposed by contracts and deadlines. Methods have been developed for aerial remote sensor data-gathering in large-area survey that will increase the efficiency of these surveys.

It takes much less time to look for environmental and cultural resources information on a series of aerial photographs of an area than it does for a survey crew to perform a blanket survey of the same area. Aerial photographs are much more efficient than topographic maps for indicating the location of transects and discovered sites, as anyone who has ever compared the two methods can attest (Loose and Lyons 1976:69-71).

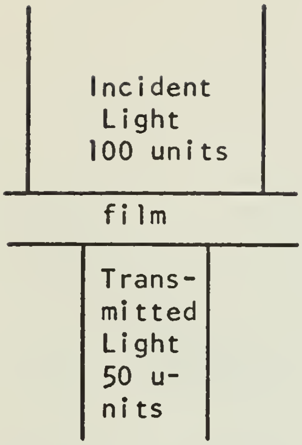
But perhaps the fastest way to examine an area is by instructing a computer in what to look for and then letting the computer search the data for the targets of interest. The kinds of targets the computer can identify, be they archeological sites, vegetative zones, land forms, or other features, will be determined by a number of factors such as target size, system resolution, and contrast with surrounding environment. The kind of examination performed will depend on what the researcher is attempting to identify. To understand this approach, it is first necessary to determine how photographic information can be turned into a computer-compatible form.

PHOTO DENSITY

Photographs consist of metallic silver crystals unevenly spaced on some base, either white paper or a clear film. (The following discussion comes mainly from Dupont 1966.) When light is shown through developed film the silver absorbs some of the light. Depending on the amount of silver on the film, more or less light will be transmitted through the film. The ratio of the light that strikes the film to the light that is transmitted through the film is called the transmittance at a specified point on the film. Transmittance can be expressed either as a ratio or as a percentage. For instances, it is possible for a point on a sheet of film to have a 50% transmittance factor.

The reverse of film transmittance is opacity, i.e. the amount of light that is not transmitted by the film. Thus, opacity is the reciprocal of the transmittance ratio. In other words, transmittance is expressed mathematically as $T=I_t/I_o$, where T is transmittance or transmission factor, I_t is transmitted light, and I_o is incident light, or the amount of light that actually strikes the film. Opacity, then is the reciprocal of this value or O=1/T or I_o/I_t. For example, if I_o, the amount of light that strikes the film, is 100 units, and I_t, the amount of light that is transmitted through the film, is half the amount, or 50 units, then T, transmittance, or the amount of light that passes through the film is I_t/I_o, 50/100, or .5, which is the same as 50% Opacity in this example is I_o/I_t, 100/50, or 2. Both of these measurements state that twice as much light strikes the film as is allowed to pass through it. Figure 1 illustrates this point.

It is possible to use the opacity measure to obtain another measurement which is much easier to deal with. This measurement, density or photo density, is the logarithm of opacity. The convenient aspect of density is that it is an additive measure. If two pieces of film of differing transmittance values are superimposed, the resultant transmittance value will be the product of the two. However, because density is logarithmic, the resultant density will be the sum of densities of the two pieces of film. For the calculation of exposure, filter packs, and other photographic concerns, this logarithmic nature is extremely important. For the purposes of this paper, it is important only that the concept of photo density be established. The larger the density value, the darker the point on the film.



$$I_o = 100$$

$$I_t = 50$$

$$Transmittance = \frac{Io}{I_t} = \frac{50}{100} = 0.5 \text{ or } 50\%$$

$$Opacity = \frac{1}{t} = \frac{1}{I_t/I_o} = \frac{100}{50} = 2$$

$$Density = \log_{10} \text{opacity}$$

Transmittance	%	Opacity	Density
1.0	100	0	0.0
.5	50	2	0.3
.25	25	4	0.6
.10	10	10	1.0
.01	1	100	2.0
.001	.1	1000	3.0
.0001	.01	10000	4.0

(after DuPont 1966:15)

Figure 1

The relationship between the photographic measurements of transmittance, opacity, and density.

DIGITIZATION

In the conversion of photographic data to data usable by a computer, photographic images can be turned into numerical values in several different ways. An instrument known as a "densitometer" provides instanteous density readings for points on film. A light source of known intensity shines through the film through a standard aperature, usually a round hole, and the transmitted light is read from the opposite side. The densitometer presents the readings in density values. It is possible for an operator to scan a photograph with a manual densitometer taking a series of readings and recording the values obtained. However, this is extremely slow and inaccurate since it is difficult for the operator to move the photograph the correct distance before taking the next reading.

One solution is to use a scanning densitometer. Scanning densitometers automatically take readings at preselected intervals across a photograph, a much faster and more accurate way of digitizing a photograph.

Another solution is to use a closed-circuit television system that is equipped with a scanning videometer. Since a television display is simply a series of small dots with varying intensities, the voltage input to each dot on the screen, or picture element, called a pixel, can be read and either converted to a density value or recorded as some function of the voltage.

ELECTRONIC SCANNERS

A method of obtaining computer-compatible data more efficiently than digitizing photographs is to use an electronic scanner to collect the original data (see Morain and Budge, in press, for discussion). An electronic scanner carried in an aircraft scans the surface of the earth with a light sensitive instrument and records the variations in the earth's reflectance directly onto tape. The size of the angle of view of the instrument, the altitude of the aircraft, and the instrument configuration will determine the size of the pixels for that scanner, and hence its ground resolution capabilities (Morain and Budge, in press). If objects on the ground are smaller than one pixel, the surrounding environment will contribute to the value recorded by the scanner (Figure 2). Unless the edges of the pixels exactly concide with the edges of an object, some smearing of the object's borders will occur (see Figure 3).

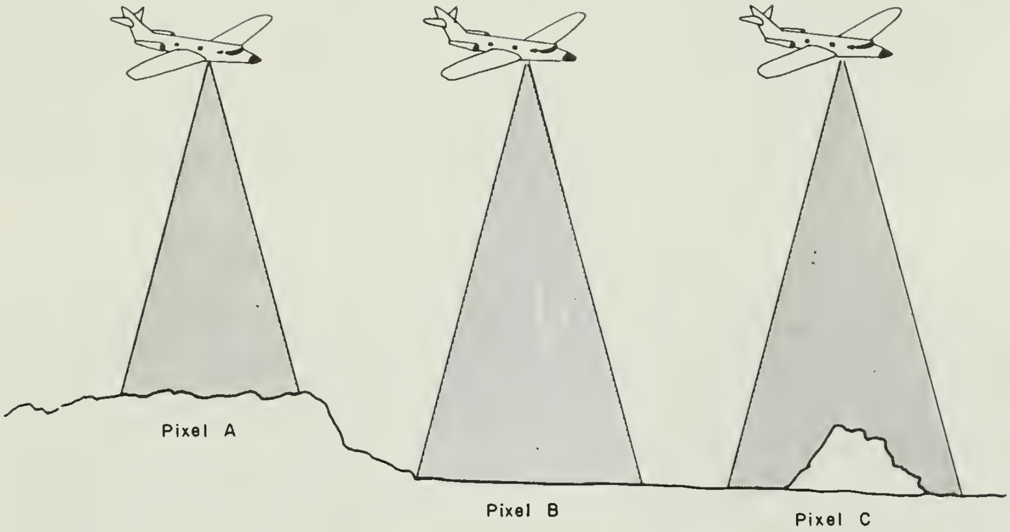
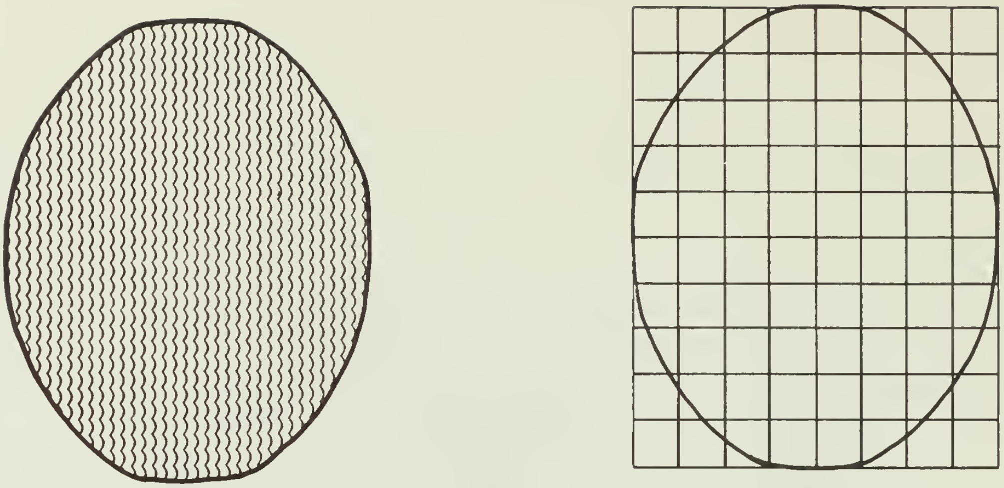


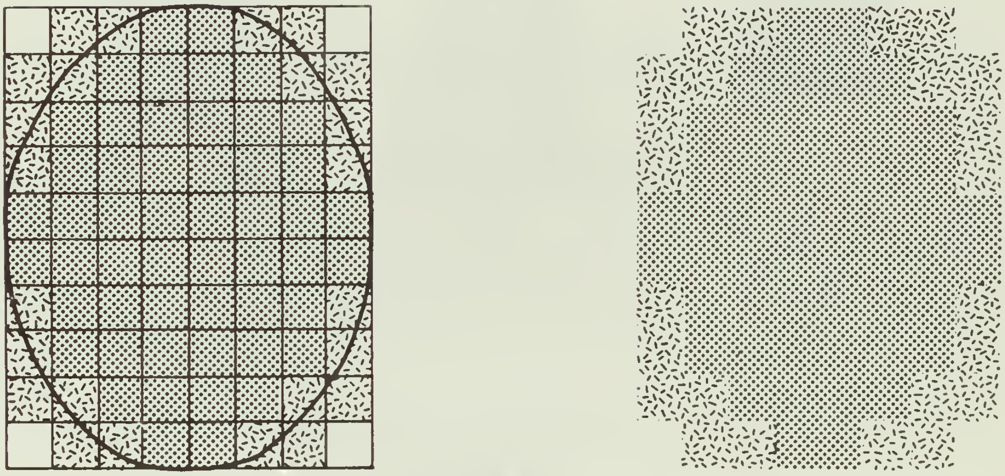
Figure 2

An image pixel is a composite of all reflectances within the sensors' instantaneous field of view. Materials larger than a single pixel, as in pixels A and B, will give a reading expressive of that material. Objects smaller than a single pixel, as in pixel C, will give a reading that is a composite of the object plus the surrounding environment.



a. Target Shape

b. Pixel Pattern



c. Pixel Densities

d. Final Image

□ no density

▨ partial density

▩ maximum density

Figure 3

An object with edges that do not coincide with the edges of pixels will be distorted. The oval object, a, when viewed by pixel pattern b, will give values shown in c and a final image shape indicated in d.

One advantage of electronic scanners is their ability to obtain what is known as multi-spectral data. Electronic scanners interpret the electromagnetic spectrum as a series of narrow bands, each band containing a specified range of wavelengths (see Figure 4). The scanner will record the spectral response of an object within the field of a pixel as a group of densities by recording a value for of the different bands. For example a green object will elicit high spectral response in the bands that record "green" light, but low response in all other bands. If an eleven-band scanner is used to record the object, the first three bands may show low responses, the next three high responses, and the last five low responses again. The specific values found in all eleven bands or channels at a particular pixel can be used to develop what is called a signature for that object (Figure 5).

It is important to recall that photographs are actually composites of many factors that contribute to the image. For example, in an aerial photograph, the density of a grassy meadow results not only from the spectral response to grass in the meadow, but also from other factors such as color of the soil, amount of haze in the air, angle of the sun, light intensity, etc. For this reason, it is difficult to relate photo density values directly to objects in the world without rigorous field-checking. However, the more familiar a researcher is with the area of study prior to undertaking photo interpretation, the more reliable are the interpretations that are made. The premise behind viewing photographs of an object rather than the object itself is that interpretation is reliable to a high degree to begin with.

IMAGE MANIPULATION

Analog Techniques

It is possible to manipulate photographic images in several different ways. The best known is the use of various darkroom techniques to increase contrast, or improve interpretability of highlight or shadow areas. One useful technique is known as edge enhancement. Positive and negative transparencies of the same area can be superimposed and viewed on a light table. When slightly offset, light is transmitted through the images along the edges of objects. Because the shapes of cultural features are frequently regular--lines, circles, or rectangles--edge enhancement permits easy discrimination of non-natural objects.

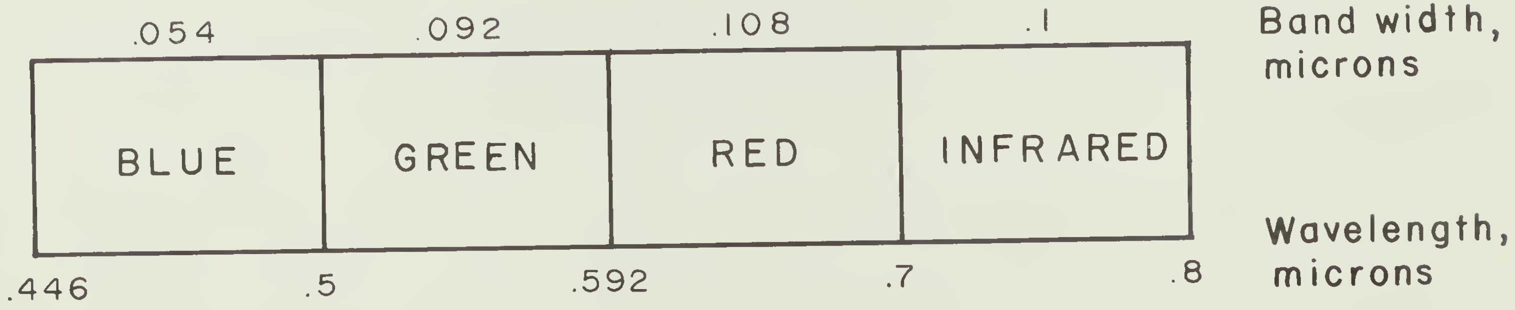


Figure 4

Possible configuration of an electronic scanner's bands.

Channel	Response	Density
1	.40 - .43	.02
2	.43 - .46	.04
3	.46 - .50	.08
4	.50 - .53	1.20
5	.53 - .56	1.50
6	.56 - .60	1.20
7	.60 - .63	.16
8	.63 - .66	.08
9	.66 - .70	.04
10	.70 - .80	.02
11	1.10 -1.30	.02

Figure 5

An example of the kind of spectral response that can be used to develop a signature.

Electronic image manipulation can be performed by special closed-circuit television systems designed for this purpose (see Lyons and Avery 1977). In a manner similiar to the techniques discussed above, the constrast of an image on a television monitor can be increased or decreased to aid in the interpretation of an aerial photograph. Electronic edge enhancement can also be performed on a television monitor by creating both positive and negative images on the screen and then offsetting one from the other by introducing a time delay into one image (Figure 6).

A technique known as density slicing is accomplished by dividing a black-and-white image into a series of discrete density levels and then displaying each different level as an arbitrary color. The colors are usually arranged in an order that differs from the order of colors in the visible light spectrum to permit sharp distinctions between subtle differences in photo density (Figure 7).

A final procedure that can be performed electronically is the conversion of photo density to "elevation." A series of horizontal lines is projected across a screen and the lines are then modulated vertically as a function of photo density. Bright (low density) objects are usually modulated the most, dark (high density) objects modulated the least (Figure 8). Linear features appear as projections above or below the surrounding environment.

Digital Techniques

A useful manipulation technique involves conversion of images to a computer-compatible form through a digitizing procedure, after which a computer is instructed to manipulate either a closed-circuit television system or a printing device. The advantage of using a computer to perform image manipulation lies primarily in the ability of a computer to deal with large masses of data and to perform almost any kind of manipulation. It is possible to compare several images of the same area or object at once and look for changes in the images. Data from several bands of multispectral imagery can also be manipulated in various ways. Bands can be numerically added to each other, ratioed, or subjected to various other mathematical procedures. The resulting data can then be displayed in the manner that will make the data easiest for the viewer to interpret. Manipulations of this type make it possible to exaggerate certain aspects of an image beyond the capabilities of any other technique. For instance, invisible information, such as thermal infrared characteristics, can be coupled with visible light to yield an image that can be produced in no other way (Morain, Budge, and Komarek n.d.).

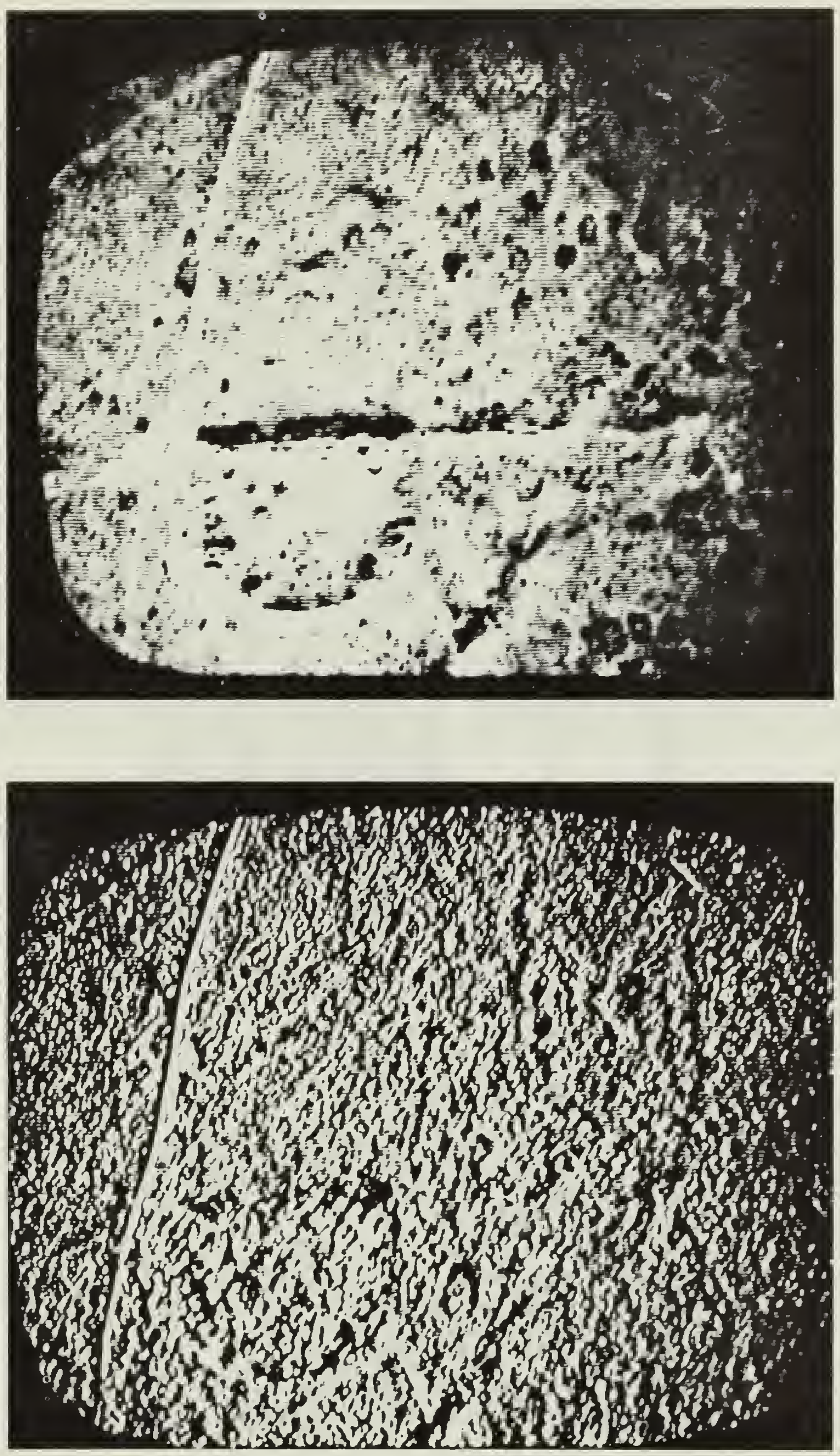


Figure 6

Electronic edge enhancement. Upper photo: before enhancement. Lower Photo: after enhancement. The system used to produce these photos is an International Imaging Systems Digicol.

Figure 7

Density slicing with the International Imaging Systems Digicol. Upper photo: before density slicing. Middle photo: band arrangement and width. Lower photo: density-sliced image.

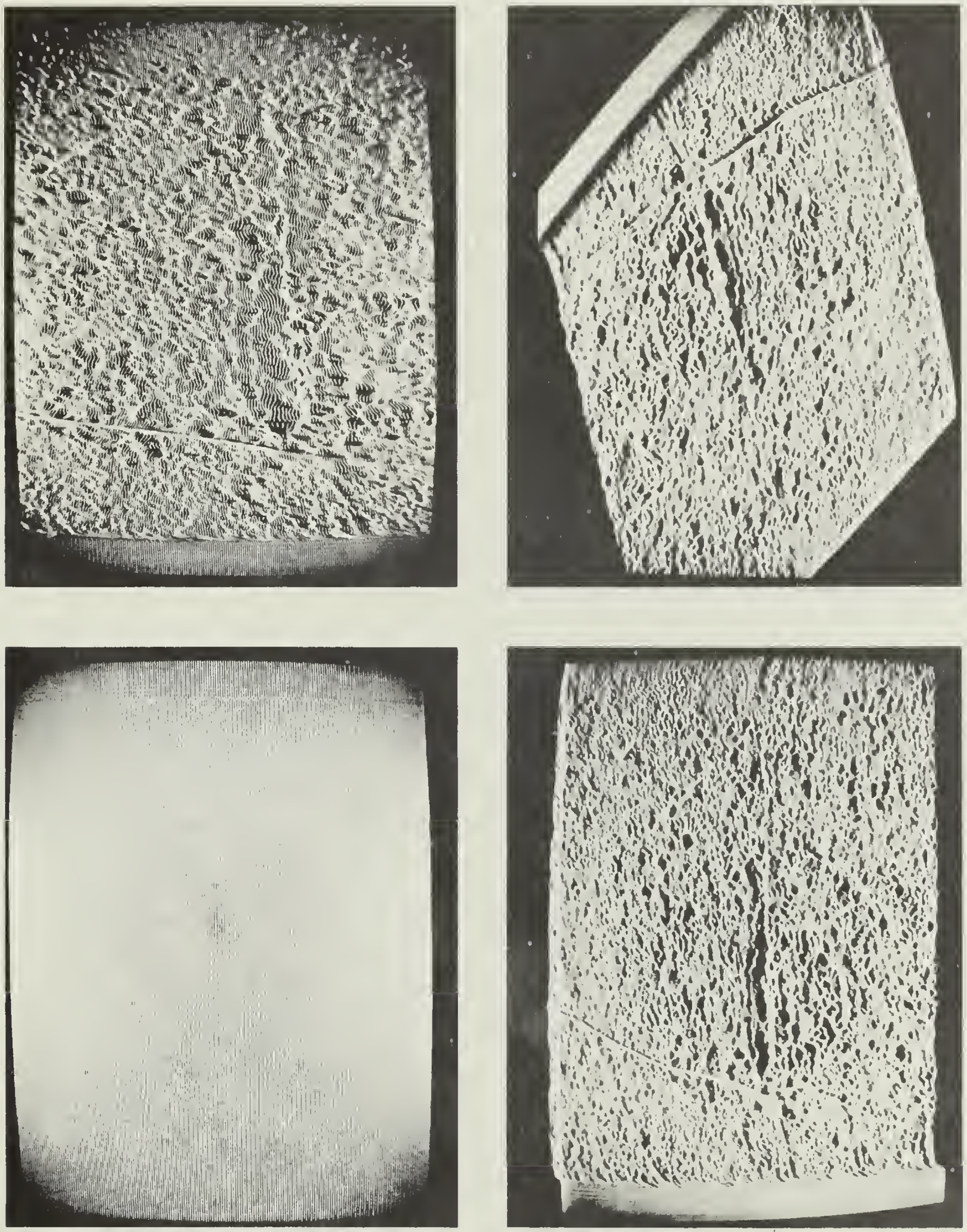


Figure 8

Perspective display. Horizontal lines are modulated vertically and can be viewed from varying angles.

One of the most effective uses of computer analysis of multispectral data is in the supervised development of spectral signatures (see Williams 1977 for discussion). In supervised signature development the reflectance of a known target on the ground is examined and its signature determined. The computer then searches all pixels of values that correspond to that signature within a specified tolerance. All pixels meeting the criteria are then displayed in one manner--all other pixels being displayed differently. The interpreter should remember that factors such as sun angle, shadows, vegetative cover, haze, etc. can act to confuse the computer by obsuring true density values, thus assigning some pixels to improper categories. Correct assignment of pixels, however, is possible through sample field verification.

Unsupervised signature development is also possible. In this procedure, a cluster analysis is performed on the data in all channels for each pixel, the resulting clusters being identified as the targets with a field check identifying the targets.

Supervised signature development is a much more efficient method of using computer time. A supervised search of data reveals those pixels that have the highest probability of being the same as the object used to train the computer. In an unsupervised search, the clusters that result may have little or no relationship to the categories required by a research design. For instance, if a researcher is interested in discovering vegetative species, an unsupervised search may be able to discriminate only at a total plant community level. Conversely, if the investigator needs only to distinguish plant communities, an unsupervised search may discriminate individual species, causing the researcher a good deal of extra work.

STRATIFICATION

On advantage of using remote sensor data for archeological purposes is that non-cultural units that have affected the location of archeological sites can be identified. Since most archeological sites are not directly visible on most aerial photographs, visible natural features thought to have influenced site location in the area--vegetation, landform, soils, surface geology, etc.--are pinpointed. The features identified can then be used to develop a predictive scheme that will project possible site locations in areas that have not yet been ground surveyed.

Once the categories on an image have been decided upon, it is necessary to determine whether the categories identified are in fact what they are suspected of being and whether they are adequate to demonstrate the intended variability. In other words, once a series of environmental categories has been defined and mapped from remote sensor data, it is necessary to field check those categories to determine whether they are accurate. In most instances, they will be. For example, grasslands will rarely be confused with forests. It must then be determined whether the identified categories can yield appropriate predictive information. It may prove that the vegetative categories decided upon are too fine for the level of discrimination for which they were intended. If it is determined that the same kinds of archeological sites occur in more than a single vegetative zone, it may be possible to combine zones to reduce data handling problems. Or, it may be discovered that several kinds of sites occur in what was categorized as a single vegetative zone. In this case, it may be necessary to discriminate at a finer level than was done originally.

Using a method such as that just described, updating of the initial map can be done in stages to arrive at the best stratification scheme for the task at hand. It may be that several classes of data are required to reflect all the different kinds of site locational variability. If maps of the surface vegetation of an area do not adequately reflect the archeological site variability encountered in an area, other variables--soils, slope, rainfall, elevation--may need to be included. It is well to remember that site function influences location: habitation sites are often located near arable soil; lithic scatters near game trails; even sites of similiar function but of different cultural affiliation might have been located in response to different environmental conditions. For these reasons, it is essential to examine each environmental variable vis-a-vis each site type. Again, this can be done most effectively using such well-known computer techniques as factor analysis (see Rummel 1970 for discussion).

The final test of the predictive capabilities of a stratification scheme can be performed only by rigorous field checking. Sample areas can be examine to evaluate whether site locations in fact occur in expected proportions. If not, further updating of stratifaction categories may be necessary.

CONCLUSIONS

A major goal of any of the procedures discussed here must be to aid the cultural resource manager in gaining information about the status of the resource he is managing. Only with the most reliable data can intelligent decisions concerning the exploitation of cultural resources be made.

Execution of the large area research programs now being thrust upon archeologists is also most efficiently conducted through the use of remote sensing procedures. Information derived from regionally-oriented multi-disciplinary research projects can be coordinated easily using remote sensing. After acquisition of the original information in the form of aerial photos or computer tapes, many different types of data, usable for many different types of studies, can be derived.

Though fieldwork has been the primary data-gathering strategy in archeology, the introduction of remote sensing procedures (Lyons 1976; Lyons and Hitchcock 1977; Lyons and Avery 1977) can aid immensely in preparation for field activities. The massive data collection techniques of remote sensing coupled with the massive data handling capabilities of computers provide archeologists with a means for deriving the greatest possible amount of information before excavation or other destructive field investigations are initiated.

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ECOLOGICAL MAPPING FOR PURPOSES OF SAMPLE STRATIFICATION IN LARGE-SCALE CULTURAL RESOURCES ASSESSMENT: THE NATIONAL PETROLEUM RESERVE IN ALASKA

Galen N. Brown
James I. Ebert

INTRODUCTION

In April and May of 1977, the National Park Service initiated the large-scale cultural resources assessment of the National Petroleum Reserve in Alaska (NPRA), an area of nearly 23 x 10^6 acres extending from the Arctic Ocean southward to the crest of the Brooks Range. Since this area is soon to be opened by the Bureau of Land Management to petroleum exploration, time is a crucial factor, and the problems created by an enforced 2-year survey time limit are further complicated by the extremely short 8-10 week summer field season dictated by the Arctic climate. Yet another constraint on fieldwork in NPRA is the extreme inaccessibility of much of the area, where wet tundra conditions allow travel only by air (largely only by helicopter) and foot. While area to be covered, personnel access, time and funding are factors in the planning of any archeological survey these mild difficulties become severely-felt restraints in very large-area surveys like that of NPRA. It quickly becomes apparent that some more "traditional" practices of cultural resources survey -- some of which are actually required by law and policy -- are either unrealistic or impossible.

One such practice is "inventory" survey, and it is the thesis of this paper and others in this volume (Ebert, this volume; Lyons and Scovill, this volume) that there is, for practical purposes, no such thing. Cultural remains left behind by past people are distributed as they are because of the necessities and possibilities presented people by their environment -- and this enables one to sample, rather than attempt to find "all the sites", and predict distributions of sites and materials. While it has been suggested at times in the archeological literature that random sampling should be employed as a first, unbiased sampling stage (Hill 1967; Binford 1964), this would be appropriate only if sites and materials were distributed in a homogeneous manner -- and they never are. An ecologically-informed, stratified sampling design is more economical and faster, for the archeologist starts from the beginning with an explicit model; the products of human behavior are the result of adaptation to varying conditions under which their makers lived.

One of the most comprehensive and efficient means available to the archeologist for the ecological stratification of a survey area is through remote sensing, the practice of collecting data without physical contact with their source -- usually through aerial or space imagery. Especially appropriate for large-area stratification is Landsat space imagery, which is telemetered to the earth by a satellite which covers almost the entire surface of the globe each 18 days (two satellites, Landsat I and Landsat II, actually provide coverage each 9 days, and a third is to be launched early in 1978). This imagery is collected in 4 bands, which provide a means for many multispectral combinations and the enhancement of various ground features; in addition, it is relatively correct geometrically and has been used extensively in the past for purposes of thematic mapping. Each frame covers about 100 x 100 nautical miles, thus providing a regional overview; nominal resolution is about 200 x 200 meters using unenhanced imagery, but in practice much smaller features, such as roads, can be detected.

In response to the problems which were to be encountered in the NPRA cultural resources survey, it was determined that the area would be ecologically stratified, using Landsat bands 5 and 7 imagery, as a basis for initial sampling.

CARTOGRAPHIC METHODS

After a preliminary literature and map search, no suitably-scaled or detailed cover-type maps were found which covered the entire study area. Vegetative maps exist only for parts of NPRA and are of too large a scale to be of use for purposes of regional stratification. In 1973, the Joint Federal-State Land Use Planning Commission for Alaska produced a map (scale 1:2,500,000) and classification scheme describing Alaskan vegetation which was judged to be too general for our needs.

The preliminary ecologic stratification of NPRA was begun in the summer of 1977 using Landsat imagery at a scale of 1:1,000,000; scenes were ordered which were obtained when plant communities and their boundaries would be most easily apparent, which is during the time of maximum vegetative growth -- from June to early August on the North Slope. Scale of the base map on which delineations were to be drawn was also an important consideration. A map which is too large is cumbersome and impractical in the field. On the other hand, a map too small could not show accurate and clear delineations of units. A compromise was met and plans were set for a map to be made at a scale of 1:500,000; this can be considered a medium-scale map. Image scenes ordered were at scale 1:1,000,000 requiring an enlargement of 2x for compatibility with a 1:500,000 base. The base map chosen had to have a minimum of unnecessary information, such as political nomenclature or topographic shading which might confuse the reader. It was decided after careful consideration of many potential maps to enlarge the Barrow and Umiat USGS 1:1,000,000 scale (North America) sheets printed with shaded contours. Fortunately, political names were few and topographic shading appeared primarily only in the southern margins of NPRA where the highest peaks of the Brooks range occur.

Because of the time-lag inherent in acquiring imagery, map construction progressed in two phases. The preliminary mapping stage was for the most part an attempt to assess the feasibility of mapping ecologic zonation utilizing black-and-white Landsat band 7 imagery exclusively. Upon completion of this preliminary phase subsequent imagery needed for complete NPRA coverage arrived and a revised map edition was compiled. A total of seven Landsat 2 scenes were available for coverage of the study area; these were:

Scene Identification #	Date
2113-21572	15 May 1975
2506-21340	11 June 1976
2506-21343	11 June 1976
2524-21331	29 June 1976
2539-21153	12 July 1976
2557-21152	1 August 1976
2557-21155	1 August 1976

MAP CONSTRUCTION METHODOLOGY

Interpretation of the imagery proceeded according to traditional qualitative techniques based on tonal and textural differences observed in each scene. Boundaries were drawn on acetate overlays for each of the images. Of course, delineations and boundary locations are subject to criticism and debate in some places; often two or more interpreters and stringent ground truth are required to resolve this sort of problem. Delineations on the eight overlays were transfered to the base map with the aid of an Artograph, Inc. Map-O-Graph. Some corrections were made on the preliminary map work sheet; these included line closures and line revisions.

Boundary representations have always been a problem of concern to vegetation mappers. Very often in the real world sharp distinctions between cover types does not exist. This is particularly true in places of gradual climatic or elevational changes. Hueck (1960) established three conventional categories of boundary marking for vegetative maps: a continuous solid line for accurate boundaries, dashed lines for reasonably accurate boundaries, and dotted lines for inferred, vague boundaries of vegetation. We have adapted this format in our delineation--because of the absence of ground truth data, it was felt dashed lines are appropriate at this stage. In some instances sharp, easy-to-detect boundaries are observed on imagery. This is a result of dramatic differences in topography, climate, soil, or water economy within short distances.

COVER-TYPE CLASSIFICATION

Ecologic cover-type mapping for purposes of sample stratification is the preliminary stage to be followed eventually by more refined sampling stages. At the preliminary level, the scale of category classifications, or strata, should not be unnecessarily fine. Therefore, in the first edition of this map only five cover-type units were defined. Later, additional imagery made possible spatial extension to include ecologic zones not defined in the preliminary edition. Two more units were then added for a total of seven cover-type units.

It is widely accepted among archeologists that there are relationships between environment and human behavior, past and present, though the causality behind these relationships is not fully understood in all cases. Generation of a predictive site distribution model should involve inspection of sufficient strata or environmental zones to help resolve the problem of explaining behavioral differences. However, an overabundance of defined ecologic/cover-type zones may make comparisons obscure and differences between units become less unique. For this reason, only 7 units were defined on the final map. In addition, because of small scale 1:1,000,000 interpretation and delineation of actual plant associations, discrimination of communities or families is impossible. This dictates that the legend must be broad. A recently-published USGS Professional Paper (Anderson, et al. 1976) discusses comparability of remote sensor data from varying altitudes and scales with systematic land use/cover classification schemes. Spatial resolution is the basis for defining four information levels corresponding to sensor platform altitudes. Landsat data in the form of black and white prints, scale 1:1,000,000, is classified by Anderson in Information Level I; at this level, his classification scheme indicates only one Arctic cover type, "Tundra", as distinguishable. In contrast, we feel confident that at least seven categories can be distinguished.

Also important to the thematic cartographer, in addition to numbers of categories, is the idea of label consistency. A binding parameter, when speaking of physiographic terms, is that all units in a legend must relate to each other -- for instance, when a floristic legend describes plants taxnomically at the family or genus level, species names should not be included. The legend must be of uniform consistency and be constructed with the purpose of the map in mind.

Because places exist in NPRA that are not vegetated, i.e. beaches of shifting sand and bald mountain peaks, a solely vegetative legend was not strictly appropriate. The map instead shows varying cover types, whether they be organic or inorganic. This map does discriminate vegetation but not a completely floristic or physiognomic basis. Instead, an ecological approach was employed. An ecologic/cover-type map describes the relationship of vegetation to one or more environmental factors affecting it, such as soil type, topography, climate, altitude, hydrology, etc. The predominant environmental factor affecting vegetative spectral signatures in NPRA is ground surface wetness or soil moisture. Soil wetness in turn responds to numerous other environmental parameters, of which several were listed.

Landsat's sensor, a multispectral scanner, receives and records radiant energy from the earth in 4 wavelength bands. Our imagery was produced from the infrared band 7. We chose to execute mapping utilizing this band especially because of the unique signature recorded from water bodies. Moist or wet places on the earth appear as dark tones or black. Our observations led us to believe that tonal contrast, though not spectacular in the tundra, is related to surface drainage. Light -toned areas on image scenes are better-drained, higher in elevation, or steeply sloping; supportive evidence for this is that fewer oriented lakes are seen in places of highest tones. Foothill and mountain areas are also of very light tone.

Categories defined for the preliminary edition of the Ecologic/ Cover-Type map (Fig. 1) were five in number:

A. Wet and/or dry sandy surfaces (beaches).
B. Moist Tundra.
C. Very moist to wet Tundra.
D. Wet Tundra (standing water in places).

In addition, a category was defined that represents the floodplains. Though very difficult to observe on this small scale imagery, this category is inferred in some locations. This unit is always accompanied by another of the above units, and is designated:

E. Brush.

Upon receiving the additional imagery necessary for the complete coverage of NPRA, a second stage (revised) edition of mapping was initiated. Methodology was essentially identical to that for the preliminary edition. Band 5 as well as band 7 image scenes were inspected for suitability.

Two more cover types units were added in the compilation of the revised edition (Fig. 2). These were:

F. Bare Rock with Alpine Tundra in places.
G. Alpine Tundra.

Interpretation of bare rock surfaces was relatively straightforward due to great tonal contrast in these areas observed in both spectral bands. Distinction of bare rock from water bodies was possible because of rough rock texture compared to smooth water surfaces. Subsequent NASA high-altitude color infrared imagery flown during the summer of 1977 revealed that many bare rock zones are not entirely devoid of vegetation, but instead host sparse Alpine vegetation in protected places. For this reason the term Alpine Tundra was lumped with the bare rock category.

Alpine Tundra is distinguishable from moist Tundra because of its lighter tonal signature. It is found in places of higher elevation and lower ground moisture subject to a more severe climatic regime than moist tundra. It is very probable that species classified in the moist tundra category do in fact co-exist with species of the Alpine Tundra ecozone. Following with this premise, plant species are not necessarily inseparable according to the categories defined. We were not mapping particular plant habitats but instead delineating areas of similar tonal and textural attributes.

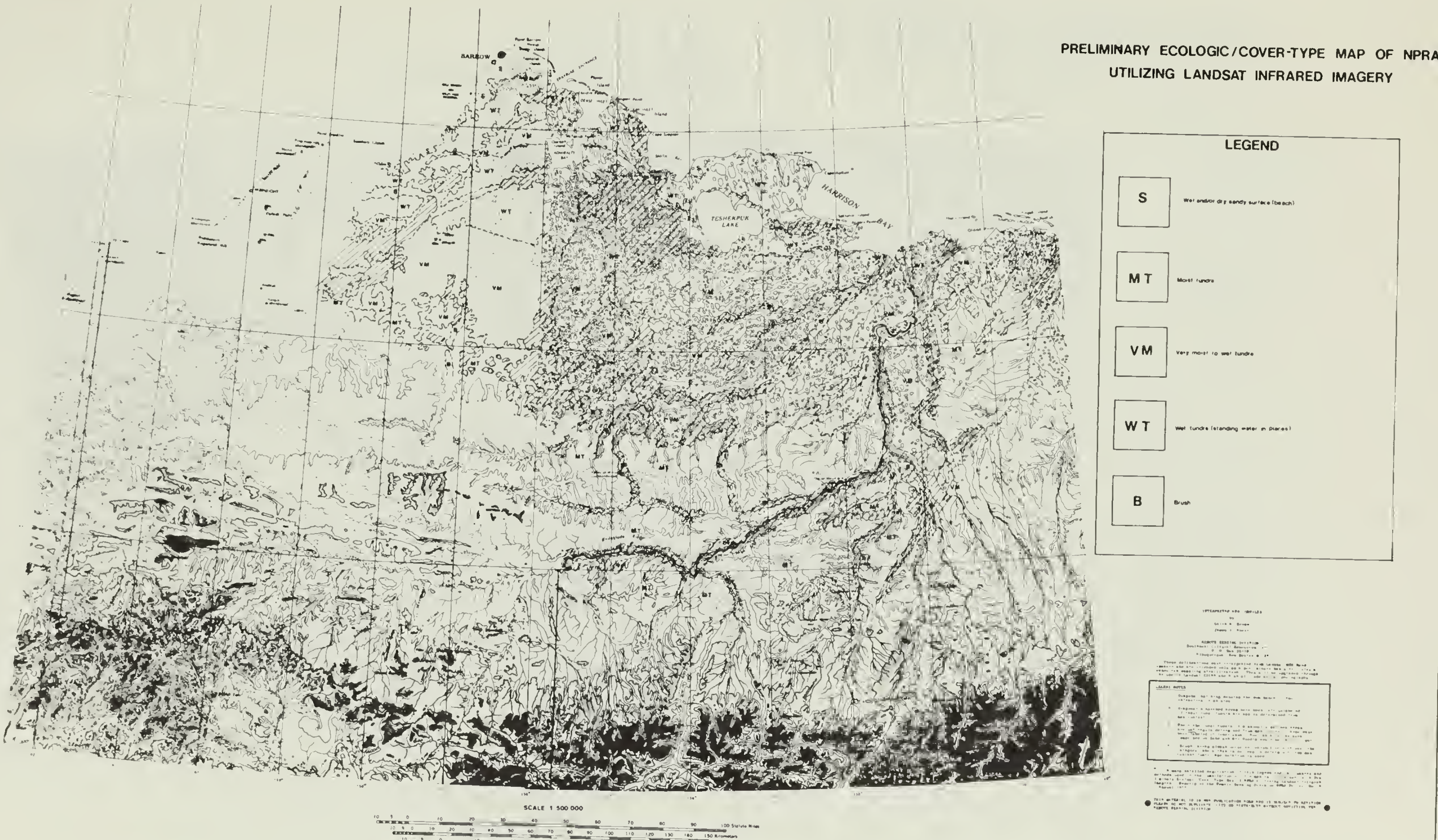

Figure 1

Preliminary Ecologic/Cover-Type Map of the National Petroleum Reserve in Alaska. The original compilation was made at a scale of 1:500,000. Five cover types were discriminated in the first Interpretive effort.

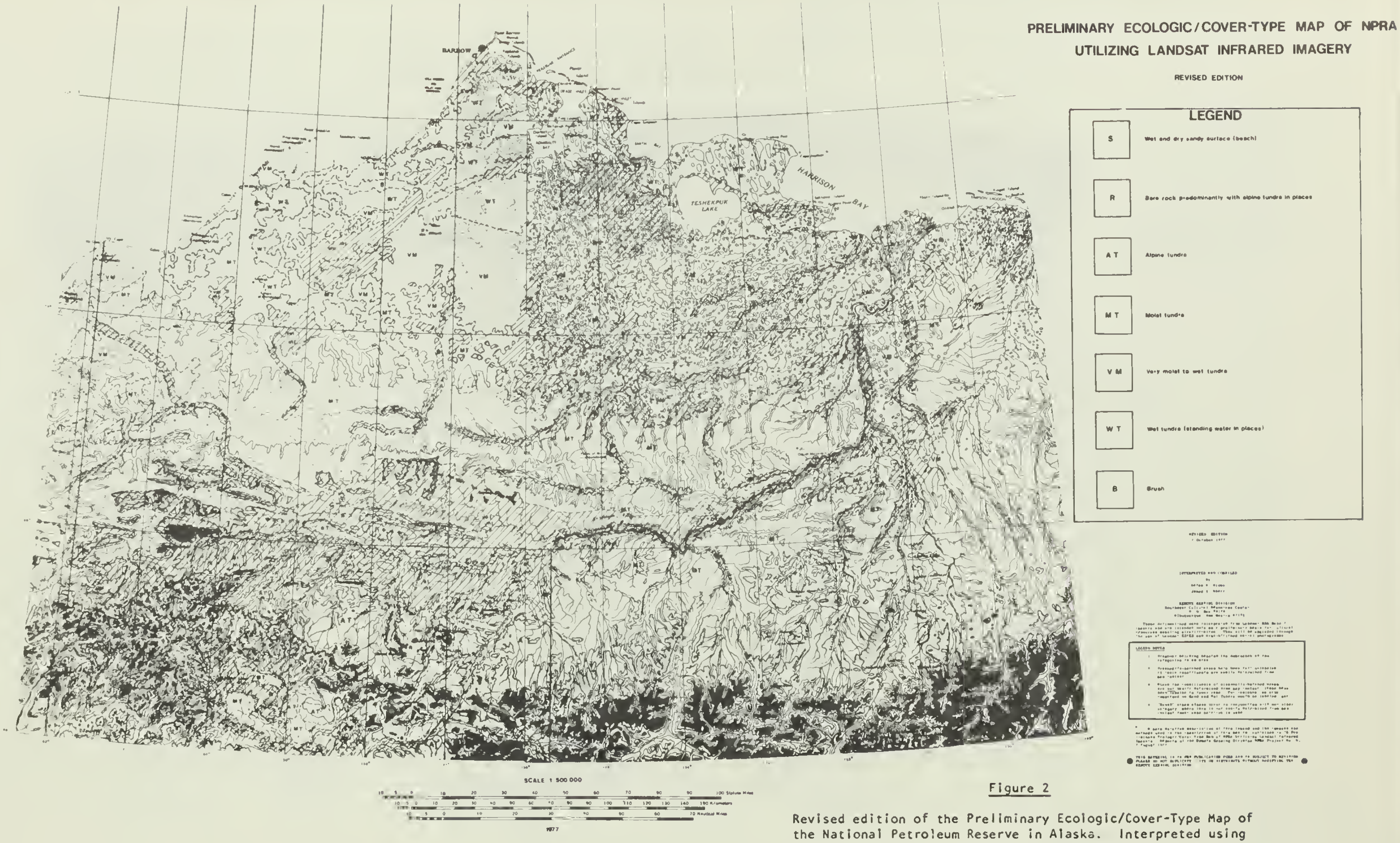

Figure 2

Revised edition of the Preliminary Ecologic/Cover-Type Map of the National Petroleum Reserve in Alaska. Interpreted using more complete imagery coverage than available when the map in Figure 1 was compiled, this map includes 7 discrete cover types. A magnifying glass is recommended for close inspection of map details.

It was discussed earlier in this paper that cover types often do not have sharp boundaries (thus the need for dashed delineations). In southern parts of NPRA, due to great elevational diversity and soil moisture fluctuations, two cover types exist in short distances in many places. In the foothills province, this was especially apparent. A massive transition zone is indicated on the map for Moist and Alpine Tundra vegetation; in order to graphically display transition zones, diagonal alternating bars are employed. These are of equal width, and represent the co-existence of cover types.

The southernmost, mountainous part of NPRA is a place of extreme elevational and climatic contrast. Because of great physiographic variability over short distances, boundary locations tend to be more generalized than in any other physiographic province. With the inclusion of transition zones, a total of 13 effective cover types results.

CONCLUSION

The realization that all cultural resources survey activities result in samples and not "inventories" relieves the archeologist from any temptation to dwell on "unique" occurrences or specific sites, at least in the assessment stages of his project. Instead, emphasis is placed on the informed stratification of the study area. The ecologic/cover-type mapping of the National Petroleum Reserve in Alaska, discussed in this paper, demonstrates the utility of relatively low-resolution space imagery in the process of cultural resources sampling of this sort.

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REMOTE SENSING MONITORING OF IMPACT ON CULTURAL RESOURCES

by

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All resources, natural and cultural, are subject to impact -- directly, indirectly, or potentially -- as the result of two forces, man and nature, working singly or in concert. Such impact is inescapable and continuous, but may vary in effect from beneficial to adverse. However, many of these same effects are capable of alteration -- archeological sites may either be avoided or they may be excavated and stabilized, grazing in an area may be limited or even halted in order to prevent additional disturbance to cultural remains, drainage patterns may be changed to prevent flooding, and devastated areas may be re-seeded or forested and the ensuing changes monitored through time.

Legally classified since the passage of the National Environmental Policy Act of 1969 (NEPA) as cultural resources, archeological sites -- unlike some other resources -- are non-renewable. As a result, the impact of federally funded projects on such resources requires a formal assessment or evaluation and determination of significance in order to permit consideration of the effect of disturbance to, or destruction of, cultural remains. These statements must not be limited to direct impact, but must consider the indirect and potential (anticipated) effects that might result from alterations to the site or its environment, for every cultural resource in the area under study (for a discussion of NEPA and other pertinent legislation see King 1975; McGimsey and Davis 1977).

However, the need for such determinations presents several major problems. Although the number of archeological surveys undertaken and completed, particularly in the Southwest, has increased significantly in recent years, no federal agency has succeeded in inventorying 100 percent of the archeological sites within its holdings. Furthermore, no federal agency possesses the requisite funding to monitor, on a continuing basis, the condition of previously located cultural resources on lands under its jurisdiction. At least partial amelioration of the situation is possible, however, through the application of remote sensing techniques -- specifically the use of aerial photography -- to these and to other problems inherent in cultural resource management.

The monitoring of impact on cultural resources is not really a new field of endeavor, as can be attested by the lengthy studies of such well known-structures as the Leaning Tower of Pisa, and the equally well known studies of flood damage and control in Venice. Further, such techniques have long been used by the Soil Conservation Service and the U.S. Forest Service, among others, to determine effects of flooding, insect infestations, fires and the like on natural resources. That such techniques would be valuable to cultural resource managers, particularly on the scale at which cultural resource management is practiced in the United States, should go without saying. However, although recognized and accepted by a small coterie of archeologists as a powerful tool (Gumerman and Lyons 1971; Gumerman and Neely 1972; Lyons 1976; Lyons and Hitchcock 1977; Lyons and Avery 1977), it appears that the majority of cultural resource managers either do not know about many of the monitoring capabilities of the remote sensing techniques presently available or, if they do, have a tendency to restrict their use to such specialized problems that their full potential cannot be realized. For example, not infrequently in the past, when aerial imagery has been made available to archeologists, it has been considered secondary to, or even less useful than, U.S.G.S. topographic quadrangle maps for the purposes of site survey and location. Yet, aerial photographs provide incontrovertible visual evidence of the way an area appeared at a given point in time -- something that topographic maps simply cannot do. Further, because of its visual content, aerial imagery permits precise location and relocation of sites -- a quality that is particularly useful in areas of low topographic relief.

Aside from their obvious use during archeological survey, remote sensing techniques also provide an invaluable means of monitoring patterns of impacts on the environment over extended periods of time through the use of sequential photography. Perhaps most important of all is the fact that remote sensing techniques are non-destructive, and therefore do not themselves impact cultural remains.

If the most effective results are to be obtained when impact is monitored through the use of remote sensor techniques, however, two basic requirements must be met: the acquisition of a good data base, i.e., the aerial imagery necessary to provide documentation of the past and present appearance of the area under study; and a realistic managerial program that recognizes and provides for past, present and anticipated human or natural impact(s). Of the two, the latter requirement is of significantly greater importance than the former, for without the management plan to guide research and interpretation, the data base is essentially useless regardless of its comprehensibility. To require the remote sensing technicians to divine the problem without first-hand working knowledge of an area is a waste of time. Whether the problem is one of direct impact to cultural remains as the result of human or natural causes, or is the result of somewhat more indirect impact on a regional level must be determined in advance. Although it is difficult, of course, to provide for all eventualities, a common sense approach to known problems should enable the manager to approximate all but the most unexpected impact(s).

Although of tremendous value to the cultural resource manager under certain circumstances, much of the historical imagery for the country contains inherent limitations in type of coverage and scales available. For that reason, additional imagery will almost certainly be required for any given project. However, the decision as to what types of imagery will prove most useful should rest with the remote sensing technicians. Depending upon the situation, of course, it may be desirable to have the area photographed more than once for comparative purposes; again, the determination of the coverage, type and scale of imagery best suited to the type of impact being monitored and to the funds available, should be made by the remote sensing specialist. For example, in areas of deciduous vegetation, it may be beneficial to obtain not only black-and-white and/or true color imagery during winter months, but also false color infrared during the spring or even at the height of the growing season. Further, variance in the time of day at which the photographs are taken may prove useful because of varying shadow lengths. All such requirements should be planned in advance and made part of the bidding documents. However, because every manager's needs and requirements will vary from region to region and with the type of impact involved, it is impossible to state at this time that any one flight interval or specific type of coverage or scale is better than another; that depends wholly upon the situation at hand and the managerial assessment of the situation.

Assuming the acquisition of the necessary imagery and accurate assessment of the problem, the first step in the monitoring process is one of photo interpretation and comparison of earlier and later coverage of the area under study. Such interpretation can be performed through the assessment of individual photographs or frames, but it is preferable to use stereo pairs and a stereoscope to gain the third dimension of depth otherwise lacking. Upon the identification and location of pertinent (to the project) soil types, vegetative zones, land forms, visible cultural remains and the like, overlays, uncontrolled and controlled mosaics, and/or photogrammetrically prepared maps may be produced for further use. In addition, the imagery may be digitized and manipulated for supplemental or supportive data. Upon the completion of the data gathering and interpretive stages, field checks may be required to determine ground truth, schedules revised to allow for greater or lesser or different types of coverage and ultimately, if possible, measures taken to eliminate or alter the effects of the impacts observed. In the latter case, it may be found desirable to continue the project, on at least a short term basis, to study the effects of any alterations that have been implemented. It should go without saying that reports of the entire project be published or otherwise be made available to both the profession and the public. Following are examples of several projects undertaken by the Remote Sensing Division of the Southwest Cultural Resources Center with monitoring applications.

Although it extends into southwestern Colorado, southeastern Utah and northeastern Arizona, the largest portion of the San Juan Basin lies in northwestern New Mexico. It has been estimated that there may be as many as 30,000 to 40,000 archeological sites within the region as a whole. Nearly 8,000 sites, ranging in date from Paleo-Indian through the recent historic, have been recorded for that portion of the basin in New Mexico, but only a small percentage of the region has been completely and intensively surveyed. Furthermore, in addition to its wealth of cultural remains, the San Juan Basin contains vast amounts of economically recoverable oil, gas, coal and uranium. Finally, it should be noted that only a very small portion of the area is privately owned, and that more than 70 percent of the surface is under Federal (specifically, Bureau of Land Management and Bureau of Indian Affairs) control. In short, it might be said that the San Juan Basin represents a cultural resource manager's nightmare.

Beginning with the use of coal during the early historic period by the Spanish, and continuing with the "official" discovery (by the U.S. Geological Survey) of oil in northwestern New Mexico in 1882, the opening of the Hogback oil field in 1922, the discovery in 1950, near Grants, New Mexico, of one of the most lucrative uranium deposits in the world, the development of the San Juan gas fields in the early 1950's and the opening of strip mining operations for coal in the early 1960's, there can be no question that major land modification activities have already occurred in the Basin. Hand in hand with industrialization is, of course, a large population increase in the area and concomitant disturbance of cultural remains brought about by new housing developments and recreational facilities, among other things. Because of the national energy crisis and the wealth of natural resources in the area, however, such topographic modifications can only increase in the future. It takes no seer to predict that the San Juan Basin in New Mexico will cease to exist, as it is presently known, within the next several decades.

On the other hand, as the result of exploration and industrialization, the San Juan Basin is one of the most carefully and completely photographed areas in the State, if not in the entire Southwest. Beginning with Charles Lindberg's limited coverage of Chaco Canyon in 1929, continuing with Soil Conservation Service work in the 1930's and U.S.G.S. mapping photography in the 1950's and 1960's, the Basin has been photographed from the air in whole or in part innumerable times. When such "low altitude" coverage is combined with the Landsat data available since 1972, the coverage is both intensive and extensive. It is this base that is being utilized by the Remote Sensing Division of SWCRC for vegetative mapping and cultural resource predictive studies for the BIA/NPS San Juan Basin Project now underway. Base maps drawn from the 1930's SCS imagery have been prepared and will be used for comparative purposes to identify and study large scale impact to date. The same maps will, of course, form the basis for monitoring the same and other impacts in the future.

Such maps should prove most useful in determining the effects of indirect impact on cultural resources -- perhaps the most crucial of concerns to the manager. For example, if it can be shown that a strip mine's effects on a drainage system are detrimental to cultural remains outside expected impact areas, the condition of those sites can be watched closely and protective measures can be increased if practical. Finally, it is not impossible that determinations of actual impact, instead of simple approximations, will save considerable sums of money, since fewer excavations would result.

Although it is obvious that large numbers of archeological sites will eventually be destroyed in the San Juan Basin, a yet unknown percentage will be preserved. Following is an example of one such preservation project.

Kin Ya'a, an impressive Chacoan pueblo with masonry walls standing over 20 feet in height, is located some 30 miles southwest of the major portion of Chaco Canyon National Monument, near Crownpoint, New Mexico. The site is not only located within the area known as the Grants Uranium Belt, but it is also underlain by important sub-bituminous coal deposits recoverable through strip mining. Prior to 1972, however, Kin Ya'a existed much as it had for the previous several hundred years, subjected primarily to natural environmental forces and only occasionally to human impacts. In 1972, Mobil Oil Corporation was awarded leases and instituted plans for uranium exploration in the area. Upon completion of the required archeological survey and grant of clearance, drilling activities were initiated and have continued to the present.

Although almost none of the cultural resources in the immediate area of the site were directly impacted by drilling activities (the exceptions are segments of two prehistoric Chacoan roads not recognizable on the ground), the indirect impact is notable. Of further, and much greater, consequence is Mobil's decision to mine. The initial plans had called for a relatively small development (no more than 50 acres would be subject to direct impact), but more recent proposals call for _in situ_ leaching of the uranium. In many respects, the original proposal -- unlikely as it may sound -- is infinitely preferable to leaching. Since the mine and the necessary production areas would be completely contained, the majority of the cultural remains around Kin Ya's would be threatened primarily by indirect means only -- most noticeable would be loss of the environmental integrity of the area. In the case of the leaching process, however, few, if any, of the extant drill holes can be used, and where now one exists, up to five new holes will be drilled. Each hole is relatively small in diameter, but attendant impacts include nearly constant vehicular traffic to and from the sites (since the drilling will take place around the clock), the installation and operation of the drilling rigs, and the construction and use of mud and spoil pits. Further, when the process becomes operative, aboveground pipelines will be constructed from the area of drilling to the area of processing. Although archeological sites will be avoided (fenced where necessary) during the construction, drilling, and processing activities, few, if any, other areas will remain untouched. Finally, upon the removal of the uranium in any one drilling complex, that area will be restored to its original appearance as nearly as possible. This will include not only the removal of all equipment, but in those areas where the soil has been heavily compacted, deep ripping of the surface to a depth of 18-24 inches for improvement in percolation prior to reseeding or other revegetation efforts. If the reclamation process is done on a hole by hole basis, any further disturbance would be kept to a minimum; however, if this is not feasible, the results could be incredibly destructive. Since the entire project is scheduled to last no more than 20 years, it was decided that Kin Ya'a offered an excellent opportunity for the development and testing of monitoring techniques.

As a result of past disturbance and that anticipated for the future, the Remote Sensing Division of the National Park Service's Southwest Cultural Resources Center prepared a series of maps of Kin Ya'a and surrounding area from imagery taken prior to Mobil's drilling activities. These maps, when printed on clear mylar, can be laid over more recent imagery of the same scale (or scales adjusted accordingly) for immediate, visual, impact assessment. In addition, since these "before" photographs provide incontrovertible proof of the condition of the area prior to any disturbance, they should prove invaluable during the reclamation process.

Finally because it appears highly possible that movement will occur within the fabric of Kin Ya'a as the result of vibrations produced by a nearly constant stream of heavy vehicles and/or blasting, it was decided that the site presented an ideal opportunity to test terrestrial photogrammetric techniques -- that is, the quantitative measurement of the site derived from photographs taken from a controlled horizontal plane as opposed to the more common vertical or oblique angles -- in a little used context. Although they are increasingly used for recording architectural detail for purposes of historic preservation, such techniques have been limited in archeology to the mapping of such difficult access sites as Keet Seel and Mummy Cave Ruin (Lyons and Avery 1977:82). Obviously, of course, many sites do not lend themselves to the use of such techniques, but where it is applicable, terrestrial photogrammetry provides a means by which it is possible to detect and measure even slight movement or shifting within a structure.

In the case of Kin Ya'a the ground control and monuments (or datums) necessary to permit accurate mapping are being set in the project area by Mobil Oil Corporation. Because the monuments will be permanent, they will be used for sequential studies that will allow precise determination of deterioration or movement within the structure as the result of construction and mining activities. Kin Ya'a will be photographed with a Kelsh Terrestrial Photogrammetric camera and the resultant stereoscopic imagery prepared and mapped. The maps produced -- one of the site as a whole in addition to architectural elevations -- will provide the basis for all future monitoring studies of the site. However, in the future, instead of preparing additional maps for comparative purposes, the original map will be compared immediately with the new imagery. If shifting or deterioration are detected, additional maps will be prepared for measurement and illustrative purposes. Further, it is possible, during the mapping stage(s), to digitize the three-dimensional coordinates of the site and features within the structure, and have them entered automatically on computer cards by the operator of the plotter (cf. Pouls, Lyons and Ebert 1977; Lyons and Avery 1977).

How frequently it will be necessary to photograph Kin Ya'a can only be approximated at this time since scheduling will be dependent upon both the mining technique selected and on the intensity on the activities in the area. Once the effects can be determined with some accuracy, however, scheduling can be revised as necessary to monitor the condition of the structure. Such techniques, of course, are applicable to structures endangered by industrialization throughout the world.

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