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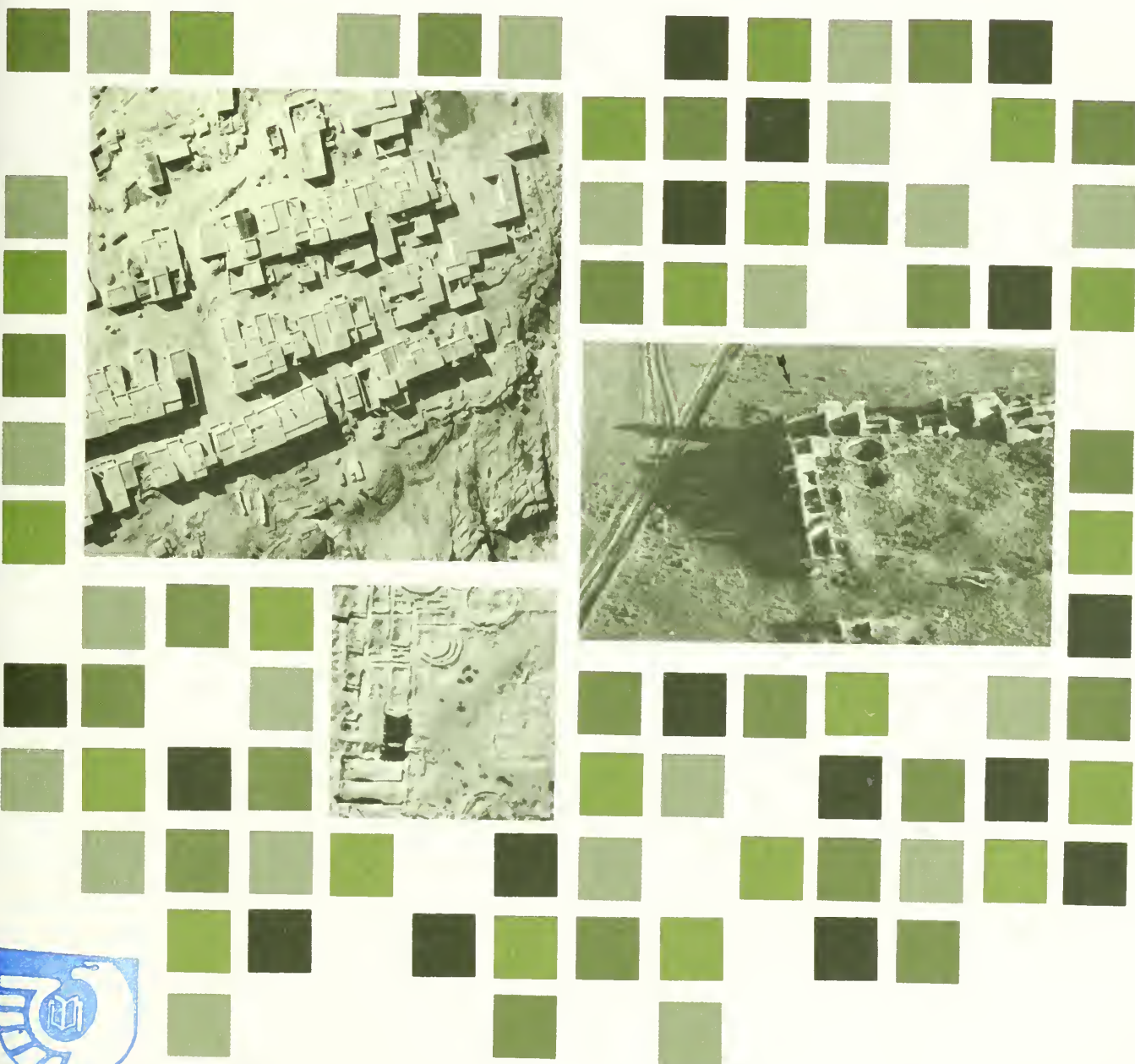
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# REMOTE SENSING

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## Applications to Cultural Resources in Southwestern North America





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# REMOTE SENSING

## Applications to Cultural Resources in Southwestern North America

Eileen L. Camilli  
Linda S. Cordell

Supplement No. 8

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

Edited by Barbara L. Daniels

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## Preface

Remote sensing of cultural resources is not new to the Southwest. Due to the often spectacular nature of cultural resources in this region, and to the vast expanses in which they often occur, comprehensive and economical means of finding, sampling, and recording are of paramount importance. Many current archeological techniques, including the use of remote sensing, have been pioneered there. When Charles Lindbergh photographed the ruins of Chaco Canyon and other prehistoric population centers in New Mexico in 1929, however, he could hardly have imagined the wide range of photographic and other data-gathering techniques that have come to be included under the heading of remote sensing. Fifty years later, these techniques are not only available to the cultural resource scientist and manager, but are experiencing enthusiastic and widespread use. This publication, which is number eight in the National Park Service's remote sensing *Handbook* series, discusses remote sensing methods with potential for solving cultural resources problems in Southwestern North America, and illustrates the use of these methods with case studies of actual applications.

Another facet of Southwestern archeology that the early pioneers of cultural resources remote sensing would probably not have imagined is the enormous scale of forces threatening sites and materials there. Mining of energy-producing resources and the construction of vast missile launching sites does not simply disturb a site or two, but causes entire *landscapes* where past peoples lived and worked and left their mark to literally disappear. One of the most advantageous aspects of remote sensing as applied to cultural resources is that it allows the recording of relevant environmental information in addition to data on cultural materials themselves, a necessary adjunct to the interpretation of past behavior and the formulation of sampling and conservation plans. This publication and the others in this series, which have been designed to present remote sensing applications to cultural resources in an understandable and useful manner, should be of help as the pace of present cultural activities as well as our obligation to the past increases in the Southwest.

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**Figure 1** Oblique photograph of Pueblo Bonito ruin, Chaco Culture National Historical Park taken during Lindbergh overflight, 1929.

# Introduction

Remote sensing techniques were perceived as valuable aids to analysis early in the history of archeological research in the Southwest. The natures of both the prehistoric remains and the Southwestern terrain were amenable to the techniques of aerial photography. Standing architectural and other cultural features were easily identified from the air without the obstruction of dense vegetation cover. In the early 1920s it was recognized that ancient irrigation canals existed in the Salt and Gila River Valleys of southern Arizona. By 1929, however, because of destruction by modern agriculture, only about 10 percent of the canals observed in the earlier part of the decade could be recognized (Deuel 1969). This situation led to aerial reconnaissance in 1930 in order to map the canal network. Some 322 km of irrigation canals in the Salt and Gila Valleys were subsequently mapped on the basis of the striations disclosed on aerial photography (Judd 1930). Initial observation indicated that the canals were associated with village sites of the Classic Hohokam (Halspeth 1936). Subsequent excavation of canal sections at the site of Snaketown (Haury 1936, 1976) on the Gila River indicated a series of three canals dug between A.D. 800 and 1300 and denoted canal irrigation as one of the hallmarks of Hohokam technology.

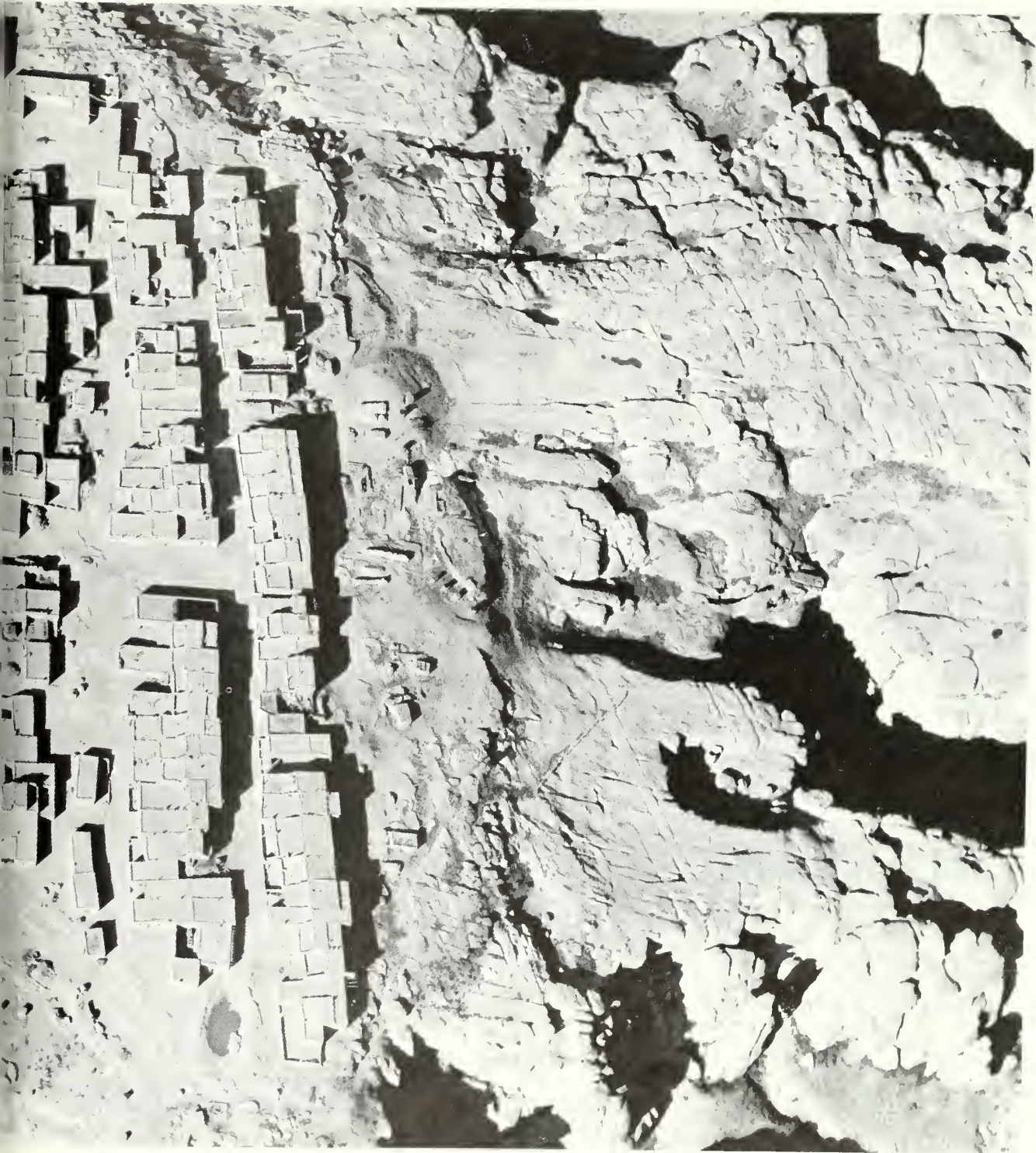
In the same decade, the capability of aerial survey reconnaissance for the detection of prehistoric ruins in the Four Corners areas was recognized (Kidder 1930). In 1930, Colonel Charles Lindbergh and his wife conducted flights across the Four Corners region photographing masonry dwellings in Chaco Canyon, New Mexico, and Canyon de Chelly and Canyon del Muerto in Arizona. The photographs (fig. 1), developed at the School of American Research in Santa Fe by Edgar L. Hewett, were used by students from the University of New Mexico to locate previously unidentified ruins in Chaco Canyon (Deuel 1969).

Early interest in the history, social organization, and religion of the modern Pueblo inhabitants of New Mexico and Arizona prompted the recording of the actual ground plan of each pueblo (Stubbs 1950). Reasons for the project were two: since the pueblo ground plans had never been recorded, documentation of the village plans was needed before further modern renovations could be completed; and it was not possible to map the villages from the ground. Aerial photography taken in 1948 was used to prepare a plan of each village (fig. 2).

Since the completion of these early investigations, a variety of imaged and digital remote sensing data have been applied to archeological problems in the Southwest. Remote sensing techniques have been used by archeologists and historians for inventory, analysis, preservation, and maintenance of the region's cultural resources. This supplement, intended as an overview for the cultural resources manager, discusses the possible applications of remote sensing data to aspects of Southwestern archeology. Sections 1 and 2 review the natural environment and prehistory of the Southwest region. Because of the great environmental diversity and complex prehistory within this region, only general descriptions are provided. Section 3 focuses on specific remote sensing techniques, their archeological data base, and the analytical framework underlying each technique. Detection and evaluation of archeological sites and features, intrasite definition and mapping tasks, regional survey procedures, and predictive analyses are presented as tools for the academic archeologist and cultural resources manager. Section 4 is provided as an assessment, from an economic perspective, of the applicability of remote sensing techniques to the management of cultural resources. Aerial photographic mapping and site monitoring procedures are also addressed.



Figure 2 Vertical aerial photograph of Acoma Pueblo (Stubbs 1950).



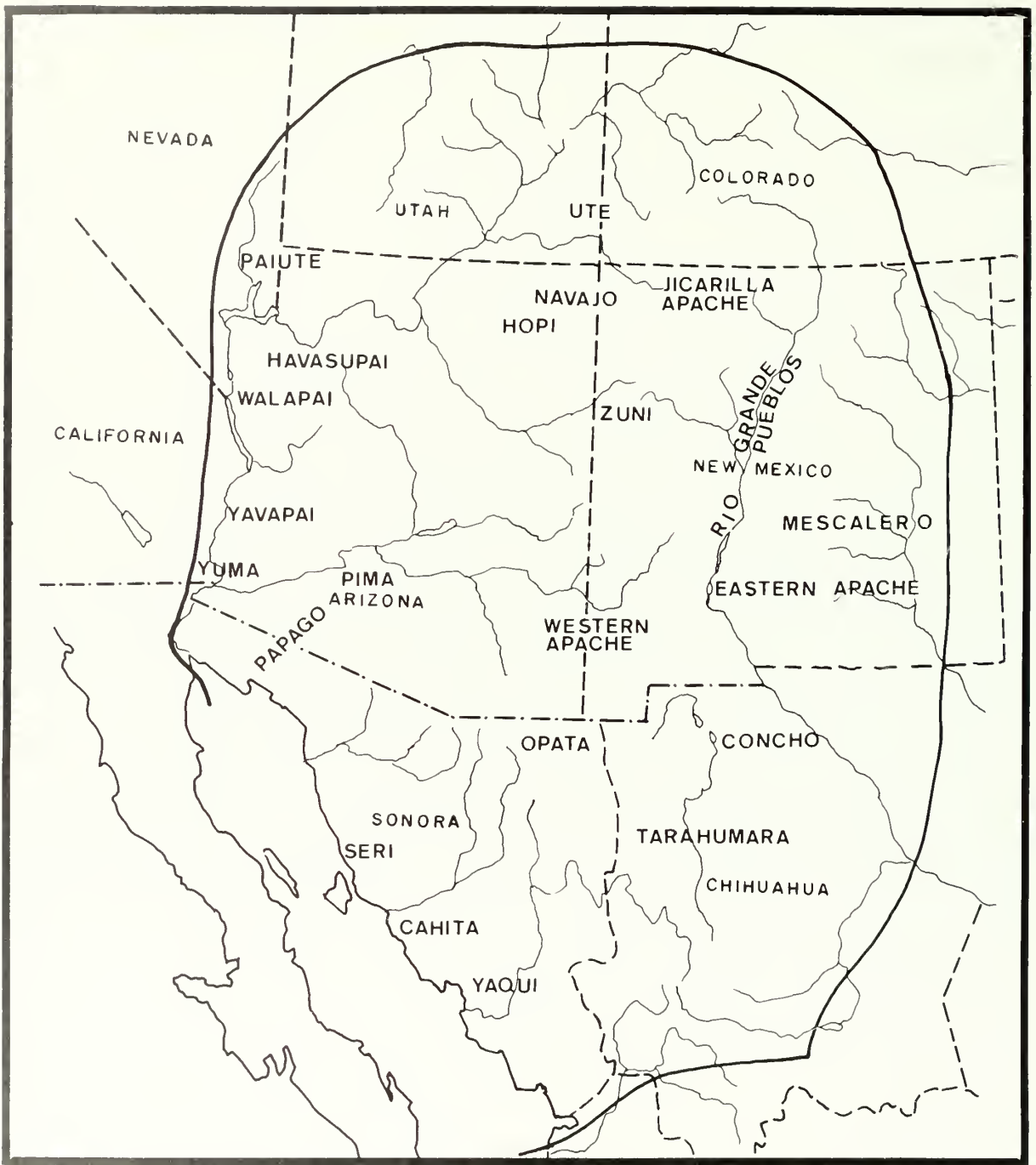


Figure 3 The Southwest region with location of major Indian tribes.



## Natural Environment of the Southwest

No natural physiographic or other features serve to delimit the “Greater Southwest”; the Southwest region as used here will include arid and semiarid portions of Colorado, Utah, northern Mexico, and all of Arizona and New Mexico (fig. 3). Common to these areas are the minimal to nearly total dependence of late prehistoric occupants on cultigens for subsistence and prehistoric adaptations characterized by the lack of a state level of political organization. While the Southwest is an extremely large and physiographically varied area, the remote sensing methods that have been incorporated in archeological investigations of Southwestern prehistory can be uniformly applied throughout the region. Attributes of surface cover, for example, geological surface deposits, vegetation, and those resulting from the interface between physiography and climate, condition the organization of remote sensing methods and projects within the region.

### Physiography

The Southwest encompasses portions of five major physiographic provinces (fig. 4): the Colorado Plateau, the Southern Rocky Mountains, the Great Plains, the Basin and Range, and the Mexican Plateau (Fenneman 1931; Thornbury 1965; West 1964).

**Colorado Plateau.** This province is characterized by great topographic diversity which results from the inclusion in the province of a number of individual plateaus each with its own distinctive physiographic features. The Colorado River and its tributaries, including the Green, San Juan, and Little Colorado Rivers, drain about 90 percent of the province (Thornbury 1965). The topography is one of broad

plateaus dissected by canyons and bounded by receding escarpments. Altitudes over most of the province are higher than 1524 m. Sharp topographic relief results primarily from deeply incised canyons with mountain ranges, such as those in adjacent provinces, lacking. The application of geomorphic criteria has enabled division of the Colorado Plateau into six sections (fig. 4) (Fenneman 1931; Thornbury 1965):

- a. Grand Canyon Section, the major topographic feature of which is the trench of the Colorado River bounded on the north by several high block plateaus.
- b. High Plateaus Section, composed of high north-trending plateaus marked on the south by terraced step-like rises.
- c. Uinta Basin Section, dominated by dissected plateaus in the lowest part of the province.
- d. Canyon Lands Section, characterized by deeply incised canyons.
- e. Navajo Section, a structural depression, the deepest part of which is formed by the San Juan Basin on the east (fig. 4). Most of the section is characterized by broad flats separated by low cuestas.
- f. Datil Section, comprises the south rim of the Colorado Plateau in New Mexico and eastern Arizona. Extensive portions of this section are covered by thick lava flows and contain lava-capped mesas and benches.

**Southern Rocky Mountains.** The Southern Rocky Mountains consist of several parallel north-south mountain ranges separated by intermontane basins. From east to west the major mountain and basin structures within the Southwest are the Sangre de Cristo Mountains, the San Luis Valley, the San Juan Mountains, the Jemez Mountains and Valle Grande Caldera, and the western-most La Plata, San Miguel,

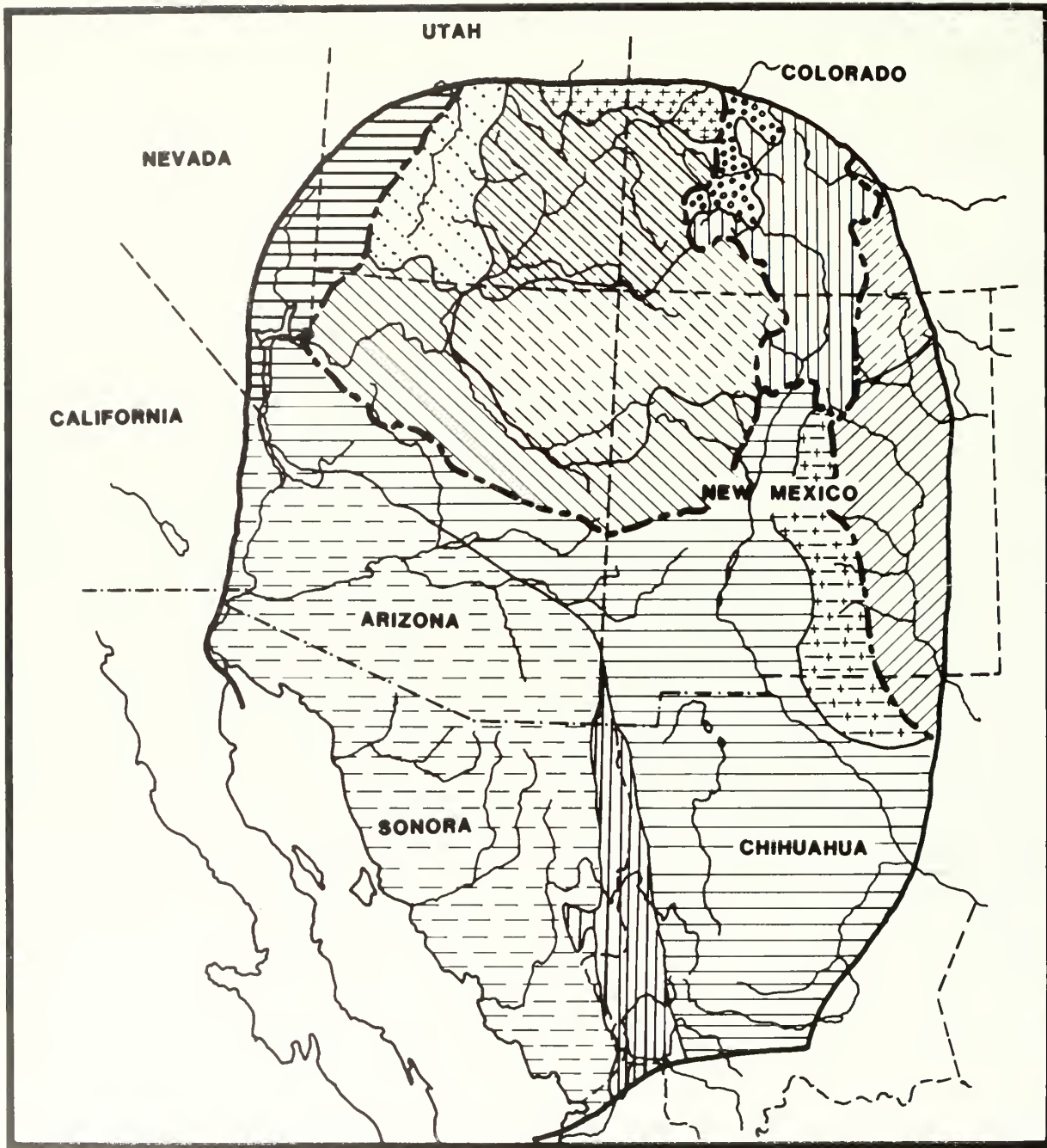















Figure 4 Major subdivisions of the Colorado Plateau, Basin and Range, and Mexican Plateau in the Southwest.

### LEGEND FOR FIGURE 4

MAJOR DIVISION	PROVINCE	SECTION	CHARACTERISTICS	
INTERIOR PLAINS	Great Plains Province	Ratan Section	 Trenched peneplain surmounted by dissected, lava copped plateaus and buttes.	
		Pecos Valley	 Late mature to old plan	
ROCKY MOUNTAIN SYSTEM	Southern Rocky Mountains		 Complex mountons of various types; intermontane basins	
	Wyoming Basin		 Elevated plains in various stages of erosion, isolated low mountains	
INTERMONTANE PLATEAUS	Colorado Plateaus	High Plateaus of Utah	 High black plateaus, in part lava copped, terraced plateaus on south side.	
		Uinta Basin	 Dissected plateaus, strong relief	
		Canyon Lands	 Young to mature canyoned plateaus, high relief	
		Navajo Section	 Young plateaus, smaller relief than above	
		Grand Canyon and Dolil Sections	 High black plateaus, lava flows, volcanic necks in part trenched by Grand Canyon.	
	Basin and Range	Sanaran Desert	 Widely separated short ranges in desert plains	
		Sacramento Section	 Mature block mountains of gently tilted strato, block plateaus and bolsons	
		Mexican Highland	 Isolated ranges (largely dissected separated by aggraded desert plains block mountains)	
		Great Basin		 Same as above

and Rico Mountains. The San Luis Valley, one of the largest intermontane basins in the province, merges with the trough of the Rio Grande on the south. In the Southwest, approximately two-thirds of the province drains east of the Continental Divide. The Valle Grande Caldera, an unusual feature on the west side of the Jemez Mountains, was formed during the early Pleistocene by a series of volcanic eruptions. The caldera is 24 km in diameter and is bounded by a number of ring faults (Thornbury 1965).

**Great Plains.** The following portions of the Great Plains Province are located in eastern New Mexico:

- a. High Plains Section, portions of which are known as the Staked Plains or Llano Estacado, is one of the most nearly level parts of the United States (Hunt 1967) with sand dunes and the depressions of Pleistocene lake beds providing the only topographic relief. The western escarpment of the Llano Estacado bordering the Pecos Valley is known as the Caprock, an area of an irregular accumulation of caliche.
- b. Pecos Valley Section, a wide erosional valley, lies between the High Plains to the east and the easternmost mountains chains of the Basin and Range Province to the west. This broad north-south depression contains widespread karst features and gravel-capped terraces.
- c. Raton Section, in northeastern New Mexico, is characterized by a group of low plateaus and lava-capped mesas.

**Basin and Range.** The topography in this province is characterized by isolated, sub-parallel mountain ranges, and alternating intermontane basins. Internal drainage is characteristic of the northern part of the province; the Colorado River and Rio Grande provide outlets for much of the southern portion. Three major subdivisions of the province are in the Southwest (fig. 4):

- a. Sonoran Desert Section, dominated by pediments and bajadas with elevations rarely exceeding 914 m (Hunt 1967), includes southeastern California, southwestern Arizona, and portions of northern Mexico.
- b. Mexican Highland Section contains high desert valleys and mountain ranges. The Rio Grande drains eastern portions of the section, the San Pedro and Gila rivers drain the western. The Mogollon Rim, an escarpment several thousand meters high,

separates the section from the Colorado Plateau in central Arizona and New Mexico.

- c. Sacramento Section contains structurally closed features, the Estancia and Tularosa Basins, and plateau-like topography. Mountain ranges separating the basins include the Gallina, Jicarilla, Capitan, and the Sierra Blanca.

**Mexican Plateau.** The Mesa del Norte, an area of folded and faulted mountain ranges separated by extensive basin plains, comprises the portion of the Mexican Plateau in the Southwest (Fig. 4). Northern portions of the Mesa del Norte are considered a southward extension of the Basin and Range Province (Robles Ramos 1942). Eastern and central portions of the Mesa del Norte contain bolsons (large desert basins) with interior drainage. On the east, the desert basins are bounded by low folded ranges and hills which trend northwest from Monterrey to the Big Bend country of Texas. An elongated area of volcanic mountain ranges, separated by high alluvial basins and bounded on the west by the Sierra Madre Occidental, represents the physiography in the western portion of the Mesa del Norte (West 1964). The Sierra Madre Occidental separates the plateau deserts and steppes from a narrow band of Pacific coastal lowlands in western Sonora.

## Geomorphic Divisions

Geomorphic divisions formulated for the Southwest region include depositional units and characteristic topographic features resulting from various geomorphic processes. Analyses of geologic deposits have contributed to the development of a framework for the dating and climatic interpretation of past environments. This research has facilitated interpretation of the nature of prehistoric adaptations to these environments. Kottowski and others (1965) and Hunt (1967) have identified five major types of surface deposits.

**Glacial Deposits.** These occur in the Sangre de Cristo Mountains (Ellis 1935; Ray 1949) and on Sierra Blanca (Smith and Ray 1941). The Sangre de Cristo Mountains received extensive glaciation during the Pleistocene, and it was in the Pleistocene or Recent time when numerous rock streams were formed (Thornbury 1965). The glaciated northeastern side of Sierra Blanca is drained by tributaries of the Pecos River. Two terraces along these tributaries may

correlate with early and late Wisconsin recessional stages on Sierra Blanca. Recessional stages of mountain glaciations have been correlated with deposition of terrace deposits along major streams at far distances from the mountains (Frye 1961; Kottlowski et al. 1965). The glacial sequence in the San Juan Mountains (Atwood and Mather 1932; Kottlowski et al. 1965; Richmond 1954) consists of pre-Wisconsin, tills and outwash of the late Wisconsin, deposits of two still younger glaciations lying in the cirque heads, and a modern rock moraine formed about A.D. 1640–1860 during the last glacial episode. The Wisconsin glaciations resulted in a system of moraines and prominent valley train terraces (Thornbury 1965). Wisconsin outwash has been correlated with moraines and outwash deposits along the upper Chama River (Muehlberger et al. 1960). Wisconsin glacial deposits in the San Francisco Mountains of northern Arizona are among the most southerly in the United States (Kottlowski et al. 1965; Sharp 1942). Other recent glacial materials on the Colorado Plateau are above 2804 m in elevation (Kottlowski et al. 1965) and consist of small moraines and rock (or talus) glaciers in cirques on high plateaus and volcanic mountains. Intensive frost action which affected unglaciated high mountains and plateaus during the Quaternary produced widespread boulder and rubble fields (Hunt 1967; Kottlowski et al. 1965). At lower altitudes counterparts of these deposits are talus cones, colluvial aprons, and debris avalanches along canyon walls and at the base of cliffs (Kottlowski et al. 1965). Recent glacial deposits in the La Sal Mountains have been dated later than 900 B.C. based on carbon 14 analyses of associated preceramic hearths (Richmond 1962).

**Fluvial Deposits.** Hack (1942) has identified three stages of alluviation, separated by periods of arroyo cutting, that are widespread in most valleys of the Colorado Plateau. These stages range from Late Wisconsin to about A.D. 1880; the oldest is Late Pleistocene and contains the remains of extinct Pleistocene vertebrates. During the Middle Holocene, a younger alluvium was deposited, the lowest levels of which contain the bones of modern fauna as well as artifactual remains and hearths of preceramic peoples who inhabited the Southwest. It has been suggested that this alluvium was deposited about the same time as the earlier of the Recent moraines and rock glaciers in the La Sal Mountains (Hunt 1967). The uppermost part of this alluvium contains the sites and irrigation systems of the prehistoric Anasazi

as well as the remains of the later Anasazi occupations between A.D. 1100 and 1300. The youngest stage of alluviation occurred after this time but prior to Euro-American settlement in the area (Kottlowski et al. 1965). The beginning of present day arroyo cutting is placed at about 1880.

Alluvial deposits have been classed as two kinds on the Colorado Plateau (Hunt 1967). In some valleys, alluvial deposits have been built up by the main stream overflowing its banks and spreading a deposit of silt across the valley floor. A second kind of alluvial deposit, resulting in a system of coalescing fans in the main valley, is formed when the main stream is not capable of carrying all of the sediment brought to it by its tributaries.

Alternating periods of alluviation and arroyo cutting reflect the alternating wet and dry periods that have characterized past climates. Alluvial deposits that formed during wet periods have been correlated with deposits in shallow lakes or playas in the Basin and Range Province. Dune sand in arroyo fill has been taken as evidence for dry conditions during the periods of arroyo cutting (Hunt 1967).

The Basin and Range Province is characterized by alluvial flats and surrounding gravel fans that extend from the flats to bordering mountains. These fans consist of coarse gravels and sand deposits and canyon mouths by mountain streams (Hunt 1967). The apex of these alluvial fans may occur at canyon mouths or farther up the canyons into the mountains. In the Sonoran Desert and Mexican Highland sections, alluvial fans as well as pediments are common. Pediments, formed around bases of low small mountains on erosional surfaces, are characterized by a dendritic drainage pattern on which gravel fans are being built. Gravel-capped pediments occur at the foot of mountains and along the base of escarpments in the Colorado Plateau.

These pediments have been interpreted as remnants of beaches reduced by erosion (Hunt 1967). In the Mesa del Norte, the bolsos are also encircled with sloping rock pediments formed by backwasting and stream and sheet erosion (West 1964).

Pre-Wisconsin alluvial sands and gravels on the Colorado Plateau have been identified in both the La Sal and San Francisco Mountains. Other pre-Wisconsin outwash deposits include gravel-capped pediments, high level gravel on canyon rims, and gravel caps on high mesas (Kottlowski et al. 1965). Fluvial deposits in the High Plains Section include alluvial sand and gravel present in abandoned Pleistocene drainage channels on the Llano Estacado and the large pluvial lake basins as well as basal

deposits of present day playas (Reeves 1972).

**Lacustrine and Alluvial Deposits.** Well defined beach and lacustrine deposits in the intermontane basins of the Basin and Range Province indicate various stages in the formation of ancient lakes. No permanent streams drain the basin, but ephemeral streams produced by intermittent precipitation form shallow lakes on the level plain of the basin. In the Mesa del Norte, the level plain is known as the *barrial* (West 1964); in the Southwest, it is variously termed *playa* or "playa-lake." The surrounding higher portion of the basin sloping toward the *playa* has been termed *bajada* in the Mesa del Norte.

Most of the surface deposits of Wisconsin or Recent age are found in the Estancia Basin, Tularosa Basin, Plains of San Augustin, and Animas and Playas Valleys of New Mexico (Kottlowski et al. 1965). The highest shoreline of the lakes within these basins has been associated with the Tahoka Pluvial of the High Plains by Wendorf (1961). Surfaces and associated sediments identified for the western margin of the Estancia Basin include an alluvial fan at the highest level and a *playa* floor at the lowest (Shuman 1959). Its shores were marked by beaches, spits, bars, and wave-cut cliffs (fig. 5).

The Llano Estacado is pitted with thousands of shallow natural depressions called "playa-lakes." Deflation and unequal deposition of Pleistocene eolian sand account for the presence of most of these small lake basins and sinks (Reeves 1972).

On the Colorado Plateau, lake deposits are an almost insignificant part of the Quaternary sediments (Kottlowski et al. 1965). Small lakes occur in depressions on lava-capped plateaus, behind landslides and end moraines, and in sinkholes and solution valleys developed on top of limestone-capped plateaus (Hunt 1964; Kottlowski et al. 1965). In the Canyonlands Section, waterpockets occur in massive sandstones (Hunt et al. 1953). Small depressions holding lakes also occur on the flat crest of the Chuska Mountains in northwestern New Mexico with most of the lake sediments of Pleistocene age (Kottlowski et al. 1965; Wright 1964).

**Eolian Deposits.** Extensive upland areas on the Colorado Plateau are covered with sand dunes. Two distinct deposits have been recognized mainly in the Canyonlands and Navajo sections. Older dunes of weathered, compact, red stained sand of early Recent ages overlie Late Pleistocene alluvium in these areas. Older deposits occur in the form of stabilized dunes. Younger sand dunes, some of which are active,

overlie Middle Holocene alluvium.

Three types of sand dune have been identified by Hack (1941): transverse, parabolic, and longitudinal dunes. The development of different dune forms depends on the ability of vegetation cover to resist the moving sand and the amount of sand available to the wind for destruction of the vegetation (Hack 1941). Transverse forms include a crescent-shaped dune whose tips point leeward; these dunes are usually free of vegetation. Parabolic dunes, long scoop-shaped hollows with points tapering windward, are associated with a thin growth of bunch grass and shrubs. They occur in deflated areas where winds are in the process of removing sand under a thin vegetation cover. Longitudinal dunes are long narrow ridges of sand extending in a direction parallel to that of the prevailing winds; vegetation covers the troughs between ridges. All three dune types may occur side by side. In the Tallahogan Dune area below Black Mesa in northeastern Arizona, beans have been planted on the dunes by the Hopi. Evidence from archeological deposits indicates that transverse dunes in the Tallahogan Dune area were stable and supported prehistoric occupations between A.D. 1000 and A.D. 1250; these dunes have since been rejuvenated (Hack 1941: 254).

Several extensive sand dune areas exist in southeastern New Mexico, none of which is considered older than the late Pleistocene (Reeves 1972). These are the Monahan, Mescalero, Muleshoe, and Lake Basin dune areas. Sand dunes are not particularly common in the Basin and Range Province in the Southwest. A small dune field is located north of Socorro on the western side of the Rio Grande. At White Sands National Monument, white sand composed on gypsum dissolved from Permian formations and redeposited in saline playas covers an area of about 402 km<sup>2</sup> (Hunt 1967). The Mountain Valley Dune field at Great Sand Dunes National Monument in the San Luis Valley is the largest in the Southern Rocky Mountains.

**Volcanic Rocks.** In the Southern Rocky Mountains, a wide variety of volcanic rocks including volcanic ash and lava flows of basalt, and rhyolite or intermediate composition occur in the San Juan Mountains. Volcanic eruptions began in the Oligocene but continued as late as the Pleistocene (Hunt 1967). The terminal stages of the Valle Grande Caldera in the Jemez Mountains occurred during the early Pleistocene. Basalt tuff and flows, and post-basalt sands including pumice lenses occur in the Jemez Mountains (Kottlowski et al. 1965).



Figure 5 Aerial photos showing shoreline of ancient Lake Estancia, New Mexico.

Eruptive igneous rock covers approximately 24,140 km<sup>2</sup> on the Colorado Plateau (Thornbury 1965). Volcanic peaks include Mt. Taylor, San Francisco Mountains, Mt. Dillenbaught, Mt. Emma, Mt. Logan, and Mt. Trumbill. The Mt. Taylor volcanic field includes Quaternary basalt lava flows which are found in the valley along the San Jose River. The San Francisco field includes hundreds of cinder cones which along with lava flows blocked drainage basins, thus forming temporary lakes. The most recent eruptions in the San Francisco field occurred at Sunset Crater around A.D. 1190 (Thornbury 1965). Cones and lava flows are present on the high plateaus north of the Grand Canyon. Lava-capped high plateaus are characteristic of this region for the volcanic field extends beyond the Colorado Plateau into the Basin and Range Province to the west.

The Sierra Madre Occidental bordering the Mesa del Norte on the west were built up by the outpouring of great quantities of volcanic materials (West 1964). The western escarpment of these mountains has been incised with barrancas (deep canyons) cut into the volcanic material by streams flowing to the coast. Canyons such as the Barranca del Cobre in western Chihuahua rival the Grand Canyon in grandeur and depth (West 1964).

## Vegetation

It is recognized that the distribution of native species of mammals, birds, reptiles, and plants in the Southwest corresponds to broad "climatic belts" or life zones (Bailey 1913; Merriam 1890, 1898), thus vegetation is described in terms of altitudinal life zones. Only broad descriptions of vegetation zones will be included here, with the application of remote sensing techniques to specific problems and managerial needs addressed in later chapters. Merriam (1898) and Bailey (1913) have defined six life zones in the Southwest:

1. *Lower Sonoran Zone.* Characterized by creosote bush which grows extensively on sandy and gravelly basin pediments rising from playas of alluvial floodplains to the mountains, this zone covers large portions of the Basin and Range Province in southwestern Arizona and New Mexico. The Lower Sonoran Zone also extends into the Colorado Plateau along the Colorado River below elevations of about 762 m. The density

and height of creosote stands vary widely. The character of the stand and associated plants is controlled chiefly by amount and seasonal distribution of rainfall (Hunt 1967). In the deserts west of the Colorado River, precipitation averages fewer than 13 cm annually and falls mainly in the winter. These deserts are characterized by creosote bush and Joshua trees. In the Sonoran Desert, where creosote is associated with succulent cacti, precipitation is distributed biseasonally. East of the Mexican Highlands most of the precipitation in basins and valleys falls during the growing season; these deserts are characterized by yuccas and creosote.

2. *Upper Sonoran Zone.* Most of the Colorado Plateau is in the Upper Sonoran Zone which ranges between 1372 and 2286 m in elevation and consists of sagebrush and pinyon-juniper woodland. At lower elevations in the zone, grasslands and shrubland predominate; in the upper portion of the zone, pinyon and juniper woodland is common. The rims of the Colorado Plateau are forested with western yellow pine (ponderosa pine), with woodlands extending between forest elevations and the lower interior desert shrub and grassland.

A composite of environmental factors, including soil type, available moisture, and elevation, are represented by these different plant stands within the Upper Sonoran Zone. At higher elevations sandy ground supports a variety of shrubs and scrub oak; gravel covered terraces and areas of deep soil support sagebrush and grama grass at higher elevations (Hunt 1967). Shadscale and curly grass grow in the lower elevations with gravel cover, while blackbrush grows in the sandy areas. Grasses tend to predominate on loams, with xerophytic types, e.g., juniper, mountain ash, shrub oak and bitterbrush, on rocky outcrops and canyon ledges. The distribution of plants is also controlled in part by ground water quality. Areas characterized by alkaline conditions contain greasewood and saltbush. Plants include cottonwood, rabbitbrush, and sacaton grass in areas where ground water is less alkaline.

3. *Transition Zone.* Though the vegetation consists primarily of yellow pine, Douglas-fir begin at about 2286 m. The upper limits of the transition zone forest extend to between 2743 and 2896 m where lodgepole pine and



aspen begin. The boundaries of this zone, while dependent on temperature and moisture, do not strictly conform to elevational contours and are conditioned in part by temperature and moisture gradients as controlled by slope and land form. On cool moist northeast slopes, the zone runs from about 2134 to 2591 m, while on southwest slopes, it ranges from 2438 to 2896 m (Hunt 1967).

4. *Canadian Zone*. This zone occurs in narrow irregular strips between elevations of 2896 to approximately 3505 m. In New Mexico, the largest continuous area lies in the Sangre de Cristo Range, although less extensive areas occur in the Jemez, Sacramento, and Capitan ranges and on Mount Taylor and Sierra Blanca. The Mogollon, San Juan, and San Francisco Mountains also contain Canadian Zone vegetation. The zone is densely forested with Engelmann spruce, with subalpine fir and aspen usually growing on elevated slopes. In southern New Mexico and Arizona, a variety of limberpine (Mexican white) also occurs. Toward the upper reaches of this zone, vegetation becomes progressively smaller until the tree line is reached.

5. *Hudsonian Zone*. Found on peaks that reach near or above the timber line, for example, the Sangre de Cristo Range, White, Capitan, Sandia, Jemez, and Mogollon Mountains, and Mount Taylor, the zone is about 305 m in vertical extent, and from about 3353 to 3658 m in elevation. It is marked by stunted growth of gnarled and dwarfed timber, mainly Englemann spruce, corkbarked fir, and foxtail pine.

6. *Arctic-Alpine Zone*. Beginning above the tree line, this zone is characterized by a short growing season of about 90 days and by a low mat of hardy alpine plants.

In a slightly different scheme, Shantz and Zon (1924: 6-27) distinguish different vegetation zones in the Southwest (fig. 6). Table 1 summarizes the principal plants, including grass and shrub species, for each zone.

1. *Chaparral*. This zone occurs in the Southern Rocky Mountains in Colorado and New Mexico, but is most characteristic of southern Arizona where it occupies a belt below yellow pine and above desert shrublands. Composition of the chaparral varies in different regions. In the Rockies, it

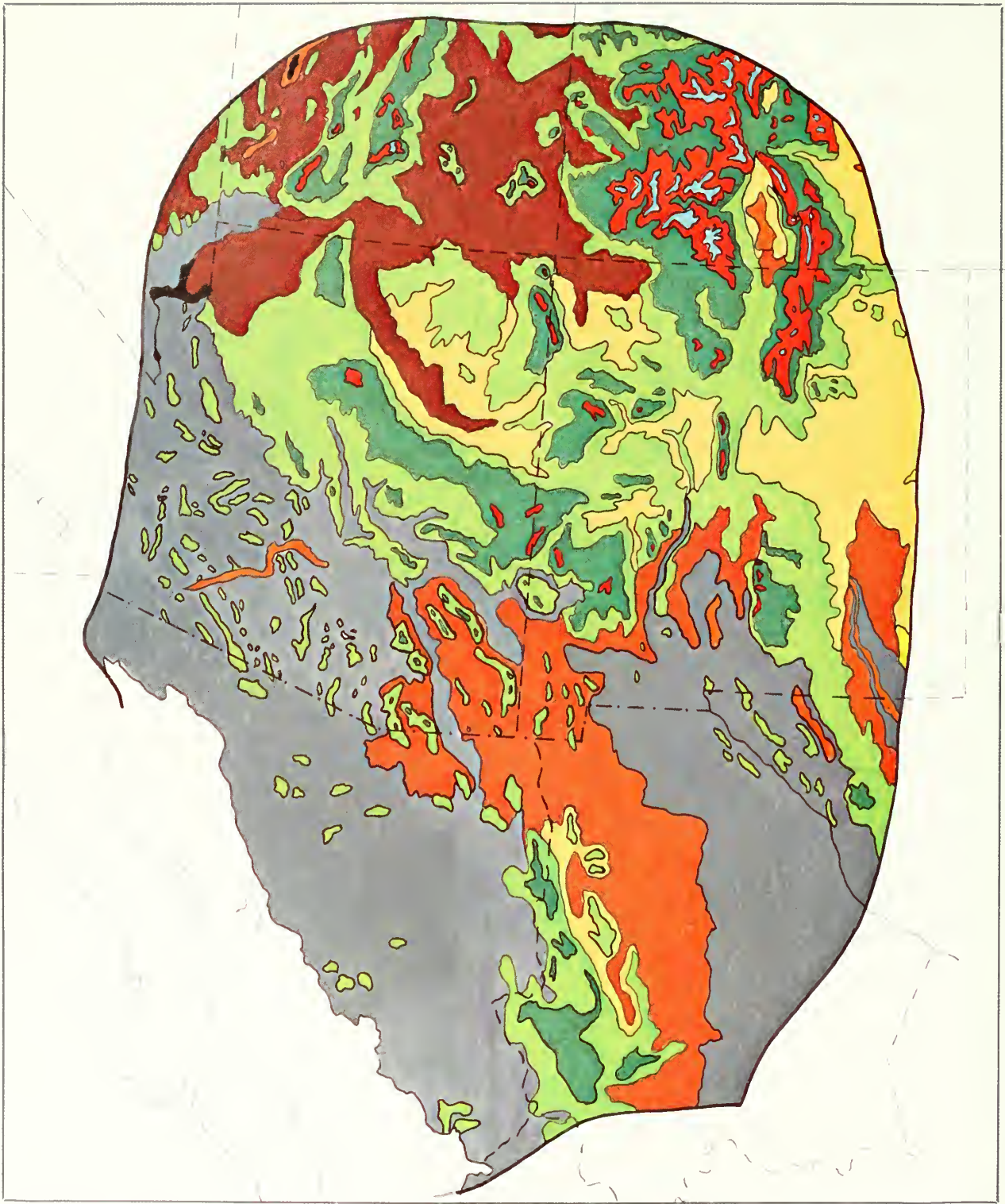
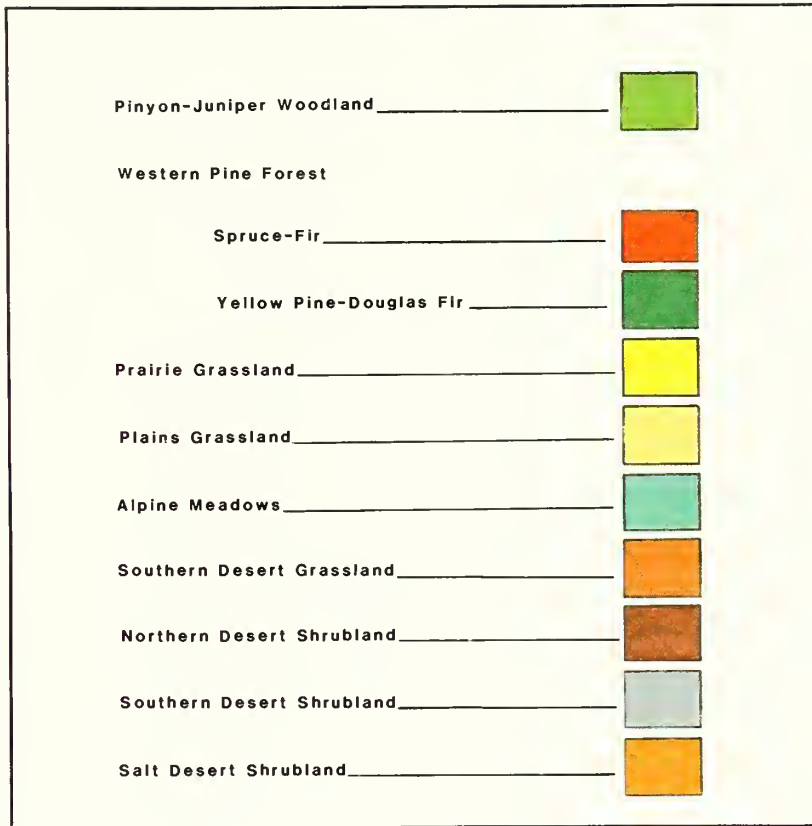


Figure 6 Southwestern vegetation zones (map after Shantz and Zon).

LEGEND FOR FIGURE 6



**Table 1.** Major plant species of Southwestern vegetation zones.

Chaparral

<i>Quercus gambelii</i>	scrub oak
<i>Q. arizonica</i>	Arizona oak
<i>Q. emoryi</i>	Emory oak
<i>Q. turbinella</i>	shrub live oak
<i>Cercocarpus</i> spp.	mountain mahogany
<i>Amelanchier</i> spp.	serviceberry
<i>Arctostaphylos</i> spp.	manzanita
<i>Sambucus</i> spp.	elderberry
<i>Prunus</i> spp.	chokecherry
<i>Rhus trilobata</i>	squawbush

Pinyon-Juniper Woodland

<i>Juniperus scopulorum</i>	Rocky Mountain juniper
<i>J. osteosperma</i>	Utah juniper
<i>J. monosperma</i>	one-seed juniper
<i>J. deppeana</i>	alligator juniper

**Table 1.** Major plant species of Southwestern vegetation zones. (cont.)

<i>Cupressus arizonica</i>	Arizona cypress
<i>Pinus edulis</i>	pinyon pine
<i>P. monophylla</i>	single leaf pine
<i>P. leiophylla</i>	
<i>var. chihuahuana</i>	Chihuahuan pine
<i>Quercus undulata</i>	wavyleaf oak
<i>Q. gambelii</i>	scrub oak

#### Western Pine Forest

<i>Pinus ponderosa</i>	western yellow pine (ponderosa pine)
<i>Quercus gambelii</i>	scrub oak
<i>Pseudotsuga menziesii</i>	Douglas fir
<i>Populus tremuloides</i>	quaking aspen
<i>Abies concolor</i>	white fir
<i>A. lasiocarpa</i>	subalpine fir
<i>var. arizonica</i>	corkbark fir
<i>Picea engelmannii</i>	Engelmann spruce
<i>Pinus flexilis</i>	limber pine
<i>var. reflexa</i>	Mexican white pine
<i>P. contorta</i>	
<i>var. latifolia</i>	lodgepole pine
<i>P. aristata</i>	bristlecone pine

#### Alpine Meadows

<i>Poa</i> spp.	bluegrass
<i>Agropyron</i> spp.	wheatgrass
<i>Danthonia</i> spp.	oat grass
<i>Festuca</i> spp.	fescue grass
<i>Carex</i> spp.	sedge
<i>Juncus</i> spp.	rush

#### Prairie and Plains Grasslands

<i>Bouteloua gracilis</i>	blue grama
<i>Buchloe dactyloides</i>	buffalo grass
<i>Agropyron smithii</i>	western wheatgrass
<i>Hilaria jamesii</i>	galleta grass
<i>Stipa comata</i>	needle and thread grass
<i>Oryzopsis hymenoides</i>	Indian ricegrass
<i>Muhlenbergia torreyi</i>	ring muhly
<i>Sporobolus cryptandrus</i>	sand dropseed
<i>Aristada</i> spp.	three-awn
<i>Chrysothamnus</i> spp.	rabbitbrush
<i>Gutierrezia</i> spp.	snakeweed
<i>Yucca glauca</i>	soapweed
<i>Andropogon scoparius</i>	blue stem bunch grass

**Table 1.** Major plant species of Southwestern vegetation zones. (cont.)

Southern Desert Grasslands

<i>Bouteloua eriopoda</i>	black grama
<i>Hilaria mutica</i>	tobosa grass
<i>Aristida adscensionis</i>	annual three-awn
<i>Aristida spp.</i>	three-awn
<i>Hilaria belangeri</i>	curly mesquite
<i>Buchloe dactyloides</i>	buffalo grass
<i>Bouteloua hirsuta</i>	hairy grass
<i>B. curtipendula</i>	side oats grama
<i>Sporobolus cryptandrus</i>	sand dropseed
<i>Yucca elata</i>	yucca
<i>Larrea tridentata</i>	creosote
<i>Prosopis juliflora</i>	mesquite
<i>Flourensia cernua</i>	tarbush

Northern Desert Shrubland

<i>Artemesia tridentata</i>	big sagebrush
<i>Chrysothamnus spp.</i>	rabbitbrush
<i>Coleogyne ramosissima</i>	blackbrush
<i>Purshia tridentata</i>	antelope brush
<i>Atriplex canescens</i>	four-wing saltbush
<i>Guitierrezia spp.</i>	snakeweed
<i>A. confertifolia</i>	shadscale
<i>Eurotia lanata</i>	winterfat
<i>Grayia brandegei</i>	spineless hop-sage
<i>Artemesia spinescens</i>	budsage

Southern Desert Shrub

<i>Atriplex canescens</i>	four-wing saltbush
<i>Prosopis juliflora</i>	mesquite
<i>Larrea tridentata</i>	creosote
<i>Flourensia cernua</i>	tarbush
<i>Franseria dumosa</i>	burro bush
<i>Cercidium floridum</i>	palo verde
<i>C. microphyllum</i>	palo verde
<i>Olneya tesota</i>	ironwood
<i>Dalea spinosa</i>	smoke tree
<i>Cereus giganteus</i>	giant saguaro
<i>Acacia greggii</i>	cat claw
<i>Fouquieria splendens</i>	ocotillo
<i>Opuntia engelmannii</i>	prickly pear cactus
<i>Pachycereus pringlei</i>	cardon
<i>Agave lechuguilla</i>	lechuguilla
<i>Dasyilirion texanum</i>	sotol

- consists mainly of scrub oak, mountain mahogany, or serviceberry, while chaparral areas in southern Arizona are comprised of open groves of oak scattered over the desert grassland.
2. *Pinyon-Juniper Woodland*. This zone forms a distinct woodland below the yellow pine forest. Pinyon predominates in the upper portion of the zone, but juniper is more abundant in the lower portions. In the south, juniper occurs with a number of small oaks and hardwood species, together with Mexican pinyon and Arizona cypress; this southerly plant configuration is found well into Mexico. In the Sierra Madre Occidental, oak and pine forests are found above 2012 m in elevation.
  3. *Western Pine Forest*. Yellow pine and Douglas fir constitute the greater part of the forests in Arizona and New Mexico.
  4. *Prairie Grassland*. This zone occupies extreme eastern New Mexico and isolated areas in the Canadian and Portales Valleys; it consists of stands of bunch grass in isolated sandy areas and open stony plains. Sandhills in eastern New Mexico are covered with bunch grass and are also associated with shin oak. The oak, seldom higher than 0.9 m, forms a dense low shrubby growth known locally as shinnery. In some areas, shinnery represents a transition to Southern Desert Grasslands, since many of the sand hills are also interspersed with mesquite.
  5. *Plains Grassland*. This zone consists of short grass plains most of which lie east of the Rocky Mountains. Grasses are low growing and shallow rooted. Higher valleys in New Mexico are dominated by grama grass. Along the mountain front, grama grass is often mixed with plants typical of mountain grassland. In areas of deficient rainfall in New Mexico, grama grass gives way to muhly grass. Grasslands dominated by galleta grass cover extensive areas in northern New Mexico and Arizona. Eastern New Mexico is dominated by almost equal quantities of grama grass and buffalo grass which occur as a uniform open sod. Yucca is an associate of the grass cover on the Llano Estacado.
  6. *Alpine Meadows*. These occur on mountain lands above timber line. The meadows are dominated by rock sedge, alpine fescue, and a variety of alpine plants.
  7. *Southern Desert Grassland*. The southern grasslands occur in New Mexico, Arizona, and extend into Mexico. In Arizona, the growth period is relatively rapid and begins as the result of summer rains in July and August. Grass cover is more open than that of the short grass plains, with pure grass cover limited in extent. Much of the surface is covered by scattered desert shrubs, mesquite, creosote bush, yucca, and emory oak. Black grama occupies gravelled slopes lying between river bottoms and the foothills of mountains in New Mexico and is common in Arizona. Crowfoot grama and curly mesquite grasses characterize the greater part of the grasslands in southeastern Arizona; scrub oak is often associated with the curly mesquite at higher elevations. In the western volcanic third of the Mesa del Norte, grama grasslands are scattered with clumps of acacia, mesquite, and opuntia cactus.
  8. *Northern Desert Shrubland*. Scatters and open stands of deciduous shrubs, usually of a common perennial species, characterize this zone. Sagebrush occupies most of the well drained highlands and is characteristic of alluvial fans and plateaus between 1219 and 2134 m in elevation. It ranges on the south to the Mexican border where it occurs in restricted areas at higher elevations. At the southern end of its range sagebrush also occurs with blackbrush and shadscale. Four-wing saltbush, snakeweed, and rabbit-brush are other common associates.
  9. *Southern Desert Shrubland*. This zone is confined to the valleys of the Rio Grande, the Colorado, Gila, and Pecos Rivers. It is not sharply separated from the Chaparral or Northern Desert Shrubland zones. Plants include saltbush in areas of considerable alkalinity interspersed with mesquite where ground water and subsoil conditions are favorable. Creosote bush, the most extensive cover in the zone, favors areas of relatively alkaline free soil. Blackbrush is another principal shrub in portions of Arizona and New Mexico. Above the creosote area is a broad zone consisting of yucca, century plant, cactus, palo verde, and related plants. These are found on rapidly eroding foothills

and ridges, rough mountain pediments, and low mountains. Vegetation is largely palo verde, cactus, ocotillo, and burro bush in southern and central Arizona and continuing south into the Sonoran coastal lowlands and upland deserts. In southeastern New Mexico scattered shrubs and yucca are the dominant vegetation. Lechuguilla is the most characteristic plant, with sotol and ocotillo constituting other important species in this yucca shrubland which continues southward into the eastern Mesa del Norte.

10. *Salt Desert Shrubland*. Drainage channels where moist soils are excessively supplied with salts contain this vegetation type. The principal plant, greasewood, distributed in valley bottoms and along drainage channels, is mixed with shadscale in northern areas.

## Climate

As discussed in the remote sensing handbook (Lyons and Avery 1977), the optimum season for which photographic flights are scheduled depends on the nature of features to be identified or mapped, the film to be used, and the number of days suitable for aerial photography within a given period of time. Both the occurrence of clear, sunny days and the condition and density of vegetation must be taken into account when scheduling an overflight. Detection and mapping of archeological sites during the drier season, for example, might be preferred because of tonal contrasts provided by varying degrees of soil moisture retention in the project area. Use of infrared color film for detection of more ephemeral cultural features such as roadways or irrigation canals emphasizes the difference in infrared between live, healthy deciduous vegetation and non-growing vegetation or other types of surface cover. In order to render photographic scheduling sensitive to specific project objectives, climatic factors both as they create unsuitable conditions for photographic coverage and as they affect vegetation, cover must be understood.

**Precipitation.** The principal source of moisture in the Southwest is in the form of rain from summer thunderstorms (Court 1974). Thunderstorms originate in a flow of moist air from the Caribbean and Gulf of Mexico arriving at the end of June (Court 1974). Rainfall is heaviest in August in New Mexico

and Arizona. The summer monsoons begin earlier in northern Mexico with late June and early July the wettest months.

Fewer convectional thunderstorms occur in August and September on the Mexican Plateau, but occasional tropical storms add to the summer precipitation (Vivó Escoto 1964). An almost continuous drought occurs from November to June in northern Mexico, with April and May usually the driest months. Over the Mexican Plateau a decrease in rainfall is also experienced during the middle of the rainy season. Known as "la canicula" or August drought, the mid-summer drought lasts for about two months in eastern portions of the Mesa del Norte (Mosiño Aleman and Garcia 1974). Winter rains and snow are the principal source of water for the Colorado River Basin from which much of southern Arizona obtains water (Court 1974). About half of the precipitation in the Southern Rocky Mountains occurs as winter snow storms, the remainder as summer thunderstorms. Portions of the San Juan and Sangre de Cristo ranges receive over 60 cm of rain a year.

On the Colorado Plateau, much of the interior precipitation is less than 25 cm annually with the southwestern rim, the Mogollon Highlands, receiving in excess of 50 cm. The Basin and Range Province is distinguished by seasonal differences in the distribution of precipitation (Hunt 1967). In the Sonoran Desert Section, annual precipitation ranges between 10 on 30 cm. Precipitation is biseasonal and about equally divided between the growing season and the winter. Average annual precipitation in the Mexican Highlands Section is between 30 and 40 cm. The Rio Grande Valley averages fewer than 25 cm of precipitation annually with the seasonal distribution of rainfall differing from the western deserts. Most rains in the valley fall during the summer growing season. Higher elevations in the Sacramento Section receive more than 60 cm of annual precipitation. The plains and plateaus of eastern New Mexico have been characterized as an area of moderate rainfall. The basin of the Pecos River below Santa Rosa receives 30 cm of annual precipitation. On the plains east of the Sangre de Cristo Mountains and on the Llano Estacado, rainfall exceeds 30 cm annually. Two arid sections of northern Mexico are separated by the Sierra Madre Occidental. The high central deserts on the Mexican Plateau receive about 40 cm and the low deserts of western Sonora in northwestern Mexico, fewer than 20 cm annually.

**Snow cover.** Snow cover, where it occurs, may either

obscure or enhance archeological features for photographic coverage. The first date of snow cover for lower elevations in Colorado is between November 1 and 15 (Court 1974). Higher elevations in the San Juan Mountains receive the first snow cover of 1 cm or more around October 15. Over most of the rest of the Southwest the average annual date of the first snowfall with 1 cm or more of snow on the ground is between November 15 in the north and January 1 in the south. Most of the Basin and Range Province in southern Arizona and New Mexico averaged no snowfall whatever for between 30 and 50 percent of the years for which these data were recorded. Rapid dissipation of 1 cm of snow can be expected over most of the Southwest. Depending on the temperature and percentage of cloud cover, a light snow can normally disappear within one day.

More serious scheduling constraints are imposed by heavier snowfall. The average annual first snow cover measures 2.5 cm or more in depth. The Basin and Range Province in Arizona and New Mexico, except for portions of the Mexican Highland Section, is exempt from heavier snowfall until after January 1. Areas drained by the Colorado and Gila Rivers in western and southern Arizona and the Rio Grande Valley up to the 35th parallel of latitude do not receive snowfall between 30 and 50 percent of the years recorded.

There is no question that heavy and continuous snow cover is not desirable when scheduling photographic overflights. Light discontinuous snow cover may, however, serve to enhance certain topographic features. Light discontinuous snow cover can be blown by winds into shallow linear depressions on the ground surface where it remains protected from the sunlight by shadows thrown from the lip of the depression. Under these conditions, high tonal contrast is provided between the

depression and the surrounding terrain (fig. 7). Similar results with shadow marks may be achieved by an overflight during a period of low sun angle; detection of such shadow marks may require early morning or late afternoon photography.

Average annual dates of the last snow cover range between February 1 in south-central New Mexico and May 15 in the northern mountains. Scheduling of an overflight during this time would provide for conditions of minimal vegetation cover.

**Duration of Sunshine.** The maximum amount of sunshine in the United States occurs in the Southwest. In southwestern Arizona and adjacent portions of California, the sun shines on the annual average of nearly 90 percent of the total amount of time between sunrise and sunset. Because of fewer numbers of hours of daylight and the great frequency of cloud cover during the winter months, the percentage of sunlight is usually lower in winter than in the summer. Table 2 lists the average length of the day between sunrise and sunset on June 21 and December 22 for three latitudes in the Southwest.

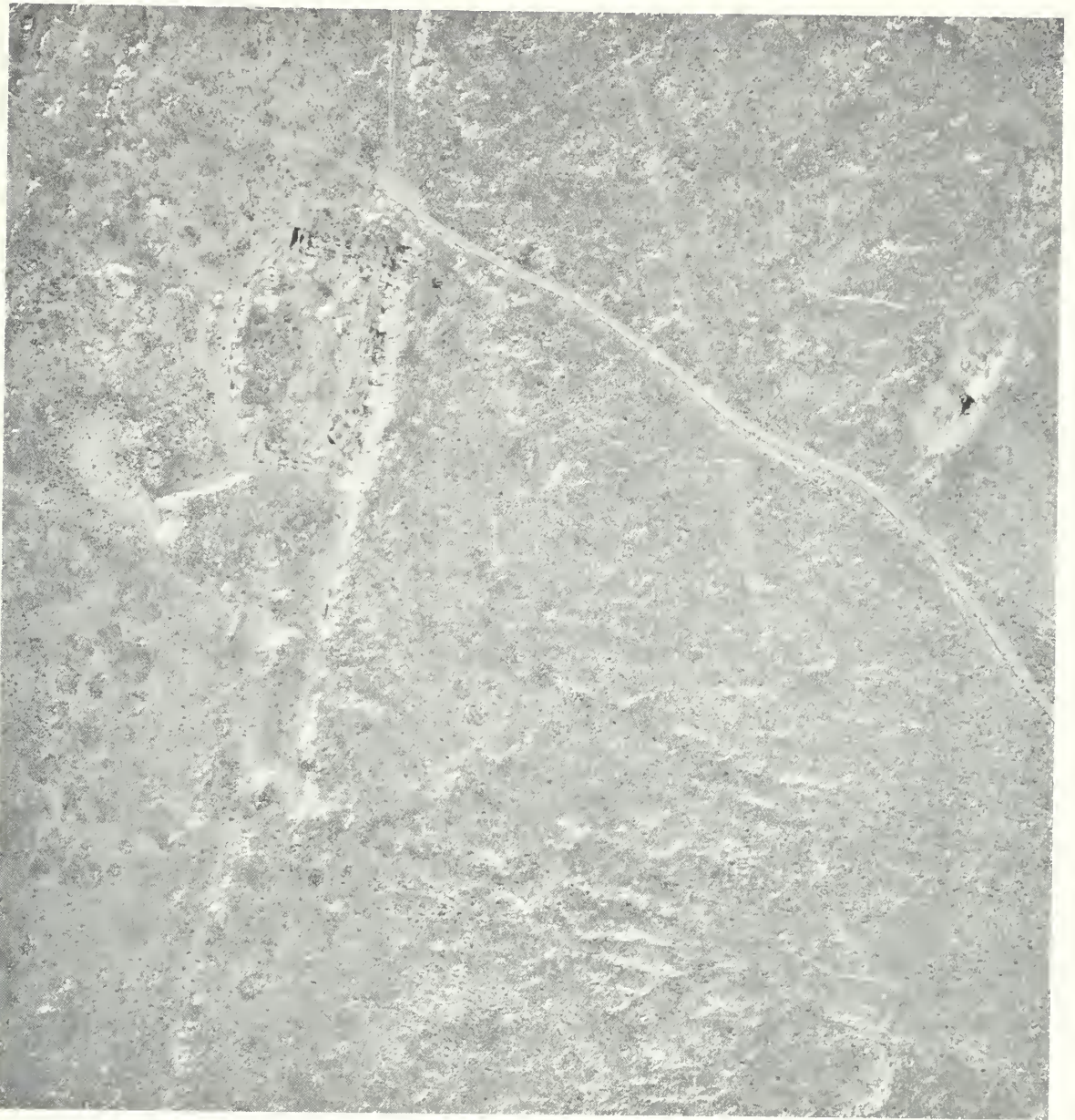
In most of New Mexico, Arizona, and southeastern California, winter days are sunny with the area receiving about eight hours of sunshine daily. During the winter, southeastern California and southwestern Arizona receive about 80 percent of the possible sunlight. The rest of the Southwest receives about 70 percent, with the exceptions of extreme northern Arizona and southeastern New Mexico which receive only 60 percent of the possible amount of sunshine in the winter. During the spring, the maximum amount of sunlight in the Southwest is received in the Lower Colorado Valley where the average for three spring months is 12 hours per day, or about 90 percent of the possible amount. During the summer, about 80 percent of the possible amount

**Table 2.** Average length of day: sunrise to sunset.\*

Latitude	June 21	Dec. 22
	(days in hours and minutes)	
32° 30'	14.17	10.01
35° 00'	14.31	9.48
37° 30'	14.45	9.34

\*After Kincer (1928).





**Figure 7** Snow cover enhancing linear depression near Pueblo Alto ruin, Chaco Canyon.

**Table 3.** Average number of days suitable for aerial photography by state and month of year\*

Month	Arizona	New Mexico	Colorado	Utah
Jan.	15.3	10.5	7.5	7.1
Feb.	13.2	8.4	5.8	5.8
Mar.	15.7	8.7	5.7	7.0
Apr.	18.3	8.3	4.6	7.1
May	22.0	8.1	4.6	7.8
June	23.7	10.5	7.0	12.6
July	15.8	5.4	5.5	11.0
Aug.	15.8	5.3	5.4	11.3
Sept.	20.2	10.2	10.3	14.2
Oct.	21.5	14.0	11.3	13.7
Nov.	8.3	12.7	9.4	10.4
Dec.	16.2	12.3	8.4	7.6
Total per year	216.0	114.4	85.5	115.6

\*After Lyons and Avery (1977:85).

is received throughout for the Southwest. Table 3 gives the number of clear days during each of the four seasons.

**Frost Free Period.** When growing vegetation is a necessary component of photographic analysis, knowledge of the onset of low temperature conditions of sufficient severity to destroy vegetation is necessary. The occurrence of the first and last killing frost is dependent on both latitude and altitude. In portions of the Southern Rocky Mountains Province, a killing frost can occur on or before September 1. Highland and mountain areas, e.g., the eastern Colorado Plateau, the Mogollon Highlands, Black Mesa, Sacramento Mountains, and the foothills of the Southern Rocky Mountains, are subject to frost during September. The Basin and Range Province in northern Arizona as well as the Great Plains in New Mexico are subject to frost in October. Later frosts occur in November over southern Arizona and New Mexico and along the Colorado River Valley into southeastern Utah. Later freezes, when they occur,

begin in December in southern Arizona and the lower Colorado and Gila Valleys.

These areas are also characterized by the earliest dates (before March 1) of the last killing frost. With the exception of the Mexican Highland Section, the Basin and Range Province in Arizona receives its last frost during March. The Lower Rio Grande and Pecos Valleys and the Colorado River Valley into southeastern Utah also see the onset of the growing season during March. The majority of the Colorado Plateau, on the other hand, does not receive its last frost until the month of May. The growing season does not commence until June in the southern Rockies.

If vegetation cover figures prominently in the interpretation of remotely sensed data, two factors will necessitate careful monitoring of growth conditions. First, the dates of the frost free period for any given year will fluctuate from the average annual figures, and, second, optimal reflective conditions are not always apparent from visual inspection of the

vegetation on the ground. It may be desirable to monitor the extent of plant growth necessary for the detection of cultural features with several overflights in the early spring. In forested areas, differences in the canopy and understory growth can also be monitored with successive overflights. These differences might prove effective in the definition of cultural features which would otherwise be obscured by heavier growth later in the season.



## Cultures of the Southwest

### Introduction

There is good evidence that the Southwest has been inhabited continuously for about 11,500 years. Within this span of time, three adaptive strategies have been distinguished. The earliest period of human occupation (during the final portion of the Pleistocene) is termed Paleo-Indian and refers to an adaptation based on hunting and gathering. The following strategy—Archaic—was based on hunting and gathering with emphasis on a wide range of resources. After about 3000 B.C., these included domestic maize, which had been obtained from the Mexican highlands far to the south. At about A.D. 1, a third, involving sedentary communities based primarily on horticulture, was identified. Emphasis in the following discussion will be placed on the kinds of archeological remains characteristic of each subsistence mode in order to indicate the nature of the data base to which remote sensing techniques may be applied.

### Paleo-Indian Period

Paleo-Indian occupation of the Southwest has been characterized as an adaptation by highly mobile, small family groups substantially dependent on big game hunting for subsistence. This way of life presents the problem of low archeological visibility in that the remains of briefly occupied camps contain neither the structural remains nor the accumulation of refuse by which later archeological sites are usually identified. In addition, the relatively great antiquity of Paleo-Indian remains means that they have been subject to geologic processes that have altered both

the remains themselves and the landscapes on which they were originally deposited.

Research among modern hunters and gatherers indicates that the seasonal round of activities results in several different types of site use. Campbell (1968) has distinguished site types which include base camps, temporary hunting camps, kill sites, and overnight camps among the big-game hunting inland Eskimos of Alaska. Few of these activity loci will be visible to the archeologist thousands of years later. Judge (n.d.) suggests that four types of Paleo-Indian sites (camps, kill sites, processing sites, and quarries) may be distinguished on the basis of relative proportions of artifacts and faunal remains. Except when unusual circumstances, such as modern gravel quarrying or mining, reveal Paleo-Indian remains *in situ*, most sites are found where erosion has exposed Pleistocene deposits. Thus, mammoth bones may be exposed in the cut bank of a modern stream or artifacts may be recovered from a caliche surface after eolian deflation has removed more recent overburden. Even under circumstances most favorable for preservation, such as deposition in a dry cave, only the most durable archeological materials are likely to survive. These include lithic tools and the debris from their manufacture and the more substantial faunal remains, including tools made of bone. Under rare circumstances, hearths and carbonized plant materials may be preserved.

Within the Southwest proper, three major Paleo-Indian complexes are distinguished, although none of these is exclusive to the Southwest. The oldest, well dated material belongs to the Clovis Complex (9500–9000 B.C.) and is distinguished by the presence of a particular kind of lanceolate, fluted projectile point and faunal assemblages that include mammoth, an extinct form of bison, horse, camel, sloth, peccary, deer, rabbit, turtle, and others (Irwin-Williams 1979; Judge n.d.). The Folsom Complex

(8800–8200 B.C.) followed Clovis and is characterized by a very distinctive, finely made, fluted projectile point and a hunting technology that apparently focused on relatively small herds of extinct bison. The varieties represented in faunal assemblages associated with Folsom finds are somewhat diminished from those of Clovis times, the *Rancholabrean* fauna having by this time become extinct (Irwin-Williams 1979). In the Southwest, the next major Paleo-Indian assemblages, those of the Cody Complex (6600–6000 B.C.), are dated much later, although in areas immediately adjacent to the Southwest, several intermediate complexes have been documented. Stone implements diagnostic of the Cody Complex are two forms of asymmetrical knives, and excellently crafted, lanceolate, slightly shouldered projectile points. Cody subsistence seems to have centered on specialized bison hunting using drive and jump techniques.

In addition to these three complexes, there are two more problematic kinds of remains. The first consists of assemblages that may be older than Clovis but whose antiquity is under dispute; the second are as old as Clovis and Folsom, but seem to represent a different subsistence technology. Within the Southwest, only Hermit's Cave west of Carlsbad, New Mexico, and the Sandia Cave and Lucy Sites, east of Albuquerque, New Mexico, possibly relate to a pre-Clovis occupation (Judge n.d.). Hermit's Cave contained mammoth and dire wolf remains and a hearth. Radiocarbon dates from the hearth and burned logs within the cave range between 11,000 and 9800 B.C. The dates have not been disputed, but the association of the dated material with human occupation has (Haynes 1967; Judge n.d.; Schultz and Martin 1970). Sandia Cave and the Lucy Site are the only two localities that have yielded the distinctive shouldered Sandia points. The Lucy Site, exposed through eolian deflation, contained a mixed archeological assemblage. Sandia Cave yielded faunal remains that included mammoth, mastodon, horse, camel, and bison. Radiocarbon dates obtained from the Sandia Cave deposits were in excess of 20,000 B.C. However, there has been a considerable amount of confusion and dispute about the dates themselves, the provenience of the Sandia points within the cave, and the stratigraphy of the cave (Judge n.d.; Stevens and Agogino 1975).

Those assemblages that are as old as Clovis and Folsom but may represent a different way of life are generally referred to as the Sulphur Springs stage of the Cochise Culture. Specific sites include the Double Adobe Site and the lowest levels of Ventana Cava,

both in southern Arizona (Haury 1950; Sayles and Antevs 1941). Radiocarbon dates from the appropriate levels of these two sites range from about 9000 to 6000 B.C. (Haynes 1967). Both sites contain the remains of Pleistocene fauna, but the Sulphur Springs Cochise artifacts do not include projectile points. Typical lithic artifacts include choppers, scrapers, and cobble grinding stones, items that are generally characteristic of later Archaic cultures. Haury (1950) suggested that the Sulphur Springs Cochise might represent a seasonal occupation by Clovis hunters. Duncan (1971), on the other hand, proposed that the Sulphur Springs material represents Clovis base camps and processing areas, their locations being determined by locally available running water, which she believes should not have varied seasonally under conditions of greater climatic equability at the end of the Pleistocene. Figure 8 illustrates the locations of major Clovis, Folsom, and later Paleo-Indian sites in the Southwest.

## Archaic Period

Although bison hunting continued to be a viable subsistence strategy in other areas, increasing desiccation in much of the Southwest resulted in the disappearance of the grassland habitat necessary to sustain large bison herds, and there was an economic shift (about 6000 B.C.) to hunting smaller game and the use of a greater variety of plant resources. High group mobility seems to have decreased, with the establishment of seasonal base camps as a part of the annual round. Limited activities, such as hunting, stone quarrying, and plant processing, were apparently carried out at locations spatially separated from the base camps (Irwin-Williams 1967, 1979).

Within the Southwest, Irwin-Williams (1967, 1979) distinguishes four regional variants (fig. 9) of this way of life: the Oshara tradition in the north, the San Dieguito in the west, the Cochise in the south, and a southeastern tradition represented by Archaic sites in the Tularosa Basin and eastward in New Mexico (Human Systems Research 1973). In general, Archaic material is recovered from two different archeological situations. Cave sites were widely used and generally contain well preserved faunal and botanical remains, in addition to stone tools. Open sites sometimes contain hearths, but more frequently consist of scatters of stone tools and lithic manufacturing debris. Unless the open sites contain

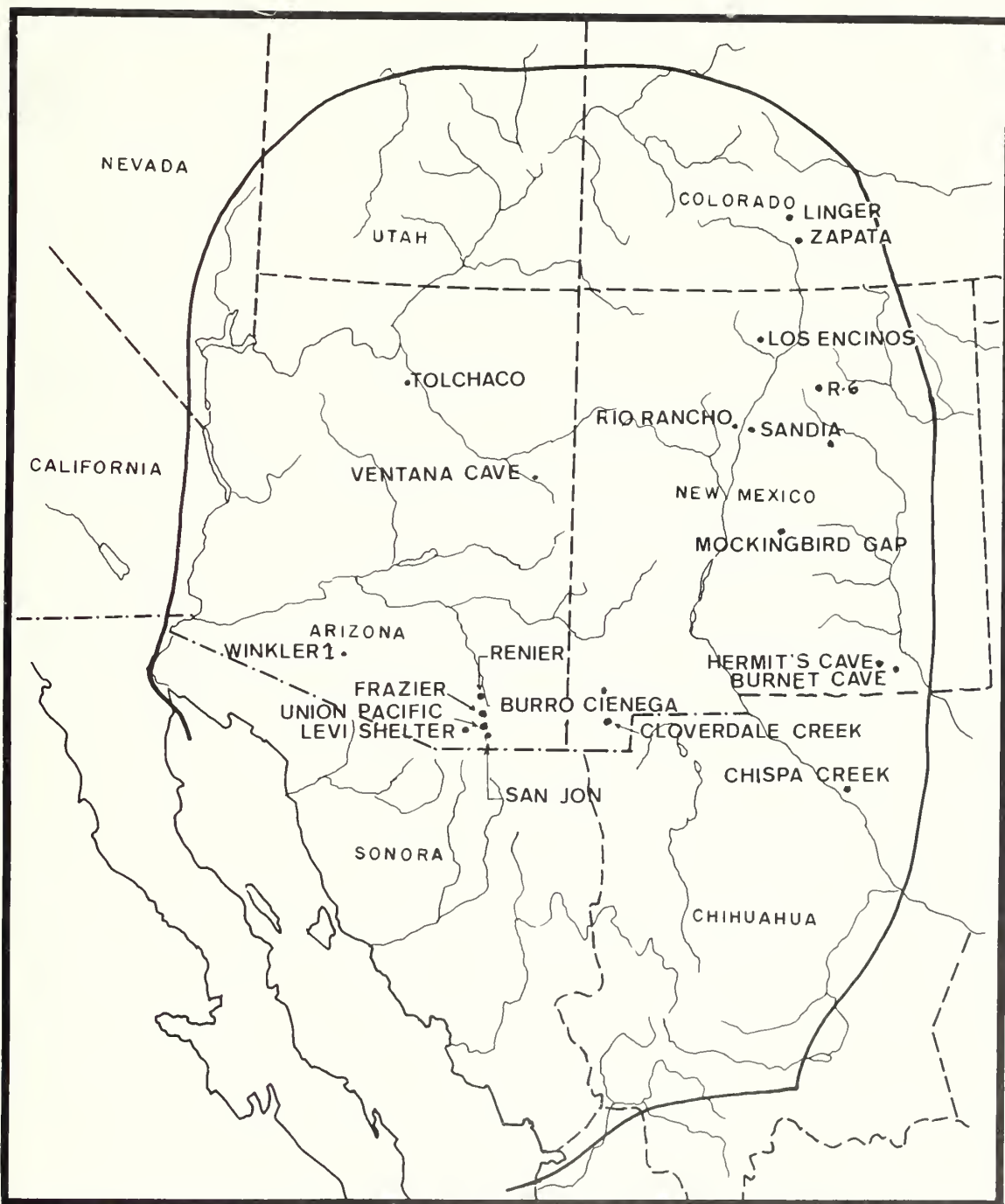


Figure 8 Locations of major Clovis, Folsom, and later Paleo-Indian sites in the Southwest.

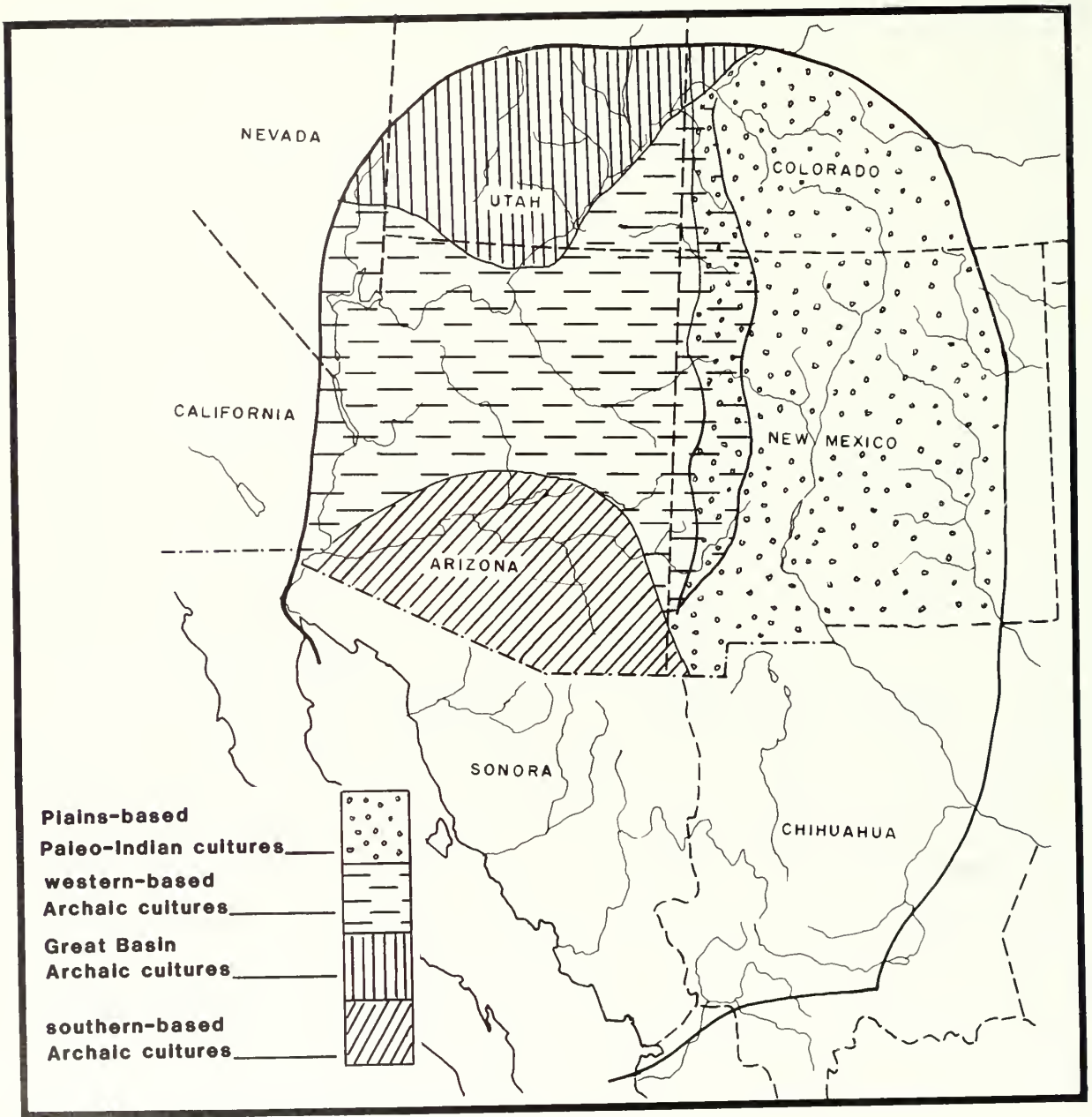


Figure 9 Regional variants of Archaic traditions in the Southwest.



distinctive projectile point types or other diagnostic Archaic artifacts, they are often difficult to distinguish from limited activity loci of later cultures. For this reason and also because the Archaic in the Southwest has received less archeological attention that it merits, settlement distributions, demographic patterns, and the microenvironmental correlates of specific settlement and activity areas are poorly known. Irwin-Williams' (1973) report of the Oshara Archaic in the Arroyo Cuervo area indicates that cliff top, canyon head areas were important base camp localities, hunting camps were located at higher elevations in the Jemez Mountains, and quarries occurred where there are outcrops of suitable raw material, particularly basalt.

By about 3000 B.C., the Archaic adaptation came to include the use of domestic maize which had been introduced from central Mexico. Because botanical remains are better preserved in dry caves, these sites have provided the evidence for the use of this cultigen. It is important to note that maize seems to have been integrated into the Archaic subsistence pattern with little or no alteration of the Archaic way of life. Apparently, it was used in much the same way as other grasses, i.e., ground in metates with a mano or hand stone, and its introduction did not include major technological changes. At Bat Cave, on the southern margin of the Plains of San Augustin, New Mexico, maize occurs with typical Chiricahua phase Cochise artifacts (Dick 1965). At Tularosa Cave, near Reserve, in the Mogollon Mountains of New Mexico, maize also accompanies a typical inventory of Archaic artifacts (Martin et al. 1952). The same situation applies to the Cienega Creek site in east central Arizona (Haury 1957; Martin and Schoenwetter 1960) and to Swallow Cave (Mangelsdorf and Lister 1956) at the eastern edge of the Sierra Madre Occidental in northwestern Chihuahua. Despite the eventual importance of horticulture in the Southwest, late Archaic archeological sites in which maize occurs do not differ markedly from those of the earlier Archaic in which it does not. There is currently no clear evidence for a resulting decrease in group mobility; the development of storage facilities and accumulation of refuse deposits did not occur until much later. Irwin-Williams (1973) notes an increase in both the size and number of late Archaic sites in the Arroyo Cuervo area which appears to correlate with the introduction of maize and indicates an increase in population size.

It was not until 300 B.C. that the settlement and technological changes normally associated with horticulture in arid settings become apparent in the

Southwest. It is important to observe that the earliest evidence for these changes did not come from the relatively well watered areas of the Southwest but from Snaketown, a village on the north bank of the Gila River in the southern Arizona desert (Haury 1976). Botanical evidence indicates that during the initial occupation of Snaketown cultivated crops included maize, squash, beans, and cotton, although these were still probably supplementary to wild plant foods, particularly mesquite and cactus (Bohrer 1979). Nevertheless, Snaketown was a year-round community with midden deposits, storage facilities, and irrigation canals (Haury 1976). Elsewhere in the Southwest, sedentary communities, which were clearly dependent upon cultivated crops, did not occur until somewhat later, usually between A.D. 1 and 500.

With the beginning of sedentary communities, the Archaic adaptation came to an end and regional variations in the cultural traditions in the Southwest became marked. Archeologists distinguish four major traditions or archeological cultures within the Southwest (fig. 10), each of which displayed considerable internal homogeneity as reflected in settlement patterns, artifact types, and rates of cultural change: (1) Hohokam of the lower Gila and Salt River drainages of southern Arizona; (2) Mogollon of the mountainous areas of the Mogollon Rim country of Arizona and New Mexico and the Sierra Madre Occidental of Chihuahua; (3) Anasazi of the Colorado Plateau areas, and eventually, the northern Rio Grande Valley; and (4) Patayan, the least well known tradition, which centered in the Colorado River area. In addition, areas on the northern Colorado Plateau (as well as portions of the Great Basin in Utah and Nevada) were occupied by a tradition archeologists have labeled Fremont.

## The Hohokam

The Hohokam were formally distinguished as a discrete cultural entity by Harold Gladwin (Gladwin and Gladwin 1933). In 1934, the Gladwins established a broad scheme of temporally significant Hohokam cultural stages, which, although modified, are still in use today. These are, from earliest to latest, Pioneer, Colonial, Sedentary, and Classic. Haury (1976), in the recent discussion of the Hohokam based on his reexcavation of the Snaketown Site, places the beginning of the Pioneer Stage at 300 B.C. The Pioneer Hohokam cultivated corn, and probably

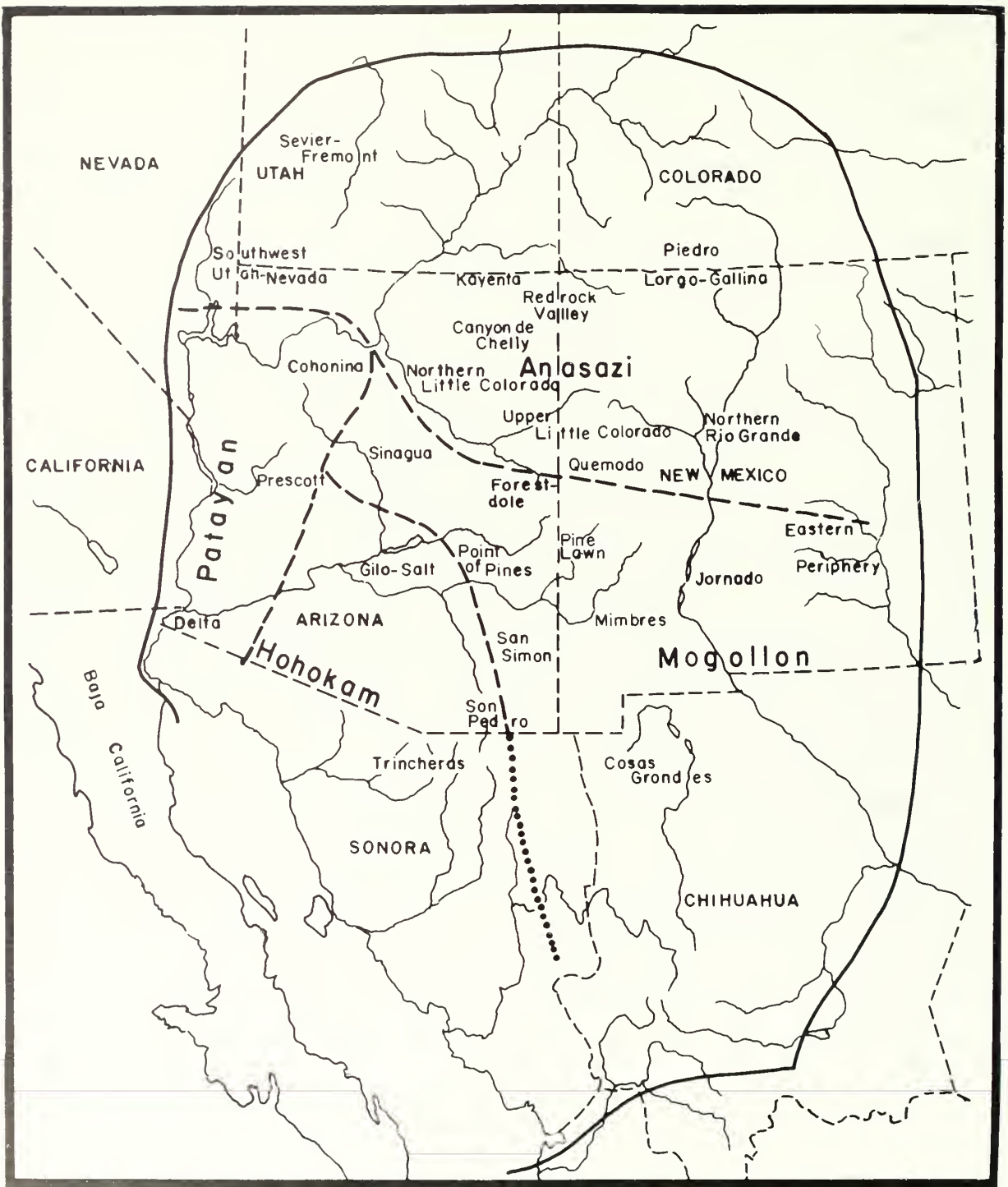


Figure 10 Major archeological traditions in the Southwest

beans and squash, built and maintained irrigation canals, and produced fine ceramics and items of ground stone and marine shell. Because the technological sophistication of the early Hohokam appears to have no precedents in the earlier San Jose phase of the Archaic Cochise Culture, Haury (1976:351-352) concludes that the Hohokam were a migrant group from some as yet unidentified locality in Mesoamerica. An alternative view emphasizing Hohokam continuity with Archaic populations is presented by Martin and Plog (1973:172-173). Haury suggests that the changes in Hohokam Culture from the Pioneer stage through the Classic Stage represent primarily an in situ cultural evolution with periodic "infusions" of elements from Mesoamerica. After A.D. 1200, Mesoamerican influence seems to have declined, and, for a while, the Hohokam were brought into more active intercourse with Pueblo peoples from the north. This interaction included receiving the immigrant peoples (Salado) into the area during the Hohokam Classic Stage. The influence of the Pueblos did not last beyond the fourteenth century. The modern Pima Indians of Arizona are considered descendants of the Hohokam (Haury 1976).

The Hohokam are known for especially fine workmanship in ground stone and shell. Ground stone items include relief-carved and sculpted vessels and palettes, as well as mortars, pestles, and edge-shaped metates. Marine shell items are present from the beginning of the Hohokam sequence and include a great variety of pendants, beads, and bracelets. In addition to carving both geometric and representational motifs on shell ornaments, the Hohokam produced intaglio patterns by etching shell with a weak acid they may have obtained from fermented cactus juice (Haury 1976:318). The copper bells found at Hohokam sites were most likely imported from Mexico as finished items (Haury 1976:278).

Hohokam pottery was produced by coiling, finished either by scraping or paddle and anvil smoothing, and fired in an oxidizing atmosphere, giving the paste a relatively light color. The characteristic mode of decorating pottery was by painting, and red-on-buff designs are common. Hohokam wares display scroll and hachured motifs, as well as a great variety of representational life forms including plants, insects, birds, and mammals. Humans are depicted performing a variety of activities. The Hohokam produced many more clay figurines than other Southwestern cultures (Haury 1976:191-268).

The "core area" of Hohokam settlement was

along the Gila and Salt Rivers: water from the rivers was critical for irrigation; the reeds and grasses of the river banks were used in domestic construction; and fish perhaps provided an important supplemental source of food. Contemporary peoples, possibly the descendants of the San Jose Cochise, lived farther from the rivers and relied more heavily on the mesquite, cacti, and vertebrate fauna available in the desert. In general, the material culture of those of the "Desert Branch," who lived at some distance from the rivers, did not differ substantially from that of the riverine Hohokam until the Classic stage when the Pueblo presence markedly changed the settlement pattern of the riverine Hohokam but not of the desert dwellers.

In general, the Hohokam represent a very successful, highly stable adaptation of horticulturalists to extremely arid conditions. Their subsistence depended on canal irrigation, and the canals themselves are one of the hallmarks of Hohokam Culture. In addition, the Hohokam built adobe-faced platform mounds and very large (120 by 30 m), elliptical ball courts (Willey 1966: 245). Despite the coordination of labor implied by the canals, platform mounds, and ball courts, pre-Classic Hohokam settlements were not very large, and social stratification is not apparent in either domestic architecture or burials. Domestic architecture shows a considerable amount of variation through time, but houses were characteristically of reed-and-thatch construction with slightly depressed adobe floors. A fire hearth near the entryway and roof-support posts are usually the only interior features. Houses of the Pioneer Stage are larger than those of any other time period, and, again with the exception of the Classic Stage, villages do not appear to have had internal organization plans. During the Hohokam Classic Stage, rectangular adobe surface rooms, arranged in compounds, were built in the riverine area, apparently as a direct or indirect consequence of the presence of the Puebloan Salados. It was during this period that the multistory adobe "great houses," such as those at Casa Grande and Los Muertos, were constructed. A few inhumations are known from all Hohokam time periods, but cremation was the more typical method of treatment of the dead, especially in the riverine area. Although the recent work at Snaketown demonstrates that the cremation ritual must have involved the participation of several groups of people, Haury (1976:164-171, 351-357) believes the society was essentially egalitarian.

Despite the considerable amount of detailed information about the Hohokam in the literature and

the use of the terms "typical," "diagnostic," and "characteristic" in the foregoing discussion, it is well to keep in mind that the Hohokam are known primarily from archeological surveys and the excavation of only a few sites. That we know as much as we do about the Hohokam is a tribute to the quality of the excavations carried out in the area. However, not enough is known about the range of variability in Hohokam sites of all time periods. Answers to questions dealing with the structure of Hohokam society, the degree to which the Hohokam participated in interregional trade networks, acted as brokers of Mesoamerican technology and ideology, and ultimately responded to the constraints of their environmental setting will depend upon far more information than we have today.

## The Mogollon

Formal recognition of the Mogollon as a separate cultural tradition was made by Haury in 1936. Most of the literature available on Mogollon archeology results from work carried out by three research institutions: Gila Pueblo (Haury 1936; Sayles 1945), the Field Museum of Natural History (Martin et al. 1940, 1943, 1952), and the University of Arizona (Longacre 1970; Zubrow 1971). Although most archeologists who have worked with Mogollon material prefer to use phase designations that refer to chronological developments within very small local areas, Wheat (1955) proposed a general framework of Mogollon stages that is useful when discussing the entire Mogollon area. From earliest to latest, Wheat's stages are Mogollon I (ca. 100 B.C. -A.D. 400), Mogollon II (A.D. 400-600), Mogollon III (A.D. 600-900), Mogollon IV (A.D. 900-1050, and Mogollon V (A.D. 1050-1200).

Some of the earliest dates for maize in the Southwest come from the mountainous region along southeastern Arizona and southwestern New Mexico and adjacent areas of Chihuahua. Martin (1959) and others (Martin et al. 1950) describe the Mogollon as the direct descendants of the San Pedro Cochise who had cultivated maize in this relatively well watered region, and, by about 100 B.C., had adopted a sedentary life style and produced ceramics. Martin specifically cites continuity in artifact types, e.g., basin-shaped metates, several types of projectile points, scrapers, etc., as well as continuity in resource exploitation, as demonstrating the link between the Archaic Cochise and the Mogollon.

Although maize seems to have become increasingly important to the Mogollon through time, they continued to exploit wild plant foods such as walnuts, pinyon nuts, acorns, yucca fruit, cacti, wild grapes, grasses, and game such as mule deer, turkeys, bighorn sheep, and rabbits, all of which had been a part of the Archaic economy as well.

There are a number of similarities between the Mogollon and the Hohokam. Ceramics in both areas are oxidized red wares which are decorated with red paint. Small villages are found in both areas; house form is similar; and the Mogollon also made a considerable amount of marine shell jewelry, including bracelets. However, the differences between the two traditions are evident, not only in material items represented, but also in the nature of the adaptations and their rates of change. The features characteristic of the Hohokam from the early stage of their development, such as platform mounds, ball courts, very elaborate work in stone and shell, are not present in the Mogollon area. Mogollon Culture changed only gradually, and it was not until late Mogollon times that large villages of aboveground rectangular rooms, elaborately decorated ceramics, and water control features occurred in the Mogollon area. The relative abruptness with which these features appeared in the Mogollon area, as well as the fact that they are temporally late in comparison with the Anasazi area, has often been interpreted as an Anasazi migration into Mogollon country (Willey 1966:199). Other interpretations, however, which depend on increased population, climatic variability, and responses to diminished effective moisture for crops, are equally reasonable (J.J. Brody, personal communication, 1977; Martin 1959; Zubrow 1971). The Mogollon Culture is sometimes represented as a stable and successful adaptation by horticulturalists to relatively well watered mountains (Martin and Plog 1973:180-193). It should be remembered, however, that in its more southern extension along the Mimbres River and into Chihuahua, Mogollon territory included some of the most arid portions of the Southwest. Unfortunately, the archeological work in the Mogollon area has concentrated on the mountainous portion of the territory, and thus the interpretive statements may be biased.

Mogollon I villages consist of small numbers of pit houses, located almost exclusively on high bluffs above areas of alluvial deposition. House size varied, but interior storage pits and hearths are common features. After Mogollon I, pit house villages occur more frequently on or adjacent to

bottom land that would have been suitable for agriculture. Throughout the Mogollon sequence, until about A.D. 1050, there were only minor changes in village form and domestic architecture. Martin and others (1950:556-569) note that in the Pine Lawn area, near Reserve, New Mexico, there was a decrease in the size of pit houses from early to late with a concomitant increase in the number of pit houses per village through time. "Special" structures, marked by unusually large size and parallel floor grooves, are present from the earliest villages and are usually interpreted as ceremonial rooms or kivas. Entryways, which are often absent in Mogollon I sites, appear more frequently through time and are commonly oriented toward the east. During late Mogollon times, the slab-lined pit houses were rectangular. Finally, there was a shift to aboveground rectangular masonry rooms organized in room blocks around open central plazas.

Primary inhumation was the characteristic mode of treatment of the dead. Cremations did occur but were rare. Burials were often placed in abandoned rooms and in pits under room floors, which were then replastered with adobe. Shell ornaments are the most common burial goods. Between about A.D. 950 and 1050, however, in the Mimbres Valley of New Mexico, burials were accompanied by imaginatively decorated black-on-white bowls.

As noted above, early Mogollon ceramics were plain reddish ware. Later, geometric designs were painted on the brown interiors of bowls and exteriors of jars. Surface treatment (corrugations, fillet rims, indented corrugations, and combinations of corrugations and incisions) is common on unpainted vessels. In Mogollon IV, black paint on a white slip was used, a style that reached its most sophisticated development in the Classic Mimbres Black-on-white ware of Mogollon V. This distinctive and aesthetically appealing ware, includes both remarkable geometric painting and representational motifs.

It should be remembered that the Mogollon area continues beyond the current international boundary and far into northern Mexico. Recent work by DiPeso (1974), in the area between the Rio del Carmen and the Rio Bavispe of Chihuahua, indicates that between A.D. 700 and 950, developments roughly paralleled those farther north. However, contiguous surface rooms, rather than pit houses, were constructed between about A.D. 950 and 1060. In addition, the presence of copper tinkler bells, pyrite mirrors, and turquoise beads indicate the beginnings of an extensive system of trade. From

A.D. 1060 until 1340, the entire region came to be dominated by a single town, familiar in North American literature as Casas Grandes, but labeled by DiPeso with the Nahuatl name, Paquimé (DiPeso 1974:292-295). During this time elaborate water control features including canals, check dams, and linear borders were constructed. Paquimé became a large town with multistory dwellings, a ceremonial precinct, ballcourt, craft areas, and a sewer system. DiPeso (1974:290-390) believes that the construction of Paquime was organized by traders from a state in northwestern Mexico. DiPeso relies on descriptions of the *puchteca*, a class of trader-spies known to have existed during Aztec times, as an analog for a group he envisions at Paquime. Thus, he sees the trading class as having mobilized the native population, bringing them into economic interaction with the traders' home state. No large numbers of traders would have been required to accomplish this. The most immediate problem with the *puchteca* model is that there is no evidence of such people in Mexican states prior to the Aztec, whose occupation postdates the settlement at Paquime. A second problem is that, although DiPeso believes the traders came from a state in the Zacatecas area, the specific location of such a parent state is not yet known.

The Salado, the Puebloan group that lived in the Hohokam area for a time, also seem to have occupied the Mogollon area. Salado sites, which are characterized by aboveground villages and specific polychrome pottery types, are present in the upper Gila River area and the Mimbres Valley. Unlike the situation in the Hohokam area, however, the Salado movement into the Mogollon region seems to have been into vacated areas, for the Salado are not found in the same villages as the Mogollon.

Late Mogollon sites, those dated from A.D. 1000 to about 1400, show an increase in site size, use of masonry in aboveground rectangular rooms and incorporation of rectangular ceremonial rooms into room blocks. There was a concomitant development of water control features, the type being determined by the terrain. Most of the information of this late Mogollon manifestation results from work in the Hay Hollow Valley of Arizona at the Carter Ranch and Grasshopper Sites (Longacre 1970; Zubrow 1971). After about A.D. 1450, most of the old Mogollon territory was abandoned. Martin (1959:141) believes that the modern pueblo of Zuni contains direct descendants of the Mogollon. It is also possible that peoples of Mogollon origin are living among the people of the Rio Grande pueblos, as will be discussed below.

# The Anasazi

The Pecos Classification (Kidder 1927), a series of developmental stages, was initially proposed as a framework to account for prehistoric development in the entire Southwest. It is considered applicable only to the Anasazi area and to best fit Anasazi developments in the San Juan River drainage. Thus, the Anasazi continuum was the first recognized prehistoric cultural tradition in the Southwest; but definition of the Anasazi has become increasingly clarified only as the other cultural traditions have been defined. The Pecos Classification divides Anasazi prehistory into two Basketmaker and five Pueblo stages (Basketmaker II and III; Pueblo I–V). The original classification included Basketmaker I as a separate stage, but it has since been subsumed under the late Archaic cultures. In 1936, Frank H.H. Roberts, Jr., suggested a revision of the Pecos system which is followed in some secondary sources (e.g., Wormington 1961), but has not been adopted widely in the primary literature. As is the case in the Mogollon area, most archeologists prefer to use sequences of phases that apply only to small geographical areas within the Anasazi area; these are so numerous that any attempt to synthesize them would require a volume itself. Fortunately, when phase designations are used, reference is usually made to the placement of specific phases within the Pecos Classification. Dates for each of the stages of the Pecos system are given here for convenience, but the reader should be advised that they will only approximate chronological developments in any particular locality. Basketmaker II is generally dated from about A.D. 1 to 400, Basketmaker III from A.D. 400 to 700, Pueblo I from A.D. 700 to 900, Pueblo II from A.D. 900 to 1100, Pueblo III from A.D. 1100 to 1300, Pueblo IV from A.D. 1300 to 1500 and Pueblo V from A.D. 1550 to the present (Wiley 1966:199–215).

As has been noted above, Irwin-Williams (1973) views the Anasazi as an outgrowth of the Archaic Oshara adaptation of the northern Southwest and sketches the basic continuity in her work in the Arroyo Cuervo area. Evidence for small villages, which were probably occupied year-round, comes largely from the more northern portion of the Anasazi territory in the Navajo Reservoir District of the San Juan Valley and from areas near Durango, Colorado (Eddy 1961; Morris 1927, 1939; Morris and Burgh 1954). These settlements, which are considered representative of Basketmaker II, date from about

A.D. 1 to 400 (Eddy 1966:472), somewhat later than the earliest manifestations of both the Hohokam and the Mogollon. Basketmaker II dwellings are relatively small structures consisting of shallow subsurface depressions, some of which are paved with flat cobbles, central, circular heating pits, and probably, cribbed log walls. Settlements were small, arranged in no particular plan, and generally located on Pleistocene benches overlooking river bottom land (Eddy 1966:473). Although Basketmaker II was originally defined as a nonpottery making stage, fired ceramics have been found in Basketmaker II sites in the Navajo Reservoir District. Within the Navajo Reservoir District, all Basketmaker II villages contained one over-sized structure, interpreted as being the “intercommunity kiva” (Eddy 1966:477). Charred corn cobs and milling stones indicate heavy utilization of plant foods; faunal remains include deer, elk, and mountain sheep (Eddy 1966:477). Throughout the rest of the Anasazi sequence, hunting seems to have been of considerable economic importance in a subsistence pattern similar to that of the Mogollon but in contrast to that of the Hohokam.

During Basketmaker III, several distinctively Anasazi characteristics developed. First, true pit houses with contiguous fire pits and ash or warming pits, ladder holes, deflectors, partition walls, and sipapu were built. The sipapu is thought to represent the *shipap* or place where pueblo peoples emerged from the underworld and is represented by a small hole in the floor, usually close to the back wall. The pit house floor features, excluding the partitions, were later incorporated into Anasazi kivas, and the pit house form was retained as a ceremonial room long after aboveground rectangular rooms became domiciles. Second, ceramics came to be widely used, and although brown wares were found at the beginning of this stage in the Navajo Reservoir District (Eddy 1966:481), gray wares, fired in a reducing atmosphere, became an Anasazi hallmark later in the Basketmaker III stage. Third, there was increased use of both interior and exterior storage facilities. There also appears to have been a replacement of the spear thrower by the bow and arrow (Eddy 1966; Glassow 1972).

During Basketmaker III, there seems to have been a considerable increase in population, as inferred from an increase in the number of sites. Settlements were located close to arable land, either on the first bench above watercourses or on alluvial fans. In both the Navajo Reservoir District and at Shabik’eshchee Village in Chaco Canyon, an

especially large, and in the former case, elaborate structure is identified as the community kiva (Eddy 1966:479; Roberts 1929). It is not known whether the population increase in Basketmaker III and the introduction of the pit house represent migration into the Anasazi area by the Mogollon (Eddy 1966; Martin et al. 1950) or primarily internal population growth and resultant architectural changes (Glassow 1972).

Throughout most of the Anasazi area during Pueblo I and II, there was a shift to aboveground rectangular structures, used first as storage rooms and later as domiciles. Pit houses were retained as kivas, although kiva form varied somewhat from one locality to another. Only in the northeastern periphery of Anasazi territory were pit houses retained as dwellings. There is considerable variation in the kind of construction used in aboveground dwellings (e.g., jacal, adobe, and wet- and dry-laid masonry), as well as in the ceramic inventory. In general, decorated wares consist of black-painted, largely geometric designs on a white slipped vessel. Unobliterated coils were typically left on jar necks of gray utility wares and, later, exterior corrugation characterized vessel walls. Pueblo I villages are arranged in relatively long rows of rooms behind proto-kivas and kivas (Brew 1946; Hayes 1964, 1975). During Pueblo II, villages became somewhat more compact and kiva features more varied from one locality to another (Hayes 1964, 1975). Beginning in Pueblo I, the hard cradle board which produced the occipital cranial deformation characteristic of the Anasazi was used. Trade, particularly in marine shell ornaments and ceramics, occurred widely throughout the Anasazi area; however, the amounts and kinds of items exchanged do not seem to indicate highly structured trade networks involving corporate control (Eddy 1966; Judge 1976).

Changes, including a number of population shifts, began in the Anasazi area between A.D. 1050 and 1100. The Navajo Reservoir District was abandoned, and people of this area apparently moved north into Mesa Verde (Eddy 1966:505). In Chaco Canyon (Judge 1976), there was significant increase in population and a greatly accelerated rate of culture change. The population of the northern Rio Grande Valley also seems to have increased at this time. During Pueblo III, developments in the Anasazi "heartland," including the Mesa Verde, Kayenta, and Chaco Canyon areas, greatly eclipsed those in other areas of the Southwest except for the Cases Grandes region. The ruins of this period are among the most spectacular of any in North

America. Pueblo III was a time of construction of towns of large size, the development of elaborate soil and water conservation features, and, in the Chaco area, the construction of an impressive roadway network. Although the large and architecturally complex towns are the most familiar ruins identified with Pueblo III, much of the Anasazi population continued to live in smaller villages. Within Chaco Canyon itself, relatively poorly constructed settlements (Hosta Butte phase sites) are contemporary with impressive structures such as Pueblo Bonito (Dean 1970; Lipe 1970; Vivian 1970). Whether the aggregation of populations into towns was the result of changes in social organization as a response to environmental deterioration or whether aggregation indicates participation in an interregional trade network is, at present, not resolved (Judge 1976; Vivian 1974).

Beginning in the late A.D. 1100's and continuing into the 1400's, the major centers of population were abandoned, were the northern and western margins of Anasazi territory. The abandonments have yet to be satisfactorily explained; however, the fact that they did not occur simultaneously argues against a single catastrophic occurrence. During Pueblo IV, Anasazi territory shifted to the northern Rio Grande areas and to those containing the modern settlements on the Hopi mesas and the pueblos of Zuni and Acoma. Settlement size continued to be very large as evidenced by such sites as Tyounyi (Bandelier National Monument), Arroyo Hondo, Tsankawi, Sapawe, and Paa-ko (Cordell 1975a; Judge 1974; Lambert 1954; Schwartz and Lang 1972). In addition, Pueblo IV sites display a number of features that related directly to Pueblo society as known in historic times: polychrome and glaze-decorated ceramics, kiva murals, depictions of kachina figures in murals and rock art, incorporation of rectangular kivas in room blocks, and retention of circular kivas particularly in the northern Rio Grande area.

Pueblo V, or "Historic Pueblo," dates from the arrival of the Spanish in the Southwest, and, although 1540 is a convenient beginning date, it should be remembered that it was not until the 1600s that Spanish culture had much impact on the Pueblo way of life. The Spanish presence in the 1600s was characterized by European diseases that devastated much of the native population, and warfare, religious persecution, and slavery. Between 1610 and 1680, Spanish colonists moved into New Mexico and established settlements along the Rio Grande Valley from the Socorro area to the Taos Valley (Jenkins and

Schroeder 1974). By the 1640's, the Plains Apaches had begun successful raiding expeditions against both outlying Spanish settlements and Pueblo villages east of the Rio Grande Valley (Jenkins and Schroeder 1974). Spanish abuses finally led to the Pueblo Revolt (1680), when the Pueblos united and temporarily drove the Spanish out of New Mexico. After the reconquest in 1692-1694, Pueblo life gradually changed. Although many features of Pueblo society, particularly religious beliefs, language and kinship organization, have been largely retained, the Pueblos came to depend on a mixed economy, at first including livestock and crops brought by the Europeans, and later wage labor. From the reconquest until 1821, New Mexico remained a northern frontier of the Viceroyalty of New Spain administered from Mexico City.

## The Patayan

The term Patayan was applied by Harold S. Colton (1945) to the archeological cultures that might be considered ancestral to the ethnographically known Yuman speaking groups of the Colorado River Basin: the Yuma, Cocopah, Maricopa, Havasupai, Mohave, and the Walapai. A more inclusive designation, Hakataya, is used by Schroeder (1960) and others (Martin and Plog 1973), to refer not only to the Colorado River peoples, but also to all archeologically known groups between the Riverine Hohokam and the Mogollon and Anasazi west of the Mogollon Rim. Use of either term is not just a matter of semantics but reflects differences of opinion regarding both Hohokam origins and the meaning that should be attributed to ceramic and architectural variability among sites from the area south of the Grand Canyon to the areas below the confluence of the Gila and Colorado Rivers. The interested reader is referred to discussions in Martin and Plog (1973), McGregor (1965), and Schroeder (1960). The term Patayan is retained in this discussion, and the geographic area is limited to the Colorado River and adjacent uplands from about the Grand Canyon to the river delta. Even this area has been further divided into a number of branches that are differentiated primarily on the basis of ceramic types: Cohonina, Prescott, Cerbat, Amacava, La Paz, Palo Verde, and Agua Fria.

Because the area of the Patayans is the least well known archeologically in the Southwest, areal

chronology is poorly controlled. Apparently the region was inhabited by hunters and gatherers until relatively late. Pottery making and agriculture are not well documented until about A.D. 600. Early pottery in the Cohonina area varies, but gray wares, some with red pigment applied after firing, are the most common. Brown wares predominate in the areas to the west and south. The differences in ceramics seem to result from variations in firing techniques, because paste is uniformly sandy with a high mica content. In the Cohonina area, settlements consist of scattered hamlets with diffuse trash deposits; house types vary from pit houses in the eastern portion to lines of rectangular wattle-and-daub rooms in the west. There is some debate about the form of burial as both inhumation and cremation seem to have been used (McGregor 1965:245-251).

Somewhat more is known about the Patayan region during later times, (A.D. 900 to 1250). In the Cohonina area, valley bottom sites contain a variety of house types, including pit houses, ramadas, and rectangular surface structures with contiguous rooms. Another type of house, referred to as a patio house, also occurs in valley settings. These consist of a living room attached to a wall that surrounds an open patio. Construction was of wattle-and-daub with masonry footings. Pit houses occur in valley settings and caves were used seasonally in the Cerbat area. In the lower portions of the Colorado River Valley (the Amacava and La Paz areas), three topographic features supported settlement: in the valley bottom, sherd scatters occur on sand bars and in dune fields; rock shelters on the first terrace above the river were used as dwellings; and lithic scatters indicating workshops and hunting camps are found in small recesses in the stone cliffs above the river (McGregor 1965:302-303).

An understanding of the adaptive strategy employed by the peoples living in the Patayan region may be gained by referring to studies of Yuman agriculture and ethnobotany carried out by Castetter and Bell (1942). Under conditions of unpredictable flooding, Yuman-speaking Indians adapted a fairly flexible settlement strategy. Individual plots of land were not owned by families or other kin groups; rather, when the annual flood subsided, individual families or groups of families would build temporary structures on any available agricultural land. Those built near fields would probably not be used more than once, since they would be destroyed in the next annual flood and the cultural remains redeposited. This may account for the ceramic scatters found in the valley bottom locations in the Amacava and La



Paz areas. Resources that were more secure than agricultural produce were also important, and it is likely that the rock shelter camps and other structures found well above the river were located near the wild plant and animal foods that would have meant survival when crops were not obtained.

Very little is known about the Patayan area between about A.D. 1200 and the time of modern Yuman speakers. A general continuity is more or less assumed, but the specific ancestry of each Yuman-speaking group is either unknown or disputed (Euler 1963; Martin and Plog 1973; Schwartz 1966).

## The Fremont

Morss recognized a culture on the northern half of the Colorado Plateau that he termed Fremont, the name taken from the river in east central Utah (1931). The tradition was thought to be "peripheral" to the Anasazi of the southern plateau. The nature of the Fremont adaptation has become increasingly clarified as the archeology of adjacent areas to the south has become better known. The designation, Fremont, is now used to represent all post-Archaic archeological manifestations north of the Anasazi area (fig. 10) (Lipe 1978). Of the five regional variants of the Fremont that have been defined (Marwitt 1970), two—the Uinta Fremont (A.D. 650–950) and the San Rafael Fremont (A.D. 700–1200)—are centered on the Colorado Plateau portion of Utah and extend into adjacent western Colorado.

As with the Anasazi, dependence on maize agriculture and use of a plain gray pottery manufactured by the coil and scrape method characterized the Fremont. Other techniques of the Fremont subsistence and settlement strategy differ from those of the Anasazi and are considered to be related to the former's occupation of more northerly latitudes; for example, their subsistence practices placed greater emphasis on hunting and gathering than did those of the Anasazi. A distinctive variety of maize, Fremont Dent, which may have been developed in response to agricultural conditions in Utah, was grown (Winter 1973). According to Lipe (1978) agricultural conditions probably included both a shorter and drier growing season. The location of villages on valley sides where tributary streams enter the main valley has been taken as evidence of a response to the weakening of a summer monsoonal rainfall pattern as one moves north through Utah

(Lipe 1978). Initial Uinta Fremont occupations were of small pit house villages of from three to five dwellings. In the Uinta Basin, these were located on ridges or isolated buttes and, hilltops above flood plains. Pit house construction varied, but generally consisted of a shallow circular pit with randomly spaced post holes; later construction techniques included the use of both wet laid masonry and adobe "turtlebacks." In later times, Uinta occupations were located in broad valleys and exceptions to the small village pattern are found. Caldwell Village (Ambler 1966) in the Uinta Basin contained over 20 pit houses and extensive midden debris. The conclusion that the site was repeatedly occupied is based on evidence of the building of pit houses on the burned remains of earlier structures. No storage facilities, with the possible exception of pits, have been found at open village sites. Marwitt (1970) interprets the absence of storage facilities as a possible indication that horticulture was not as important in the Uinta Fremont area as it was to the south and west.

Although the San Rafael archeological materials were those first used by Morss (1931) to define the original "Fremont Culture," most of the investigation in this area has consisted of survey and limited testing undertaken prior to 1940 (Jennings 1978; Marwitt 1970). As of 1970 only the Turner-Look Village Site had been adequately sampled by excavation (Wormington 1955). Lack of sound and consistent evidence from radiocarbon and tree-ring dating analyses enable only estimates of the beginning and ending dates for the San Rafael period of occupation. San Rafael sites include both circular and rectangular pit houses and a variety of construction techniques. Jennings (1978) lists several architectural features characteristic of the San Rafael Fremont not found in other Fremont areas: uniform use of four central roof supports; plastered pit house walls; use of slab pavement in fireplaces; combinations of stone masonry with jacal and coursed adobe construction; and slab-lined pit houses. Open village sites contain no more than a dozen rooms in use at one time (Marwitt 1970). Marwitt (1970) suggests that brush shelters located in protected sites were temporary intermittent occupations possibly associated with hunting or seasonal collecting. No kivas, or other structures interpreted as having a ceremonial function, have been found in Fremont sites, nor is there any evidence for ditch irrigation as practiced by other prehistoric Southwestern groups.

Fremont occupation on the northern plateau terminated between A.D. 950 and 1200. Radiocarbon dates indicate the end of a Fremont horticultural

adaptation in the Uinta Basin by about A.D. 950. It has been suggested that during this time, a shift in subsistence practices from horticulture to hunting and gathering occurred (Marwitt 1970). Although most of the early research on the Fremont was concerned with their origins and the subsequent abandonment of the Fremont area by horticulturalists (Aikens 1966; Gunnerson 1963, 1969), i.e., a kind of "where did they come from and where did they go" discussion, recent research had tended to emphasize the development of the Fremont adaptation to local environmental characteristics (Aikens 1970; Jennings 1974). Geographic divisions of the Fremont "variants" are now recognized as having distinct ecological correlates based on topography, altitude, latitude, availability of water, land suitable for agriculture and exploitable resources (Marwitt 1970). Much more work is needed to examine the patterns of material culture as they correlated with environmental factors.

## Southern Athabascans

The historically known Navajos and Apaches speak Athapaskan languages which relate these peoples to various groups in the interior of western Canada, Alaska, and the Pacific Northwest Coast. Within the Southwest culture area, the Navajos and Apaches occupy land that surrounds and interdigitates with Pueblo land. Tracing the beginnings of Athabaskan residence in the Southwest continues to be a very difficult problem, because these peoples have displayed considerable adaptive flexibility over time. Glottochronological studies indicate that the southern Athapaskan speakers diverged from their northern linguistic relatives about 1000 to 600 years ago (Hoijer 1956). Although Huscher and Huscher (1942, 1943) have argued, on the basis of circular masonry houses and pointed-bottom pottery from Colorado, that the Athabascans followed a route through the Rocky Mountains to the Southwest. Hester (1962) placed their route farther east in the plains of western Nebraska, Kansas, and eastern Colorado. The current consensus favors the Plains route, which suggests that the Athabascans might have practiced agriculture as did Plains groups before they entered the Southwest. It is significant in this regard that the name "navaho" probably derives from the Tewa terms *nava* (field) and *hu'u* (canyon) (Dutton 1975; Harrington 1920; Luomala 1938).

Most scholars currently place the arrival of the Athabascans in the Southwest shortly before the arrival of the Spaniards; however, recent studies of dental morphology from skeletal remains dating from A.D. 1075 to 1190 from the Trinidad Lake area of Colorado may indicate the presence of Athabascans at an earlier time (Turner 1977). If the latter suggestion is substantiated, it is especially important to note that the ceramics accompanying the burials from Trinidad Lake are similar to Rio Grande types and would not have been recognized as Athabaskan (Turner 1977). The difficulty in defining the earliest Athabaskan adaptation (whether hunting and gathering or hunting and gathering combined with some agriculture) and its associated material culture is one of the problems of Athabaskan archeology.

The earliest historical references to Apache groups appear to be those of the 1541 Coronado Expedition. The people, identified as Querechos, and later Vaqueros, were encountered in the New Mexico-Texas Panhandle region (Schroeder 1973:124). Spanish chronicles also refer to the "Janos," "Jocomes," and "Mansos" of the western plains margin who were probably ancestral to eastern Apache groups (Basehart 1973). The earliest historical reference to the Navajos appears to be the 1629 account of Fray Geronimo Zarate-Salmeron who was told by the Jemez of "Apaches de Nabaju" living in the Chama River area of New Mexico (Luomala 1938). Following the Pueblo Revolt and De Vargas' reconquest of New Mexico in 1692, Pueblo refugees joined Navajo groups in the Largo-Gobernador area. This Refugee Period was one of considerable Athabaskan-Pueblo interaction and possibly the time that the Navajos became acquainted with livestock raising of the Pueblos (Brugge 1963). The time of the late eighteenth to the early nineteenth century was marked by increasing hostilities among the Navajos and Pueblos, Spanish, Utes, and eventually, the United States. The period culminated in the removal of 6447 Navajos and more than 400 Mescalero Apaches to the Bosque Redondo (Fort Sumner, New Mexico) in 1863 where it was hoped that the Athabascans could be taught to accept a farming way of life. The Bosque Redondo "experiment" was a disaster: crop failures and disease decimated the incarcerated peoples. The Navajos and the Apaches in 1886 accepted treaties which gave them reservations within their former homeland (Dutton 1975:12).

Despite the difficulties in defining early Athabaskan material remains, Brugge (1963:19) notes that prior to the Pueblo Revolt, Navajo

ceramics were probably of a generalized Woodland type produced by a paddle and anvil technique. The oldest identifiable Navajo ceramic type is Dinetah Utility ware and its variants. This is a sand-tempered ware, produced by coiling; jar forms predominate (Brugge 1963). During the Pueblo Refugee Period, Dinetah Utility ware continued to be manufactured. Jars were generally large with pointed bottoms, and a few bowls were of this type, as well. In addition, the Navajos produced a distinctive polychrome pottery, Gobernador Polychrome, which was influenced by several contemporary Pueblo styles. The ware is generally orange with designs painted in red, black, and white (Brugge 1963:19). In the Mount Taylor-Chaco area, a micaceous variety of Dinetah Utility ware was produced, which Brugge (1963:20) suggests may have been made by the Jicarillas or other Plains Apaches who had been driven from their territories by Comanche expansion.

Brugge (1963:20-21) considers 1750 as the beginning of a transitional period consisting of several changes leading toward more recent Athabascan patterns. First, the Polychrome ceramics became more variable in form and inferior in quality. The resultant type, Navajo Painted, also declined in quantity, much of it eventually being produced for ethnographers, collectors, and for ceremonial use. After 1800, the utility ware, Navajo Utility and Pinyon Utility, show changes that relate both to increased mobility and "ethnic identity." Changes related to mobility are the use of sherd temper, which produces a sturdier paste, an increase in wall thickness, and rounded bottoms and cylindrical bodies, shape modifications that make transportation somewhat easier. Finally, decoration consisted of either an applied or molded fillet around the neck of the jar. In Athabascan sites representing recent decades, of course, native ceramics of any type are rare, as Euro-American manufactured utensils have replaced them.

Although both geographic and temporal variations occur in house types, it is generally assumed that the forked-stick hogan is the oldest Navajo dwelling type (Kluckhohn et al. 1971:143-202). Refugee domestic architecture consisted of masonry "pueblitos." For obvious reasons, these were located in easily defensible locations, but are nonetheless often of quite impressive extent.

House types show considerable variability; for example, Reichard (1928) noted a seasonal preference by the Navajos for tents during the summer and hogans during the winter. Hogans may be multisided cribbed log structures, or circular or multisided stone

buildings. Conical hogans were apparently the preferred type in the early part of the twentieth century (Kluckhohn et al. 1971:155). It should be noted that because of the requirements of herding, houses are not occupied continuously for a great length of time. Luomala (1938) notes that a series of hogans and corrals are built at various sheltered places located near water, grazing land, and fuel. Generally, winter locations are in the foothills or on mesas where fuel is available, while lower elevations are selected in spring. Surface remains of Navajo sites may include hogan remnants (including circular depressions) with an ash or charcoal heap to the east, corral walls or corral areas denuded of vegetation, and the remains of brush shelters or ramadas. Sweat houses, usually built in the side walls of arroyos, may not be preserved (R.A. Goddard, personal communication, 1977). Tent camps, consisting of a tent base and one or two ovens with little cultural debris, may constitute the remains of a summer sheep camp (Allan et al. 1975:133). Despite the relative recency of Athabascan remains in the Southwest, the high mobility of groups dependent on herding frequently precludes similar visibility of Athabascan archeological sites.

## Western Europeans

Before the advent of dendrochronology and other refined dating techniques, Southwestern archeologists usually excavated sites for which historic documentation existed in order to apply the "direct historical approach" to prehistoric data (Kidder 1920; Kroeber 1916; Nelson 1914). Thus regional chronologies were derived by working back from the present or the documented past. Unfortunately, historic sites were neglected for years until independent chronometric dating techniques became available. Today, there is a revived interest in historic archeology, which is oriented toward both elucidating the way of life of the early Euro-American settlers in the Southwest (Goss 1975; Hayes n.d.; Olsen and Beezley 1975; Robinson 1976) and using documentary and archeological data to test general propositions about human adaptation and the nature of archeological remains (Reher 1977; Zubrow 1974).

The first Europeans to colonize the Southwest were, of course, Spaniards. The initial entradas, under the command of Francisco Vazquez de Coronado took place in 1539-1542. New Mexico was

not colonized however, until Oñate brought in the first settlers in 1598. Franciscan missions were first built along the Rio Grande in New Mexico and at El Paso. The expeditions into southern Arizona, lead by Father Eusebio Francisco Kino, did not take place until the late 1600's. The Spanish colonial effort involved two goals: to convert the Indians to Christianity and establish missions among them, and to establish settlements for Spanish colonists. The Spanish colonial caste system and slaving practices led to the creation of *genizaro* communities, settlements of hispanicized non-Pueblo Indians who were armed and could protect colonial settlements.

Seventeenth-century churches and mission buildings were constructed almost entirely of native materials, with sandstone or adobe walls, ponderosa pine vigas and usually packed clay floors. The mission station consisted of two parts: the church and the convento (living quarters). As Parsons (1975) noted, the churches did not conform to the true cruciform plan with deep transepts, but had a long narrow nave that could be spanned with a single heavy viga. The interior church walls were coated with several layers of plaster, often mixed with gypsum or kaolin to provide a hard, smooth surface. Burials were placed beneath the altar and interior church floor. Separate campos santos (burial grounds) were not common until the later portion of the late eighteenth and early nineteenth centuries (M. Weigle, personal communication, 1977). The convento consisted of a single row of rooms contiguous with the church and arranged around a patio (Bunting 1976).

Mission buildings at the pueblos were generally placed outside the pueblo proper but with the church door oriented toward the community (Parsons 1975). At some of the early missions, such as Pecos, Kuaua, and Gran Quivera, traditional Indian kivas were built in front of the church. At the Hopi villages of Awatovi, a portion of the pueblo was demolished in order to make room for the mission buildings. Following the expulsion of the Franciscans in 1680, the mission buildings were gradually remodeled by the Indians. Fletcher (1977) has documented a shift in room dimensions to those characteristic of Hopi rooms once the architectural constraints of the mission walls no longer interfered with room design. Five pre-Revolt churches were repaired following the Reconquest and have been in use "more or less" ever since (Bunting 1976): Zia, 1614; Isleta, 1629; Acoma, ca. 1644; Halona (Zuni), ca. 1660; El Paso (Cuidad Juarez), 1662.

Except for the mission buildings themselves, a

few iron implements, such as door latches and nails, and the introduction of the Spanish *horno*, or oven, Europeans did not significantly alter Pueblo material culture at first. Eventually, however, the economic changes brought about the introduction of livestock and new crops resulted in significant changes, e.g., the building of corrals for domestic animals, streets wide enough to permit passage of wagons and automobiles, and the adoption of Euro-American domestic facilities and furnishings.

Following the Pueblo Revolt and De Vargas' Reconquest, Spanish colonial settlement took several forms. Some colonial settlements were laid out in a defensive plan, with each family occupying a series of rooms enclosing a large central area or plaza. Such communities are found in the mountains, on the plains of the eastern frontiers and even in valleys in the heart of Spanish territory (Bunting 1976). The typical house of the seventeenth century consisted of two and three relatively large, multipurpose rooms (Bunting 1976). Large residences are represented by the hacienda, a rectangular house built around two courtyards. The placita (courtyard in front) had one set of front gates; the rear gates opened into the back courtyard which served as a corral. Spanish colonial houses excavated at the site referred to as Carnué, east of Albuquerque, consisted of a single room with an attached shelter or ramada. The houses contained a corner fireplace and had an outside *horno*. Two groups of houses, each arranged around a plaza; were surrounded by an adobe wall. The occupation at Carnué was a brief one in the 1760s.

Although some manufactured items, e.g., olive jars, majolica ceramics, and iron tools, were used in the colonial villages, they were rare due to the difficulties of transporting goods from Mexico City by wagon. In Hispanic communities along the northern Rio Grande, "Spanish" pottery is indistinguishable from the local San Juan red wares. Whether the pottery was obtained from the Pueblos or produced by Spanish women using Indian manufacturing techniques is not known.

The opening of the Santa Fe Trail in 1821 and subsequent incorporation of the Southwest within the United States naturally had great impact. Economic expansion under the domination of the U.S. brought with it the Territorial Style of architecture. This style, an extension of the Greek Revival manner characteristic of the eastern seaboard between 1820 and 1850, is divided into three phases (Bunting 1976). The Early Territorial Style (1848-1865) appeared with the availability of sawn lumber and window glass. Buildings in this style in

Santa Fe and Las Vegas, New Mexico, are characterized by pedimented lintels over doors and windows. In addition to plain moldings, Early Territorial millwork used fairly heavy 15 by 15 cm (6 by 6 in.) portal posts with chamfered corners (Bunting 1976). Construction continued to be of adobe brick with flat, earth-packed roofs. The Middle Territorial Phase (1865-1880) houses were built on a symmetrical plan based on a center hall or room; elaborate entrances and large windows are other conspicuous features. The great variety of building types and construction methods used was in

part dictated by the availability of construction materials: in areas where straight logs were scarce, adobe arches served as lintels; jacal construction of mud-plastered heavy log walls was used in mountainous areas on either side of the Rio Grande Valley (Bunting 1976). Late or Folk Territorial Style (1880-1920) developed as a folk art in isolated mountain villages of northern New Mexico. Here, the style of doors and windows produced by village craftsmen was based on decorative themes improvised from details of the earlier phases.



## Remote Sensing of Southwestern Cultural Resources

### Introduction

Remote sensing methods applied to cultural resources include the use of aerial photography, airborne and satellite scanner imagery, and photography taken from a variety of platform types. Although several of the more sophisticated methodologies are still in an experimental stage with respect to cultural resources investigation, wide use has been made of aerial photointerpretation for site survey and site and feature identification from photography. Both photogrammetric and direct tracing methods have been implemented for the mapping of archeological sites and the measurement of cultural material volumes and distributions. With the recognition that human adaptation must be viewed systemically within the context of the relationship between human behavior and the natural environment, investigation of environmental phenomena with remote sensing methodologies has been implemented. Section 3 reviews important applications of remote sensing techniques to Southwestern archeological resources, and their potential for contribution to the documentation of cultural resources, programs of research, analytical strategies, and management problems.

### Aerial Photointerpretation

The utility of aerial photography for Southwestern archeology has been recognized since the 1890's (Deuel 1969) and has recently been systematically investigated by a number of researchers (Gumerman and Kruckman 1977; Gumerman and Lyons 1971; Jorde and Bertram 1976). The reader is referred to the remote sensing handbook (Lyons and Avery

1977) and to the above publications for a technical description of the mechanical data acquisition systems involved in aerial photography and the principles upon which these are based. This section is devoted to a description and evaluation of the applications of black-and-white, color, and infrared color aerial photography to archeological field methods and problems in the Southwest. The interpretation of aerial photography has been applied to four broad aspects of archeological methodology. These include use of photography in site survey for locational and regional mapping purposes, site and feature identification from photography, site mapping, and environmental mapping in conjunction with regional research problems.

**Site Survey.** While many archeologists have utilized aerial photography, especially black-and-white coverage, in conjunction with regional site survey, the interpretation methods and benefits have been largely unpublished. Black-and-white photography affords several benefits for regional site survey. First, in many areas of the Southwest, photographic imagery of this type is already in existence. A listing of U.S. government agencies that can provide data on photographic coverage can be found in Lyons and Avery (1977). In addition, a survey of federal, state, and U.S. military organizations has been compiled which describes imagery missions, availability, and costs (May 1978a, 1978b). Second, aerial panchromatic photography is less expensive in comparison with other forms of aerial imagery.

It has been noted (Loose and Lyons 1976a) that the accurate recording of site locations on topographic maps often presents a major technical problem for the surveyor. There are a number of ways in which the use of aerial photography can overcome this problem:

1. Subjective interpretation of topographic features from maps is eliminated.
2. Photography can provide an up-to-date road map of the study area.
3. Extremely accurate recording of site location is possible.
4. Use of photography enables survey within precise boundaries.
5. Accurate recording of site location with photography enables site relocation at a later date.

Aerial photography can also provide an archival data base from which information concerning site location and immediate environment may be extracted for analysis. The use of black-and-white photography as an archival data source has been undertaken recently in conjunction with site survey on the Navajo Indian Irrigation Project (N.I.I.P.) south of Farmington, New Mexico. As a part of the Upper Colorado River Storage Project, the N.I.I.P. is designed to irrigate approximately 110,000 acres of Navajo Reservation land south of the San Juan River in northwestern New Mexico. Construction of the project has been undertaken by the Bureau of Indian Affairs which has required archeological clearance as specified in Federal antiquities regulations. Recontouring and cultivation of the project area may effectively obliterate all but the most deeply buried archeological remains in this portion of New Mexico. An attempt is being made to systematically record archeological sites and excavate a select number of them; however, all information pertaining to site location, physiographic setting, and other environmental circumstances cannot possibly be recorded. Because of this problem, a permanent photographic record of site locations is being maintained. Orthophotographs (photographs on which the displacement of images due to tilt and relief has been removed) at a scale of 1:4800 are on file with the Bureau of Indian Affairs' Farmington Office and form the basis of this record. Site locations were marked on each orthophoto and a listing of site number and photography designation prepared for portions of the N.I.I.P. In this way, information concerning site location in relation to drainage pattern, vegetation, and an extensive system of longitudinal sand dunes characteristic of the project area is preserved for future analysis. Hopefully, future large-scale mitigation of archeological resources will include the recording of site locations on a photographic base as a standard conservation measure.

Aerial photographs can be instrumental in both

the planning and performance of an on-the-ground survey. Aerial photographs were included in the implementation of a sampling design of Cedar Mesa, located just north of the San Juan River in western San Juan County, Utah (Matson and Lipe 1975). Archeological survey on the mesa involved a survey of 400 m<sup>2</sup> quadrats selected at random from within natural drainage units. A photo mosaic for each target drainage was prepared from 1:4800 scale black-and-white photographs. A mylar overlay sheet was prepared on which both the 400 m quadrat system was drawn and drainage unit boundaries delineated. Quadrats were numbered and selected, and quadrat boundaries copied from the overlay onto aerial photos. These photos were then used to locate the corners of the quadrats on the ground. Quadrat boundaries were walked and the actual location was drawn on the photo. The photo scale for this survey project was such that individual pinyon and juniper trees as well as small bushes could be identified on the image, enabling the recording of single surveyed sites within each quadrat on the photographs. This procedure was particularly beneficial for field orientation on Cedar Mesa since the largest scale maps available for the area were 15-minute USGS topographic quadrangles, which while useful as road maps would have enabled neither precise on-the-ground location of the sampled quadrats nor precise site location on maps.

Survey planning in conjunction with an areal stratification was also facilitated with the use of aerial photography in a survey of the eastern foothills of the Manzano Mountains in central New Mexico. During the summer of 1979, a joint University of New Mexico Field School and USDA Forest Service archeological survey of this area was implemented (L.S. Cordell, personal communication, 1979). The survey served as a training exercise for the students and aided in the Forest Service inventory process. Color aerial photos taken in June of 1971 were used to both plan and conduct the survey in the field and to map the location of sites and surveyed areas. Survey planning included the production of a photo mosaic on which an initial stratification was drawn, distinguishing vegetated areas from those areas denuded of plant cover. Stereo pairs onto which the stratification was transferred were then taken into the field, and 1.6 by 0.4 km (1 by ¼ mi.) survey transects and site locations were recorded directly on the photographs. Since topographic maps were unavailable for some of the area and existing topographic coverage proved to be dated and inaccurate, this survey procedure would not have been possible



without the use of aerial photography. The imagery also proved to be reliable for discrimination in the field between the vegetated and denuded strata, and students carried magnifying glasses and stereoscopes in order to inspect the imagery when needed. Since most prehistoric cultural remains were located in heavily vegetated woodlands, sites which could be seen on the imagery included only historic structures in open meadows.

Morris and Manire (1976) have described an accurate and inexpensive technique for recording site locations and other cultural data pertaining to individual sites in Canyon de Chelly National Monument. The procedure includes the use of enlarged black-and-white aerial photographs at a scale of 1:500 in the field along with conventional topographic maps as site location aids. Locational data from the photos are transferred to USGS topographic quadrangles and the plotted site locations are used to determine Universal Transverse Mercator (UTM) coordinates. In this way, a permanent record of both the original field data (photos) and a retrievable data base (a computer file of site locational coordinates and other data) can be obtained. The most important benefit of the procedure, however, is the ability to obtain very accurate locational data.

Photointerpretation can also contribute to a preliminary assessment of the density and nature of cultural resources in an area in the absence of field work. Matheny (1971) has suggested, for example, that despite a lack of money and time to walk the rugged terrain of southeastern Utah, large Pueblo architectural sites can be detected with aerial photography and possibly with infrared scanning (see following section on Airborne Scanner Imagery). He notes that Anasazi masonry structures and the worked stone components of walls are clearly discernible on aerial photographs. Photointerpretation of this kind would involve the development of a recognition pattern facilitating the identification of structures and other features.

**Site and Feature Identification.** Image reading skills and the electronic and stereoscopic equipment necessary for archeological interpretation of aerial photography have been reviewed in Lyons and Avery (1977). Physical indications on the ground surface which enable identification of cultural features include differences in the height, color, and density of plants (crop marks), in the color, texture, or moisture content of the soil (soil marks), and contrasting tones resulting from shadow marks. The development of a

recognition pattern involves understanding the variations in the above factors that could be caused by the presence of cultural features. Particular types of cultural manifestations appear differently when photographed in different physiographic settings. This necessitates a familiarity not only with the type of imagery to be interpreted but also with local terrain and vegetation characteristics.

Interpretation of cultural features (anomalies) from aerial photography has been attempted at Hubbell Trading Post near Ganado in eastern Arizona (Jacobson 1978). The trading post, first established in 1875 by William Leonard and later sold to John Hubbell in 1879, was purchased by the National Park Service in the late 1950s and made a National Historic Site. The present monument consists of a new store and hacienda built in 1900, a guest house, barn, utility shed, and several prehistoric sites surrounded by historically cultivated fields. The site area was flown in October, 1977, by the Koogle and Pouls Engineering firm of Albuquerque and standard panchromatic aerial photographs at a scale of 1:3000 were obtained. Photointerpretation from a mosaic of prints resulted in the production of an overlay on which trees, drainages, irrigation ditches, fence lines, roads, the Hubbell building, prehistoric ruins, and monument boundaries were sketched. Interpretation also focused on identification of anomalous features classified as either variations in soil color or changes in vegetative cover (Jacobson 1978). All vegetative and soil changes noted on the photography were ground checked for association with cultural and structural remains. Most anomalies interpreted from the imagery corresponded to vegetative differences in surface cover related to drainage patterns in the fields surrounding the trading post. Denser vegetation and differences in species composition were associated with low spots or irrigation features. The final map produced after the field check depicts the locations of prehistoric lithic and ceramic scatters identified during field reconnaissance and the irrigation canals and ditches in the historic field system.

This initial attempt at interpretation of irrigation features indicated that existing ditches and canals could be accurately located and mapped with aerial photography and that this would be useful information for future development of the trading post. Development plans would include cultivation of the Hubbell fields which had been farmed and irrigated prior to the sale of the trading post to the National Park Service.

Usually, the specific physiographic characteris-

tics of an area, good soil moisture retention qualities, lack of surface vegetation, surficial geologic deposits, etc., can result in the appearance on aerial imagery of anomalies representing cultural remains. Since this configuration of environmental circumstances and cultural remains may not occur throughout a region, the predicted cultural remains may not appear on a particular set. As a result, remote sensing experiments for the detection and location of particular archeological features are often "tailor made" to a certain area with positive results; however, "tailor made" remote sensing methods will not be successful in discovering or analysing cultural remains in all places.

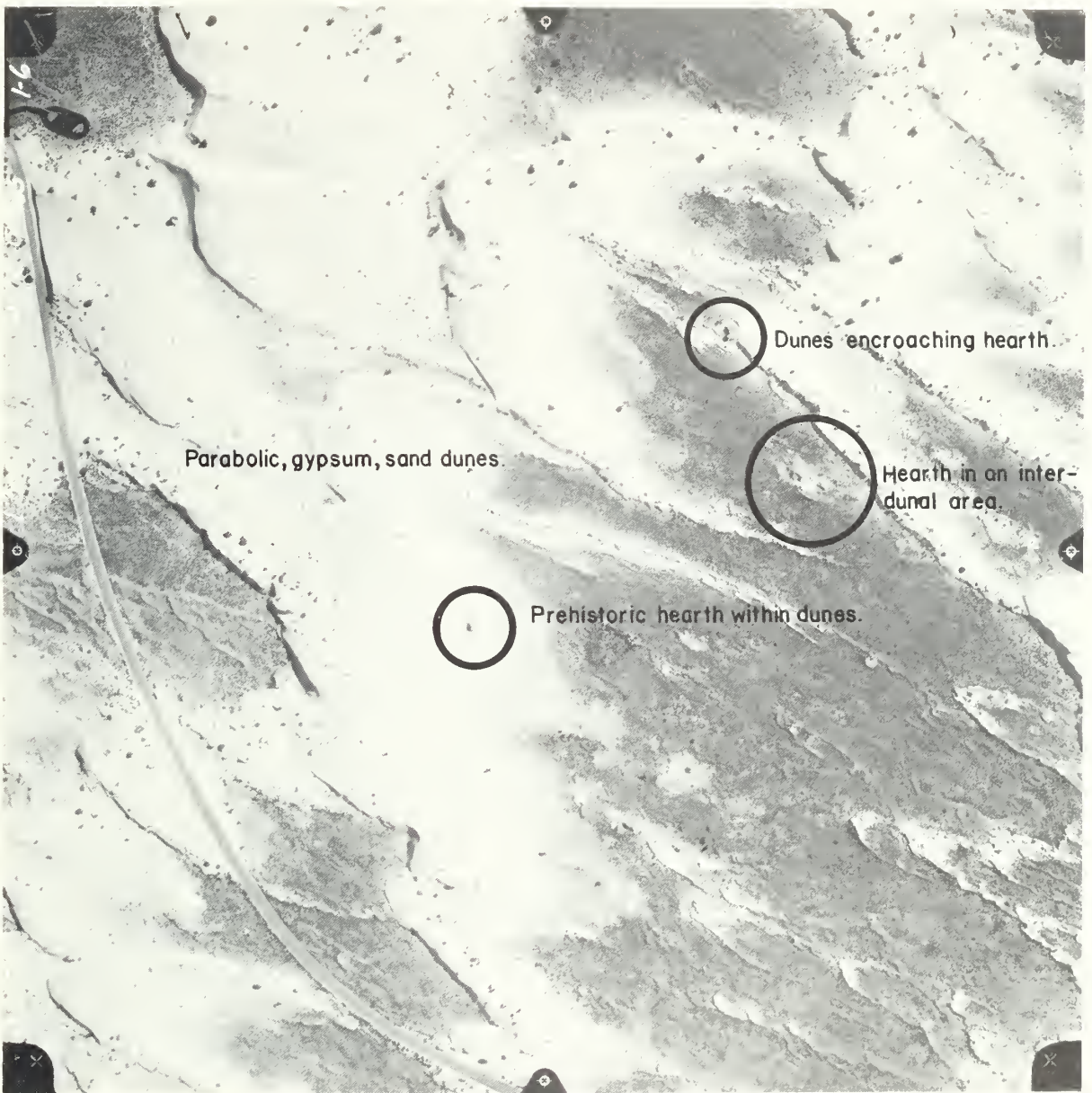
Application of remote sensing methods to cultural resources management at White Sands National Monument has been dependent on the chemical and mechanical structure of the gypsum sand dune environment of the monument. The remains of extensive hearths which were presumably the sites of plant processing activities carried out by the inhabitants of the area during the Archaic and Pueblo periods are present along the eastern dune front of the monument and extend almost 1.6 km into a dune field to the west. Prehistoric fires have affected the structure of the gypsum sand on which they were built with the result that sands directly beneath a hearth are less vulnerable to water and wind erosion than surrounding, unburned areas. Ebert (1979a) observed that as the sand dunes moved with the wind, hearths were left behind in the form of conical mounds. It was reasoned that the distinctive tonal characteristics of hearth features, as well as their form, would allow their detection and mapping using stereo aerial photographs. Toward this goal, a series of 1:5000 scale panchromatic aerial photographs covering some 1.9 km<sup>2</sup> of the monument along the dune front were inspected with a mirror stereoscope, and features believed to be hearths marked on transparent overlays. Differences in tone and texture of hearth features of the imagery allowed their identification. Hearths appear darker than active gypsum sands and lighter than interdunal flats (fig. 11). Hearth sand is also of a coarser texture than active sand or that in interdunal areas. Groundtruth checking at the monument determined that the interpretation has been totally faithful. This procedure suggests that exposed hearths can be monitored as they are alternately exposed and covered by sand movement, and that with this methodology an inventory of known hearths can be developed. With the inventory as a base from which to draw materials for dating and hearth content

analyses, future researchers can better understand past human activities at White Sands.

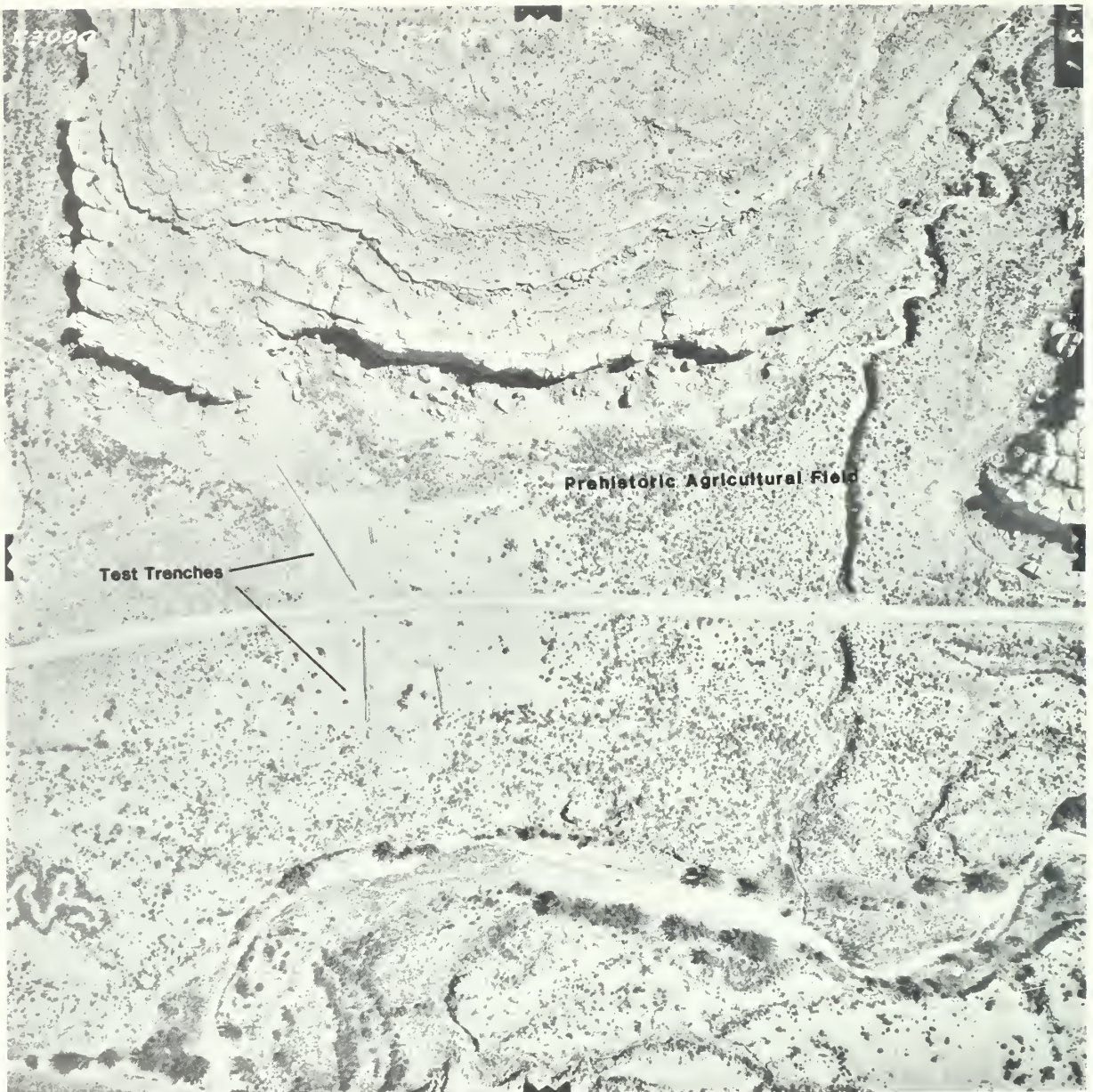
Young and Potter (1980) have analyzed and mapped vegetation and relief over sites in Chaco Canyon in order to explore the possibility of using vegetational anomalies as indicators of archeological sites in this area. Because of slight differences in soil pH, texture, and moisture relations caused by the depressions of prehistoric rooms, compaction of floors and weathering of clay mortar out of walls, Young and Potter were able to identify local differences in vegetational composition on sites. Species identified as having indicator value included black greasewood, pale wolfberry, alkali saccation, and pinnate tansymustard. Black greasewood, for example, grows over compacted floors of rooms on knolls where the species is not normally found and over some deeply buried sites where it is greener, taller, denser, and greater in diameter than surrounding plants (Young and Potter 1980). Using these plant indicators, archeological sites were located through ground survey without the prior knowledge of site locations. Vegetational anomalies in the monument area could also be identified on black-and-white and color aerial photography (fig. 12). Inspection of photography prior to field checking has several obvious advantages. Rather than surveying for vegetational anomalies on the ground, they can first be located on low-altitude aerial photography and their locations transferred to field maps. Field inspection of the sites can then be carried out in a direct manner with the photography acting as a locational aid and as a permanent photographic record.

Since the early 1970's, archeological investigations in the San Juan Basin of New Mexico have included research into an extensive prehistoric roadway system. The extent of the mapped roadway network (fig. 13) in the basin that has been identified from aerial photointerpretation is presently in excess of 483 km. The roadway network connects major Pueblo sites through the San Juan Basin with outlying population centers and lesser sites. Construction of the system has been placed between A.D. 1000 and 1100 (Lyons and Hitchcock 1977). Several functions have been inferred for the roadways, including communication links, transportation routes for goods and materials, and simple passageways for individuals and groups (Lyons and Hitchcock 1977).

The prehistoric roads appear on the ground as slightly depressed linear features averaging approximately 9 m in width (fig. 14). In some places



**Figure 11**    Hearth features in White Sands National Monument.



**Figure 12** Vegetational anomalies, lack of brush cover, indicating the presence of prehistoric field, Chaco Canyon.

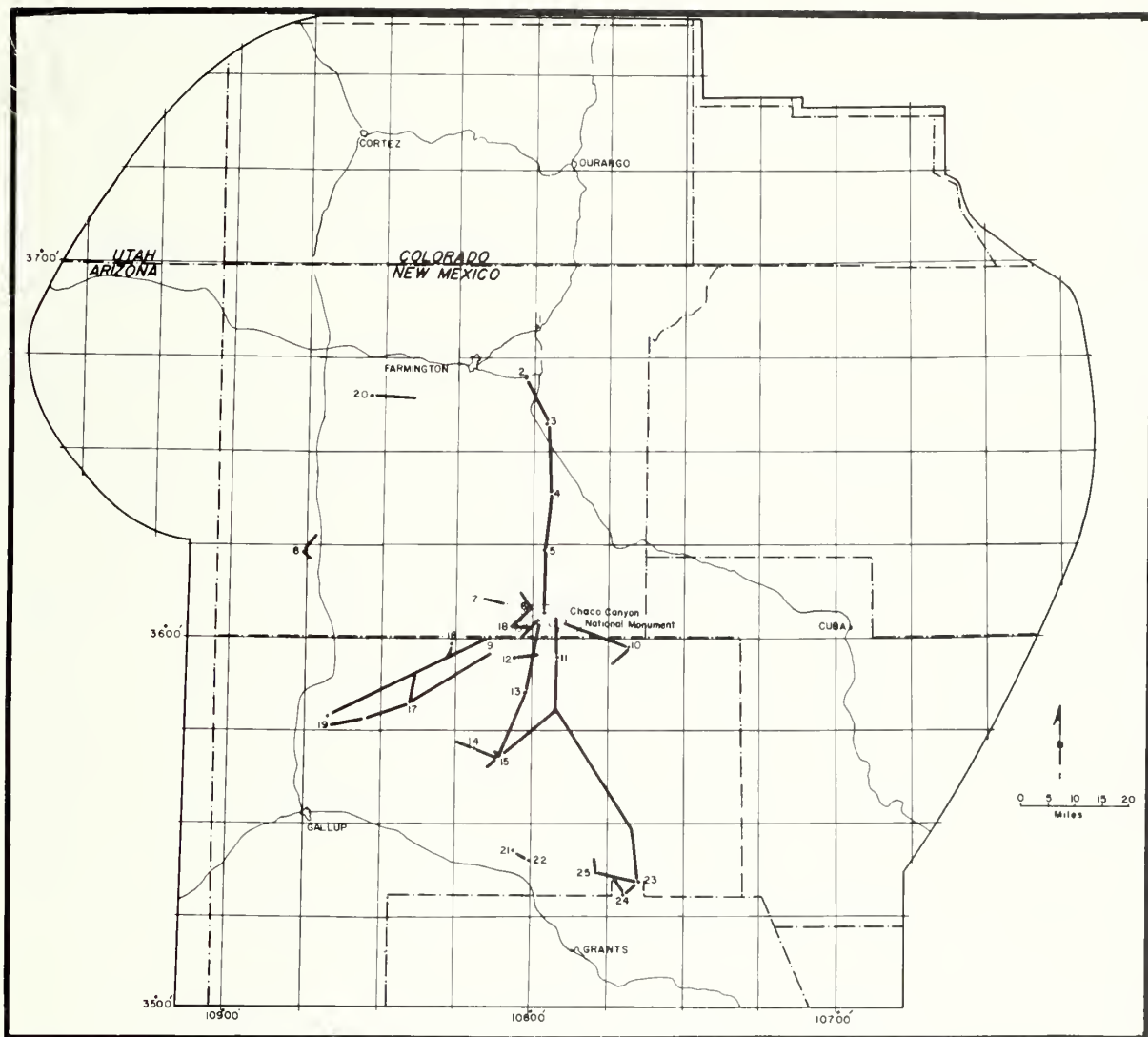


Figure 13 Mapped roadway network identified from photography, San Juan Basin, northwestern New Mexico.

### LEGEND FOR FIGURE 13

- |  |                          |
|--|--------------------------|
| 1. Aztec Ruins                         | 13. Bee Burrow           |
| 2. Salmon Ruin                         | 14. Muddy Water Place    |
| 3. Kutz Canyon Pueblo<br>(Twin Angels) | 15. Kin Ya'a             |
| 4. Halfway House                       | 16. Indian Creek         |
| 5. Pierre's Site                       | 17. Standing Rock        |
| 6. Casa Del Rio                        | 18. Kin Klizhin          |
| 7. Lake Valley                         | 19. Grey Ridge Community |
| 8. Skunk Springs                       | 20. Hogback House        |
| 9. Kin Bineola                         | 21. Casamero (LA8779)    |
| 10. Pueblo Pintado                     | 22. Andrew's Location    |
| 11. Greenlee's Ruin                    | 23. San Mateo            |
| 12. Upper Kin Klizhin                  | 24. El Rito              |
|  | 25. Kin Nizhoni          |

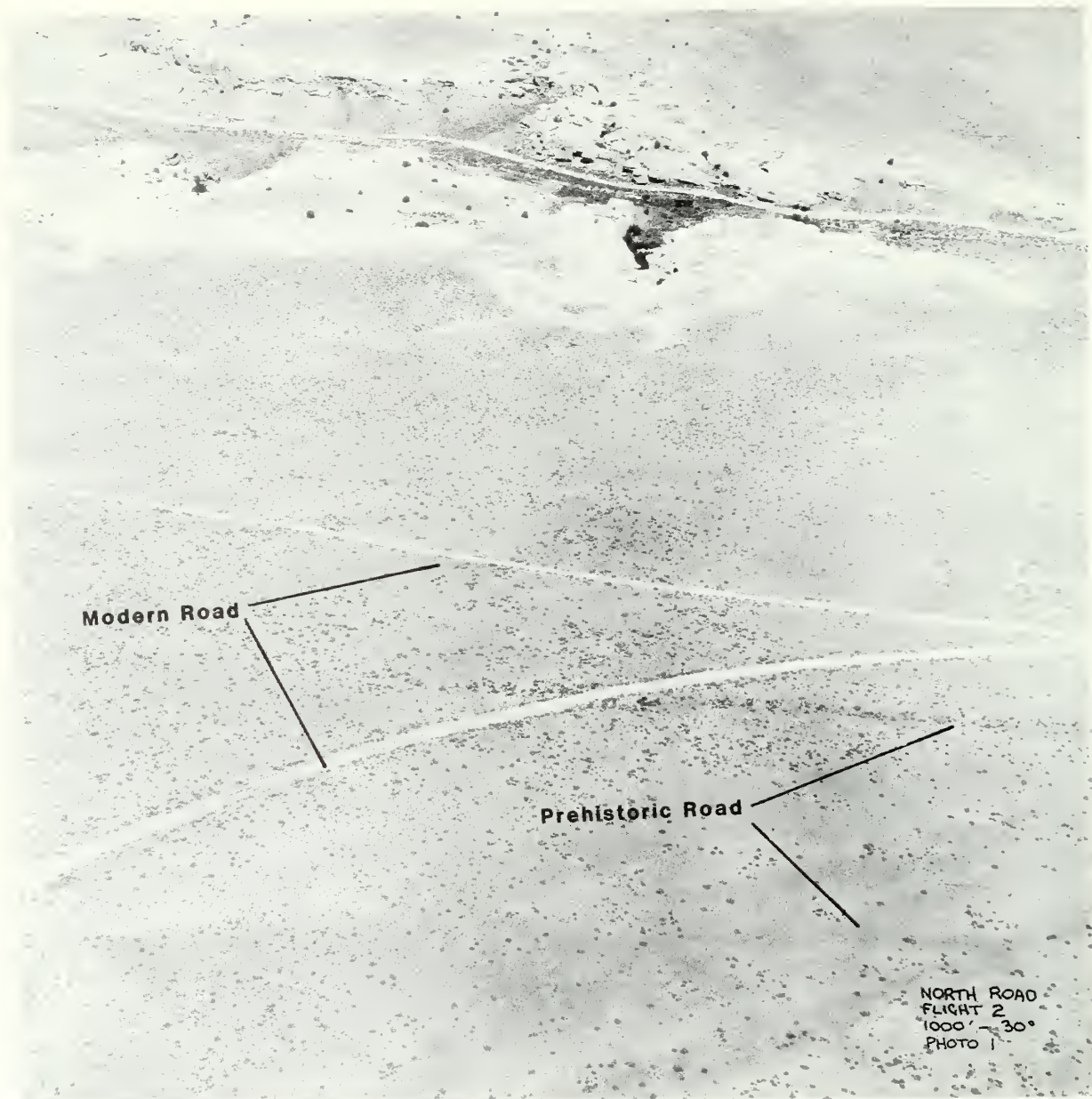


Figure 14 Oblique photo of linear depression indicating presence of prehistoric road.

roadway segments are characterized by banked earth along their lateral edges or by masonry walls (Obenauf 1980; Ware and Gumerman 1977). Identification of road depressions on black-and-white aerial photography has been the primary method by which roadway segments in the area have been detected. Ware and Gumerman (1977) have summarized road attributes which can be identified through interpretation of black-and-white aerial photography and by on-the-ground survey. These attributes include a subtle difference between vegetation density along the road bed and the surrounding terrain. This phenomenon has been attributed to greater soil moisture content along depressed roadway segments which results in increased vegetation density (Lyons and Hitchcock 1977). Where active arroyo cutting is present, the opposite is true. A general decrease in plant density characterizes the edges of roads (Ware and Gumerman 1977). The presence of roadway depressions in the Pueblo Alto area has resulted in the rechanneling of small arroyos down the course of the depressions. This also increases the visibility of the segments on the black-and-white photography.

Long shadows produced during the early morning also enable discernment of depressed roadway segments. Recent investigations of the roadway network leading to Pueblo Alto in Chaco Culture National Historical Park have utilized aerial photography taken of this area with a light, discontinuous snow cover. The snow which had drifted into depressed road segments provided optimum contrast between the road and the surrounding terrain (T.R. Lyons, personal communication 1979).

In addition to termination at or near large Pueblo centers, roadways are associated with a variety of other features, e.g., cuts through knolls or low hills. Several researchers (Lyons and Hitchcock 1977; Vivian 1972; Ware and Gumerman 1977) have commented that road segments are often cut through or over minor natural obstacles rather than around them. Test trenches have also delineated stone rubble and masonry curbing on roadway segments at Pueblo Alto (Ware and Gumerman 1977). Among the most spectacular of the associated features are the stairways cut into the sandstone canyon ledges at the termination of road segments. The stairways descend the cliff edges and talus providing access to the canyon bottom. One of the best known is "Jackson's Staircase" described by photographer William Henry Jackson in 1877 (Holsinger 1901) (fig. 15).



Figure 15 Jackson's Staircase, Chaco Canyon.

Other associated archeological features include concentrations of ceramics scattered along the roadway course. A recent survey in the Nose Rock area by the Laboratory of Anthropology in Santa Fe, New Mexico, located a series of sherd scatters arranged in a linear fashion across the survey area (Doleman 1976). Further investigation of this phenomenon in conjunction with an archeological inventory of the area (Camilli and Seaman 1979) found that these sites were all associated with the Kin Ya'a road system (Obenauf 1980), a roadway leading from Chaco Canyon southwest to the site of Kin Ya'a located east of Crownpoint, New Mexico.

Interpretive studies of road alignments have utilized black-and-white aerial photography at a scale of 1:32,000 and 1:3000 (Lyons and Hitchcock 1977; Vivian 1972; Ware and Gumerman 1977). In addition, some 150 color infrared oblique transparencies (35 mm) have proved useful in delineating road alignments. Color composite multiband photography at various scales was also obtained and used for road feature interpretation. It was reasoned that different spectral bands monitored by multiband imagery would be capable of isolating cultural and natural features not visible on the ground. Inspection of a multiband image of the sand dune topography in the Escavada Wash area north of Chaco Canyon revealed a dark streak aligned with known prehistoric road segments leading north from Pueblo Alto. The dark linear feature appeared where a portion of a known road segment was covered by a parabolic sand dune (fig. 16). Field inspection of the target area indicated several differences in composition in that portion of the dune under which the known road segment had been projected. Initial field inspection indicated that the sand was more compacted over the projected road segment. Several test pits dug into the sand dune indicated that the compacted sand over the projected road alignment held moisture closer to the dune surface than did portions of the dune away from the alignment. The Remote Sensing Division has suggested that the near infrared color band would record the traces of the buried road segment because of the greater soil moisture retention properties near the surface. It is possible that the compacted road surface below the dune may have caused greater soil moisture retention along with portion of the dune over the road alignment.

Aerial photography has been used to locate and identify a network of prehistoric water control and other cultural features in the Kin Bineola area of the San Juan Basin. The area was flown for stereo

coverage in black-and-white photography at a scale of 1:6000 and a photogrammetric map at a scale of 1:1200 compiled with a two projector Kelsh plotter equipped with a stereo alternator. Observation of the photography and the photogrammetric map indicated several unusual geometric patterns reflecting the existence of water control features. Where linear features crossed extremely flat slopes a number of spot elevations were obtained to aid in determining the direction of flow of possible canals.

All detected surface anomalies were checked by a ground survey crew. Approximately half of the features consisted of natural anomalies on the landscape, and about 10 percent of the anomalies located by photointerpretation were not visible or recognized on the ground. Surface survey identified prehistoric cultural features which had been located by photointerpretation, including field houses, habitation sites, a prehistoric dam, canals, feeder ditches, and some features of unknown use. Other features thought to have been water carrying facilities were revealed to have anomalous elevation differences that could not have been easily perceived by observers on the ground.

Photointerpretation and photogrammetric procedures, in this instance, aided in the delineation of some cultural features and in the demonstration of an unfeasible interpretation of other features.

Irrigation canals and ditches, terracing and bordered garden plots have also been located in Chaco Canyon with the aid of remote sensing techniques (Vivian and Matthews 1964). The most clearly defined agricultural feature within the canyon is an earth-bordered garden near the ruin of Chetro Ketl. A study of this garden plot by the Remote Sensing Division combined remotely sensed data with geological and archeomagnetic data. Geologic data were studied to determine how much alluviation or erosion might mask a prehistoric field, while archeomagnetic data were used to determine the contemporaneity of the field and the ruin. An aerial photograph at a negative scale of 1:600 was used to plan field procedure (fig. 12).

On-site experimentation with an electron spin magnetometer (Loose and Lyons 1976b) focused on a square "field" observed on black-and-white imagery of the canyon floor. Values obtained with the instrument were averaged and interpolated by an IBM 360 computer which produced a contour map based on units of magnetic density. The plot obtained has been described as good evidence that irrigated earth-bordered garden plots were responsible for the rectilinear patterns observed on the imagery. An





**Figure 16** Sand dune anomaly indicating presence of known prehistoric road segment.

archeomagnetic data of A.D. 1250 was obtained for the Chetro Kettle field (Loose and Lyons 1976b: 147). Excavations indicated that the surface of the garden plot was quite flat, varying fewer than 2 cm from true horizontal. Other evidence for the planned nature of the Chetro Kettle field includes the right angles formed by the garden plot borders as determined from both ozalid and original air photos. The field borders intersect consistently within 1 percent of 90° and the east-west axis of the field lies on an azimuth of 113°. Loose and Lyons (1976b) note that the alignment could reflect the prehistoric farmer's concern with aligning agricultural features with certain cosmic directions since 113° is close to the alignment of solstic markers in Chaco Canyon.

Ebert and Lyons (1980a) have documented the history of the Hohokam canal system on the site of the modern city of Phoenix, Arizona, and its environs. The linear depressions representing canals were recognized in the area before 1929, and the canals first documented with aerial photography in 1930 (Judd 1930). Recent interpretative experiments on this canal system utilized photographic data and low resolution digital data derived from satellite platforms. Visual interpretation and electronic enhancement of portions of Skylab II and Landsat space imagery permitted the identification of nearly 80 km of Hohokam canals visible primarily because of their effects on the configuration of land use in present day Phoenix. The interpretive experiments illustrated that even in urban areas which have been extensively altered in recent times, patterns of land use during prehistoric times can be detected.

Suggested mitigation procedures for remotely sensed "ephemeral" archeological features such as roadways and canals have been proposed (Ebert and Lyons 1980b). Proper mitigation procedures must take into account the type of theoretical information which would be lost if these features were destroyed. A three-phase mitigation plan with the goals of the accurate identification of feature location and the preservation of these data has been suggested:

1. Analysis of existing appropriate remote sensor imagery by a photointerpreter to determine whether or not ephemeral features, such as roadways, exist.
2. Further manipulation of remote sensor imagery including experimentation with the scale, sun angle, photographic emulsion or sensor type, and other aspects of the total remote sensing methodology.
3. Groundtruth checking of remotely sensed features. Groundtruth may be accomplished

by on-the-ground inspection of the areas in question, perhaps assisted by low-altitude imagery, or inspection from light aircraft or helicopter. Low altitude 1:4000 scale Soil Conservation Service black-and-white mapping may provide this type of coverage.

**Site Mapping.** Various remote sensor data and mapping techniques have been applied to the production of archeological site plans. Photogrammetric manuscript maps represent the most detailed, accurate, and expensive mapping methods. Architectural features and topography are also mapped in detail with terrestrial photogrammetry which is used to create planimetric drawings and topographic drawings of architectural exterior views. Other available methods range from simple tracings of information from orthophotos or uncorrected aerial photography to the use of stereophotography and planimetric plotting with radial line plotter or stereometer. The remote sensor data base may include aerial photography flown to project specifications, photo enlargements, or photography obtained with a variety of low-altitude or ground-base platforms. Methodological goals involved in the production of site maps include plans for structuring and recording excavations, the documentation of architecture as a conservation measure, and impact monitoring of standing architecture.

Experimentation with site investigations of large pueblos in Chaco Culture National Historical Park has included the use of photogrammetric mapping procedures and digitization of architectural data (Pouls et al. 1976). Site maps were prepared for the large pueblos within the monument using coordinately controlled aerial photography and precision stereo plotters. The goals of the experiment were two: 1) the acquisition of detailed maps from photogrammetric procedures that would be more accurate than those prepared by traditional on-the-ground engineering surveys; and 2) a savings in time and cost for the mapping of large architectural sites.

Establishment of field control prior to obtaining aerial photography was a necessary component of the project. Control points were established to include an elevation at each corner of a rectangle enclosing the area to be mapped plus an additional vertical point somewhere in the middle of this rectangle along either outside edge. Once the aerial photography was obtained, a planimetric site map at a scale of 1:600 was compiled using precision cartographic plotters. In addition to cultural and planimetric features, the microtopography was plotted with a contour interval

of 0.3 m during the stereo compilation procedures. Unusual terrain features such as vegetative anomalies, subtle soil changes, and linear features were also plotted.

One of the interesting results of such an experiment is the capability for reconstruction of architectural features with the use of computer graphic programs. Not only can a perspective drawing be prepared from any vantage point above the site, but various phases of occupation of a large architectural site can be reconstructed graphically using quantified structural data as a base. Another advantage of the methodology is the capability for precise measurement of material volumes in mounded sites from terrain data. Pouls and others (1976) review the economics of photogrammetric procedures; as they indicate, the number of sites that can be photographed in a single mission significantly affects the final cost.

Recently, panelling of control points with white plastic stripping and measurement of horizontal and vertical control points were undertaken for 41 large pueblo sites throughout the San Juan Basin (Marshall 1979) prior to obtaining aerial photography. Black-and-white aerial photography of each site at a scale of 1:3000 was taken into the field during measurement of control points and all apparent cultural features visible on the aerial imagery were ground checked with technical notes made for use in annotation of the photography. Until recently, it was supposed that these large pueblos formed outlying communities from the centrally located site groups in and near Chaco Canyon. It has been recognized, however, that a network of community centers probably existed throughout the basin. Those sites lying outside the canyon are little known; until this project was undertaken many had never been

mapped or recorded. Ongoing mineral exploration and development in this portion of New Mexico, which is rich in energy resources, has made the accurate recording of these cultural resources imperative.

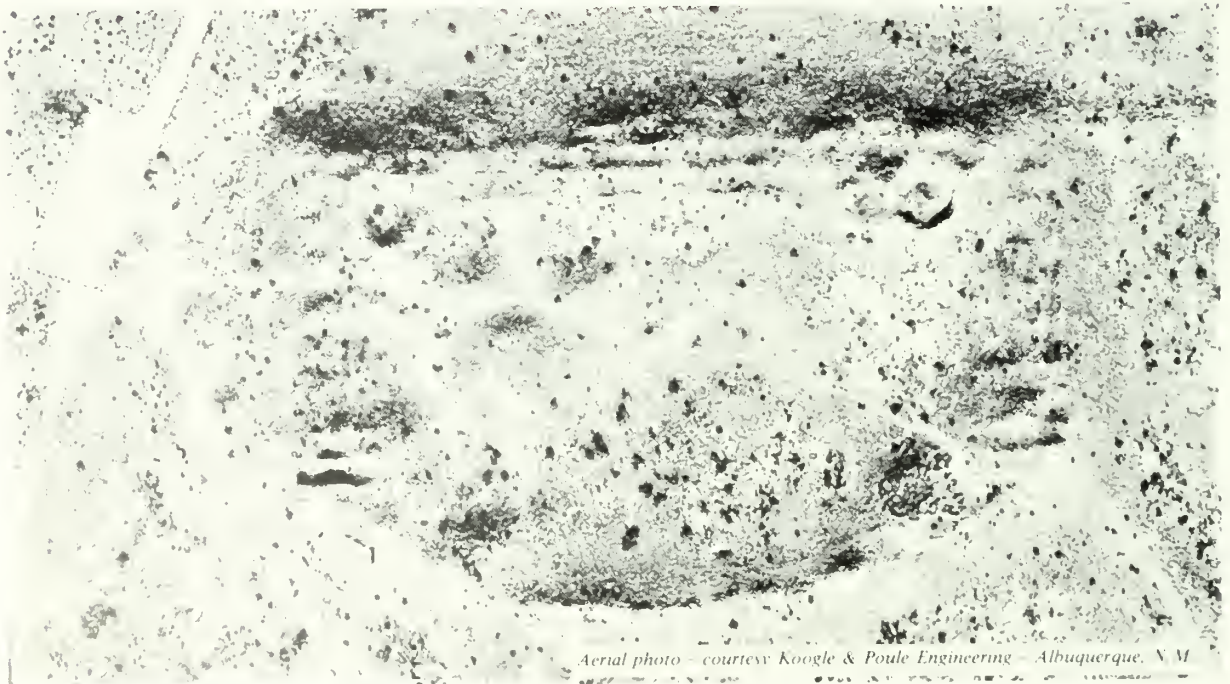
A series of four photogrammetric site maps made from photography obtained between December, 1972 and June, 1979 was prepared for the site of Pueblo Alto in Chaco Culture National Historical Park to aid in planning the excavation of selected portions of the site by the Chaco Research Center of the National Park Service. The pre-excavation site plan was produced at a scale of 1:1000 and with a contour interval of 0.3 m. Mapped depressions within the ruin (fig. 17) provided clues to the presence of subterranean rooms or kivas and helped to determine the placement of a series of test trenches in the lower portion of the plaza area. The 1976 site plan (fig. 18) was produced at a contour interval of 25 cm. Prior to obtaining the photography from which this plan was made, all discernible walls within the pueblo were cleared of overburden to enable the mapping of individual rooms and room blocks within the ruin. Rooms and features on this site plan were labeled and the plan used as a general reference map during excavation. Enlarged versions of the map were also used to record wall abutments and doorway placements throughout the site and to map connected rooms. A subsequent 1977 photogrammetric manuscript map of the site (fig. 19) was produced by adding excavated features from that year to the 1976 base map. Thus, the expense incurred in producing the two later maps did not include the production of completely new base maps. The series of four photogrammetric maps provided documentation for each phase of excavation while maintaining the original ground surface of 1972.



SCALE: 1:1000

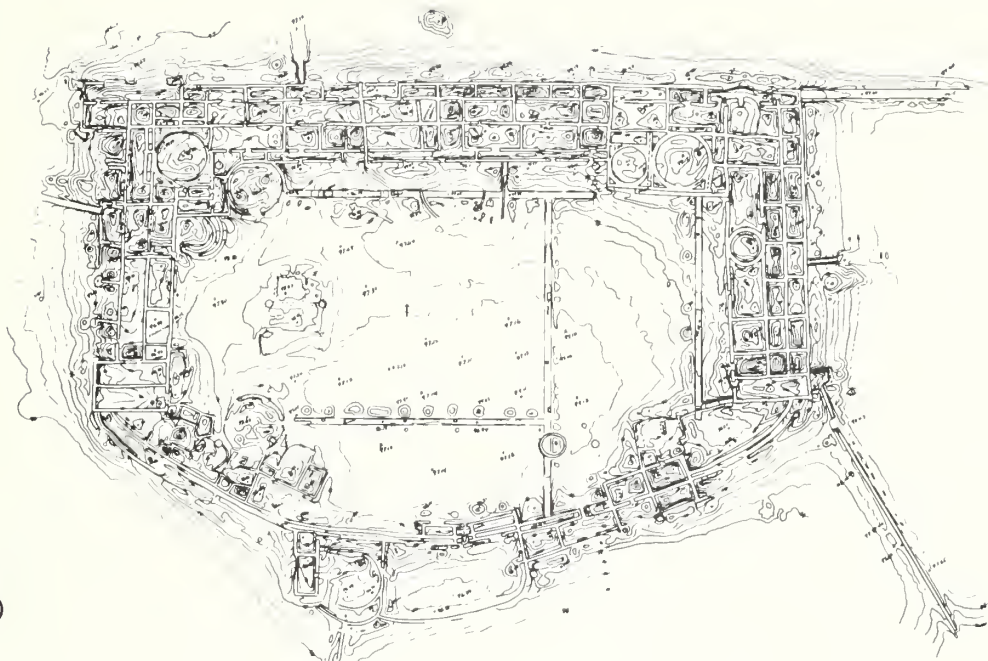
**OLD ALTO  
BEFORE EXCAVATION**

CONTOUR INTERVAL: 0.3 m



*Aerial photo - courtesy Koogle & Poule Engineering - Albuquerque, N.M.*

**Figure 17** Photogrammetric manuscript map of pre-excavated site, Pueblo Alto, Chaco Canyon.



SCALE: 1:1000

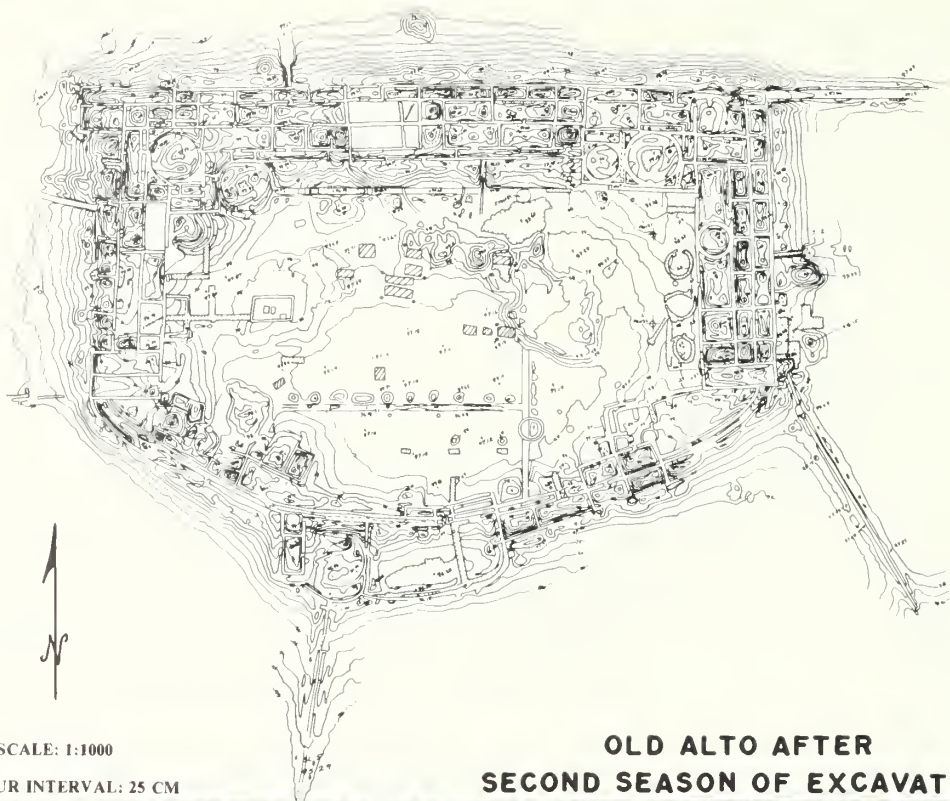
OLD ALTO  
AFTER STRIPPING OF WALLS

CONTOUR INTERVAL: 25 CM



1976 Aerial photo - courtesy Koogle & Poule Engineering - Albuquerque, N.M.

Figure 18 1976 Pueblo Alto site plan after initial clearing.



SCALE: 1:1000

CONTOUR INTERVAL: 25 CM

**OLD ALTO AFTER  
SECOND SEASON OF EXCAVATION**



Figure 19 1977 photogrammetric manuscript map of Pueblo Alto, following excavations.

Drager (1976) developed a method of calculating population estimates using aerial photographs taken by Stanley Stubbs (1950) of 25 modern pueblos. While this method does not attempt to explain the relationship between population and architecture variables, Drager's study is a valuable demonstration of the techniques available for the quantification of structural data using remote sensing techniques. A number of structural variables were measured from Stubbs' maps with a Bausch and Lomb 7-power magnifier which had a reticle calibrated in 1/10 mm divisions. Structural characteristics measured included the area in each pueblo under roofs, plaza area, kiva area, number of rooms by occupied floor, and total site area. Using a number of statistical correlations, Drager demonstrated that the total area contained under roofs minus kivas was the most relevant measure for estimating the population of modern pueblos (table 4). Published population data were also taken from Stubbs (1950).

This relationship was further refined by measuring the areas under roofs (minus kivas) as discrete floor levels for 12 of the pueblos. It was found that the highest correlation with population ( $r=0.759$ ) was obtained for the first floor level.

Ireland (1980) developed a simple mapping technique called photointerpretive mapping in which a stereoscopic model, neither rectified nor corrected for tilt or distortion present in the photo, is used. Distortion is inherent in the images as radial displacement and scale differences. Ireland indicates that the accuracy which can be achieved may be as good as some ground mapping techniques. Since the map produced is a map in plan rather than a topographic map, it is not necessary to set and survey ground control panels. The scale of the maps

produced depends on the nominal scale of the photographic negative.

These restrictions are balanced against the fact that this mapping technique is about half as expensive as controlled photogrammetric techniques (Ireland 1980). The mapping method includes the use of a clear mylar overlay on half of a stereoscopic model on which features seen stereoscopically in the photographs are traced. The overlay tracing is then enlarged, projected on drafting paper, and traced (fig. 20). Subsequent comparison of distances between topographic and cultural features on the photointerpretive maps with those on USGS topographic quadrangles has revealed that the photointerpretive technique averages a 4 percent deviation from the actual distances measured. Photointerpretive mapping as compared to simple sketch mapping is thus quite an accurate technique. When compared with on-the-ground survey or photogrammetric methods, the technique can be a cost effective mapping procedure.

Photographs taken from a terrestrial or ground station provide the data base for the photogrammetric recording of the facades of cultural resources. Borchers (1977) describes the application of terrestrial photogrammetry to the recording of essentially flat surfaces and for the delineation of topography on these surfaces. Borchers (1980) reviews aspects of photographic coverage, position, photogrammetric equipment, and the role of hand measurements in recording, since portions of some walls are not visible on photographs taken from a ground station. He also describes (1977) the aspects of the subject which should be included in the field and photographic records as well as requirements of the final photogrammetric drawing.

**Table 4.** Pueblo population and remotely derived habitation area data.\*

Pueblo Site	Population	Total Area Under Roofs Minus Kivas (m <sup>2</sup> )
Oraibi	87	4109
San Ildefonso	170	7047
Jemez	883	13321
Taos	907	11389
Santo Domingo	1106	21707
Zuni	2671	16143
$r=0.652$		

\*After Drager (1976:161).

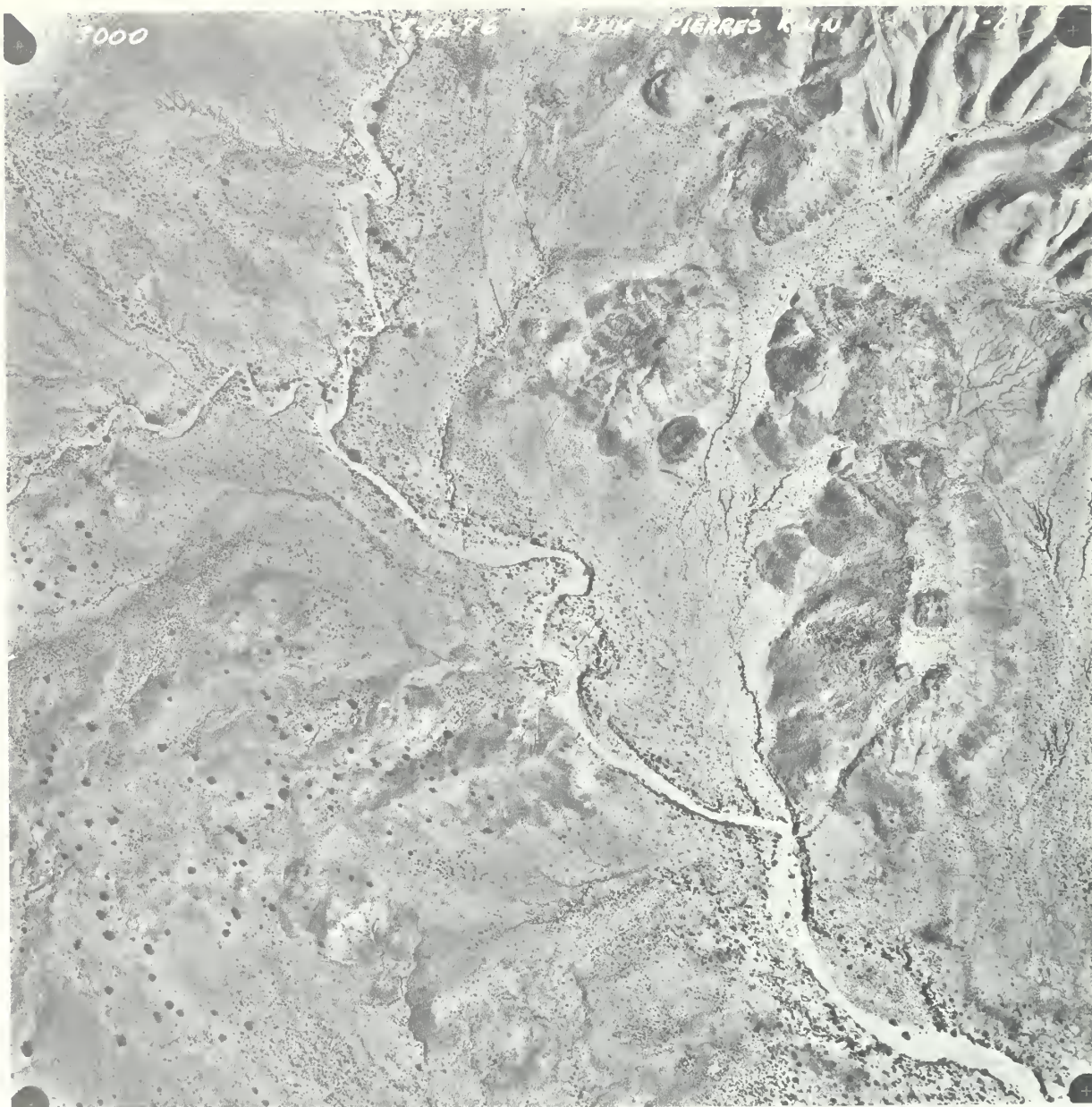
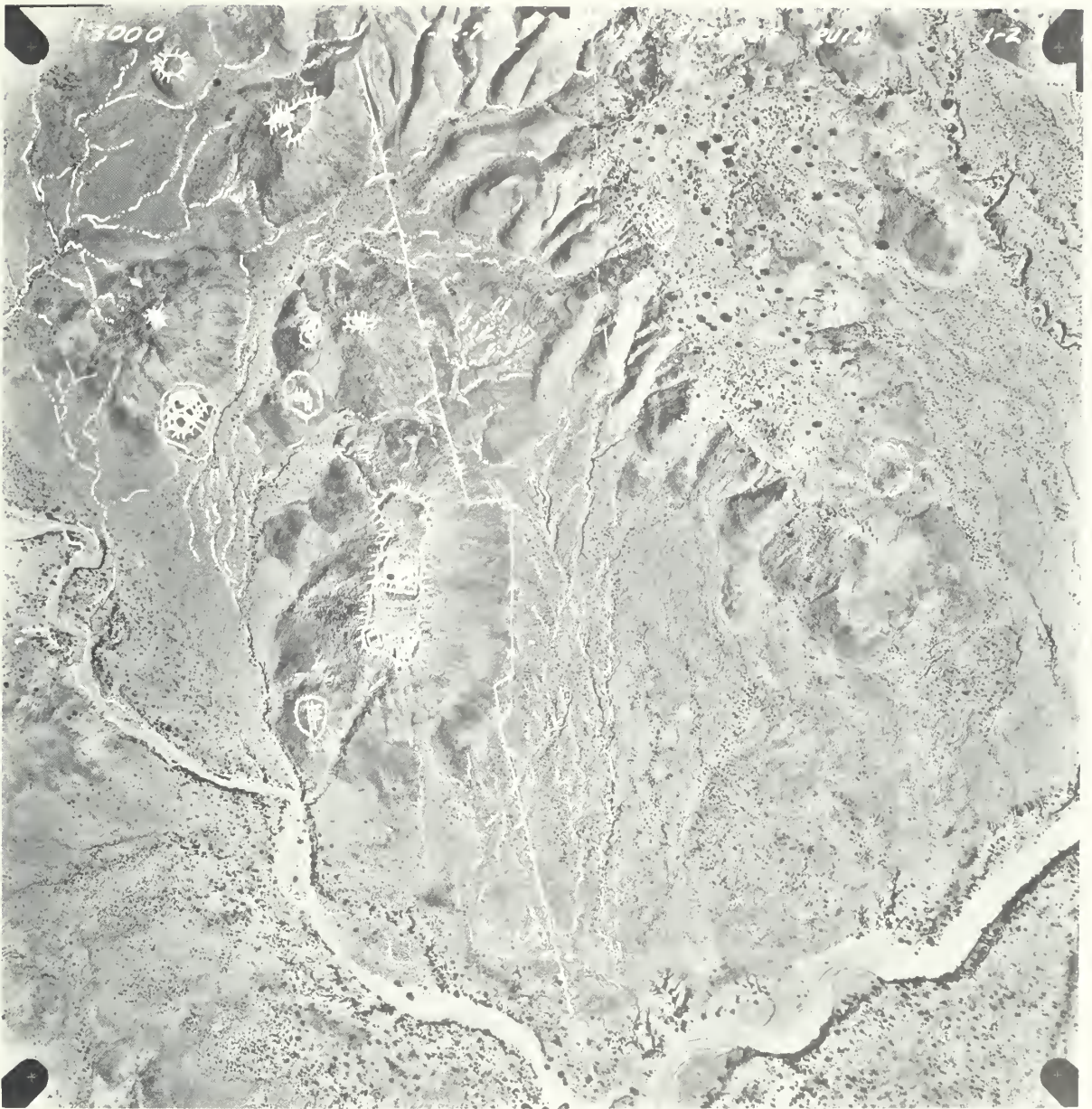


Figure 20 ( 1 - 1 ) Photo of Pierre's Site, San Juan Basin, New Mexico.





**Figure 20** ( 1 - 2 ) Photo and overlay tracing of Pierre's Site, San Juan Basin, New Mexico.

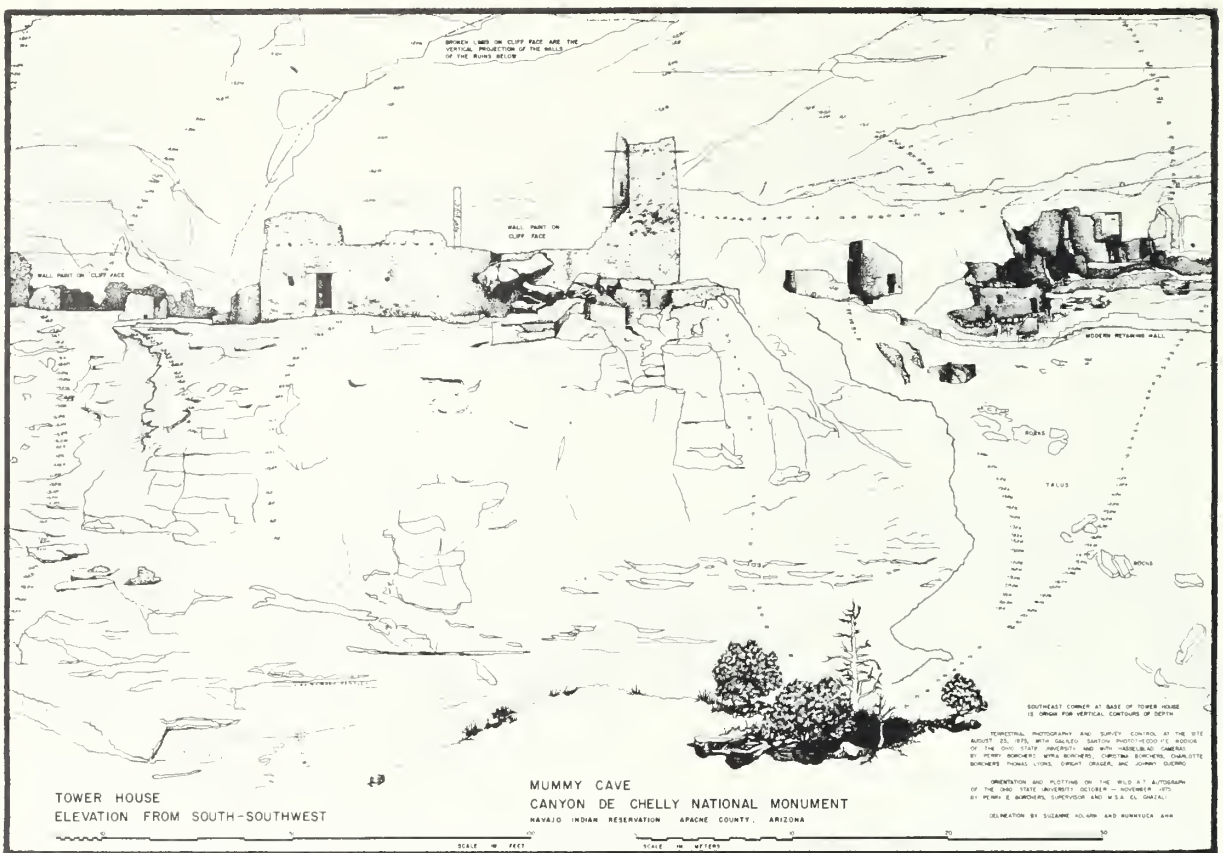


Figure 21 Planimetric drawing of Mummy Cave Tower House, Navajo National Monument, Arizona.

Photogrammetric plotting from ground-based photography has been implemented to produce the elevation drawing of the architectural form of prehistoric cliff dwellings in northeastern Arizona and the topographic drawing of each natural cliff setting. Terrestrial photogrammetry has been used to produce elevation drawings of Mummy Cave in Canyon de Chelly National Monument and the ruins of Keet Seel and Betatakin in Navajo National Monument. Contour lines on these drawings (fig. 21) represent vertical slices through the cliff overhang and the talus slopes and projecting rock base below the ruins (Borchers 1977). The vertical contours express the ground form in relation to standing architecture on the sites.

The facades of historic Pueblo buildings have been mapped utilizing aerial stereo photogrammetry

(Borchers 1977). Aerial recording of Indian pueblos in the Southwest has been undertaken by the New Mexico State Planning Office and the Historic American Buildings Survey. In addition, historic Spanish towns along the upper Pecos River Valley in New Mexico were recorded by aerial photography for the Historic American Buildings Survey. The accurate recording of buildings is dependent on a mapping procedure which produces elevation drawings from the aerial oblique view of building walls necessary to plot windows, doors, and projecting beams in section (Borchers 1977). Survey control for these maps is based on ground photography taken with a phototheodolite.

The photogrammetric recording of standing architecture has made possible the development of a methodology for monitoring impacts of mining

exploration and extraction on such architecture. The Kin Ya'a monitoring project (Ebert and Lyons 1978) was devised by the Remote Sensing Division as part of a cost-efficient cultural resources management program. The pueblo ruin of Kin Ya'a lies at the center of an area which was relatively intensively occupied during Pueblo II and III times. The pueblo itself contains a number of partly standing walls and the remains of a tower-kiva at least two stories high. Kin Ya'a also lies on a primary prehistoric roadway leading south from Chaco Canyon and is associated with a number of other prehistoric roadway segments in the immediate vicinity. The acceleration of mining and extractive activities in the San Juan Basin has resulted in the need for a fast, accurate, and efficient means for assessing potential and actual impacts on cultural resources. With vertical aerial imagery at a scale of 1:3000 taken before impacts (7/25/1973) and after the initiation of exploration (9/13/1976), photogrammetric maps were produced which provide a baseline picture of the appearance and measurements of the pueblos prior to and during the onset of exploration in the area. Subsequent mapping of Kin Ya'a on a horizontal plane used controlled terrestrial imagery and photogrammetric mapping methods. To accomplish this, control points were set at critical places on the pueblo wall and distances between these points measured. The initial, "pre-impact" terrestrial stereo photos were compiled, using a photogrammetric plotter, into a map of the surface of each wall or other surface of interest. Using photos taken approximately 6 m from wall faces, it was determined that a Z-coordinate (horizontal plane) accuracy of 0.3 cm ( $\frac{1}{8}$  in.) could be obtained. According to Ebert and Lyons (1978), such accuracy is fully sufficient for the scale of monitoring being undertaken at this site, since factors such as wind sway and diurnal temperature change would make more accurate measurement meaningless.

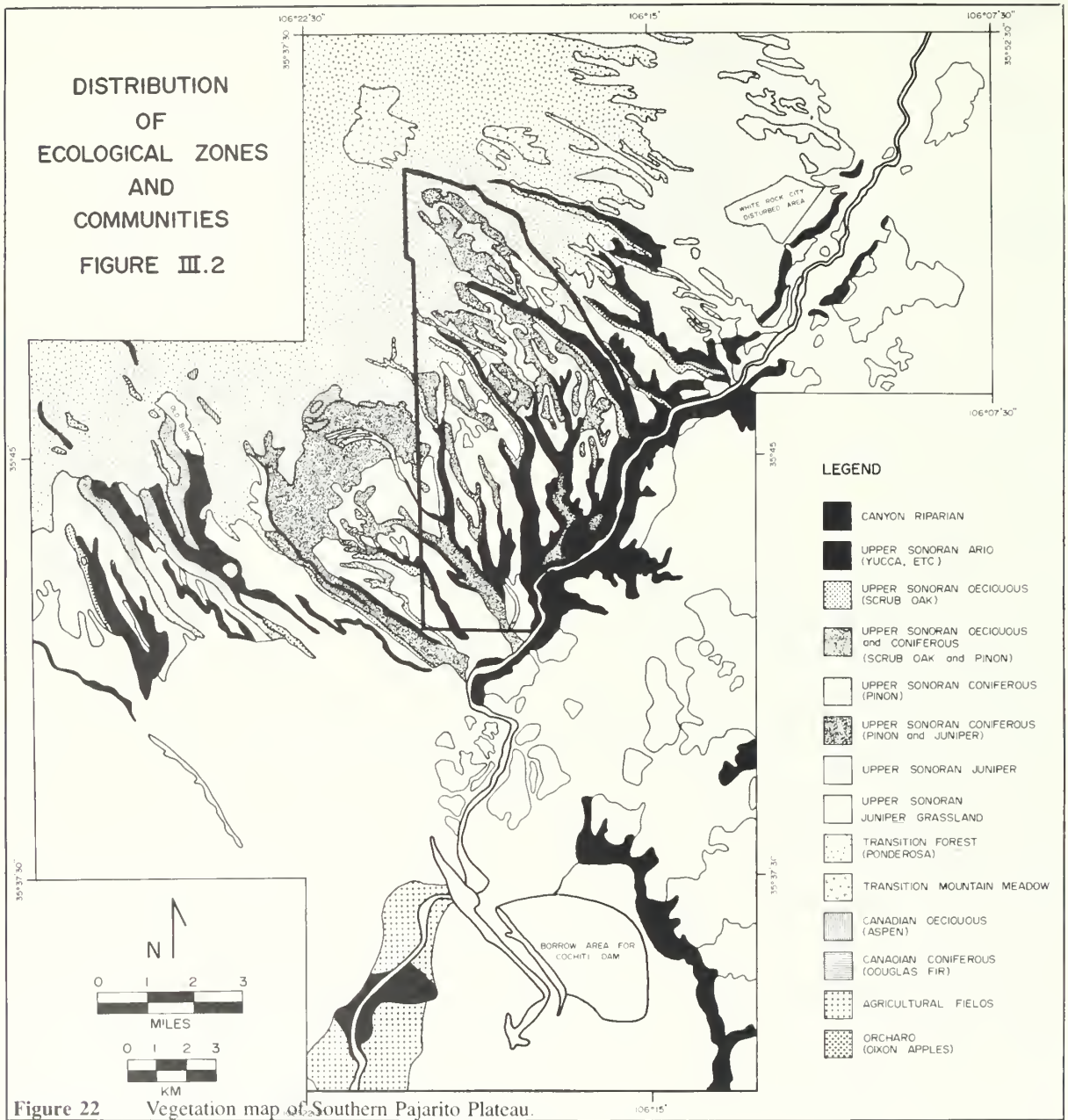
Additional terrestrial imagery taken from the same camera stations and using the same control points will be exposed at intervals during ongoing explorative and extractive activities in the Kin Ya'a vicinity. Each set of stereo images of wall faces will be directly compared to the initial imagery in the photogrammetric plotter and deviations noted. As an interpretive process, the procedure does not necessarily require additional plotting and drafting except where changes are noted.

Thus the impacts of extractive activities, e.g., drilling, digging, the construction of leaching pits, the fluctuations of the water table, and the operation of heavy equipment in the vicinity of standing

prehistoric walls, can be monitored.

**Environmental Mapping and Analysis.** Mapping and analysis of environmental characteristics from aerial imagery in conjunction with archeological research in the Southwest have taken several forms. Aerial imagery presents an ideal medium from which to map any natural surface features. The most common subject of environmental mapping and field work has been vegetation. Detailed maps of plant types and communities have been produced directly from aerial imagery. Because aerial photography presents all information concerning surface cover in a single format, however, environmental or ecological stratifications have been attempted with both black-and-white and true color imagery. Surficial geologic deposits and geomorphological features present another subject for mapping from aerial imagery. While environmental mapping problems concern the production of overlay tracings and the manipulation of photo and map scales, remotely derived measures of environmental diversity have also been obtained from the analysis and interpretation of photograph density profiles. This type of data, available in the form of a point density digital readout or a graph on a video monitor, can provide the archeologist with a new method by which to control and relate environmental information to an archeological data base.

Interpretation of aerial photography has been used to determine the vegetative content and structure of a region. Archeological investigation on the southern Pajarito Plateau in New Mexico in conjunction with the Cochiti Archeological Project included an ecological stratification of an area in excess of 600 km<sup>2</sup> (Biella and Chapman 1977). Because of the large size of the area to be investigated, it was determined that aerial photointerpretation would be an accurate and economical means of carrying out a vegetative stratification. Color infrared photography at a scale of 1:114,000 flown in August of 1973 by NASA was used in the development of a vegetative map (fig. 22) of the southern Pajarito Plateau area (Drager and Loose 1977). True color imagery flown during the same mission was used later to verify mapped determinations. Ecological zones derived from imagery interpretation were plotted on a mosaic of USGS 7.5 minute topographic quadrangles. Initial results of the stratification included delineation of Upper Sonoran, Transition, and Canadian ecological zones as defined by Bailey (1913) as well as identification of twelve native plant communities and two types of



modern agricultural fields. Because of the inability of the infrared film to distinguish between different communities (pinyon, pinyon-juniper, juniper), a category of Upper Sonoran Coniferous was developed. In evaluating the accuracy of the vegetative map produced from aerial photography, a ground based map of a small portion of the original study area, illustrating principal vegetation types of Bandelier National Monument, was used. Although some discrepancies were found between the two maps, the strength of the aerial-based study is apparent in that map produced agreed closely with the ground-based study. Correction and adjustments in the aerial maps were made after a few brief well planned ground checking sessions. This is in contrast to an expensive long-term ground study in which the entire surface area is surveyed for vegetation communities.

A vegetation map has been made from aerial color transparencies at a scale of 1:6000 for Chaco Culture National Historical Park (Potter and Kelley 1980). Since the photography contains information concerning all types of surface cover, not just vegetation types, it was possible for Potter and Kelley to establish correlations among physiography, soils, vegetational growth form, and species composition from the aerial imagery for each of the major vegetation types defined in the Chaco Canyon area. Both an ecological survey performed prior to the aerial mapping and several trips to the monument for ground checking provided verification for the vegetation types and the boundaries between them. The authors stress the close relationships among vegetation and features of geology, physiography, and soils. They also note that when dealing with the species level of vegetation, some species, because of a unique growth form or height, may be identified from aerial photography while others may be indistinguishable from surrounding species. If an understanding is developed of the many factors which affect interpretability, a knowledge of the predictable relationships among various factors will contribute to a more meaningful delineation of vegetation types.

Just such an interrelationship of environmental factors was the focus of an environmental or "ecozonal" stratification of the Coal Gasification Project (CGP) study area (Reher 1977) in the northern San Juan Basin. Distinctive ecological divisions were mapped from 1:12,000 scale black-and-white aerial photographs. The strata are based on impressions of what constituted significant combinations of vegetation and physiography. Reher points out that, as such, "the strata" overlap and dif-

fer in some ways from the way a plant ecologist, geologist, or soils expert would subdivide the area. Field reconnaissance confirmed that ecozonal boundaries may coincide with plant communities, plant associations, or relative frequencies of species present.

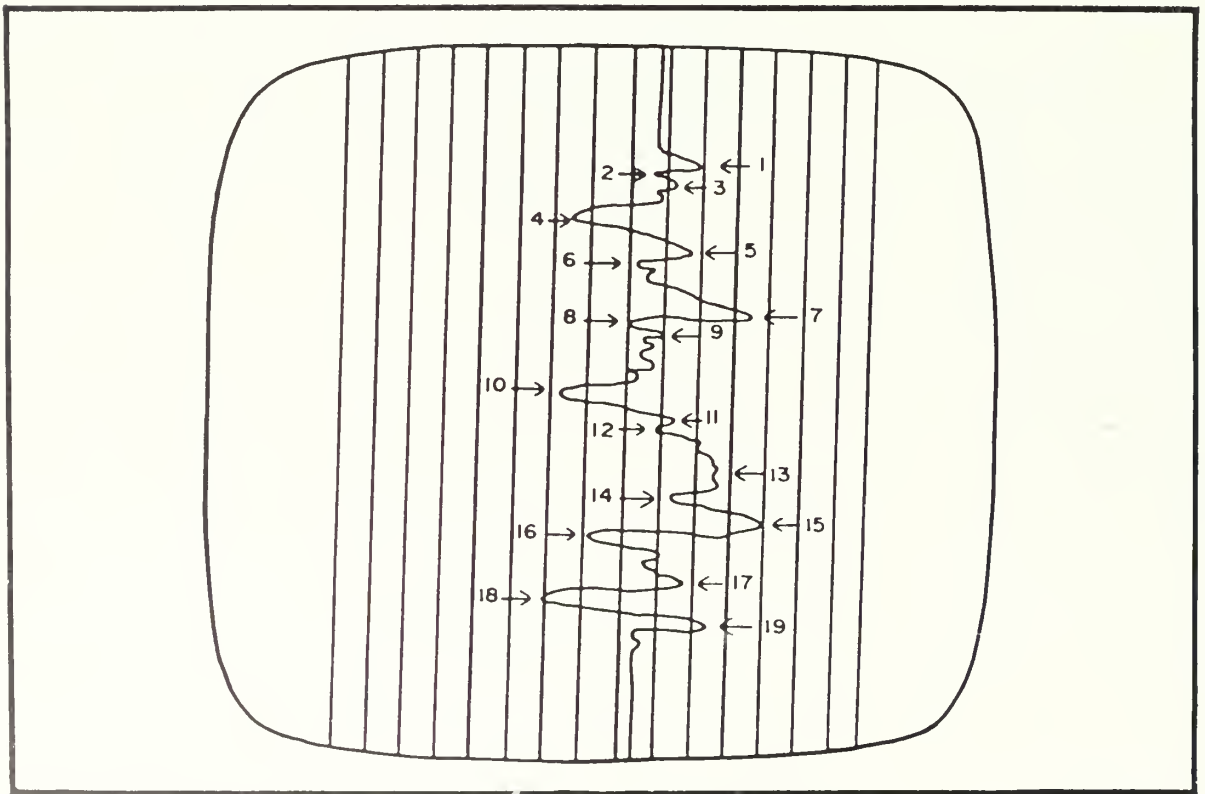
Seven major strata were delineated within the 151 km<sup>2</sup> CGP lease area. Correlation of the site survey information with the stratification indicated that prehistoric occupation over the study area is differentially distributed through time with respect to vegetation and physiography. Eighty-two percent of the Archaic occupations, for example, occur in an Upland Sand Dune ecozone. A clear bias toward lowland areas was noted for later Anasazi manifestations. Interestingly, badlands areas were utilized with relative intensity by the Navajos. In order to appreciate this latter observation, it should be understood that badlands have been described as areas with "A high content of salts, as well as rapid runoff and low soil moisture...in...raw clay and rock outcrop and hematite lag gravel areas" (Reher 1977:22). Because the stratification indicates occupational biases, it provides useful comparative data with which to examine other survey areas in the northern Great Basin.

In addition to the stratification, other remote sensing techniques implemented during the course of the CGP survey included that of a remotely derived diversity measure. The methodology of the latter was developed in response to the observation of the differential or nonrandom distribution of sites in relation to various environmental strata. An explanation of Archaic site placement based on prehistoric subsistence practices and the ecological characteristics of the arid Southwest was posited; it was reasoned that Archaic sites would be more likely to occur in areas of high ecological diversity. In this case, ecological diversity is a combination of the number of species represented in an area, as well as their relative abundance. In order to implement this concept, two complementary diversity measures were derived: one was based on remote sensing techniques (Ebert and Hitchcock 1977) and the other on on-the-ground mapping. The former measures were obtained with an International Imaging Systems Digicol device which produces a visual graphic readout of the intensity of light transmitted through a photographic emulsion, in this case using black-and-white photos. Fluctuations in this graphic representation were presumed to relate to some aspect of ecological diversity. Readings were first taken along a line which bisected a photographic image as it

appeared on the video screen of the device monitor. Actual measurement of the diversity index was accomplished by counting peaks on the graph of emulsion density which appeared on the video screen (fig. 23). Peaks were counted with a "filter" constructed of a sheet of transparent mylar drafting film ruled with 1.3 cm (1/2 in.) vertical lines; it was determined that only peaks of more than 2.5 cm (1 in.) on the screen would be counted. A "diversity" index was derived for each photo frame within the survey area. This number corresponds to patterns of light and dark on the photographic emulsion; it was also determined through ground survey to be sensitive to the overall patchiness of plants and topography (Ebert and Hitchcock 1977).

Use of remote sensor data at Yellowhouse Reservoir near Zuni, New Mexico (Hunter-Anderson 1978) was directed toward determining the environmental changes likely to occur with different climatic changes (Ebert 1978). Climatic trends as evidenced in precipitation records were compared with black-and-white aerial photos for patterns of co-occurrence between the meteorological record and surface vegetation. The aerial photographs ranging in scale from 1:15,840 to 1:31,680 were used as a record of vegetation distributors in the area in the years 1934, 1957, and 1974.

Vegetation distributions were measured along three transects which were perpendicularly layed out on the predominant vegetation zones as shown in the



**Figure 23** Representation of the Digicool screen showing an experimental method of measuring environmental diversity. When a fluctuation of the graph line, showing density variations across a photograph, extended farther than one of the grid lines, it was counted. The total number of such graph peaks counted in each frame was used to quantify "diversity" or fluctuation across a portion of the study area.

photographs. These transects were used to quantify the distributions of grass, shrub, and woodland communities on the appropriate frames of imagery; boundaries of the vegetation communities were measured along each transect. Measured vegetation boundaries were then converted to on-the-ground distances in proportion to the scale of the imagery inspected. The graphed data were then compared to precipitation and temperature trends in order to discern correlations between the distributions of plants and climatic changes (Ebert 1978). It was concluded from this exercise that following a period of average precipitation, grass and shrub vegetation appears mixed or more diverse below the tree line, and that the tree line in this area appears to have been descending between 1935 and 1974. This experiment in turn suggested a series of more detailed studies which could be carried out in order to better understand trends in the seasonal components of climate as they affect vegetation patterns.

Aerial photointerpretation has also been used in a geomorphological/archeological study designed to investigate the effect of geomorphological processes occurring after deposition of archeological material. Alberto Gutiérrez and James I. Ebert (personal communication, 1979) of the Remote Sensing Division reasoned that the relationship between geomorphological and sedimentary processes and archeological remains would be a measureable one and useful in the prediction of correlation of those remains expected to be found during survey with those located. The mapping of alluvial and colluvial deposits, sources and their present extent, and any post-depositional changes and alterations is presently being undertaken for the Chaco Canyon area. The mapping method involves visual interpretation of 1:6000 color transparencies flown in 1974 and interpreted using the Richards MIM-2 light table and Bausch and Lomb Zoom 95 Stereoscope. The mapping base was compiled by enlarging 1:24,000 orthophotoquads to a scale of 1:12,000 and drafting the boundaries of geomorphological deposits on overlays for a preliminary field check (fig. 24). Interpretation of orthophotos in the field allows for the use of orthophotoquads both as locational aids and interpretive devices. Orthophotos also allow the compilation of a drafted line map by tracing directly from the boundaries on the orthophoto base map.

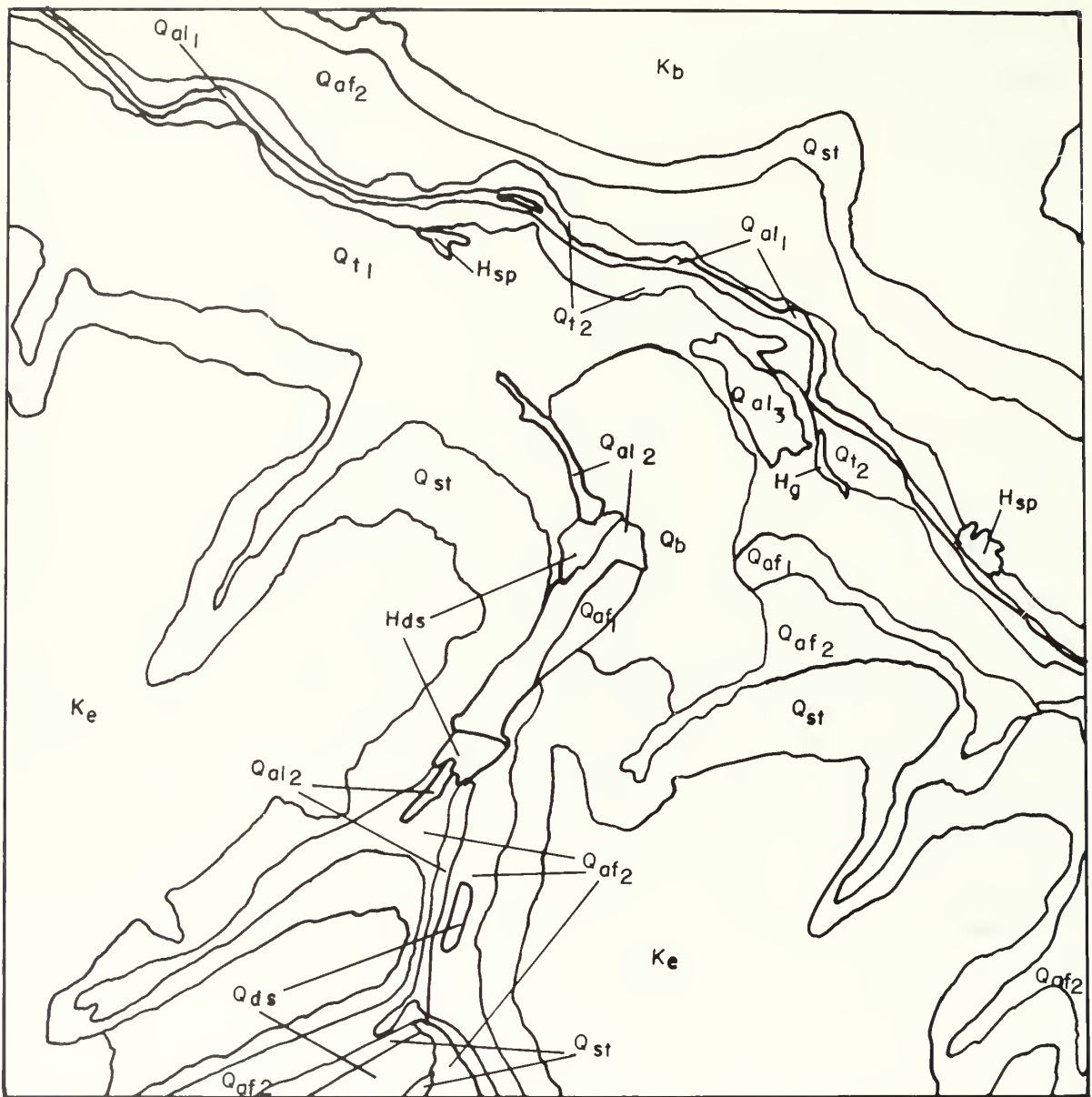
After the relative sequence and nature of the geomorphology are ascertained, these will be analyzed and compared with data collected on the ground during a 10-year intensive survey of Chaco Culture National Historical Park. This survey

provides an excellent data source, because a concerted effort was made during the field work to record even the most ephemeral cultural resources. This study will hopefully yield information on the nature of geomorphologically induced biases in site distribution seen during the ground survey. Future surveys may allow for adjustment in these biases if an area is interpreted accordingly prior to survey. Also, since archeological materials can sometimes be dated more precisely than alluvial or colluvial deposits, geologists may be able to date deposits of Pleistocene or Holocene age.

In order to better understand prehistoric population distribution in an ecotonal area of central Arizona, aerial photographs were utilized to both detect cultural features and delineate subenvironments (Gumerman and Johnson 1971). Of major importance were studies of drainage basin geometry which could be mapped with the available aerial photography (Weed 1978). Natural hydrological networks in the area consist of a dendritic system, in which small branching primary and secondary streams drain large areas creating broad alluvial plains, and a trellis system in which secondary and tertiary streams join a main straight channel at right angles. Questions were formulated as to the feasibility of prehistoric water management in both systems.

## Oblique Photography

Several advantages for oblique photography over standard, higher altitude vertical aerial photos have been noted (Safken and Ebert 1978). For example, oblique imagery can be more economical than broad coverage of a large area using expensive vertical techniques, since the former is shot from relatively low altitudes at targets of opportunity or areas of suspected occurrence of cultural remains. The discriminations of shadow, soil moisture, soil texture, and vegetative patterns not so readily discerned on vertical images may be possible with oblique imagery because of the control of the angle of the sun's rays in combination with the perspective of oblique photos. In addition, oblique imagery is not only useful in defining cultural resources but also in discerning vegetation distributions and other surface cover characteristics. For these reasons, the Remote Sensing Division has undertaken a program of experimentation with the range of oblique photographic methods available to the cultural resource manager.



**Figure 24** Map of geomorphological deposits in a portion of the Chaco Canyon area prepared from color aerial photography by the Remote Sensing Division, National Park Service.

**LEGEND FOR FIGURE 24**

DESCRIPTION OF GEOMORPHIC UNITS			
Map Unit	Designation	Landform/Photo Description	Stability Dominant Processes
Hg	Holocene Gulches	Localized discontinuous drainage, 1-3m deep, up to 300m long	Unstable, rapidly eroding.
Hds	Holocene Dam Sedimentation	Well-vegetated, fan-shaped deposits behind dams or diversions	Rapidly aggrading, anastomosing channels, date from 1930's.
Hsp	Holocene Soil Pipes	Arcuate depressions or collapsed soil pipes on terrace edges	Soil piping, mass movement highly unstable, eroding rapidly



**(LEGEND CONTINUED)**

Qaf <sub>1</sub>	Quaternary Alluvial Fan 1	Topographically-raised, irregular-shaped deposits; vegetation density slightly higher than Qaf <sub>2</sub> or Qt <sub>1</sub> .	May or may not contain active, incised channels.
Qaf <sub>2</sub>	Quaternary Alluvial Fan 2	Conical fan-shaped fill associated with major side canyons; light-medium tone.	Relatively stable surface, some graded to Qt <sub>1</sub> surface. May contain buried soils or humus-rich layers.
Qal <sub>1</sub>	Quaternary Alluvium 1	White, incised meandering-straight channel in central valley with vertical walls.	Active alluvium, thickness 0-1.5m. Erosion/aggradation dominate.
Qal <sub>2</sub>	Quaternary Alluvium 2	Tan-light grey alluvium in incised channels with steep banks, cutting through alluvial fill in side canyons.	Active alluvium in major tributaries of Chaco Canyon, many individual channels and cut/fill sequences
Qal <sub>3</sub>	Quaternary Alluvium 3	Light-toned alluvium associated with surface traces of fossil channels, high vegetation density	Inactive alluvium, mostly reworked Qal <sub>2</sub> material Thickness 2-4m.
Qb	Quaternary Badlands	Banded grey to dark brown beds following topography, high drainage density. Little vegetation.	Relatively impermeable shales with interbedded sandstones; covered by 0-0.7m of weathered mantle. Easily eroded, active surface
Qc	Quaternary Fine-Grained Colluvium	Light-brown, fine-textured, irregular shaped deposits near extensive shale and sandstone outcrops	Sheetwash material derived from valley sidewall sandstones and gentler shale slopes at their base.
Qds	Quaternary Dune Sand	Light brown, linear, topographically high deposits associated with Ke bedrock mesas and buttes. Bushes, no grasses, no established drainages.	No integrated drainage development, little erosion. Dunes aligned N 60°-70° E where linear. Thickness 0-2m.
Qst	Quaternary Talus	Medium-tone bands along base of sandy bedrock cliffs. Large angular blocks of sandstone talus on shale slope	Larger talus blocks stable, localized creep, sheetwash and debris flow deposits.
Qt <sub>1</sub>	Quaternary Terrace 1	Highest terrace incised by current Chaco Arroyo (Qal <sub>1</sub> ). Large areas of low relief within main canyon. Vegetation sparse.	Oldest, inactive terrace; interbedded with alluvial fans, sheetwash and colluvium from side canyons.
Qt <sub>2</sub>	Quaternary Terrace 2	Discontinuous light brown fine-textured areas between Qt <sub>1</sub> scarp and active arroyo (Qal <sub>1</sub> ).	Youngest terrace or floodplain of present arroyo (Qal <sub>1</sub> ) in some areas. Stability varies, 1-3m above channel.
QT <sub>(st)</sub>	Quaternary Tertiary Pediment Deposits (Stable)	Undulating surface with poorly-integrated surface drainages, dark in tone. Vegetation sage and grass.	Stable alluvial, colluvial and eolian deposits resting unconformably on eroded Tertiary and Cretaceous deposits. Little runoff or sediment produced on these highly permeable deposits.
QT <sub>(pt)</sub>	Quaternary Tertiary Pediment deposits (Transitional)	Tan sand texture, scattered vegetation and integrated surface drainages. High drainage density, parallel to dendritic drainage pattern.	Produces significant runoff and high sediment yields; occupies zones between QT <sub>(st)</sub> mesas and unvegetated badlands.
Kb	Cretaceous Sandy Bedrock (Buried)	Light tan-white bedrock with discontinuous veneer of eolian sand, local sheetwash alluvium.	Intermittent aggradation/erosion by sheetwash, eolian processes.
Ke	Cretaceous Sandy Bedrock (Exposed)	Light tan-white exposed bedrock with very sparse vegetation; fine-textured with joint patterns clearly visible. Cliff House and Picture Rocks Formations.	Flat surface with little or no cover, sheetwash and eolian erosion.

Photographic prints and transparencies were taken by the University of New Mexico Photo Services during a series of low altitude flights over Chaco Culture National Historical Park for evaluation of oblique aerial photography. The target areas chosen for the experiment were a portion of Chacra Mesa, the general vicinity of the Chetro Ketl field (Loose and Lyons 1976b) and Casa Rinconada, and an area around Pueblo Alto (fig. 14).

The photographic series of Chaco Canyon provides 8 in. by 8 in. prints and 70 mm (2 $\frac{1}{4}$  by 2 $\frac{1}{4}$  in) transparencies which document the following components of oblique aerial photography (Meleski 1978):

1. Type of Film
  - a. Plus-X black-and-white to provide negatives for projection prints made on Kodak RC paper.
  - b. Ektachrome Medium Speed film for the transparency stock.
2. Elevation
  - a. 500 feet
  - b. 1,000 feet
  - c. 2,000 feet
3. Side of target with sun at 30 degrees.
4. Camera look angle.
  - a. 30 degrees
  - b. 45 degrees
  - c. 60 degrees
5. Angle of light or target
  - a. 30 degrees
  - b. As near above target as time of year permits.

Measurability has been stressed as one of the most important factors in ensuring that oblique photography is useful for cultural resources management. Once anomalous features have been interpreted from the imagery, it is important to note accurately their location on maps so that they can be relocated. Safken and Ebert (1978) list a number of practical and methodological considerations which must be taken into account to ensure this accuracy:

1. Quantities necessary for proper map orientation and measurement from oblique photo areas:
  - a. *Camera lens focal length.* Especially with oblique imagery taken at low altitudes, the camera focal length should be determined empirically at an optical laboratory.
  - b. *Altitude of photography.* Since this is very critical at low altitudes, an accurate aneroid barometer might be carried. Standard aircraft altimeters may not be sensitive

enough for this purpose.

- c. *Reference horizon.* The horizon must appear on oblique aerial imagery to allow the application of a proper perspective grid for measurement. Since this is definitionally impossible in low-angle oblique photography, Safken and Ebert (1978) suggest devising an optical mirror or prism which would allow the sighting of the horizon and would record this in each frame. The mirror could also be attached to a protractor and provided with a sighting line, allowing precise positioning of a hand-held camera.
- d. *Precise marking of plumb point.* Plotting of the area covered by oblique photos requires that the ground point directly below the camera at the time of exposure be marked when possible. One way suggested to establish plumb points for each exposure of a sequence would be to determine, as accurately as possible, the beginning and ending plumb points of a photo sequence, the distance of the flight line, and the bearing of the line. The data required for this include ascertaining the location on a map of at least the beginning frame, the precise magnetic bearing of the flight line, and the speed in frames per second of the camera. Another method suggested would use a distinct ground feature or point in the photo such as a bend in a stream, rock outcrop, ridge, etc., which is discernible on a topographic quadrangle. This point, once located on the map, plus the exact altitude, direction, and reference horizon, would be used to find the plumb point for each photo.

A method of recording these data constantly during the flight of one line would be to use a portable tape recorder equipped with three microphones: one carried by the pilot, who would record compass bearing, speed, altitude, etc., of the aircraft; another by the camera operator who could describe identifiable landmarks; and the third attached directly to the camera to record shutter clicks, thus providing a precise time reference. The microphones plus earphones for the pilot and photographer would facilitate in-flight communications.
2. It was indicated that a fixed airplane/camera mount is unworkable because of transmitted vibration. In addition, unless a fixed mount is extremely flexible, there will be no way of

quickly correcting for crab angles of the aircraft. In order to orient the on-the-ground location of oblique photo coverage using the magnetic bearing of the aircraft's path, it is necessary that the orientation between the camera's line of sight and the central axis of the plane be known for each exposure.

3. Many features are delineated in oblique aerial photos because of shadows formed by very slight topographic variation at the ground. For this reason, it is important that preliminary experiments be undertaken in unexplored areas at a wide variety of sun angles. It is suggested that these range in approximately  $10^\circ$  increments from a sun elevation of  $10^\circ$  through  $50^\circ$  or  $60^\circ$ . This will require flights of long duration, or a number of shorter flights at different times of the day; it will also be necessary to accurately record the time for each flight line so that the sun's angle can be determined.
4. The aircraft must be stable at speeds below 120 knots, for 80 to 90 knots is the preferred maneuvering speed. The plane must offer an unobstructed view of the ground, therefore the wings should be attached above the cockpit. For photographic purposes, there must be no perspex windows; however, it is preferable to remove the window or the door, remembering in the latter instance to secure the equipment.
5. Many cameras are adequate for oblique photography. A large format with good optics and low distortion is required. Some archeologists use 35 mm; however,  $2\frac{1}{4}$  by  $2\frac{1}{4}$  inch or larger is preferable. The larger format cameras with sheet film are bulky and too slow to reload for some photo missions. A motor driven rewind feature is best. This allows more efficient use of time for composition and fewer runs over the area. The lens must be fast enough to shoot fine-grained slower films in the low light of early morning or later afternoon at  $1/250$  of a second or faster.  
Many films are available. Commonly panchromatic black-and-white and infrared black-and-white, color, and color infrared are used. Each situation will dictate which combination of films is best.
6. Planning. Before any flight mission is begun, a thorough flight plan with direction, altitude, number of photos, time of day, etc.,

must be developed. Such details cannot be dealt with even by the most experienced photographers in the tense, noisy, windy environment of the aircraft cabin. Without the quality of imagery, many substandard time consuming and expensive retakes may be necessary.

Use of oblique photography in the Chaco Canyon area recently included the comparison of uncontrolled black-and-white photographs of Pueblo Pintado, taken with a mounted Hasselblad by Alberto Gutierrez (Remote Sensing Division), with black-and-white obliques of the same site taken in 1929 by Charles Lindbergh. Although the resolution of Lindbergh's camera was far less than that of the more modern optics, comparison of the two photos (figs. 25a, 25b) shows that a substantial portion of one of the standing walls collapsed in the 50 years separating the exposures. Sequential photography, even if not strictly metric, can often be used to document such changes.

## Balloon and Bipod Platforms

Detailed photogrammetric mapping of site excavations can be accomplished with controlled vertical photography taken from low-altitude platforms. Low-altitude photography has a different place in archeological methodology than high-altitude vertical aerial photography. The use of ground-based or other low-altitude vertical photography for mapping artifact assemblages and architectural features has been shown to eliminate a bias which results from the need in traditional mapping techniques to arbitrarily plot points and interpolate between them (Klausner 1980). In addition, controlled vertical photography of this type presents all surface information on a site in one format. With this format, prints can be manipulated to suit particular recording needs and no information potentially critical to a map display is lost.

One ground-based platform is the Bipod Camera Support System (fig. 26) designed and built by Whittlesey (1966). Klausner (1980) points out that the bipod's advantages over other available ground-based platforms include its low cost, light weight, portability, and relatively simple method of operation. Klausner describes the bipod's construction and equipment specifications for camera, light meters, film and filters, and provides a manual for the use of a 30-foot portable bipod camera support.



**Figure 25a** Aerial oblique photograph of Pueblo, Pintado, at Chaco Culture National Historical Park, taken in 1929 by Charles Lindbergh. Lindbergh photographed many archeological sites from the air at about this time and is regarded as one of the pioneers of aerial archeology. Photograph courtesy of the Museum of New Mexico.



**Figure 25b** Aerial oblique view of Pueblo Pintado taken in 1979. Note that segment of wall that was standing in 1929 has collapsed (arrow).



Figure 26 Bipod camera support system.

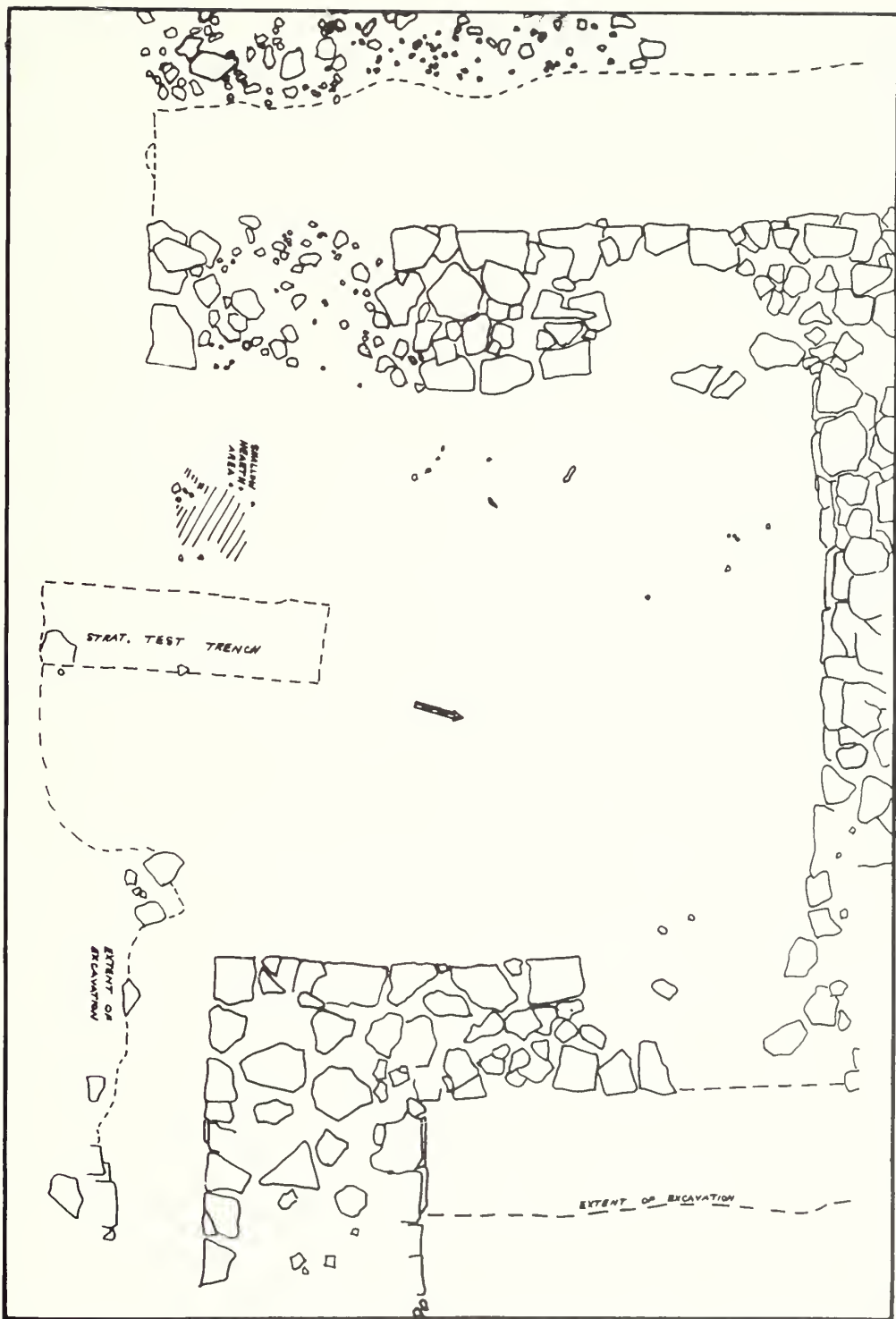
As with any photogrammetric mapping technique, maps are not derived from the measurement of the subject matter itself but rather of controlled photographs of that subject matter. Accurate maps are produced with stereoplotters which interpolate distances within established control points. It is also possible to make measurements from photographs with simple and inexpensive equipment. Boyer (1980) describes a method of taking measurements from stereopairs which compensates for such sources of image displacement as camera tilt, terrain displacement, and the use of camera equipment which does not control for the geometry of the film (nonmetric cameras).

Several applications of vertical ground-base photography to site mapping have been described (Klausner 1980). Perhaps the most useful application from a managerial viewpoint is the ability to map sequential phases of excavation beginning with photography of the unexcavated site surface. Bipod photographs taken from the same position at different phases of an excavation can aid the

archeologist in preexcavation planning and in planning subsequent phases of earth and fill removal. Klausner (1980) includes bipod photographs of the first and last excavated levels of a room in Pueblo Alto. Figure 27 is a map of a walled feature projecting from the Pueblo Alto ruin. The precise outlines of the wall components were made with the use of monoscopic bipod photography thus eliminating the need to interpolate between controlled points along the wall as one must with conventional mapping techniques. Subsequent comparison of measurements made from this map with those taken of the actual wall indicate the map to be as accurate a representation of the subject as a plane table map. Mapping by this method is also considerably faster than by conventional techniques.

Bipod photography is an ideal and economical method for the spatial recording of artifact location as well. With the current concern for "site structure," traditional methods of mapping have attempted to incorporate a method (piece plotting), which assigns individual artifacts a three-dimensional coordinate. Piece-plotting, a very time consuming and frustrating experience in the field, can alternatively be accomplished with the use of bipod stereophotography. An entire site plan that maps noncontiguous features can be constructed with bipod stereophotography. Both the techniques of planimetric plotting with the use of a radial line plotter and stereometry, in which differential parallax (the displacement of images due to a change in the point of observation) is measured under a stereoscope with parallax wedge or stereometer, can be implemented to produce maps of the distribution of individual artifacts across a site.

A tethered balloon support for aerial cameras constitutes an alternative method for the low-altitude recording and mapping of archeological sites. Although numerous archeological studies have utilized balloon photography in the Mediterranean and the Near East (Whittlesey 1970, 1971; Bevan 1975), experimentation with this type of platform has just begun in the Southwest. Experiments with the *Aeolus*, a pressurized, balloon support (fig. 28) also designed and built by Whittlesey, have been undertaken by the Remote Sensing Division. The potential range of camera altitude with the *Aeolus* platform support is between 20 and 1000 m. This results in a possible range of negative film scales from between 1:400 and 1:20,000 with a 2½-by-2¼ inch format camera equipped with a 50 mm lens. The aerodynamic design of the *Aeolus* permits controlled flights in winds of up to 24 km per hour at flying elevation.



**Figure 27** Map of "Blockhouse" adjacent to Pueblo Alto, Chaco Culture National Historical Park, made with the use of bipod photography.



**Figure 28** Aeolus balloon camera support.

A camera or tandem cameras are held in a yoke below a gimbal frame suspended about 10 m below the balloon. The yoke is designed to hold a Hasselblad EL-500 alone or a Canon AE-1 alone, a Hasselblad in tandem with a Canon, or two Hasselblads or two Canons (Whittlesey 1980). The cameras are electronically advanced by radio control with the radio receiver mounted on the gimbal frame. Once the camera is suspended from the yoke, the lens hangs in a true vertical position permitting acquisition of vertical stereophotography from which photogrammetric maps can be created. The camera is activated from a radio ground transmitter. Both the transmitter and receiver are powered by double strength sealed ni-cad batteries which when fully charged assure two or more hours of flight to a range of about 1000 m in altitude (Whittlesey 1980).

In the Southwest helium is preferred to hydrogen as an inflation medium for reasons of both

cost and safety. A total of 32.2 m<sup>3</sup> of helium is suggested for a mission of several days. This amount includes the filled capacity of the balloon and an additional 20 percent of that capacity for refreshment and adjustment during balloon use. Six pressurized tanks filled to 150 atmospheres pressure will provide 349 m<sup>3</sup>.

In order to obtain comprehensive photo coverage of an area or a series of photos to create a mosaic, an optimum elevation for flight is between 400 and 600 m. Target points on the ground and camera elevations must be planned in advance with the preparation of a sketch map indicating the size and location of each frame on the ground. For example, with a camera focal length of 50 mm and a negative film format of 55 mm<sup>2</sup> (2¼ in.<sup>2</sup>) the corresponding area framed on the ground with the camera at 610 m in altitude would be 110 m<sup>2</sup>. Once higher altitude photography has been obtained, a series of photos allowing more detailed coverage of each target area may also be made by dividing the original area on the ground into quadrants and lowering the balloon. Photography from higher altitudes is best taken early under the soft light of morning to avoid confusing shadows (Whittlesey 1980). Photographs taken in late morning will yield detailed coverage with strong, narrow, clear shadows outlining feature details.

## Airborne and Satellite Scanner Imagery

Scanners are optical/mechanical or optical/electronic devices which record portions of the electromagnetic spectrum, usually somewhat more selectively than most photographic sensor systems. As the scanning device is propelled across an area to be scanned by its airborne platform, radiation from the ground is transmitted to one or more optical or electronic sensors by means of an oscillating or rotating mirror which scans perpendicular to the line of flight. The resolution of the scanner is dependent upon flight altitude, the mirror's field of view, and the speed of the aircraft, and is usually quite low when compared to potential resolution of photographic data collection methods. It is not the spatial resolution that makes scanners a promising data source; it is rather that a particular portion of the electromagnetic spectrum can be detected through selective adjustments. When several detectors are



used in a scanner, the same mirror can expose these successively or simultaneously to radiation from the ground. Thermal infrared scanners usually detect only one band; other scanner configurations have been developed to detect 4 bands (Landsat), or 9 bands and 11 bands (Bendix Corporation). These latter devices are called multispectral scanners.

The advantages conferred by multispectral scanners are several. First, relatively simple data storage and transmission are possible using simple digital values collected by each scanner; these values are later "reconstituted" as images or analyzed in complex ways on the ground. Perhaps the most important contribution of multispectral scanners to remote sensing is that they produce far more information than panchromatic or even color ("3-band") photography, because they record spectral responses in greater detail, i.e., using more steps. In addition, scanner data are flexible in that they can be used in varying combinations and with different filter combinations to produce imaged scenes.

The single significant problem with scanner data is that it is extremely expensive to collect, at least from airborne sources. Consequently, airborne scanner data are presently only being used experimentally by cultural resource managers in the Southwest.

Satellite scanner imagery, on the other hand, is of increasing importance to archeologists since it allows a general, regional overview providing the flexibility and information content of multispectral scanner data at a low price. Landsat data are probably the most important source of "new" methods and techniques in Southwestern cultural resources study today, as will be discussed below.

**Thermal Infrared Scanning Imagery.** Data from the thermal infrared region of the photographic spectrum (light wavelengths longer than 1.0 micrometers) have been useful in supplementing conventional aerial photography, panchromatic, color and color infrared films (film emulsions sensitive to light wavelengths between 0.4 and 0.9 micrometers). Avery (1977) describes an infrared sensor as a scanning device that functions something like a television receiver by producing a nearly continuous image from a series of line scans. Infrared scanners do not record the terrain directly but rather register wavelengths longer than 1.0 micrometer producing a final image which is printed onto photographic film. Thermal radiation results from reflected solar energy or from internally generated

heat. Dark tones on a thermal infrared image (Lyons and Avery 1977: fig. 6-3) depict cool thermal signals, while white or relatively light shades depict relatively warm areas.

Aerial infrared scanner images of the eastern part of the San Francisco volcanic field northeast of Flagstaff, Arizona, have revealed the presence of linear features which subsequent investigations have identified as prehistoric agricultural plots (Gumerman and Lyons 1971; Schaber and Gumerman 1969). Identification of the linear features was made possible because of the disturbance these features caused in the mantle of black ash and cinders covering the volcanic field. The volcanic materials were deposited in A.D. 1066 or 1067 when Sunset Crater erupted. The appearance of the agricultural plots on the ground was described as clusters of parallel rows or ridges of fresh gray-black basaltic ash alternating with subdued troughs in buff soil derived from the weathering of underlying basaltic cinders and ash. On the thermal infrared imagery, the ridges appear as white bands resulting from higher radiant temperatures during daylight hours and possibly from a denser growth of desert grasses. The agricultural plots are not immediately obvious on conventional aerial photography and only one of the plots was recognizable on the ground (Schaber and Gumerman 1969: fig. 2).

**Multispectral Scanner Imagery.** Several studies of the environment in northwestern New Mexico have utilized Landsat imagery to conduct analyses which involved the division or stratification of an area into ecological zones or surface cover-types. These studies have focused on the Jemez Mountains (Camilli 1979a), a corridor from Crownpoint to Bisti, New Mexico (Camilli and Seaman 1979), and the Navajo Indian Irrigation Project (N.I.I.P.) (Camilli 1979b; Fanale and Drager n.d.). In addition, an ecological stratification was undertaken to delineate surface cover-types in the entire San Juan Basin in northwestern New Mexico (Camilli n.d.) in conjunction with the Bureau of Indian Affairs' San Juan Basin Regional Uranium Study. Each study was undertaken in order to determine expectations regarding the presence of cultural resources in areas of unknown archeological potential. The studies relied on archival research from which an inventory of known archeological resources and surveyed portions for each study area was compiled. These inventories were then considered within a framework in which the expected frequency of occurrence for

these remains was calculated for environmentally differentiated portions of the study area.

The environmental aspect of these analyses involved the identification of environmental zones within which the occurrence of certain archeological resources was assumed to be predictable. Nonrandom distributions of the archeological resources were anticipated because of the demonstration of environmental correlates with known archeological remains. Past surveys have indicated, for example, that there may be biases present in the determinants of archeological site location, e.g., soil types, presence of water, locations sheltered from weather conditions, and the presence of certain raw materials. Because the distribution of sites in an area may be a nonrandom one, presentation of individual surveys as uniformly representative of an entire study area would be misleading. The stratification procedures were designed to increase the precision of projections concerning the nature of cultural remains from sample (surveyed) areas to an entire region.

Stratifications were achieved with the use of Landsat imagery, a product of remote sensing of the earth by satellite. The Landsat program is conducted by the National Oceanic and Atmospheric Administration. The instruments on board Landsat include a multispectral scanner (MSS). This instrumentation system collects radiometric data in four spectral bands, two in the visible portion of the electromagnetic spectrum at 500 to 600 nanometers (green), and 600 to 700 nanometers (red), and two in the near infrared portion at 700 to 800 nanometers and 800 to 1000 nanometers (Avery 1977). A single frame of imagery covers 185 km by 185 km, approximately a 34,000 km<sup>2</sup>-area. Nominal spatial resolution of the MSS is about 80 m.

The image use in each stratification procedure consisted of a false color composite print produced by combining three of the MSS bands (four, five, and seven). Prints at an enlarged scale of 1:250,000 were used. These images had undergone a computer enhancement technique through the Geological Survey's EROS Digital Image Enhancement System (USGS 1978), which involved digital image processing techniques resulting in certain geometric and radiometric corrections, and contrast and edge enhancement. The resulting image allows optimum display of terrestrial information including vegetation cover distinctions, soils, landform, and drainage characteristics. Both satellite photography and MSS imagery as well as high-altitude aerial photography acquired by NASA, the Geological Survey, or the Bureau of Land Management are available from the

EROS Data Center in Sioux Falls, South Dakota. As of 1978, only selected Landsat scenes had undergone enhancement techniques; scenes available after 1979 have been geometrically and radiometrically corrected.

The description presented in Section I indicates that northwestern New Mexico is not an environmentally homogeneous area. Rather, variations in elevation, precipitation, soil composition, and vegetation have produced a mosaic effect on the landscape. Maps of the area which represent various environmental parameters such as soil type or vegetation community do not present all surface cover characteristics in a single format. Moreover, resolution of many of these maps provides only general boundaries. This may result in the inclusion of a study area within a single environmental zone and the exclusion of information concerning environmental variability within the area. Since stratification procedures are concerned with variability, a format in which a broad range of environmental factors can be represented is required; Landsat imagery provides such a format. Ecologic/cover-type maps have been produced from Landsat data for the National Petroleum Reserve in Alaska (Ebert and Brown 1977), and imagery has already been applied to regional environmental stratification in the San Juan Basin within a low resolution framework (Schalk and Lyons 1976).

Landsat imagery qualities meet stratification requirements in three ways:

1. The false color composite prints permit discriminations among a wide range of environmental variables within a single format. Bands 4 and 5 contain information on differences in soil composition. Band 7 provides information for discriminations between land and water boundaries and also between vegetation types.
2. The above information is presented in a systems context with the relationships among environmental factors shown over a large area. This is particularly important for the interpretation of the distribution of archeological remains, since human behavior is viewed as a response to the interactions among all the variables in an ecological system.
3. Landsat imagery is more suitable than aerial photography for stratification at the scale undertaken in regional analyses, because a single frame can cover an entire study area thus allowing for greater consistency than is

possible with large-scale multiple images.

Stratification methods were based on the detection of differences and similarities in tone and texture of the false color composite prints using standard photointerpretation techniques. After the initial identification, a number of procedures were performed to produce maps of a study area (in northwestern New Mexico) which illustrated the stratification. The first step involved the use of a transparent acetate overlay on which each stratum or ecologic cover-type was outlined. This procedure resulted in a 1:250,000 scale outline map of the environmental zones. This representation was then transferred onto USGS topographic quadrangles or prepared base maps.

Cover-types could then be field checked. Field checking in this instance includes a description of cover-type contents. This was accomplished with checklists of soil composition types, topographic features, and vegetation, and previously prepared maps of these surface cover characteristics. Since the primary data source for the cover-type stratifications is Landsat imagery, no attempts were made to redraw zone boundaries after ground reconnaissance.

A vegetational stratification from Landsat MSS imagery was also carried out for the N.I.I.P. by Fanale and Drager (n.d.). The procedures utilized for this analysis differed somewhat from that used to delineate cover-types as described above. A 1:60,000 scale enlargement of a portion of a computer-enhanced color composite Landsat scene was used. The season and year of the scene (August 16, 1973) and the large scale permitted the discrimination of subtle vegetative differences probably not visible on Landsat imagery from other available years (Fanale and Drager n.d.). The preliminary stratification was produced by dividing the image into zones or areas based on similarities in color, texture, and pattern.

After it had been classed into a number of strata, the area was then compared in the field against a checklist of environmental features including vegetation, community type, dominant or unusual species, and the density of vegetation. During the final classification and after repeated review and comparison of the field data, imagery, maps, and aerial photographs, the strata were refined and their boundaries determined. Although the final classification combines a number of environmental features, the strata are primarily differentiated on the basis of vegetation (fig. 29) (Drager n.d.).

Drager has compared the cover-type and the vegetational stratification methods with examples from the San Juan Basin and the N.I.I.P. Extensive

field examination was done in the 100,000 acres of the N.I.I.P., thus allowing mapped strata to be classified by vegetation communities found within the zones. The San Juan Basin was too large (12 million acres), to assess by field techniques; therefore, environmental zones or cover-types were derived purely from the information presented in the Landsat imagery. Rather than perform a field check and reorganize the zone boundaries, various environmental factors were monitored by overlaying the cover-type map on environmental maps of the basin and noting the contents of the zones. Field checking that was undertaken attempted to supplement this information. A table was then constructed listing the environmental characteristics of each surface cover-type; a total of 140 distinct environmental associations were found to exist in the San Juan Basin (Camilli n.d.; Drager n.d.).

Drager (n.d.) and Camilli (1979a, 1979b) describe the methods by which archeological site densities were determined for various regions based on the vegetational or cover-type stratifications. Each of the regions contained archeological sites located by previous systematic surveys of various land parcels. The densities are basically determined by dividing the number of sites found in each zone by the amount of area surveyed and projecting this figure for the entire zone. Table 5 lists archeological sites by time period and environmental zone for an area between Crownpoint and Bisti, New Mexico (Camilli and Seaman 1979).

In an ongoing cooperative research project of the Remote Sensing Division and the USGS EROS Program, personnel are examining alternate methods of deriving measures of environmental diversity from Landsat data. The derivation of a quantitative measure of environmental diversity focuses on the nature of the distribution of the many components which comprise the environment. The first stage of this research project involves experimentation with available technological methods of measuring characteristics from which an environmental diversity index can be compiled using Landsat MSS and Return Beam Vidicon (RBV) data. Four subscenes, each approximately 512 by 512 pixels (picture elements) or 25 by 25 km in size, within the San Juan Basin have been chosen for these analyses. These scenes will be analyzed digitally at the EROS Data Center. Supportive data for use in the experiment consists of the San Juan Basin Regional Uranium Study ecological zone/cover-type map of the region (Camilli n.d.). This map will be used in checking digitally-derived classifications of the area. The two

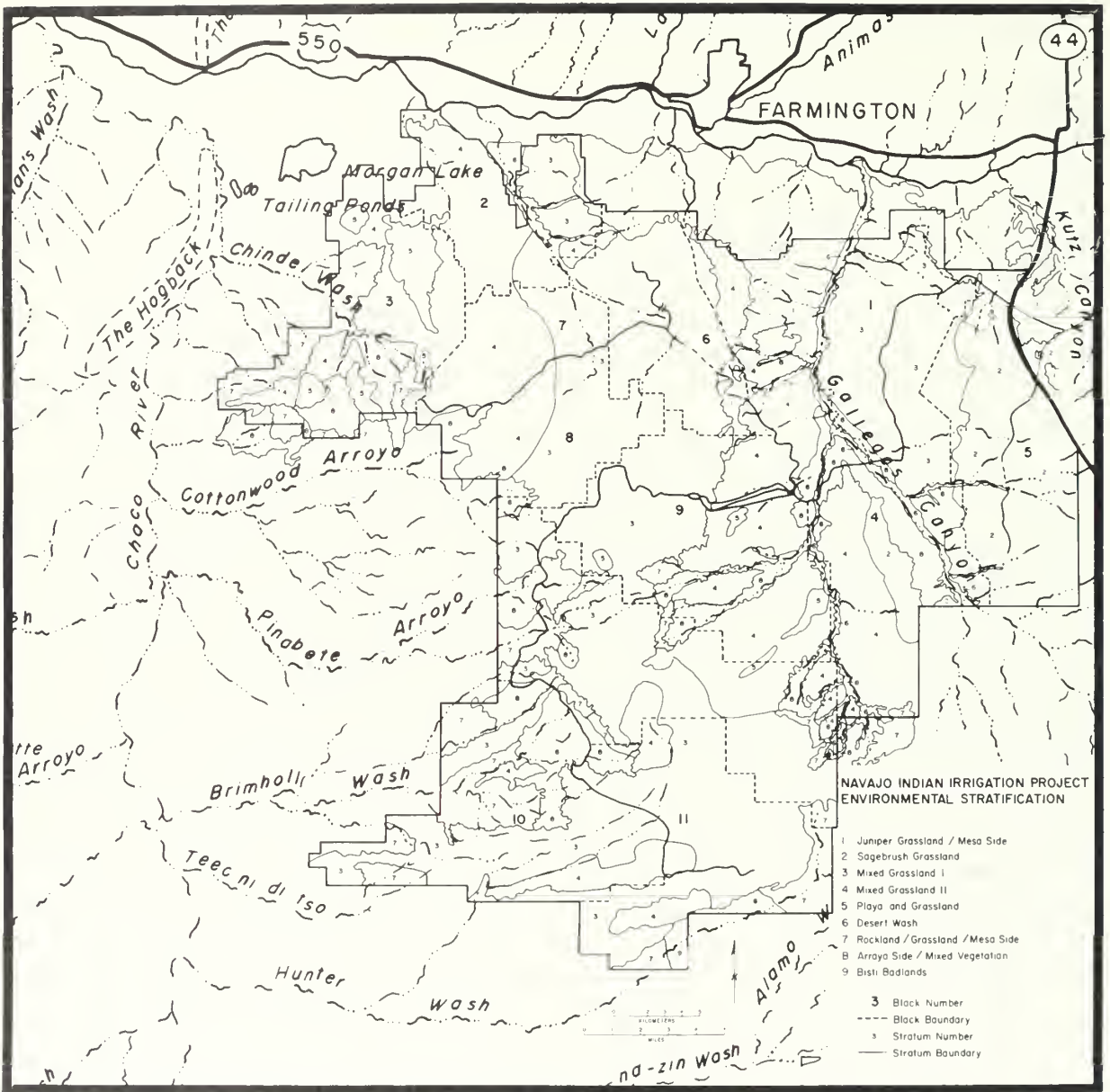


Figure 29 Navajo Indian Irrigation Project cover-type map.

**Table 5a** Site density and site sample populations for environmental zones.

Environmental Zone	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9	Zone 10	Zone 12	Zone 13
Component										
Archaic	0	0	.32	.50	.63	.69	.51	.32	.12	.22
Navajo	1.18	1.34	2.84	2.69	1.98	.78	1.75	3.15	1.36	6.73
Unknown	0	0	.37	.20	.27	.22	.15	.64	0	.11
Anglo	0	0	.05	0	0	.13	0	0	0	0
Anasazi	10.94	3.04	2.93	2.89	.99	.76	.77	9.75	.62	5.97
Site Density (/km <sup>2</sup> ) All Components	12.12	4.38	6.51	6.28	3.87	2.58	3.18	13.86	2.10	13.03

**Table 5b** Site frequency and site sample populations for environmental zones.

Environmental Zone	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9	Zone 10	Zone 12	Zone 13	Total Each Component
Component											
Archaic	0	0	7	5	7	37	14	5	1	1	78
Navajo	16	18	62	27	22	42	48	49	11	62	357
Unknown	0	0	8	2	3	12	4	10	0	1	40
Anglo	0	0	1	0	0	7	0	0	0	0	8
Anasazi	148	41	66	29	11	41	21	195	5	55	612
Total All Sites	164	59	144	63	43	139	87	259	17	120	1,095

analytical methods that measure environmental diversity using the Landsat data are clustering analysis based on successive nearest-neighbor simplifications of classified data, and Fourier transform and other power-spectrum analyses. Measures derived through these analyses will then be correlated with the San Juan Basin archeological data base.

In comparing the two sets of data, archeological and environmental, researchers have focused on the question of agriculture and its "beginnings" in the Southwest. Although first practiced during Archaic

times, it is believed that even in the later Pueblo periods, agriculture did not account for the totality of subsistence. In previous research (Reher 1977), it was theorized that nonagricultural Archaic groups, known to have exploited a wide range of plants and animals, were expected to place their sites in areas of high environmental diversity. Pueblo agriculturalists were expected to place their sites in areas of low diversity since their subsistence base depended on the intensive use and isolation of one or more plant species. In order to accommodate these ideas to the use of a scalar diversity measure in the San Juan

Basin study area, archeological sites were expected to occur in areas of increasingly lower diversity through time (Ebert 1980b).

Morain and others (1981) with the Technology Applications Center (NASA) at the University of New Mexico have explored the use of airborne spectral data as an aid in locating archeological sites in Bandelier National Monument in New Mexico. Principal components and canonical analyses were performed on a sample data matrix covering 0.34 km<sup>2</sup> in the monument. The aim of the study was to determine if these analyses would produce classifications of the environment which were capable of separating areas covered by archeological sites from surrounding terrain categories. Primary assumptions of the analyses were that in order to be detected through spectral analysis, prehistoric occupations of an area would have had to be localized and either prolonged or brief but very intense. Thus, more ephemeral occupation would not be detected.

The monument, located in the Jemez Mountains of north-central New Mexico, contains mesas formed of thick and complex deposits of ash and volcanic tuff and deeply dissected by the canyons of tributaries of the Rio Grande. The sampled study area contained ruins complexes and sites with nonarchitectural features. Spectral data were obtained with a Bendix-11 channel multispectral scanner operating in a wavelength range from ultraviolet to thermal infrared. Principal components analysis transformed the spectral data into a set of axes on which the original channels registered positive and negative values. In this way, it was possible to determine how much each spectral channel contributed to each axis and how much of the variation in the spectra was accounted for by the axis. The results of the analysis were used as input to standard color enhancement procedures and a color composite image produced. Nine test sites were also chosen for canonical analysis which, unlike principal components analysis, utilizes selected data classes to demonstrate variance in the spectral data. Images produced from these analyses were studied for areas of prehistoric disturbance and those sites were field checked. Areas located from the imagery included archeological sites as well as those areas with little or no vegetation cover nor association with cultural materials but characterized by high reflectivity. Known sites which did not show up on the imagery were characterized by lower reflectivity. Since the study produced some positive results, further experimentation was encouraged (Morain et al. 1981).

Williams (1980) has utilized computer software

to investigate the enhancement and recognition of cultural resource information contained in Bendix-11 channel multispectral images. As Williams notes, since many objects have a spectral response that is less variable than that of the surrounding terrain, the spectral signature is a primary detection feature. Methods involved in detecting an object in a multispectral image used a state conditional probability density function of the spectral signature. When this density function is displayed at each spatial location on the image, the desired feature is enhanced or detected in relation to all other objects on the imager. The natural resources in Bandelier National Monument provided the target for which low altitude digital imagery was obtained with the Bendix MSS airborne scanner, and a processing technique was implemented to determine the spectral signatures of major plant species. Typical species in the area include ponderosa and pinyon pine, juniper, scrub oak, aspen, spruce, cottonwood, and native grasses. Riparian vegetation is present in the canyon bottoms.

With discrimination between vegetation species as the goal, the information in the entire flight line was classified on a pixel by pixel basis using a conditional probability density function calculated for nine classes of data. These data classes included designations for individual species as well as for background (rocks and soil), shadow, cloud shadow, deciduous mix, and thick ponderosa/deciduous mix data classes. The final classification agreed with the actual vegetation patterns along the flight line, which consisted of heavy growth of juniper and pinyon gradually changing to ponderosa and deciduous trees at higher elevations. Spectral signatures for larger species and species that form thick growth were much more dissimilar than were signatures for smaller, thinner species; the latter tended to be more similar to background spectral signatures. The value of this study is in the demonstration that a computer system can effectively process information from low-altitude digital imagery which enables the analyst to detect and classify major species of vegetation. When refined, this capability will enable the archeologist to map specific resources or groups of resources in combinations dictated by the requirements of the limitations of the pattern of their occurrence in nature.

## Remote Sensing and Cultural Resources Management

### Introduction

Section 3 described remote sensing techniques which have been applied to Southwestern archeological resources and ways in which remote sensor data could be used in analytical procedures. This section will address the types of remote sensing methods and data which can contribute to overview, assessment, reconnaissance, survey, and mitigation phases of cultural resources management. In addition, while Section 4 is not a comprehensive review of photogrammetric and aerial photographic techniques, it is designed to give the cultural resource manager the background information needed in order to use several kinds of remote sensor products, e.g., base maps, materials for map updating, and materials for interpretive programs and displays.

### Cultural Resources Management Programs and Remote Sensing Methods

The information needs of land managers and project sponsors concerning cultural resources have been divided by Airlie House Seminar participants (McGimsey and Davis 1977) into categories of information for specific projects and information for general management needs. General management programs involve developmental planning, frequently on the regional level, for land use; specific projects are undertaken for a specified purpose in a designated location. Archeological research activities were identified which are needed to provide information for general management programs and for the evaluation of impacts due to specific projects.

Archeological research activities include the preparation of an overview, archeological assessment, and reconnaissance, intensive field study, and mitigation. Information derived during these activities provides the bases for assessments of scientific, historical, interpretive and heritage values of cultural resources and for the development of data recovery strategies.

Each archeological research activity is designed to provide information concerning cultural resources for a separate planning stage. Each stage could benefit from the implementation of remote sensing methods.

**Overview.** Overview studies, evaluations of known cultural resources, are carried out for general management programs on a regional and usually nonproject-specific basis (McGimsey and Davis 1977). The study includes a records check, literature search, evaluation of records and literature, and identification of inadequacies of knowledge concerning the resources of an area. Often however, known archeological sites have not been recorded; this lack of data causes serious problems for the evaluation of an area or region. The evaluation of unrecorded areas may benefit substantially from a review of existing aerial photography of the region as a part of the records check, for photointerpretation of this imagery can aid in the identification of architectural features and anomalies in the vegetation or soil cover which could prove to be of cultural origin. A review of general photointerpretive techniques can be found in Lyons and Avery (1977) and Avery (1977).

Aerial photography at scales of 1:12,000 or larger can be used as part of a photographic review procedure. Photointerpretation for cultural features may be accomplished without the aid of a stereoscope



**Figure 30** Viewing of stereomodel with mirror stereoscope.

or other instrumentation with very large-scale photography. Inspection of most existing photography requires the aid of a stereoscope, however. The three dimensional perspective provided by stereoscopic vision is a necessary adjunct to photo-interpretation for cultural features. In addition to providing this perspective, most stereoscopes are capable of magnification.

Avery (1977) reviews types of stereoscopes and other equipment used in photointerpretation. The most frequently used stereoscope is an inexpensive lens or pocket stereoscope with a magnifying power of 2 or 3 diameters. Only one-half to one-third of the standard print overlap of aerial stereo pairs can be viewed stereoscopically at one time with the lens stereoscope. Use of the reflecting or mirror stereoscope enables the complete separation of the

two stereo photos while they are viewed stereoscopically, permitting a view of the entire overlap zone of the stereomodel (fig. 30). A magnification capability can be provided by binocular attachments to the mirror stereoscope. The zoom magnifying stereoscope has the advantage of variable magnification paired with a capability for variable optical base distance and, in some cases, for 360° optical image rotation of each optical system. Because of the variable distance feature, the zoom stereoscope is used to study uncut roll film.

The following is a list of necessary photointerpretation equipment:

- Lens stereoscope, folding pocket type
- Stereometer or parallax bar for measuring object heights
- Engineer's scale, graduate to 0.5 mm or 0.02 in.



Drafting instruments, drawing ink, triangles, and protractor

Fountain pen for use with drawing ink

China-marking pencils or water-soluble ink

Tracing paper, vellum, drafting tape, and lens cleaning tissue

Solvent and cotton swabs for cleaning photos

Needles for point picking

Proportional dividers

Magnetic or spring clipboard for holding stereopairs

Illuminated tracing table or fluorescent desk lamp

Dot grids or polar planimeter for area measurements

Evaluation of cultural resources at the overview level must also take into account major environmental differences within a region that may correlate with the occurrence of certain kinds of archeological remains. It has been suggested that since field surveys are not usually conducted at the overview stage, environmental or other models may be used to estimate resource potential and distribution (McGimsey and Davis 1977). Remote sensor data can contribute to the identification of the location and extent of environmental correlates to major classes of archeological phenomena, enabling the general determination of resource potential which an overview requires. Types of remote sensor data that could contribute to this effort include aerial photography and satellite imagery. It has been demonstrated (see Section 3) that with the use of information on the known resource base, the predictions of archeological site frequency and distribution can be obtained with a remote sensor-based environmental model (Camilli 1979a; Ebert and Brown 1977; Ebert and Gutierrez 1980; Fanale and Drager n.d.). Such prediction can provide the information needed for planning future research and for the development of expectations regarding potential impacts on the resource base.

**Archeological Assessment.** Archeological assessments consist of a records check, literature search, evaluation of records and literature, a sample survey in the field adequate to predict the probably nature and distribution of archeological resources, and conclusions as to the effect on cultural resources of a proposed project. Since the assessment can include activities similar to those of an overview, the remote sensing methods discussed above would also apply for this research activity. Airlie House Seminar participants have suggested that field work necessary for the assessment should also be adequate to

determine logistic requirements in subsequent studies, since assessments are usually undertaken for an area more limited in size than the area addressed in an overview.

Field research and probability sampling require precise location of archeological remains and sampled areas. The use of aerial photography for site and survey area location has been discussed in Section 3. Frequently, proposed construction projects require the production of original topographic maps or orthophotomaps from aerial photography; these maps may be of interest to the cultural resource manager. Scale and resolution of this project photography may also be suitable for archeological field reconnaissance. Orthophotomaps, in particular, provide a good mapping base for the location of sites and sample units.

**Archeological Reconnaissance.** Archeological reconnaissance can include research activities already described for the overview and assessment and must include a field study adequate to assess the effect of alternative project designs on the archeological resource base. Fieldwork at the reconnaissance level is usually more detailed than fieldwork undertaken during an assessment, since it must lead to a determination of the nature and density of sites in a project area and to the development of a program of subsurface testing to permit determination of significance of sites encountered. A field survey of all alternative project locations is performed and may include some form of probability sampling. Archeologists have also been directed to develop an information base adequate to approximate the level of expenditure necessary to accomplish the mitigation plan.

On-site recording entails some form of site mapping to which remote sensing techniques can almost always contribute. Using remote sensor data, a volumetric analysis may be performed on sites for which a mitigation plan would involve substantial excavation. Photogrammetric data have been used to calculate the volume of earth, stone, and cultural debris of a site prior to excavation (Lyons and Avery 1977), allowing precise estimates of the quantity of material to be handled and removed. If archeological reconnaissance includes the excavation of controlled samples of material, these can be quantitatively analyzed. The density of cultural debris contained in the fill of measured features can be predicted for the site. In this way, budgetary estimates could utilize reconnaissance data to approximate analysis costs.

Estimates of site area may also be obtained quickly and economically using remote sensor data. One of the easiest ways to map sites from aerial photography is to trace the distribution of site features and cultural materials onto an overlay. The site area and space enclosed by architectural features can then be mapped with relative accuracy during the archeological reconnaissance phase using photography, relieving the archeologist of the need to use conventional mapping techniques in the field in order to obtain the information necessary for an evaluation and estimate of costs. Though this method produces a nonplanimetric map, the product is completely suitable for initial planning stages. It is suggested that only central portions of each photo be traced in order to eliminate as much of the radial displacement inherent in the image as possible.

**Intensive Field Studies.** Intensive field studies must provide the most complete data possible prior to execution of a particular project. This includes a comprehensive field examination of resources, collection of a reliable sample of data, description, characterization, and evaluation of resources, and determination of impacts. A mitigation proposal and cost estimate are also produced during this activity. At this stage, description and characterization usually rely heavily on mapping techniques. The production of site maps from photo overlays can be implemented with economical results.

A detailed description of resources should also rely on ground-based photography of all sites, for the pictorial qualities of photography provide the descriptive detail not possible to include on site maps. Photography depicts the particular environmental circumstances of the cultural remains. Intensive field studies may also require the production of base maps for the location of the project area boundaries, its topographic characterization, and the location of individual cultural resources. Without a reliable map of the distribution of cultural resources and the environmental characteristics that would present logistic alternatives in carrying out subsequent mitigation, the determination of impacts and development of a mitigation proposal would be difficult or impossible.

Mapping environmental characteristics which enter into a proposed research strategy may also be important for development of a mitigation plan. Ancillary studies during intensive field investigations may require description and analysis of the project area environment. Environmental mapping can be accomplished with a variety of remote sensor products including color, black-and-white, and color

infrared aerial photography, low-altitude balloon photography, and satellite photography or scanner imagery. The type of remote sensor data base used may depend on the availability of appropriate imagery and/or the cost of obtaining original imagery. Research is often needed to determine the type of imagery which will best display the environmental characteristics to be mapped. Several texts discuss the application of remote sensing to geological, terrestrial, and floral interpretation (Avery 1977; Lillesand and Kieffer 1979; Lintz and Simonett 1976; Wolf 1974). Initial investigation of imagery alternatives should include a comparison of imagery characteristics with actual environmental features; field work will help ensure successful interpretation of environmental phenomena and accurate mapping of their distribution.

**Mitigation.** Mitigation is defined as the alleviation of adverse impacts by action taken to avoid, protect, or scientifically investigate (e.g., excavate) the resources. Mitigation is thus a project specific approach and as such, can assume many forms. Preservation undertaken in conjunction with avoidance or protection alternatives, for example, entails documentation and stabilization measures. The documentation aspect can be undertaken with a variety of remote sensing techniques. Depending on the nature of the resource involved, extremely detailed documentation could take the form of low-altitude aerial photography or ground-based terrestrial photography. Comparison of this photography with on-the-ground site characteristics at intervals in the future would constitute one method of monitoring the cultural resources. A second method might be the comparison of the original photography with photography taken later from the same camera stations.

Another alternative for site documentation and monitoring includes production of planimetric and topographic maps of the resource from stereophotography. Planimetric maps show the correct horizontal or plan position of natural and cultural features. When differences in contour elevations are illustrated, these maps are referred to as topographic maps. They are especially useful for recording large architectural sites and for designing and documenting excavation procedures, although architectural features may be monitored with terrestrial photogrammetry (Ebert and Lyons 1978). The original elevations of contours and architectural facades produced from terrestrial stereophotographs may be compared with photography. This comparison could be facilitated with the use of photogrammetric plotters.

Close-range terrestrial stereophotogrammetry has been used for the rapid and precise measurement and recording of other kinds of surface sites. Two classes of surface sites (pictographs and exposed rock features) in the lower Pecos River region of Texas have been used to illustrate the applicability of stereophotogrammetry to the problem of archeological recording (Turpin et al. 1979). Planimetric, contour, and cross section plots of these archeological features have been produced from stereophotographs for these types of surface sites.

Because painted pictographs are subject to deterioration from environmental agents, the recording of these sites is of utmost importance. The rock art panels present several difficulties for recording: pictograph sites are often far above the present ground surface, limiting the use of conventional recording techniques; the rough terrain and rugged canyon walls may prohibit the transport and use of heavy scaffolding equipment needed to trace the motifs; and some of the panels are even too large to record by tracing. In addition, both graphic and photographic methods for recording rock art in the past, while they may illustrate the form and proportions of the pictographs, have failed to describe the topography of rock surface on which the figures are painted. Other problems include the bulkiness of full size tracing and the optical distortion which results from the transposition of the figures from a three-dimensional surface to a two-dimensional plane (Turpin et al. 1979).

The Texas Archeological Survey at the University of Texas at Austin tested the applicability of terrestrial photogrammetry for the recording of rock art panels in an attempt to alleviate the above problems (Turpin et al. 1979). A vertical contour map was plotted from a set of stereopairs of human and animal figures covering the wall of Painted Rock Canyon, a small tributary to the Rio Grande near the confluence of the Pecos River (fig. 31). The pictographs themselves and the rock face have been reproduced in planimetric with 5 cm contours defined by the intersection of the shelter wall with planes perpendicular to the primary axis of the camera (Turpin et al. 1979). Thus, these contours should be read as distances from the camera. One horizontal and two vertical cross sections of the small overhang in which the pictographs were located were also produced from the photography.

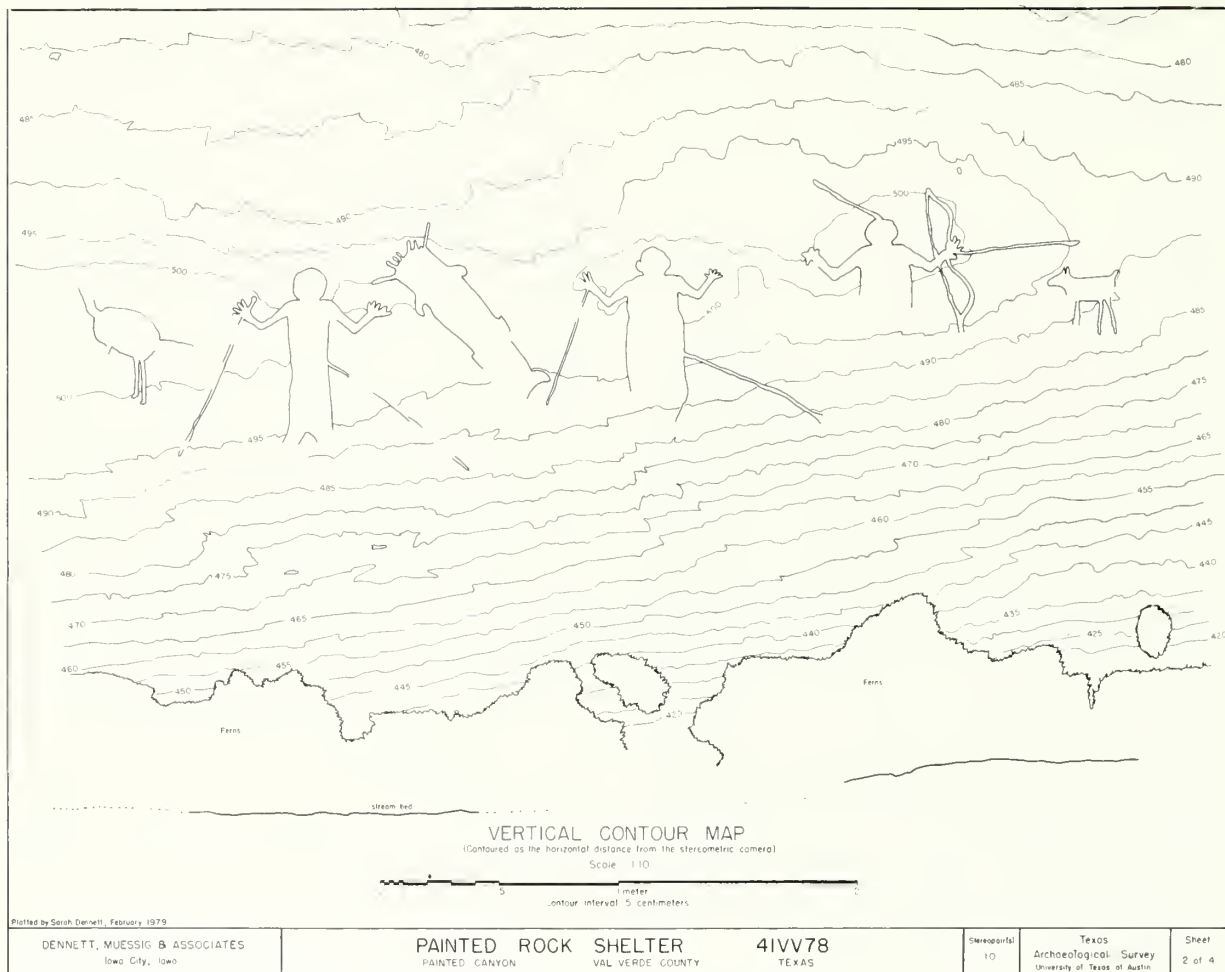
The other class of surface site recorded with stereophotogrammetry included surface scatters of rocks which have been interpreted as quarries, hearths, and earth ovens. Three sets of stereopairs

were obtained of one roughly circular arrangement of limestone blocks which were exposed on a naturally cleared surface. These photos provided the data base for a 2 cm contour plot (fig. 32), a planimetric map of the limestone blocks, the location of each artifact, and three cross sections of the ring. Elevations of artifacts, though not calculated, could have been determined within a tolerance of 5 cm. It should be noted that the photography of this site, including artifact tagging, took one hour; the entire process involved in obtaining photography of the pictographs took two and a half hours. This illustrates the time efficiency which characterizes photogrammetric recording as opposed to measurement with conventional mapping techniques.

The above exercises are excellent demonstrations of the capabilities and advantages of stereophotogrammetry for the recording of surface sites as noted by Turpin and others (1979) and reviewed below.

1. Production of vertical contour maps and cross sections as well as plan views can be accomplished from photographs taken during a single photographic session.
2. Documentation of precise dimensions is possible.
3. The technique is precise enough to allow production of overlay maps on successive levels of occupation.
4. Negatives and stereopairs constitute a permanent three-dimensional record. Plotting of pertinent data can be delayed until convenient.
5. Advantages for the study of rock art panels include the ability to examine the rock surface for exfoliation and natural deterioration. The deposition line visible at some rock art sites in the Pecos region could also be plotted and used to determine cut-and-fill sequences within the canyons. This could possibly allow for relative dating of pictograph panels in this area.

If the option is taken to investigate the cultural resource with collection or excavation procedures, both forms of data recovery could also utilize other stereophotographic methods. Documentation of data recovery procedures might also involve vertical photography taken from ground-base platforms. Bipod or tripod platforms (Bevan 1975; Harp 1975) provide ideal methods by which to map the horizontal distribution of features and artifacts through succeeding phases of excavation. Larger features may require wider coverage provided by



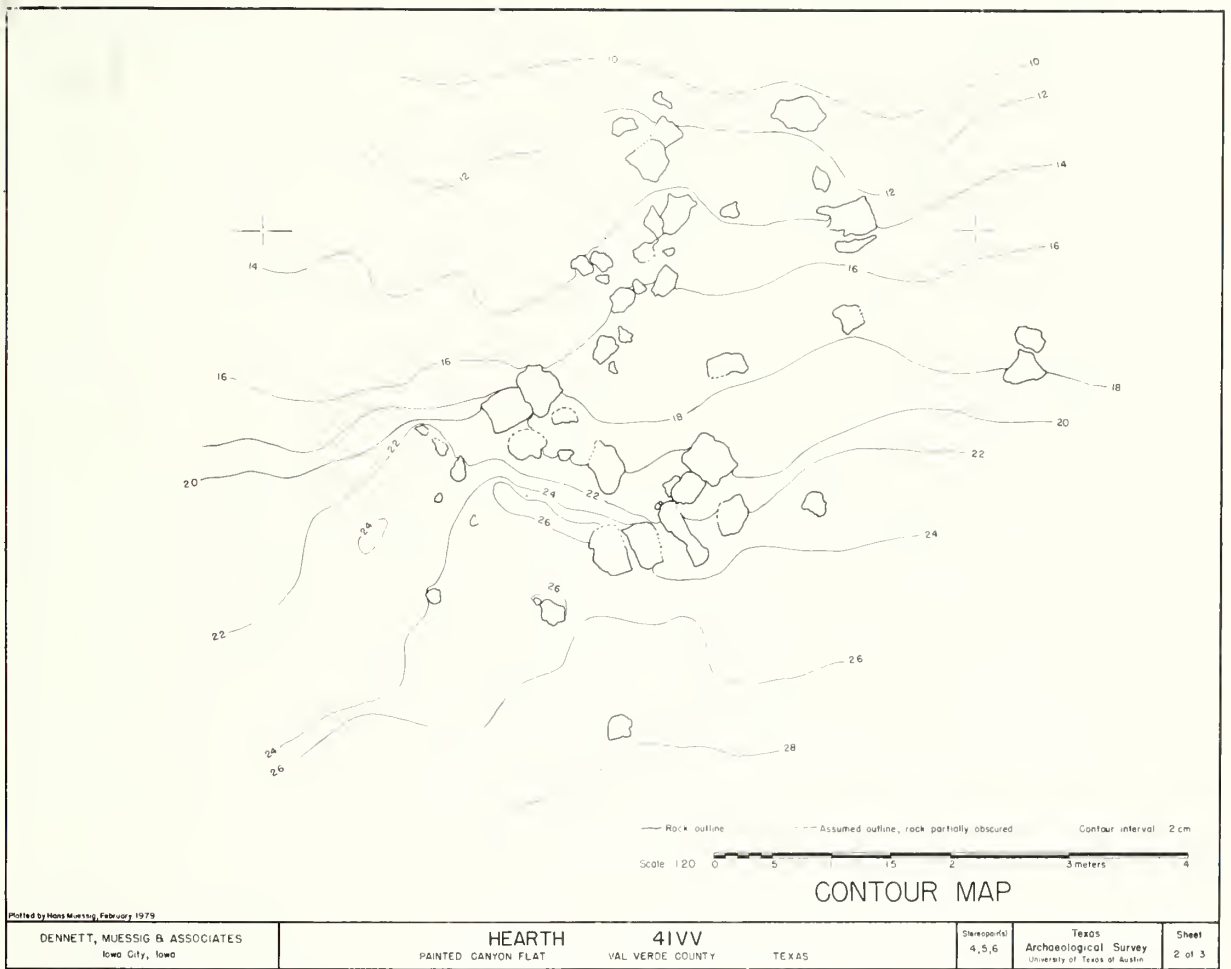
**Figure 31** Vertical contour map of pictograph, Painted Rock Canyon, Texas.

photography taken from a tethered balloon. Stereophotography obtained from both platform types can be used to produce planimetric maps, contour maps, and cross section plots of the site.

Data recovery procedures, which include the analysis of environmental data in conjunction with investigation of cultural resources during mitigation activities, can also use remote sensing products to obtain mapped distributions of natural phenomena. Environmental mapping entails the transfer of photographic detail from single nonstereoscopic exposures or stereopairs to a map base. This may be accomplished by direct tracing in the case of single exposures or by use of specialized image-transfer devices for both types of imagery. Lyons and Avery (1977) review the use of photogrammetric devices commonly employed to transfer photo detail to base maps.

## Base Mapping

Map scale is a major consideration in assessing mapping needs for the initial stages of archeological activity, including survey, and for planning and scientific investigation undertaken during mitigation. The locations of archeological features and areas in which survey was undertaken are of primary concern for sampling and intensive field studies. Adequate depiction of site locations and surveyed areas may be accomplished with 7.5 and 15 minute topographic quadrangles and aerial photographs of moderate scale. More detailed site plans or area maps may be required when planning is of primary concern, e.g., for the excavation of a major architectural site or the



**Figure 32** Planimetric map of surface artifact scatter.

development of a cultural resources area for public access. Although site mapping with simple photographic overlays has been suggested for reconnaissance and intensive survey, this method will not suffice where precise dimensions are required. As Avery (1977) states, direct tracings from photographic prints may be useful for some purposes, but because of horizontal scale variations in the uncorrected photographic image, the accurate measurement of distances from simple overlays cannot be made.

Since the physiographic position of an archeological site as well as the placement of outbuildings, roads, and paths in conjunction with an interpretive program, can greatly influence excavation methodology, production of large-scale topographic base maps is recommended when management plans require an original planimetrically correct base map.

The steps in the production of topographic maps include the following (Avery 1977; Wolf 1974):

1. Engineering control of ground targets.
2. Acquisition of vertical controlled aerial photography.
3. Development of film and production of a set of contact prints.
4. Production of a glass diapositive from each film negative for use in stereoplotting instruments. The positive image plates are oriented in the plotter and tie-ins to the base or manuscript map are established by the use of the ground control points. The resulting stereoscopic setup is referred to as a stereo model.

Wolf (1974) describes the system for making precise measurements of the stereo model with direct optical projection plotters and

stereoplotters with mechanical or optical mechanical projection systems. With direct optical projection stereoplotters, measurements can be recorded as direct tracings of planimetric features and contours of elevation onto a manuscript map of stable base material. Planimetric details and cultural features are traced first, followed by contouring.

5. Contours, drainages, and cultural features are traced onto the map manuscript by manipulation of a floating dot seen by the plotter operator within the stereomodel. The tracing process is repeated for each stereopair in a flight line, if more than two images are required for area coverage.
6. The completed map is checked for errors and is then reproduced. This stage includes a field check in which features are accurately identified and local names determined. With this procedure, photogrammetrically plotted distances and elevations are checked against field measurements. When the inking of the map is completed after field inspection, it can then be reproduced on paper by direct Ozalid process, or reproduced on a stable base material by a contact photographic process known as autopositive.

If suitable vertical aerial photography is not available for the production of a topographic map, managers must contract with a commercial firm for a photographic overflight. It is the manager's responsibility at this point to define the mapping project's goal and to draw up map specifications. Final photographic and map products should also be clearly defined. Photographic products usually include two sets of contact prints or transparencies and a set of index sheets showing the position of each photo frame over the flight lines. The final map products should be designed to depict the detail necessary for planning purposes. Wolf (1974) defines two types of photographic qualities (metrical and pictorial) that must be specified for aerial photography. Metrical qualities are needed for mapping where precise photogrammetric measurement is required. Pictorial qualities are needed for depiction of natural and cultural features on the ground surface and for successful photointerpretation of these features. Both aspects of aerial photo quality are obtained appropriate films, cameras, and lenses. Modern aerial and terrestrial metric cameras provide both of these qualities. Even high quality standard hand held cameras provide only pictorial quality.

The amount of detail in the final map product is dependent on both the map scale and the contour interval chosen. Dickinson (1979) points out that no other single feature of a map is so important as scale, since scale controls the area available for representation of detail and affects the design, accuracy, and appearance of the map. In dealing with cultural resources, an adequate map scale is one which enables the smallest objects of importance to be shown on the map. The accuracy to which planimetric positions of points can be measured from a map also depends on the scale. National Map Accuracy Standards require that planimetric features be plotted correctly to within 1/30 in.

Contour interval is controlled by terrain and map scale (Dickinson 1979). On a small map, there is less room for closely spaced contours especially in areas of considerable relief. In areas of gentle relief, however, the contour interval may have to be relatively small in order to show important features. Any feature less than half the height of the contour interval will probably not be discernible in the contour pattern (Dickinson 1979). The National Map Accuracy Standards state that for vertical mapping accuracy, the elevation must be interpolated correctly from a map to within one-half of the contour interval.

In topographic mapping, map scale, contour interval, and the capabilities of stereoscopic plotting instruments used in map compilation dictate photographic scale. Determination of photographic scale is the most important aspect of planning a photographic mission, since it is photo scale that will ultimately determine the quality of the final product as well as its cost. The enlargement ratio from photo scale to optimum map compilation scale is dependent on the capability of the stereoscopic plotting instruments. Wolf (1974) reviews the relationship between required photographic scale and the characteristics of particular stereoplotters. For double projection direct-viewing plotters, the optimum enlargement ratio is five (table 7); thus the optimum photo scale is automatically fixed at one-fifth map scale. Some modern photogrammetric plotters allow projection ratios of 6 to 10X. These devices, called "first order" plotters, allow greater map scales with smaller scale photography than the standard 5X plotters (table 8).

Avery (1977) suggests that it is desirable to specify the smallest photo scale that will meet the requirements of a given project. This approach

**Table 6.** Photo scale and map accuracy.

One inch equals	Representative Fraction	Map Accuracy
30 ft	1:360	± 1.0 ft
50 ft	1:600	± 1.6 ft
100 ft	1:1200	± 3.3 ft
150 ft	1:1800	± 5.0 ft
200 ft	1:2400	± 6.6 ft
300 ft	1:3600	±10.0 ft
400 ft	1:4800	±13.3 ft

**Table 7.** Photographic and map scale relationships with 5-diameter projection plotters.

Photographic Scale	Map Scale	Minimum Contour Interval
1:2400 1 in=200 ft	1 in=40 ft	2 ft
1:4800 1 in=400 ft	1 in=80 ft	2 ft
1:6000 1 in=500 ft	1 in=100 ft	2.5 ft
1:12,000 1 in=1000 ft	1 in=200 ft	5 ft
1:24,000 1 in=2000 ft	1 in=400 ft	10 ft

**Table 8.** Photographic and map scale relationships with Universal First Order Plotter

Photographic Scale	Map Scale at 7.5X Projection	Map Scale at 6X Projection	Minimum Contour Interval
1:3600 1 in=300 ft	1 in=40 ft	1 in=50 ft	1 ft
1:7200 1 in=600 ft	1 in=80 ft	1 in=100 ft	2 ft
1:18,000 1 in=1500 ft	1 in=200 ft	1 in=250 ft	5 ft
1:36,000 1 in=3000 ft	1 in=400 ft	1 in=500 ft	10 ft

**Table 9** Ground area coverage for a single negative at different scales.

		A	B	C	D	E	F		
Scale		Width of Photo	Area Covered by Single Photo	Distance Gain Per Exposure, Single Line	Distance Gain Per Flight Line	Area Gain Per Exposure	Net Model Gain Per Exposure	Largest Map Scale	Minimum Contour Interval
1:600	1"=50'	450' .09 mi	4.6 ac .01 mi <sup>2</sup>	190' .03 mi	315' .06 mi	1.6 ac .003 mi <sup>2</sup>	1.2 ac .002 mi <sup>2</sup>	1"=7'	.18'
1:1200	1"=100'	900 .17	18.5 .03	380 .07	630 .12	6.5 .01	5 .008	1"=13'	.35'
1:2400	1"=200'	1800 .34	74 .12	760 .47	1260 .24	27 .04	20 .03	1"=26'	.7'
1:3600	1"=300'	2700 .51	167 .26	1080 .20	1890 .36	58 .09	46 .07	1"=40'	1'
1:4800	1"=400'	3600 .68	297 .46	1440 .27	2520 .47	106 .16	83 .12	1"=53'	1.3'
1:6000	1"=500'	4500 .85	465 .73	1880 .34	3150 .60	164 .26	130 .20	1"=67'	1.7'
1:7200	1"=600'	5400 1.02	699 1.05	2160 .41	3870 .72	238 .37	187 .29	1"=80'	2'
1:10,000	1"=883'	7497 1.42	1290 2.02	2990 .57	5248 .99	460 .72	361 .56	1"=110'	2.8'
1:12,000	1"=1000'	9000 1.70	1860 2.91	3600 .68	6300 1.19	659 1.03	520 .81	1"=133'	3.1'
1:24,000	1"=2000'	18,000 3.41	7438 11.62	7200 1.36	12,600 2.39	2637 4.12	2082 3.25	1"=267'	6'
1:36,000	1"=3000'	27,000 5.11	16,735 26.15	10,800 2.05	18,900 3.58	2909 4.55	4685 7.32	1"=400'	10'

Notes: 1) All distance, area and gain for 9" by 9" aerial photographs 60% endlap and 30% side lap.  
 2) Map scale and contour interval figures are for plotting equipment with 7.5% scale of restitution.  
 3) See Figure 33 for definitions of A-F.

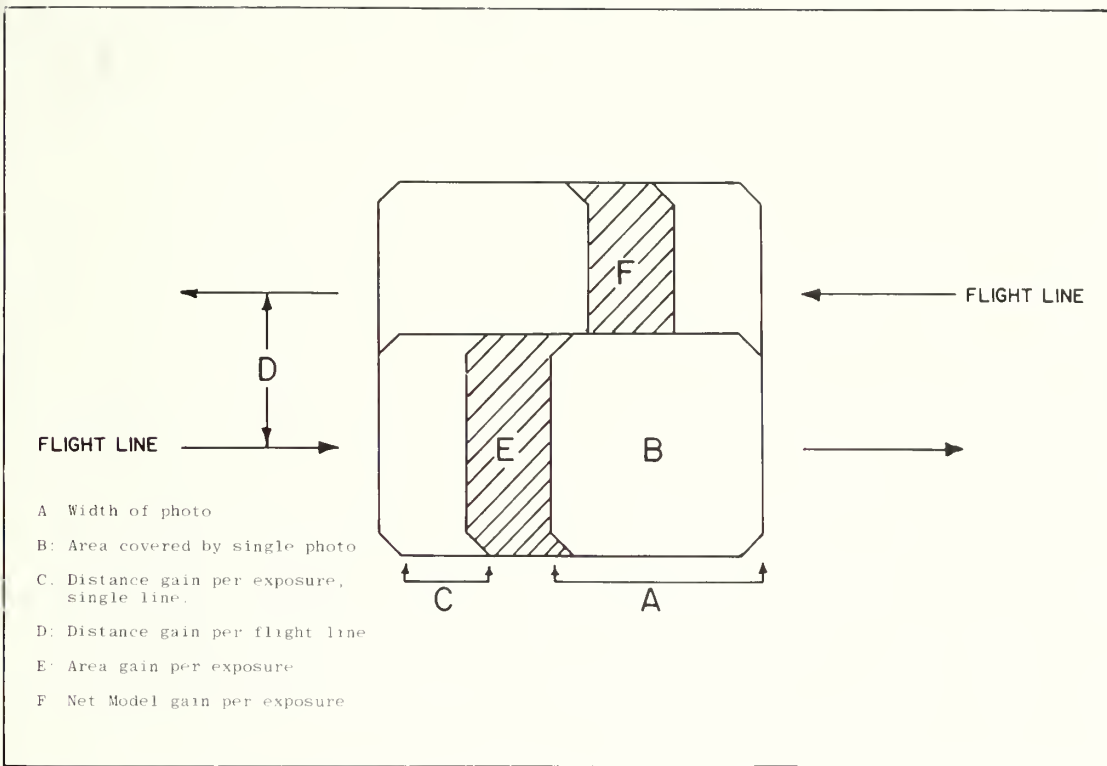
reduces cost as well as the number of stereomodels that must be handled by interpreters and photogrammetrists. For example, doubling photographic scale results in four times as many exposures necessary to cover a given area and four times the plotter time necessary for map compilation. Table 9 lists area coverage for a single negative at different scales. At a scale of 1:4800, a single negative covers 0.7 km<sup>2</sup> while at a scale of 1:2400, only 0.2 km<sup>2</sup> are covered. When obtaining stereophotography, the Net Model Gain per Exposure (F on chart) is of concern (fig. 33). This is the ground area covered on the overlapping portion of a stereopair between adjacent principal points on the photographs and extending sideways in both directions to the middle of the side lap (see Wolf 1974; fig. 10-8). This represents the approximate mapping area of each stereopair (Wolf 1974).

The two major factors, then, which affect overall project costs are photographic scale and the tract or project size. When planning a photographic mission, it is important for the manager to understand the relationship between final map scale and contour interval as they determine photographic scale and costs. It may be that project requirements will be met within a certain range of map scales, in which case the smallest required map scale and corresponding photo scale can be chosen.

## Interpretive Displays

Many options are available to the manager who uses remote sensor products for the development of





**Figure 33** Distance, area and gain quantities for 9 in by 9 in aerial photographs. (Letter designations refer to Table 9.)

interpretive displays of cultural resources. The pictorial qualities of photography for illustrating detailed and complicated scenes are widely recognized. The form of the photography varies greatly, however, and can be tailored to suit particular resource characteristics. Several of the more common photographic products suitable for use in interpretive displays include photomosaics, stereoscopic models, photoenlargements, and sequential photography or photography taken at intervals over a period of time. Use of satellite imagery for an understanding of the regional environmental setting of the resources is another relatively inexpensive method for putting together a display. Production of enhanced photography utilizing closed-circuit video devices constitutes a more sophisticated approach to the development of interpretive displays. The manager should be aware of certain specifications for photography used in any display and of the limitations of each photographic product; these are discussed below.

**Photomosaics.** Photomosaics are assemblages of two or more individual overlapping photographs

forming a single continuous picture of an area (Wolf 1974). Mosaic assembly requires the cutting and piecing together of parts of photographs ensuring that common images coincide as closely as possible at match lines between adjacent photos. The most common type of photography used for mosaic construction is vertical aerial imagery, although oblique and terrestrial photography may also be used. Photomosaics have several advantages over maps: an infinite number of objects are shown in their relative planimetric positions; objects are easily recognized by their pictorial qualities without the need for symbols or maps keys; mosaics are less expensive to prepare; and they can be easily understood and interpreted by analysts without photogrammetry or engineering backgrounds (Avery 1977; Wolf 1974).

Although the scale of a mosaic is never constant throughout due to the effects of tilt, flying height variation, and topographic relief, the quality of an uncontrolled mosaic is quite satisfactory for display purposes. An uncontrolled mosaic is prepared by matching the image details of adjacent photos. Vertical photographs which have not undergone

rectification procedures are used, and no ground control is needed. Wolf (1974) suggests the following materials for preparing mosaics:

- a. Photographs should be taken with a minimum of 60 percent end lap and 30 percent side lap. This enables use of only the central portion of each photo, reducing distortion due to relief and tilt. The percentages may be reduced in flat terrain and increased for a rugged area.
- b. The photographs should be printed on single-weight paper and care should be taken in developing and printing to obtain uniform tones on all photos.
- c. Reproduction of mosaics can be accomplished by photographing the original mosaic to obtain a negative from which prints can be made. The Ozalid process is commonly used to make prints from half-tone positives that have been prepared from the original negatives.

Alternatives to the simple uncontrolled photo-mosaic are the controlled and semicontrolled mosaics. A controlled mosaic is prepared from vertical photographs which have undergone rectification and ratio procedures. The mosaic is then constructed by matching control points which have been marked on the mounting board with ground control points on the images. Although it is the most accurate type of mosaic, scale is not constant throughout the mosaic due primarily to relief displacement (Wolf 1974). The semicontrolled mosaic is constructed using either ground control or ratioed and rectified photographs, but not both.

Orthophotomosaics offer another alternative. Orthophotos are made from vertical aerial photographs using a differential rectification instrument similar to a photogrammetric plotter but which produces a planimetric photograph instead of a map. Orthophotos are considerably more expensive to produce than uncontrolled photos. The photographic image produced, however, has had relief and tilt displacements removed so that features are shown in their true planimetric positions. All distances, angles, and areas can be measured directly from orthophotos just as from maps. With elevation contours superimposed on the image, they are termed orthophotomaps. Orthophotomosaics combine the pictorial qualities of aerial mosaics and the geometric correctness of maps.

**Stereomodel Display.** Although photointerpretation for specific cultural features or production of

photogrammetric maps may be the primary goal for obtaining vertical aerial coverage, individual pairs of stereophotographs covering portions of a study area may be used to provide a stereoscopic display for a single archeological site or small area of interest. Viewing photographs stereoscopically provides the important dimension of depth perception which may be needed for the recognition of specific features. Equipment and materials essential to stereoscopic viewing include a stereoscope, an illuminating table or fluorescent desk lamp, and photographic prints which will overlap about 60 percent of their width in the line of flight and 20 to 30 percent between flight strips for comprehensive coverage. Because of its low cost and portability, the lens or pocket stereoscope is a good instrument for use in a stereomodel display. It consists of two simple convex magnifying lenses mounted on a frame; the spacing between the lenses can be altered to accommodate various eye bases, and the legs fold or can be removed so that the instrument is easily stored or carried. Since the legs of the pocket stereoscope are slightly shorter than the focal length of the lenses, light rays emanating from the point on the photos over which the stereoscope is placed converge slightly as they pass through each lens forming a stereomodel (Avery 1977).

Avery (1977) reviews the rules for proper use of the stereoscope:

- a. Make certain that the photographs are properly aligned at all times, preferably with shadows falling toward the viewer. In using the pocket stereoscope, the photos are placed so that corresponding images are slightly closer than the eye bases which are usually 5.1 cm apart. The common overlap area of 22.8 cm<sup>2</sup> format photos taken with 60 percent end lap is a rectangular area 13.7 cm wide (Avery 1977: fig. 10F). When photos are in position for stereoviewing with a pocket stereoscope, a rectangular area may result in which the top photo obscures the bottom photo, preventing stereoviewing. In aligning the prints, one print of a stereoscopic pair is selected and placed so that the conjugate principal point of the photo is about 5.5 cm from the corresponding principal point of the other photograph. (See Lyons and Avery 1977 for definitions of these terms.)
- b. The stereoscope is placed with its long axis parallel to the flight line and with the lenses over corresponding photo images. In this way, an overlapping strip 5.5 cm wide and

23 cm long can be viewed when the stereoscope is moved up and down the overlap area.

- c. Maintain an even, glare-free illumination on the prints or transparencies and arrange a comfortable viewing position.
- d. Keep stereoscope lenses clean, properly focused (not necessary with the pocket stereoscope), and separated to the correct interpupillary distance. For most individuals, interpupillary distance is about 62 to 64 mm.
- e. Proper care of aerial photographs is important. The emulsion surface should be protected from exposure to direct sunlight or excessive moisture. Marking on prints should be avoided when they are damp. Photographs may be cleaned with carbon tetrachloride or a damp sponge. Prints subjected to heat, even that produced by a desk lamp, have a natural tendency to curl. For display purposes, transparent acetate or a similar sheet material should be used to protect and secure the stereomodel.

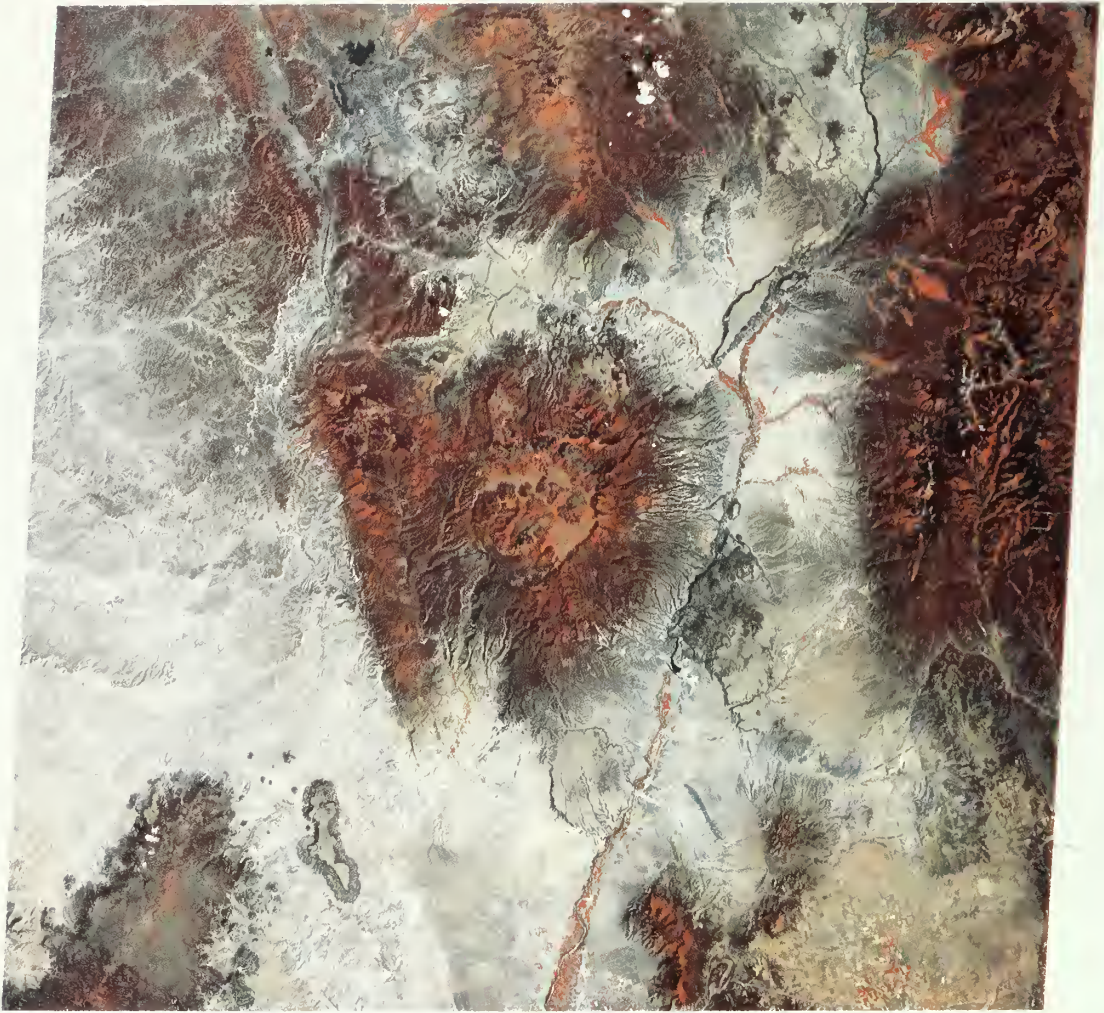
**Photoenlargements.** A photoenlargement can create not only an attractive and interesting display, but can also serve to illustrate detail in architectural or other cultural features not easily discerned on smaller scale photography. The degree of acceptable enlargement is dependent on a number of factors including the size, shape, and tone of the cultural properties of the landscape to be illustrated, and the resolution qualities of the original photograph. Extremely high quality photographs as provided by most modern aerial photography are needed. Because of the properties of the camera lenses used in taking aerial photography prior to the 1950's, aerial photography from this period may not be characterized by the high resolution qualities needed for production of enlargements.

Enlargements are produced directly from the photo negative and not from paper prints. Photoenlargements can be produced by the U.S. Geological Survey or photogrammetric firms from negatives in their files. Although enlargements may provide the necessary pictorial detail for a public display, they are not necessary for analytical purposes. Instrumentation used in photointerpretation usually requires the smaller 9 in by 9 in (22.8 cm × 22.8 cm) photo format which is also easier to handle and store than are photoenlargements.

**Sequential Photography.** An informative display of both analytical procedures and a progression of events might benefit from the use of sequential photography. Sequential imagery can be provided either by a series of overflights to obtain conventional aerial photography or by photography obtained with the use of ground-based camera platforms such as bipods, tripods, or captive balloons. Documentation of both excavation and restoration of relatively small areas or archeological sites might benefit from the use of ground-based tripod or bipod platforms discussed in Section 3. Larger sites may require the use of a tethered balloon support system or low altitude vertical or oblique aerial photography. Documentation of a series of changes in the local environment of an area containing cultural materials can also be accomplished with vertical aerial photography. Changes in vegetation cover, drainage pattern, erosion rates, land use or even the effects of water pollution can be documented over a period of time with aerial imagery; such imagery may already exist which provides photo coverage spanning several decades. Federal mapping agencies such as the Agricultural Stabilization and Conservation Service, the Forest Service, and the Geological Survey may have coverage of an area in black-and-white film at scales ranging from 1:12,000 to 1:40,000. Agricultural soil surveys prepared by the US Department of Agriculture have utilized aerial photography since the 1930's. Panchromatic aerial photographs at scales ranging from 1:15,840 to 1:40,000 have been used as mapping bases. The Geological Survey mapping imagery flown in much of the Southwest in the 1950's and 1960's provides black-and-white coverage at scales of 1:20,000 to 1:35,000.

**Satellite Imagery.** Multispectral scanner imagery taken of the earth from satellites can provide a broad regional perspective of the environment. The primary sensor system aboard Landsat, the multispectral scanner (MSS), acquires images 185 km on a side in four spectral bands in the visible and near-infrared portions of the electromagnetic spectrum. Ground resolution is 90 m (Avery 1977), i.e., an object 90 m in diameter or larger is discernible on the imagery; however, linear features in high contrast to the background landscape may be identified even if they are only 10 to 15 m wide. Landsat images can be produced from information contained in a single band in black-and-white or as false-color composites.

Appropriate bands or combinations of bands are usually selected for specific interpretive use. The interpretive potential of each color band includes the following (USGS 1978):



036-035

**Figure 34** Landsat image of middle Rio Grande Valley, New Mexico.

- a. Band 4 (green) emphasizes movement of sediment-laden water, delineates areas of shallow water, such as shoals, reefs, etc.
- b. Band 5 (red) emphasizes cultural features such as cities, buildings roads, and areas disturbed by construction, as well as bare ground versus vegetated areas.
- c. Band 6 (near-infrared) emphasizes vegetation, the boundary between land and water, and landforms.
- d. Band 7 (second near-infrared) provides the best penetration of atmospheric haze and also emphasizes vegetation, the boundary between land and water, and landforms.

The repetitive and seasonal coverage of Landsat imagery can contribute to a display of regional environmental characteristics as well as interpretation of natural and cultural dynamic phenomena. The largest single use of Landsat data, geologic studies, utilizes Bands 6 and 7. When ordering a single band of black-and-white imagery for a general purpose view of the earth's surface, Band 5 is best. The MSS false-color composite image is produced by exposing three of the four black-and-white bands through different color filters onto color film. On the composite image, healthy vegetation appears bright red, rather than green; clear water appears black; sediment-laden water is powder blue; and urban centers often appear blue or blue gray (fig. 34). The false-color composite image at larger scales provides an excellent format within which to present information concerning the regional distribution and environmental context of archeological resources.

A complete set of Landsat images is available for the Southwest, as it is for most of the world's land masses. Scenes of the Southwest are available as single black-and-white bands and high quality false-color composites. Since the launching of Landsat-2 in January, 1975, data can potentially be collected for each scene every nine days. When ordering a Landsat scene on a geographic computer search form (fig. 35), it is possible to specify minimum quality rating, maximum cloud cover acceptable, and preferred time of year for all available coverage or that of a specific date. Enhanced color composite images have been produced for scenes chosen on the basis of the quality of the image produced, the time of year (usually spring or summer), and minimum cloud cover.

Scenes are available at scales of 1:1,000,000, 1:500,000, and 1:250,000. In addition, enlarged portions of a single scene can be produced at scales of up to about 1:60,000 by special order with the EROS Data Center. The images produced are parallelograms because the image is created by an optical mechanical scanner, the movement of which is affected by both the orbital track of the satellite and the earth's rotation.

The annotations on the image border identify the image, the geographic location of each scene, and the time the data were obtained (fig. 34). Longitude and latitude tick marks annotated in degrees and minutes provide additional geographic referents along the outside edge of the image. A 15-step gray scale tablet is present on every frame. The scale is used to monitor and control printing and processing functions and to provide a reference for analysis related to a particular image.

**Closed Circuit Video Systems.** Several closed circuit video systems allow the simplification of analog imaged data. These systems possess a variety of capabilities for image enhancement and data isolation in a number of ways. Enhanced or otherwise manipulated data from an original image may be displayed on screens to isolate cultural or natural features for interpretation and to produce informative displays. The Digicol System manufactured by International Imaging Systems is one such closed circuit video device. Photographs, in print or transparency form, are mounted on an illuminated light table and a camera with a separate-mesh vidicon tube is positioned above the light table and the image. The camera produces a signal which can be translated into a visible image by the video system.

Subsystems of the device process the image input signal and supply a video output which appears on a 19-inch display screen (fig. 36). The video output presents a simplified version of the input signal and allows the interpreter to go beyond visual inspection of a photograph. While not having access to any information not already inherent in the image, the interpreter can isolate features of specific density and more fully understand the complex patterning in the analog photo by viewing these outputs. Processor subsystems of the video device can be used in the following ways (Ebert 1979b):

1. Enlargement of an image or parts of an image may be done by coupling the camera/lens with the black and white monitor through the Digicol Image Processor (DIP). This allows inspection of a small portion of a large image (fig. 37a).
2. Edge enhancement emphasizes places of maximum image contrast differences along the X-axis of the image; the orientation of this axis can be shifted by image rotation on the light table. This capability is particularly useful in the recognition of patterns in the images or the discrimination of very faint linear features (fig. 37b).
3. Three-dimensional viewing of the "density topography" inherent in an image also aids in pattern identification. The rotational viewing controls let the interpreter inspect the isometric projection of the video signal from a wide range of angles; linear features or lines of points often appear suddenly as the display angle is rotated so that the "line of sight" approaches the orientation of the features (fig. 37c).



# INQUIRY FORM

## GEOGRAPHIC COMPUTER SEARCH

U.S. DEPARTMENT OF THE INTERIOR  
GEOLOGICAL SURVEY



**RETURN COMPLETED FORM TO:**  
 U.S. Geological Survey  
 EROS Data Center  
 Sioux Falls S.D. 57198  
 FTS: 784-7151  
 Comm: 605/594-6151  
 TWX: 910-668-0310

For additional information or assistance please contact one of the following offices of the National Cartographic Information Center (NCIC).

U.S. Geological Survey  
 National Cartographic Information Center  
 507 National Center  
 Reston, VA 22092  
 FTS: 928-6045  
 Comm: 703/860-6045

U.S. Geological Survey  
 Eastern Mapping Center  
 National Cartographic Information Center  
 536 National Center  
 Reston VA 22092  
 FTS 928-6336  
 Comm 703/860-6336

U.S. Geological Survey  
 Mid-Continent Mapping Center  
 National Cartographic Information Center  
 1400 Independence Road  
 Rolla, MO 65401  
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 Menlo Park, CA 94025  
 FTS 467-2426  
 Comm: 415/323 8111

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 National Cartographic Information Center  
 National Space Technology Laboratories  
 NSTL Station, MS 39529  
 FTS 494-3541  
 Comm 601/688-3544

PLEASE CONTACT THE NEAREST NCIC OFFICE FOR INFORMATION CONCERNING THE AVAILABILITY OF CARTOGRAPHIC PRODUCTS OTHER THAN IMAGERY

DATE \_\_\_\_\_

NAME <sup>MR</sup> \_\_\_\_\_ <sup>MS</sup> \_\_\_\_\_ COMPUTER ACCOUNT NO. \_\_\_\_\_  
(FIRST) (INITIAL) (LAST) (IF KNOWN)

COMPANY \_\_\_\_\_ PHONE (Bus.) \_\_\_\_\_  
(IF BUSINESS ASSOCIATED)

ADDRESS \_\_\_\_\_ PHONE (Home) \_\_\_\_\_

CITY \_\_\_\_\_ STATE \_\_\_\_\_ ZIP \_\_\_\_\_ YOUR REF NO. \_\_\_\_\_  
(P.O. GOV'T ACCT OR OTHER)

TO INITIATE AN INQUIRY AND COMPUTER GEOSARCH COMPLETE THE FOLLOWING



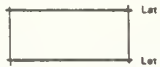
POINT NO 1	POINT NO 2	POINT NO 3
Latitude _____ N or S	Latitude _____ N or S	Latitude _____ N or S
Longitude _____ E or W	Longitude _____ E or W	Longitude _____ E or W

Imagery with any coverage over the selected point will be included.

Landsat Only (Worldwide Reference System)

Path	Path	Path	Path	Path
_____	_____	_____	_____	_____
Row _____	Row _____	Row _____	Row _____	Row _____

AREA RECTANGLE



Imagery with any coverage over the selected area will be included.

AREA NO 1	AREA NO 2	AREA NO 3
Lat _____ N or S to _____ N or S	Lat _____ N or S to _____ N or S	Lat _____ N or S to _____ N or S
Lat _____ N or S	Lat _____ N or S	Lat _____ N or S
Long _____ E or W to _____ E or W	Long _____ E or W to _____ E or W	Long _____ E or W to _____ E or W
Long _____ E or W	Long _____ E or W	Long _____ E or W

If the above geographic coordinates cannot be supplied, please specify area by GEOGRAPHIC NAME AND LOCATION (include a map if possible)

PREFERRED TYPE OF COVERAGE

	Black & White	Color or Color Infrared
<input type="checkbox"/> Landsat	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/> Skyview	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/> NASA Aircraft	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/> Aerial Mapping	<input type="checkbox"/>	<input type="checkbox"/>

PREFERRED TIME OF THE YEAR

Check maximum of three

JAN-MAR <input type="checkbox"/>	<input type="checkbox"/> ALL COVERAGE
APR-JUNE <input type="checkbox"/>	<input type="checkbox"/> LATEST COVERAGE
JULY-SEPT <input type="checkbox"/>	<input type="checkbox"/> SPECIFIC DATES _____
OCT-OCT <input type="checkbox"/>	

NOTE Seasonal coverage normally applies only to Landsat coverage

MINIMUM QUALITY RATING ACCEPTABLE

<input type="checkbox"/> 0-2	<input type="checkbox"/> 3-4	<input type="checkbox"/> 5-6	<input type="checkbox"/> 7-9
<small>(VERY POOR)</small>	<small>(POOR)</small>	<small>(FAIR)</small>	<small>(GOOD)</small>

MAXIMUM CLOUD COVER ACCEPTABLE

10%  
  30%  
  50%  
  70%  
  90%

NOTE Classification of percent of cloud cover is subjective and is relative to the amount of clouds appearing on the imagery and not on their location

APPLICATION AND INTENDED USE \_\_\_\_\_

FORM 9-1936  
(April 1978)  
Revised April 1981

Figure 35 Geographic computer search form, USGS.



**Figure 36** Closed-circuit image enhancement system.

4. A color monitor can portray one or more of 32 colors assigned to a density level or range within an image being analyzed. Video outputs consist of a false-color density sliced picture on a color monitor. Each of the selected density levels is represented on the monitor by a different color, producing a colored density contour "map" of the image (fig. 37d). The subsystem can also display a density-contoured monochrome (black-and-white) image or a full analog monochrome display of the input signal, allowing contrast enhancement of the image.
5. Monochrome enhancements using the DIP subsystem and the black and white monitor can be produced. Faint contrast differences in an image can be enhanced in the

analog mode in a manner similar to increasing the contrast on a television set.

A photographic record of the video output can be taken to allow inspection of simplified processed images without the necessity of powering the systems and can be used to produce photographic displays. Color slides or black and white prints of the screens can be made using a standard 35 mm SLR (side-looking radar) camera equipped with a 50 mm lens. By bracketing the exposure one-half to one f-stop to each side of the meter indication, a series of photos can be taken at different exposure settings to ensure successful results. Photographs can then be developed in any one of several format sizes. Photographs made in this way have considerable appeal to the public, and can serve to emphasize special features inherent in the cultural resource being interpreted.

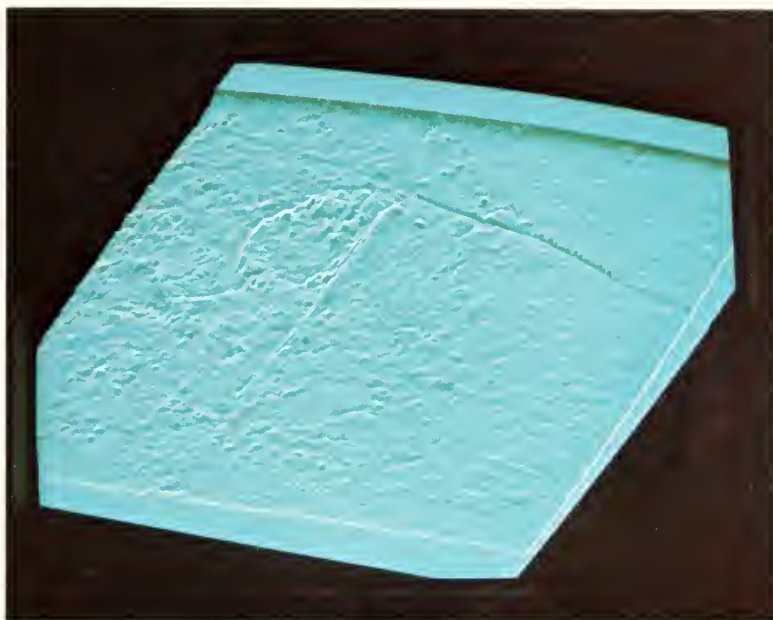


Figure 37a Black and white enlargement.

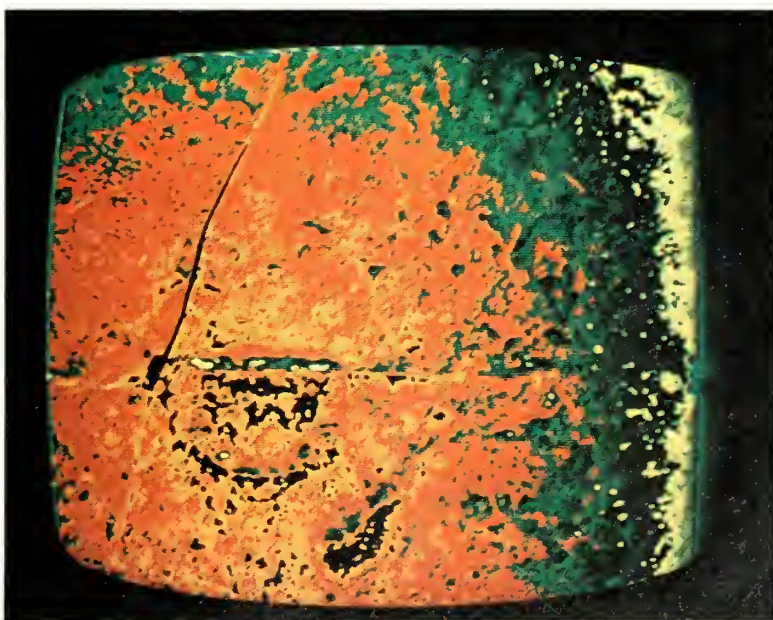


Figure 37b Edge enhancement.





**Figure 37c** Three-dimensional view.



**Figure 37d** Color density contour map.

## Section 5

### Summary

This supplement has addressed the Southwest as a physiographic region and has described and discussed the various remote sensing techniques applied to the prehistoric remains of the area. Although a number of individual remote sensing applications have been discussed, it can be seen that remote sensing methodologies, as a whole, bring accurate and precise recording capabilities, as well as technologically innovative means for the investigation of prehistoric remains, to archeological methodology. Accurate documentation of both the location of archeological sites and the character of the remains can be accomplished with the use of remote sensor products. Documentation of archeological manifestations can also take the form of interpretation of remote sensor products. Investigations of the environmental context of prehistoric occupations, including the vegetative and geological character of a locality and production of environmental diversity measures with digitized remote sensor data, constitute a new avenue of research for archeological methodology.

The *Southwest Supplement* is one of a number in a series of supplemental monographs to *Remote Sensing: A Handbook for Archeologists and Cultural Resource Managers* (Lyons and Avery 1977). The reader is referred to the handbook and the supplement series for additional literature concerning technical aspects of remote sensing methodologies and other regional applications of remote sensing to archeological problem solving and to cultural resources management. The handbook is a source of basic knowledge concerning remote sensing methodologies and applications. Supplement Number 1 (Avery and Lyons 1978) is an instructional manual. Supplement Number 2 (Morain and Budge 1978) reviews remote sensing instrumentation systems, their uses, and the applications of the techniques to archeological problems. A valuable source of reference material is provided by Supplement Number 3 (Lyons et al. 1980), which consists of a bibliography of studies in which remote sensing has

been used to investigate archeological manifestations around the world. Supplement Number 4 (Aikens et al. 1980) is a regional application of remote sensing techniques in Oregon. Supplement Number 5 (Morain et al. 1981) is divided into two sections. The first reports on the collection and analysis of multispectral data on five Anasazi pueblos in Chaco Canyon, New Mexico; and the second section discusses the application of multispectral analysis to known archeological sites in Bandelier National Monument, New Mexico. Supplement Number 6 (Baker and Gumerman 1981) is a report on the archeological application of remote sensing techniques in the North Central Lowlands (Minnesota, Wisconsin, Michigan, Iowa, Illinois, Indiana, Ohio, and Missouri). Supplement Number 7 (Avery and Lyons 1981) is a discussion of the applications of both aerial and terrestrial photography to archeological research.

In addition to the supplement series, reports published by the National Park Service Cultural Resources Management Division and the University of New Mexico present the results of particular remote sensing applications to archeology. *Remote Sensing Experiments in Cultural Resource Studies* (Lyons 1977) includes reports prepared by staff members and individuals collaborating with the Chaco Center, a joint National Park Service and University of New Mexico research facility. *Aerial Remote Sensing Techniques in Archeology* (Lyons and Hitchcock 1977) presents the results of contributions to a Society for American Archeology symposium on remote sensing in archeology held in 1972. *Cultural Resources Remote Sensing* (Lyons and Mathien 1980) contains reports describing the methods by which particular remote sensing techniques, including terrestrial photogrammetry and bipod photography, can be implemented. The reader is referred to these publications for additional information and more detailed explanations of certain remote sensing methods.

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







