SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 121, NUMBER 1

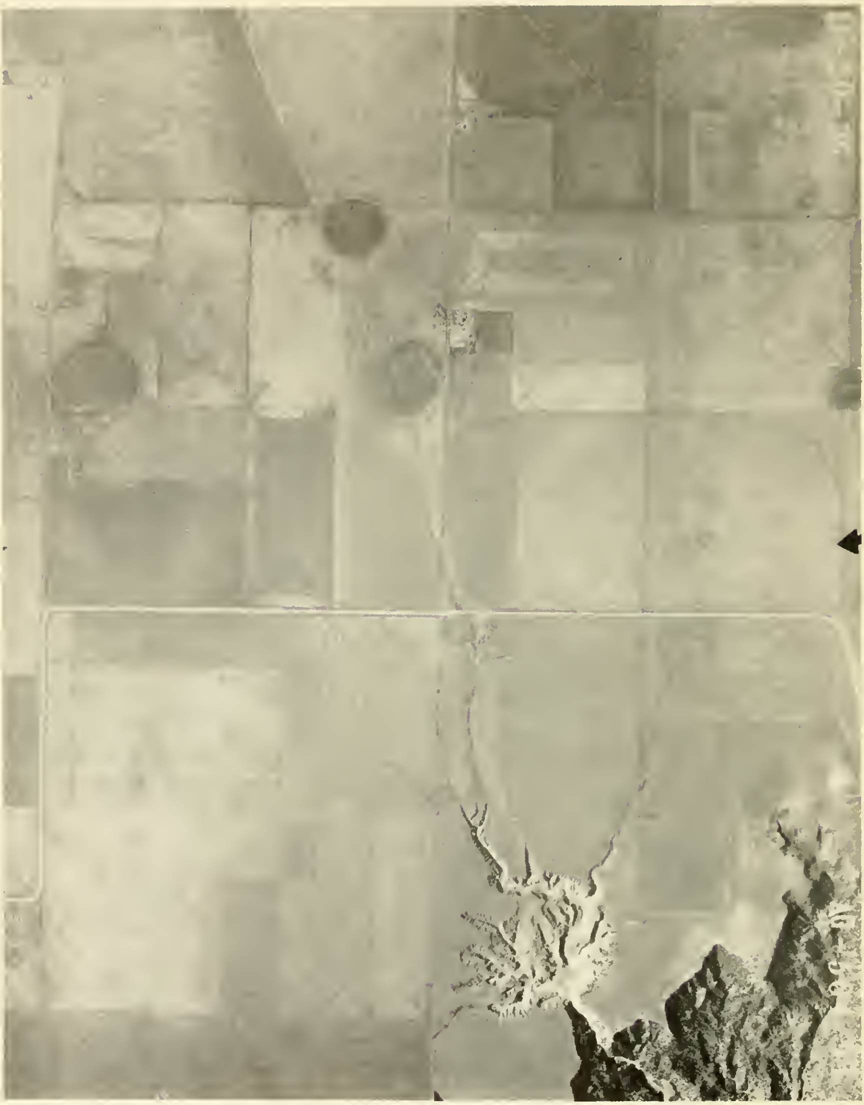
GEOLOGY OF THE SAN JON SITE, EASTERN NEW MEXICO

(With 5 Plates)

BY
SHELDON JUDSON
University of Wisconsin

(Publication 4098)

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION
MARCH 5, 1953



Aerial Photograph of the San Jon Site. North to Right.

(Soil Conservation Service photograph.)

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INTRODUCTION

GENERAL STATEMENT

The study of early man in North America has made rapid strides since an unquestioned association between man and extinct animals was discovered near the small town of Folsom, N. Mex., a generation ago (Figgins, 1927; Cook, 1927). Much remains to be learned, however. There is still a wide gap, both in time and degree of cultural attainment, between the hunting Sandia-Folsom men and their contemporaries, with their finely chipped implements, and the much later pottery-making Pueblo Indians. This gap, first emphasized by Roberts (1940), begins to close as new finds come to light (Kelley, Campbell, and Lehmer, 1940; Sayles and Antevs, 1941; Bryan and Toulouse, 1943; Bryan and McCann, 1943; Haury, 1943). Unfortunately these finds are widely scattered and usually consist of a few stone implements which tell little as to the cultural attainments of the men who made them. Furthermore, these discoveries were made in soft, unconsolidated deposits whose dating by the geologic method is still incomplete. Consequently, the intermediate cultures have a status nebulous archeologically and vague chronologically.

The San Jon site seemed to present a reliable guidepost along this otherwise poorly marked road. Preliminary reconnaissance produced stone artifacts, obviously not a part of any late pottery-making culture. These were associated with the bones of bison in stratified beds lying at the headwaters of streams having obviously terraced valleys. Furthermore, the geographic location of the site held great promise, situated as it is between the relatively well-known areas bordering the southern Rocky Mountains in Colorado and New Mexico, and the great areas of still unexplained but reputedly ancient stone cultures of central and western Texas.

The geology of the site is so singular as to quicken the interest of the most hardened investigator. Nature has apparently gone out of her way to produce a fascinating and, at first glance, indecipherable puzzle. The site is located within a small depression in the Southern High Plains. This depression has been breached, drained, and dissected to depths of 100 feet, producing a geologist's delight, a soil conservationist's nightmare. In the exposed, stratified deposits lay the bones and artifacts which drew the archeologist to the site. At first glance, magnificently exposed and varied deposits augured well for the geologist. They held hope of representing a sequence of events which would add to our present highly inadequate knowledge of the late Pleistocene [1] history of the Southern High Plains. The incompleteness of that knowledge on the one hand and the great distance of the site from the glaciated areas of the southern Rocky Mountains on the other discounted the possibility of a direct tie to the glacial chronology. Nevertheless, the presence of beds clearly deposited under conditions more moist than now exist suggested a tentative correlation with the climatic fluctuations of late Pleistocene time.

The hopes engendered by the preliminary reconnaissance have been only imperfectly realized. Archeological investigation by the Smithsonian Institution was confined to the summer of 1941. From this preliminary and necessarily incomplete investigation Roberts (1942) obtained a sequence of faunas, some of them extinct, and associated cultures. Unfortunately, these cultures are represented by too few artifacts to be too helpful in an exact dating.

The geological work, originally planned to extend through at least three field seasons, was interrupted by World War II and subsequently reduced in scope. The results, although they do not completely fulfill the initial hopes, are by no means inconsiderable. Conclusions have been reached on the following problems: (1) The character, order, and origin of the beds at the site; (2) the correlation of this sequence along the northern edge of the Southern High Plains; (3) the origin of the "depression of the High Plains" in this locality; (4) the nature and origin of the so-called "cap rock" of the High Plains in this general vicinity; (5) the correlation of the sedimentary sequence at the site and nearby points on the High Plains with successive

[1] Throughout this report the term "Pleistocene" is used in the sense suggested by Flint (1947, p. 209). In such a sense it includes all time that has elapsed since the end of the Pliocene. The terms "Recent" and "Postglacial" are abandoned as exact time designations and when used have only a local or informal connotation.

periods of erosion and alluviation in local streams of the Canadian Valley; (6) the relation of the sequence so established to climatic changes in the Southwest during late Pleistocene time; and (7) the relative and in some cases exact ages of the several cultural horizons within the sequence.

HISTORY OF INVESTIGATION

Keith Martin, a local ranchman, first discovered the site and reported his find to the Laboratory of Anthropology at Santa Fe and to the Department of Anthropology at the University of New Mexico. Dr. Frank C. Hibben, of the University of New Mexico, with the assistance of several University students, conducted a preliminary survey of the site in the spring of 1940. Animal bones and some artifacts were found. It was soon apparent, however, that the thorough investigation demanded by the site could not be reconciled with previous and extensive archeologic commitments elsewhere assumed by the University. Therefore, after a visit to the site in August 1940 by Dr. Frank H. H. Roberts, Jr., in the company of Dr. Hibben, the University of New Mexico offered to turn over its interest in the site to the Smithsonian. The offer was accepted, and Roberts directed an archeologic investigation of the site and immediate vicinity from June 20 to September 6, 1941. Archeologic work was stopped by the war. Unfortunately, Dr. Roberts was unable to resume the investigation after the cessation of hostilities because of the additional administrative burdens imposed upon him as Director of the River Basin Surveys conducted under the administration of the Smithsonian Institution in cooperation with the National Park Service, the Corps of Engineers, and the Bureau of Reclamation.

The late Dr. Kirk Bryan, Harvard University, accompanied Hibben and Roberts on their visit to the site in 1940. During the following winter, after it had been decided to conduct extensive archeologic investigations at San Jon, arrangements were made to provide for a concurrent geologic study. Dr. Bryan and the writer made a general reconnaissance of the area during the period July 6 to 16, 1941. The writer remained on the ground until September 6, carrying forward the detailed geologic investigation. Although the war interrupted the continuance of the geologic field work, the results obtained during 1941 were checked in the field by Dr. Bryan, Dr. Franklin T. McCann, and the writer in the period from August 27 to September 11, 1943. The writer returned to the problem after the war, spending the period from June 30 to September 1, 1947, in the completion of field work.

Dr. Bryan again conferred in the field with the writer from August 10 to 15, 1947.

ACKNOWLEDGMENTS

The writer is under obligation to the officials of the Smithsonian Institution who authorized the project and provided funds for the field studies of 1941 and 1947. Dr. Roberts, by his continued interest and support, has been a predominating influence in this and earlier investigations of the geology of early man. The writer is particularly indebted to him for the care and skill with which he discriminated between the several geologic horizons exposed in the San Jon excavations, for his advice on problems of correlation, and for his personal interest in the progress of the geologic study. In 1941 the hospitality of the archeological camp offered optimum conditions for work. The members of the archeological party and Mrs. Roberts contributed much in making the camp a home for the geologist.

Bryan and the writer were accompanied on the brief and hurried field trip of 1942 by Dr. Franklin T. McCann. Herbert W. Dick, of the Colorado Museum of Natural History and a member of the 1941 archeological party, spent a week on needed archeologic investigation during the 1947 season and devoted considerable time and effort in the office processing the material excavated.

Many local residents contributed to the geologic work and without their aid the field problems would have been many times multiplied. Particular thanks are due to Wayne H. Miles, of the Canadian River Soil Conservation District, Tucumcari; H. W. Mutch, formerly resident engineer of the Arch Hurley Conservancy District; Halbert N. Knapp, former chief, and D. H. McLeod, of the Southwest Quay County Soil Conservation District; and Royal A. Prentice, Tucumcari. The writer expresses thanks for information and courtesies received from M. Tom Horne, Clovis, formerly postmaster at San Jon; Mr. and Mrs. James Wilson, San Jon; Mrs. Helen Anderson, San Jon; Mr. and Mrs. Frank Wilson, Wheatland; Guy Fife, Tucumcari; D. R. Burnham, U. S. Experiment Station, Tucumcari; Mr. and Mrs. Luis C. de Baca, Newkirk; Foley Griggs, Norton; and to the many other New Mexicans who added to the success and enjoyment of the field work.

The writer's wife, Anne Perrin Judson, served as field assistant during the 1947 field season and provided technical and editorial assistance in the preparation of this report.

The late Prof. Kirk Bryan, Department of Geology, Harvard University, supervised this study in field and office from its formal

inception in 1941. His many kindnesses, both professional and personal, cannot be recounted.

PHYSICAL SETTING OF THE SAN JON SITE

LOCATION OF THE SITE

The San Jon site is located approximately 10 miles south of the town of San Jon,[2] N. Mex., from which it takes its name (see fig. 1). The town is a local trading center of slightly over 400 inhabitants. It lies on the Chicago, Rock Island & Pacific Railway and U. S. Highway 66. A paved road, State Highway 39, leads south from the town 44 miles to Clovis, N. Mex., and passes within three-quarters of a mile of the site.

The town of San Jon lies at an elevation of 4,025 feet on a gently rolling plain carved by the Canadian River and its tributaries. The plain is part of a broad valley separating two great tablelands, the Central High Plains to the north and the Southern High Plains, or Llano Estacado, to the south. The town is situated in the small valley of the San Juan[3] Arroyo,[4] which flows east toward the town of Endee[5] before turning northeast and eventually entering the Canadian River across the State boundary in Texas. A broad ridge, 200 to 300 feet high, intervenes between the San Juan Valley and

[2] The word *sanjon* is an old Spanish spelling of *zanjon,* a ditch. According to local tradition there was once a pool of water in the adjacent grassy flat. Such pools were usually called *charcos* by the Spanish, but one of long and narrow form might easily be termed a ditch. Round-ups of the early cattle days centered around the now-vanished *zanjon,* which gave the modern town its name. The present spelling is an obvious error.

[3] The name "San Juan" for this arroyo appears on Soil Conservation Service maps and is doubtless a still further corruption of *sanjon.*

[4] The Spanish arriving in the New World found that some of the smaller drainageways carried live water but that the majority were grassy-bottomed draws, marked here and there by *charcos,* or stagnant pools of water. Lacking a precise descriptive term for these drainages the Spanish applied the word *arroyo,* which in their native land referred, and still does, to a small stream of running water. It is obvious that such application of *arroyo* was not entirely correct and did not accurately describe the ephemeral streams of the area at the time of Spanish settlement. By the end of the last century and the beginning of the present these same arroyos had changed their regimes and had become steep-sided, sandy-bottomed, intermittent gullies so that their present aspect is still further removed from the original meaning of *arroyo* than it was during Spanish days. Despite its etymological inappropriateness the term *arroyo* is universally retained throughout the Southwest to designate a wet-weather stream and its vertically walled channel.

[5] Endee is obviously a phonetic rendition of an old cattle brand "ND."

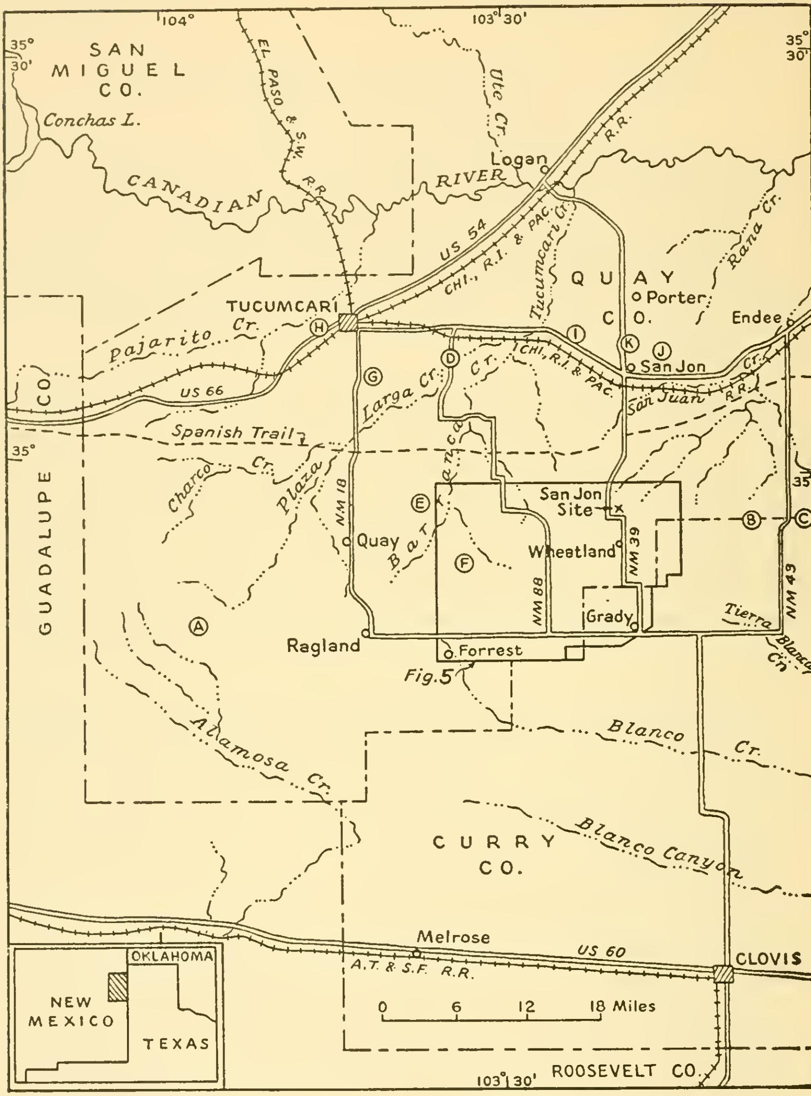


Fig. 1.—Index map of San Jon site and environs. Letters refer to localities mentioned in text.

the Canadian River to the north. South of the town the plain rises gently over a distance of 9 miles until it butts abruptly against a bold escarpment some 700 feet high forming the northern boundary of the Southern High Plains (pl. 2, fig.1). The differences in the topography, the vegetation, and the economy of the inhabitants of the High Plains and the valley are as marked as the escarpment itself. Almost on the brink of this escarpment the site occupies a position at once picturesque and strategic to the two areas, the relatively low valley plains to the north and the higher Staked Plains to the south.

CLIMATE

This section of eastern New Mexico has a continental, semiarid climate characterized by dry winters, mid- and late-summer rainfall maxima, a marked annual variation of precipitation, a high percentage of clear, sunny days, high summer temperatures, moderately low winter temperatures, and high evaporation. Rainfall is apt to be torrential, falling too quickly to be absorbed by the soil, and thus lost by rapid run-off.

The climate is remarkably similar over a wide area, a situation directly related to the lack of local topographic control. The modern climate is directly dependent upon the great distance of the area from large water bodies capable of supplying adequate moisture, the southerly latitude, and the general uniformity of the land surface.

Summary figures of precipitation, temperature, and evaporation for selected stations within a 40-mile radius of the site are shown in table 1. Figure 2 illustrates that precipitation follows the annual march of temperatures.

VEGETATION

Even as the climate of this section of New Mexico is transitional between desert and subhumid or humid climates, so is the vegetation transitional in character between desert and true grassland. The greater part of the area falls within the Upper Sonoran Life Zone, although a narrow reentrant exhibiting Lower Sonoran elements enters the area from Texas and extends westward up the Canadian River and along Pajarito Creek (Bailey, 1913).

In general, that part of eastern New Mexico here considered possesses a vegetative unity. There are no regionally significant changes in the distribution of plant life. Despite this unity, however, there are variations in plant geography. These are not explicable in terms of major climatic changes but rather in terms of local differences in elevation, bed-rock geology, surface deposits of eolian material and alluvium, changes in the declivity of slopes and the position of these slopes, relative availability of water, and the recent history of land use.

Of great importance to the present study is the relation of the vegetative cover to the variations of rainfall. During years of plentiful precipitation the grasses and perennial flowers flourish in profusion and abundance. A high percentage of the ground surface is covered by plants and the top soil is well anchored by their root systems.

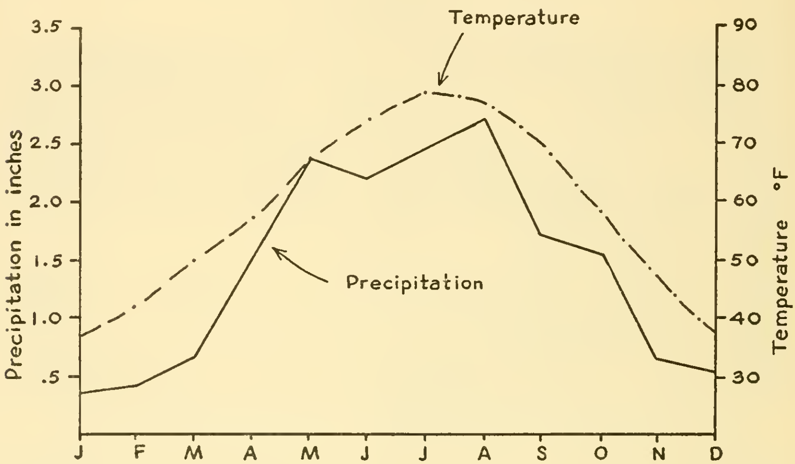


FIG. 2.—Graph showing average monthly precipitation and temperatures recorded from stations at San Jon, Tucumcari, Logan, and Clovis.

Gullying, sheet wash, and deflation are arrested by this protective mat of plants. Erosion is at a minimum. During a dry year, or a succession of dry years, deficiency of moisture reduces the percentage of plant cover. Bare patches between individual plants or small groups of plants increase in area. The plants become increasingly less effective in protecting the ground surface from erosion by wind and water. It is during such periods that gullying is initiated. At the same time sand sources are bared to the incessant winds and wind erosion commences. Concurrently with deflation of source areas of sand an already weakened vegetation in other areas is smothered beneath a blanket of wind-moved material. Thus does the intimate relation between rainfall and vegetation contribute to successive periods of stability and instability of the surficial deposits.

TABLE 1.—*Climatological data summarized from selected stations in Quay and Curry Counties, eastern New Mexico*

Precipitation in inches

Station	Yrs.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	Percent Apr.-Oct.
San Jon	39	0.29	0.32	0.55	1.26	2.24	2.13	2.36	2.82	1.39	1.56	0.61	0.58	16.11	85
Tucumcari ...	41	0.30	0.46	0.71	1.40	2.39	1.97	2.31	2.72	1.55	1.40	0.74	0.63	16.58	83
Porter	21	0.22	0.45	0.82	1.07	2.58	2.12	2.15	2.80	1.37	2.18	0.87	0.70	17.33	82
Logan	39	0.28	0.47	0.66	1.51	2.25	2.14	2.56	2.29	1.62	1.39	0.65	0.54	16.36	84
Quay	22	0.28	0.41	0.66	0.80	2.33	1.59	1.91	2.48	1.48	1.71	0.73	0.66	15.04	81
Ragland	10	0.52	0.51	0.66	1.24	3.33	2.60	2.12	2.71	2.87	1.68	0.54	0.88	19.66	84
Melrose	38	0.35	0.38	0.77	1.34	2.03	2.02	2.27	2.81	1.96	1.46	0.62	0.65	16.66	83
Clovis	35	0.35	0.41	0.69	1.39	2.47	2.72	2.44	2.94	2.36	1.83	0.51	0.60	18.71	85

Temperature in degrees Fahrenheit

Station	Yrs.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
San Jon	38	37.4	41.4	48.0	56.6	65.1	74.5	78.5	76.9	70.6	59.3	46.2	37.2	57.6
Tucumcari ...	41	37.1	41.2	48.5	56.8	65.3	75.2	78.6	77.5	70.8	59.2	46.8	38.1	58.0
Logan	36	36.7	40.0	56.0	56.0	64.7	74.4	78.8	76.8	70.3	57.8	45.4	36.3	57.5
Clovis	34	37.0	41.6	47.1	57.0	66.0	75.1	79.0	77.3	69.9	59.0	47.0	38.1	57.8

Evaporation in inches

Station	Yrs.	Apr.	May	June	July	Aug.	Sept.	Total
Tucumcari ...	36	7.673	9.309	10.697	10.839	9.554	7.242	55.314

GENERAL GEOLOGY

PHYSIOGRAPHIC DIVISIONS OF EASTERN NEW MEXICO

Eastern New Mexico lies largely in the Great Plains Province (Fenneman, 1931). The San Jon site is located in the High Plains section, a major subdivision of the Great Plains Province, which is itself divisible into three units stretching from South Dakota to Texas and here referred to as the Northern, Central, and Southern High Plains.

The San Jon site lies along the northern escarpment of the Southern High Plains or Llano Estacado (Staked Plains). This plain has a regional slope to the southeast. To the north the Southern High Plains are separated from the Central High Plains by a series of buttes and mesas, outliers of the Plain, and by the broad but lower Valley Plains of the Canadian River into which the Canadian River has incised the present canyon. Figure 3 shows the major physiographic features of the area.

ROCKS OF THE AREA

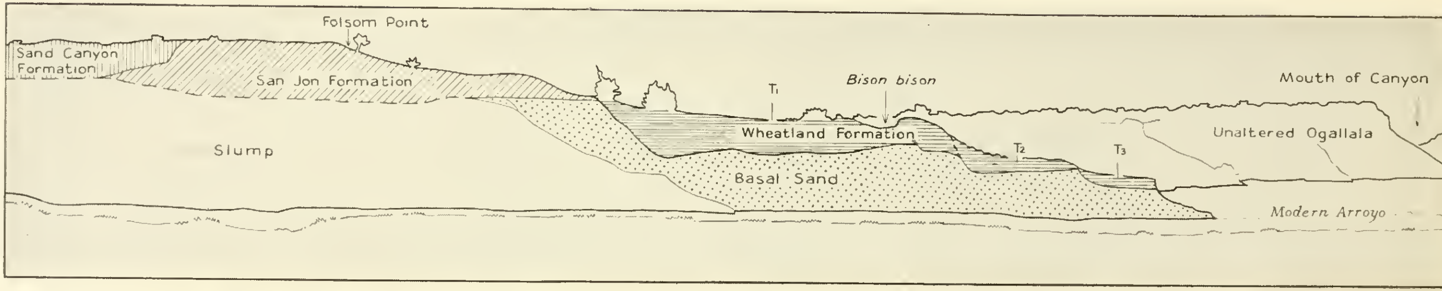
The general geology of the area is recorded in a geologic column involving pre-Cambrian, Upper Paleozoic, Mesozoic, and Cenozoic rocks. Beginning with the Paleozoic these rocks are exclusively sedimentary and flat-lying. The character, thickness, and position of these rocks determine in large measure the main topographic features and are critical in all minor features. The Pleistocene and, to some extent, the Pliocene deposits are discussed in detail in this report. For a detailed consideration of older rocks the reader is referred to Darton (1922), Bates (1946), and Dobrovolny and Summerson (1946).

GEOLOGY OF THE SAN JON SITE

GENERAL STATEMENT

Viewed from the surface of the High Plains the San Jon site lies in a broad, shallow depression over a mile in diameter. The gentle slopes of this depression are scarcely perceptible at first glance, particularly if one comes upon it from the north over the rugged relief of the "breaks" below the escarpment (pl. 2, fig. 2). The rim of depression is almost featureless, although a broad, low hill east of the site rises slightly above the general level of the plains. To the south and west lie plowed fields. The site and the slopes immediately ad-

Fig. 1 (left): View looking east along the northern escarpment of the Southern High Plains from the vicinity of the San Jon site.
Fig. 2: (right): View looking east across the depression containing the San Jon site.



Photographic panorama and landscape sketch showing relation of late Pleistocene formations to the Basal Sand at the San Jon site. T_1 etc., indicates terraces of Wheatland age. For location see figure 4.

joining it are in grassy pasture land and the edge of the escarpment is fringed with piñon, juniper, and low-growing bushes.

In the center of this shallow bowl a crow's-foot pattern of arroyos 50 to 100 feet in depth has been fashioned (frontispiece and fig. 4). The three major toes of the pattern point south, southwest, and west.

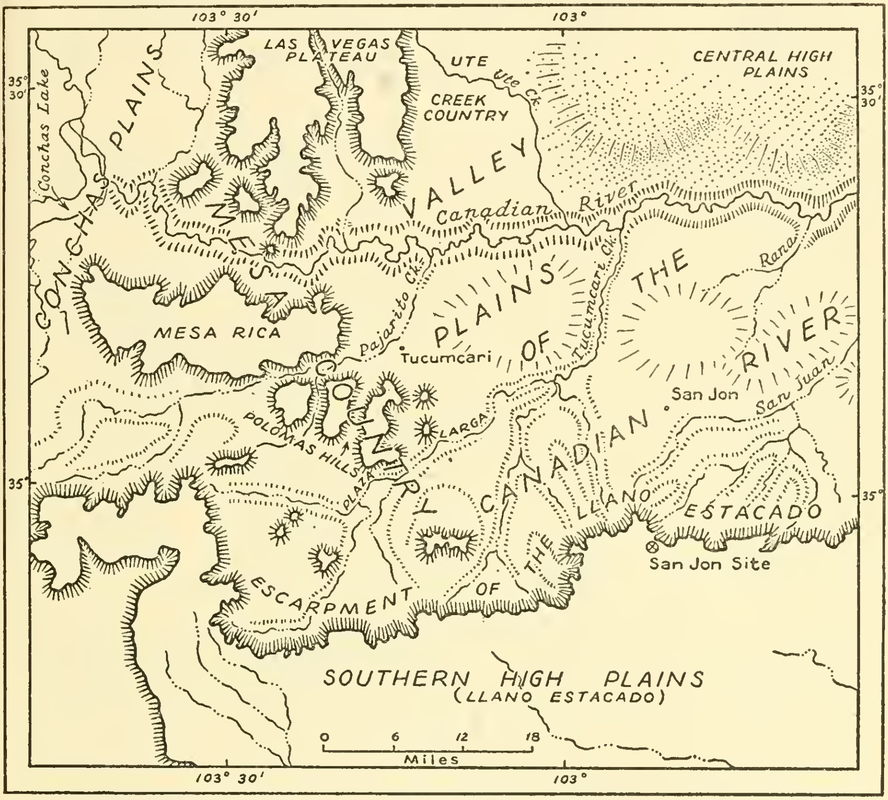


FIG. 3.—Physiographic map of a portion of eastern New Mexico.

These converge to form a single drainage, Sand Canyon Arroyo, which flows northeast through a deep narrow canyon. This canyon pierces the escarpment and the arroyo descends to the Valley Plains of the Canadian and hence via the San Juan Arroyo to the Canadian River. The dissected portion of the depression is almost completely contained within an area one-half mile in diameter. Considered in a broad way this depression is one of several depressions lying in a groove in the High Plains as discussed below.

ORIGIN OF THE SAN JON DEPRESSION

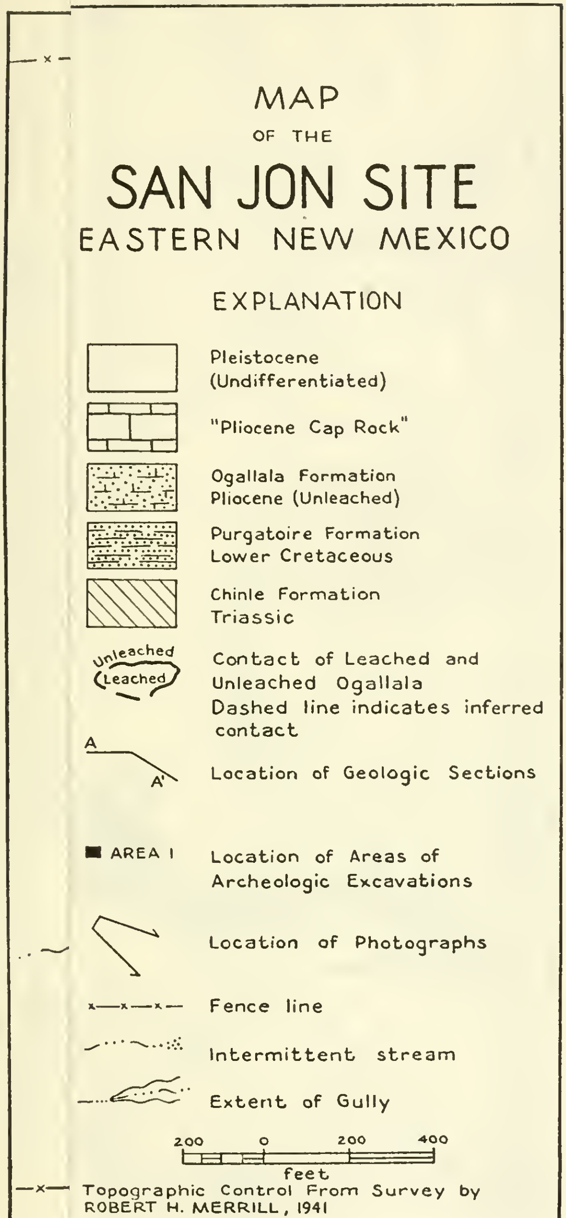
The dissected depression which contains the San Jon site is one of several depressions lying in a broad, shallow groove in the High Plains as shown in figure 5. Figure 5 shows also that there are other grooves in the Plains to the south and that these also contain depressions of varying size. These depressions, which range from a few feet across to well over a mile in diameter and from a few inches to over 50 feet in depth, are characteristic of much of the High Plains surface.

It was necessary to determine the age and origin of these depressions because the artifact-bearing beds of the San Jon site are involved in one of these depressions which has been breached by the retreating scarp of the High Plains.

A study of the depressions, breached and unbreached, shows that in this section of the High Plains the depressions are the result of alternate periods of leaching and wind deflation (Judson, 1950). During wet periods of the Pleistocene the calcareous cement of the Pliocene Ogallala formation which covers the High Plains was locally destroyed by downward-percolating ground water. During succeeding dry periods these locally leached areas suffered wind deflation. In many places sand hills resulting from this deflation are found to the east of the depressions (fig. 5). Figure 6 suggests the relation of form and process to the periods of aridity and moisture and indicates some of the variations in form which might be expected.

As noted above, the depressions are located along broad, shallow troughs. These troughs involve, in a way which is as yet imperfectly understood, the "cap rock" of the Plains, that limestone crust at the top of the Ogallala formation or above it. Certainly, however, the depressions are not due to true collapse into the underground although some collapse depressions are known from the area (fig. 1, A; Judson, 1950).

The initiation and expansion of the depressions form a feature of the Pleistocene but cannot be confined to any specific horizon of the Pleistocene. It is entirely reasonable that depressions have been forming on the Plains since the end of the Pliocene. Some have ceased to grow and have become so choked that there may be little recognizable surface expression. Were the surficial cover stripped from the Plains, the resulting surface would be literally pock-marked with the open scars of modern depressions and the healed or partially



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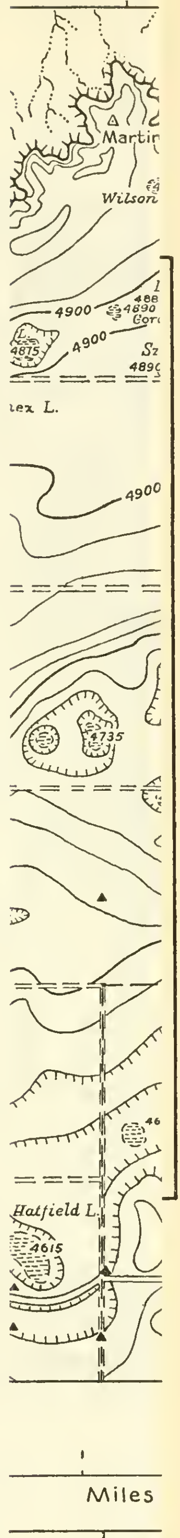

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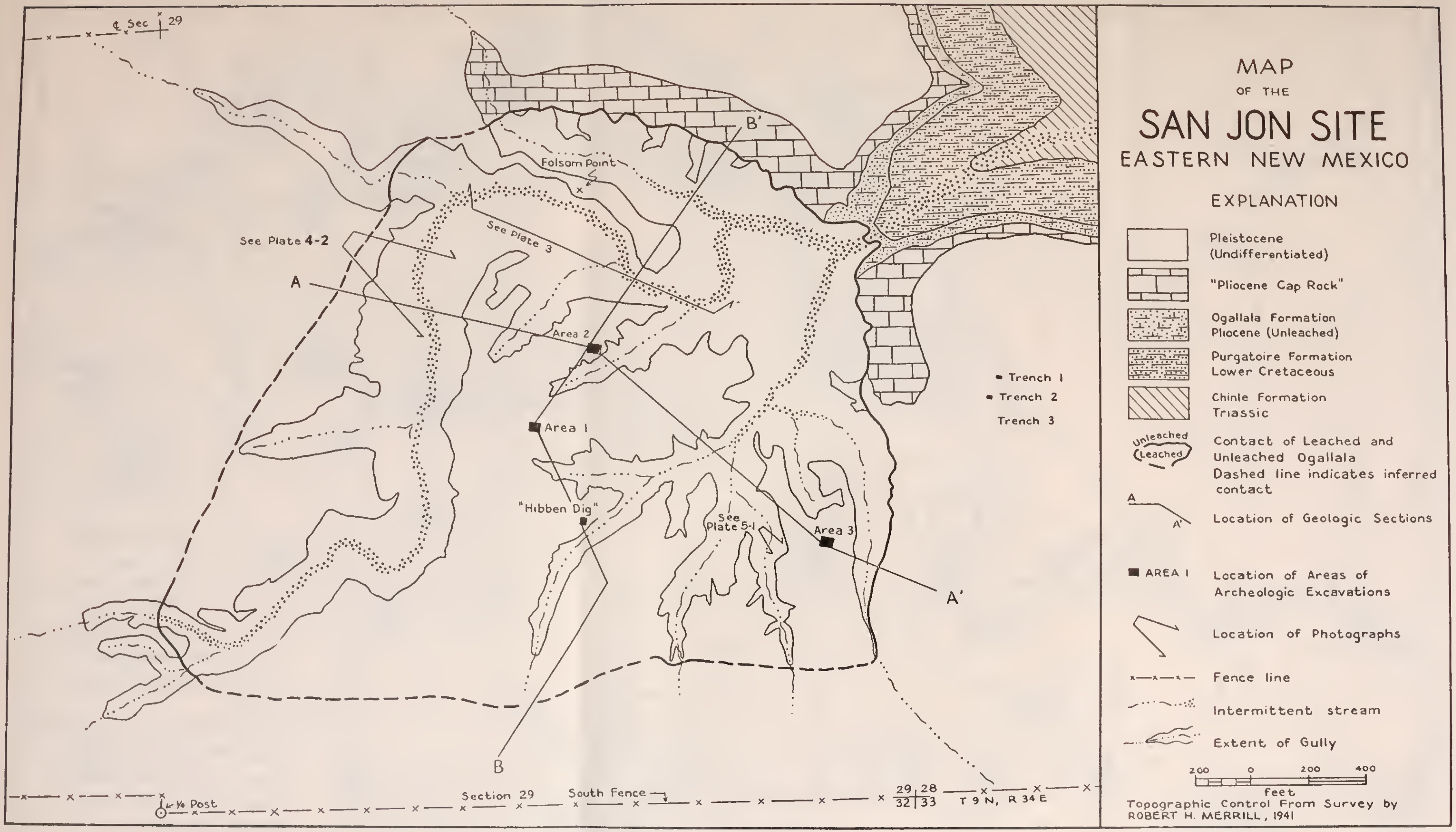
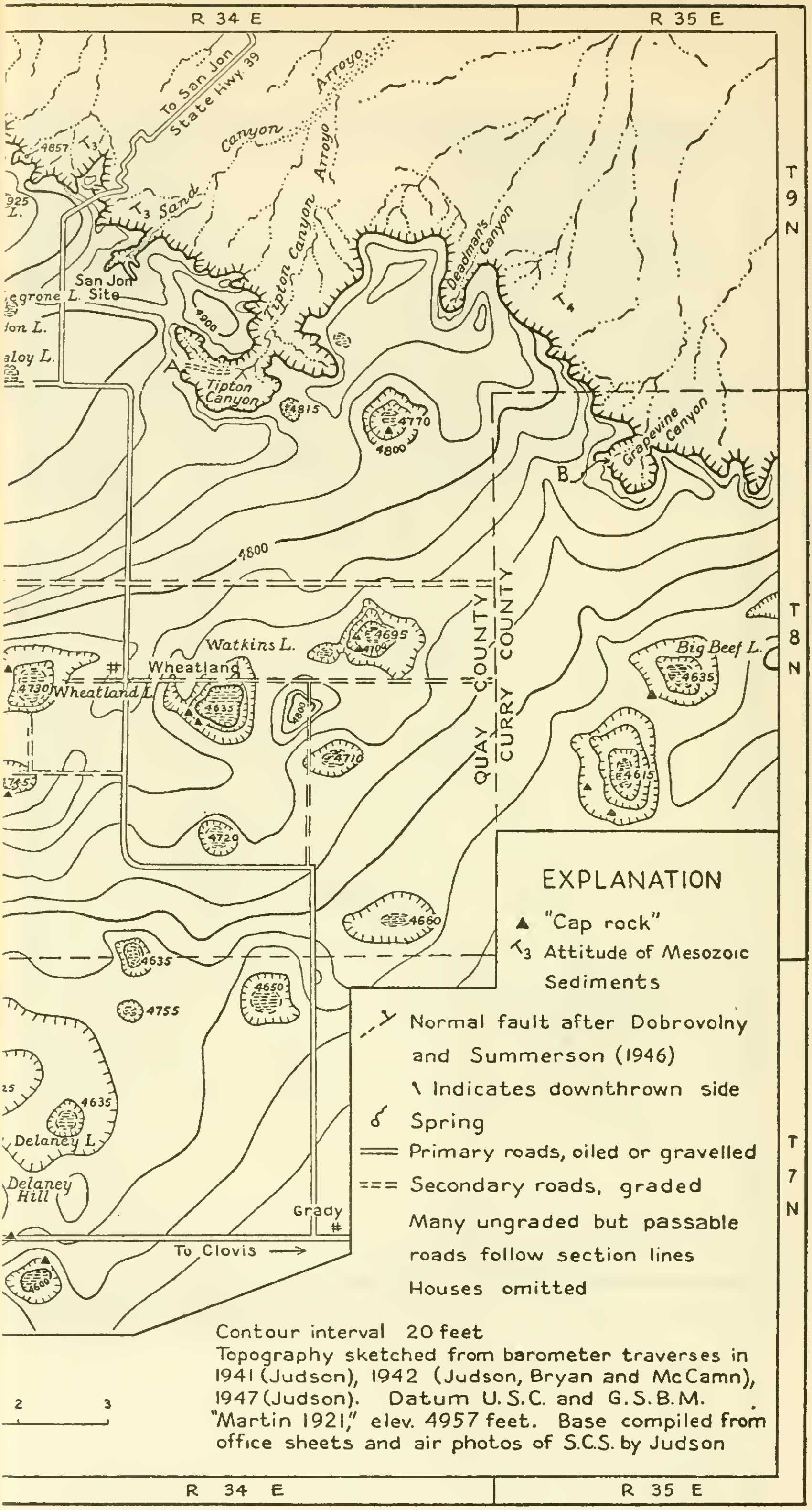


FIG. 4.—Map of the San Jon site showing location of geologic sections, photographs, and archeological excavations.



f the San Jon site.

healed scars of "extinct" depressions. The depression is characteristic not only of the Plains of the present but also of the past back to the beginning of the Pleistocene.

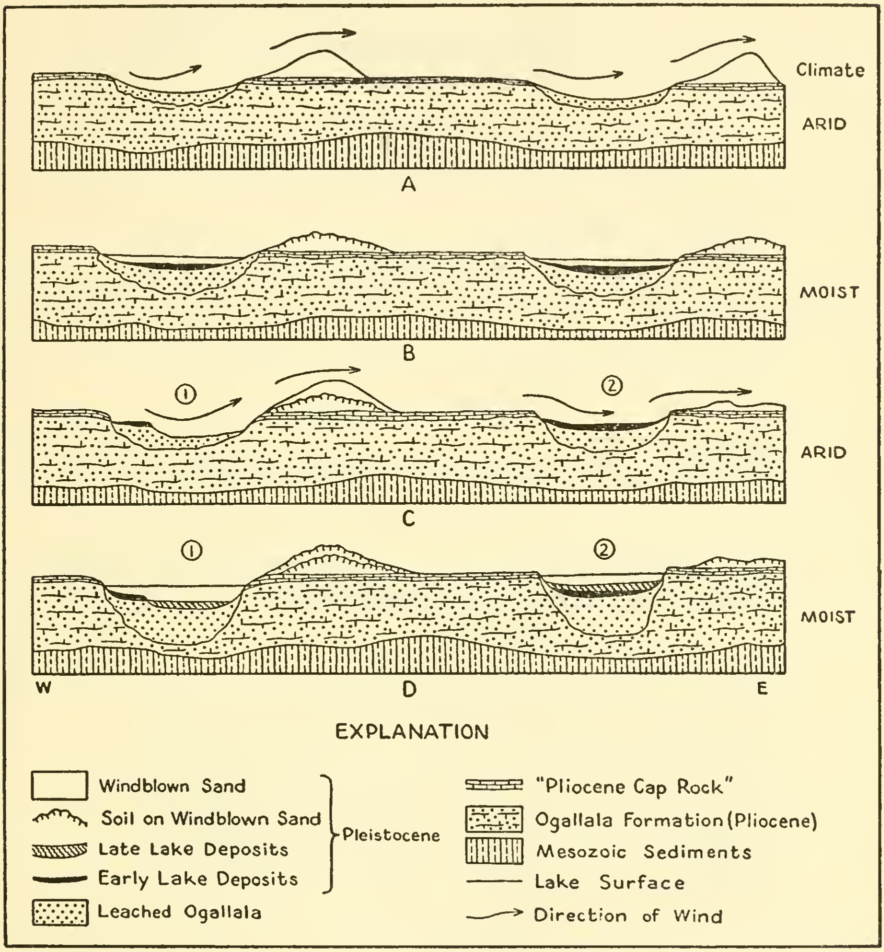


FIG. 6.—Schematic diagram to illustrate the relation of process and form to climate in the development of depressions.

DEPOSITS OF THE SAN JON SITE

The deep arroyos of the site expose a series of beds of pond and alluvial origin. They lie within and upon the rocks which form the support of the High Plains. It is obvious that the narrow canyon has been cut back into the depression which it now drains. The top of

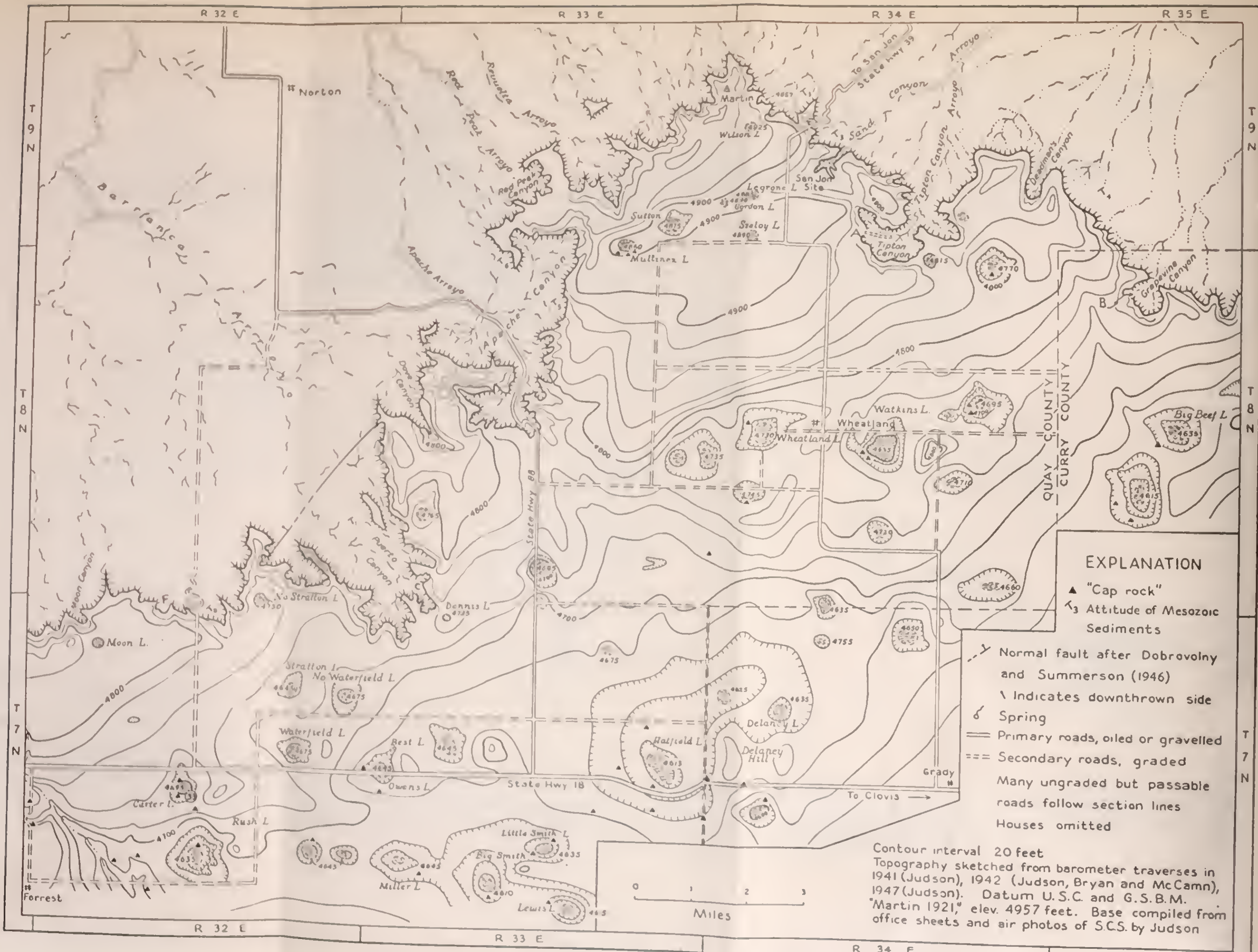


FIG. 5.—Map of the Southern High Plains in the vicinity of the San Jon site.

the escarpment is formed by Pliocene beds composed largely of white to buff calcareous sandstone with a limy plate, the "cap rock," at the top. The Pliocene can be traced almost completely around the site in a somewhat assymetrical loop as indicated in figure 4. Within this loop and overlapping it, particularly to the south, rest the beds involved in the archeological excavations. They are summarized as follows and discussed in more detail later on.

SUMMARY OF THE BEDS EXPOSED AT THE SAN JON SITE

	Feet
Modern deposits of the arroyos....................................	0 to 10
Periodically moved by flood.	
———disconformity———	
Wheatland formation	5 to 15
Low Terrace. Base 1 to 5 feet above grade of arroyos. Fine gravel, sand and silt.	
———disconformity———	
Intermediate Terrace	5 to 15
Base 8 to 10 feet above grade of arroyos. Materials as above.	
———disconformity———	
High Terrace	10 to 15
Base 20 to 25 feet above grade of arroyos. Materials as above. Contains bones of *Bison bison.* No artifacts found.	
———disconformity———	
Sand Canyon formation..	0 to 50
Reddish to reddish-brown alluvium. Alternating beds of sand and clayey-humic material. Contains numerous iron-manganese nodules averaging ¼ inch in diameter. Lime occurs as tubules and as films particularly along joints in the clayey horizons. Occurs in broad channels cut into underlying formations 40 to 50 feet above grade of modern arroyos. Contains artifacts ("Collateral" Yuma and Clear Fork (?)), bones of *Bison bison,* and the planorbid *Helisoma tenue sinuosum* (Bonnet), a modern mollusk common in the area.	
———disconformity———	
San Jon formation..	0 to 50
Zone 3	0 to 45
Dark blue-gray clay grading laterally into greenish clay and into reddish compact sandy alluvium toward the borders of the basin. Contains nodules and plates of iron-manganese oxide and concretions and plates of calcite. Lime plates occur on laminations and on strong vertical jointing. Bones of extinct bison and artifacts are found in top of the blue clay as in the planorbid *Helisoma tenue sinuosum* (Bonnet).	

Zone 2	0 to 1.5
Discontinuous lenses of fine gray-white volcanic ash.	
Zone 1	0 to 3
Crust of iron-manganese oxides, 0 to 3 feet thick overlain by bleached white sand with clay lenses 0 to 4 feet thick; grades toward periphery of basin into reddish laminated clay 5 to 8 feet thick with green clay seams in joints. This in turn grades into reddish alluvium. Proboscidian and bison bones in the clay facies.	
———disconformity———	
Basal Sand (decalcified Ogallala)	40 to 50
Upper zone, 5 to 10 feet thick, has vertical, columnar jointing. Calcareous concretions and iron-manganese flecks and clay-filled cracks. Lower zone, 35 to 40 feet thick, is a brown to buff sand without laminations. It contains vertical joints. Near the base it has calcareous concretions. In most places it is separated from the unchanged Ogallala formation by vertical contacts.	
———angular unconformity (hidden)———	
Lower Cretaceous shale and sandstone.	

Cross sections of these beds along general east–west and north–south lines and more detailed sections in the areas of actual archeologic excavation are presented in figures 7 and 8, respectively.[6] The photographic panorama and accompanying outline sketch in plate 3 illustrate the complexity of the deposits and their relations to one another,

BASAL SAND

The Basal Sand rests unconformably on the Purgatoire formation of Lower Cretaceous age. The nature of the contact, nowhere exposed at the site, is inferred from the position of the Purgatoire in the canyon draining the depression in which the site is located. Here the top of the Cretaceous has an elevation of approximately 4,700 feet and is overlain by a cemented and resistant bed 8 feet thick composed of boulders, cobbles, and gravel forming the base of the Ogallala formation. This basal Pliocene conglomerate forms the lip of a falls some 15 feet in height. The upper limit of the Cretaceous

[6] Geologic sections offer the most effective method of illustrating the geologic sequence. Areal mapping of the deposits proved unsatisfactory because of the difficulty in delimiting the deposits in plan and because of the large percentage of outcrops confined to vertical or near-vertical cliffs. The original sections were made in the field on a horizontal scale of 1 inch to 100 feet and a vertical scale of 1 inch to 20 feet. Basic topographic control was obtained from a 1941 survey by Robert H. Merrill. Secondary control was developed with a hand level and used primarily for the location of contacts.

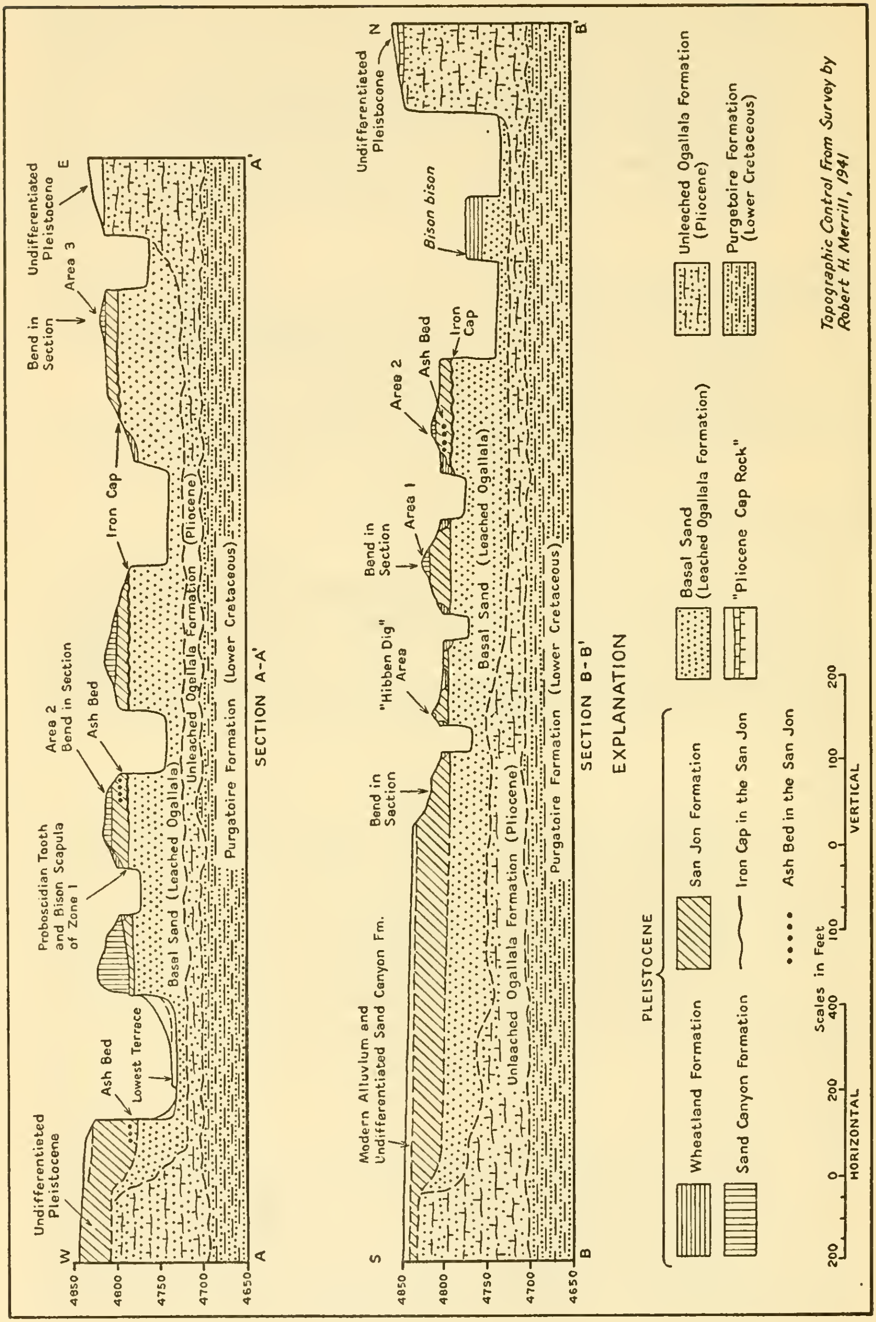


FIG. 7.—General geologic sections of the San Jon site. For locations see figure 4.

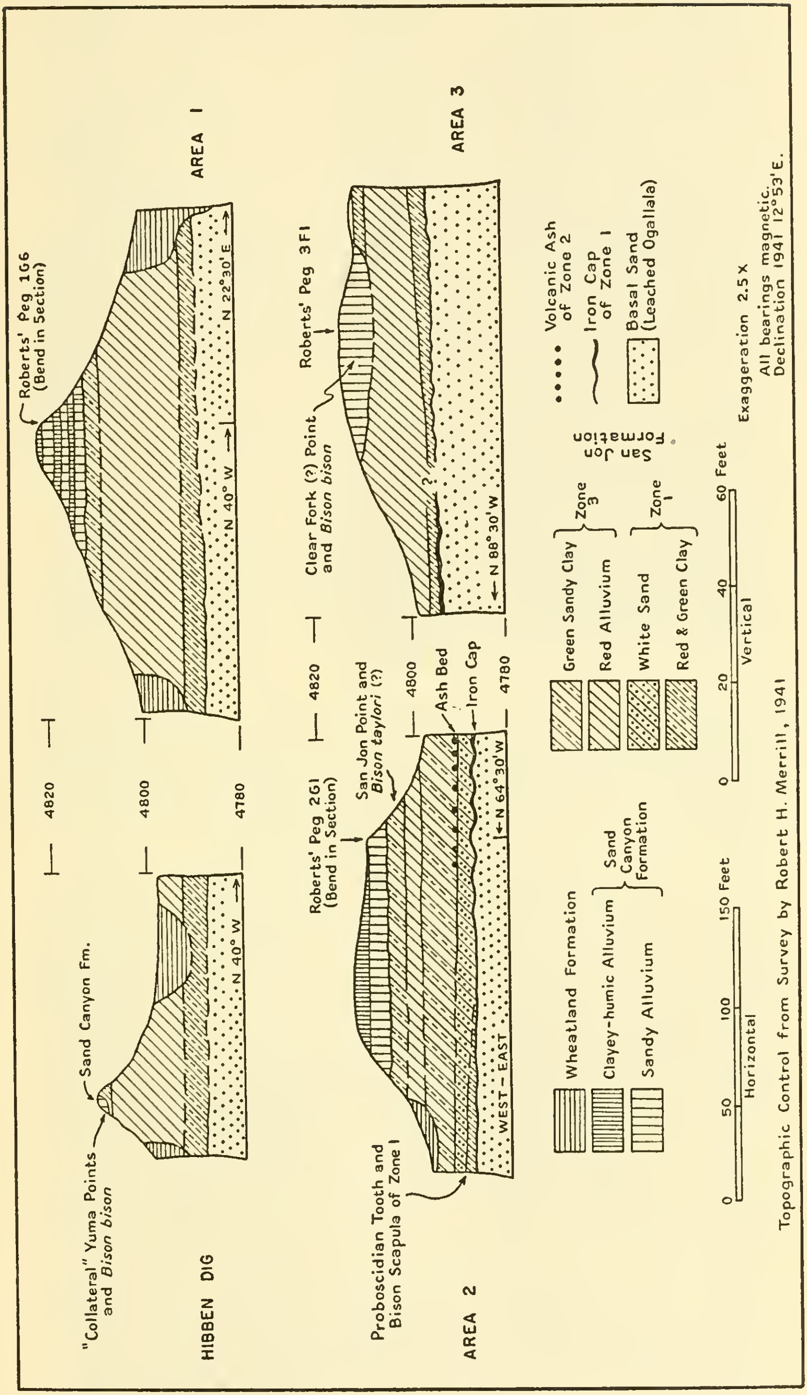


FIG. 8.—Geologic sections of areas of archeologic excavation at the San Jon site. For locations see figures 4 and 7.

in the profiles of figure 7 is shown as an irregular but essentially horizontal plane projected into the basin from the top of the Cretaceous in this falls. Patches of the basal Ogallala conglomerate similar to that at the falls may very well be present between the Basal Sand and the Cretaceous within the basin, but this possibility is not indicated in the sections.

The Basal Sand is contained within near-vertical walls of the calcareous Ogallala formation. Its friable nature and relatively even grade size suggests an eolian origin. However, a careful examination of the deposit both at the San Jon site and at other breached depressions along the northern escarpment of the Llano Estacado has shown that it is decalcified Ogallala formation (Judson, 1950). Plate 4, figure 1, shows the relation of this residuum, the Basal Sand, to as yet unaltered Ogallala formation. It was the partial deflation of this Basal Sand that created the original depression in which were laid down the deposits at the San Jon site.

The upper part of the Basal Sand is of most immediate interest. It is whitish and free of the diffused iron oxide that gives the brown color to the rest of the sand. There is a strong vertical jointing. Calcareous concretions and iron-manganese flecks occur. There are also clay-filled cracks which cut across and are obviously later than jointing and concretions. Below this zone there are bands of limonite stain. All the phenomena represent changes brought about in the Basal Sand by action begun at its upper and eroded surface. They are connected with, and the result of, processes that produced the overlying beds.

SAN JON FORMATION [7]

The San Jon formation rests on the nearly horizontal but slightly irregular top of the Basal Sand. Its thickness is controlled by the basin in which it was deposited and by the extent of subsequent erosion. The deepest part of the depositional basin was to the north nearer to the head of the present canyon than to the southern edge of the basin. At the end of San Jon time the thickest part of the deposit in the depression was at the lowest part of the basin. Later erosion, however, has reduced the original thickness, and it is probable that a complete and uneroded section is not encountered except in the southern portion of the basin. At places near the center of the basin where the original thickness is best preserved the formation is over

[7] The name "San Jon formation" is here proposed to include those strata hereinafter described. It derives its name from the San Jon site and exposures there developed are considered to represent the type exposures.

Fig. 1 (left): Leached (gray) and unleached (white) Ogallala formation at Tipton Canyon. Fig. 2 (right): Sand Canyon formation (SC) filling broad channel in the San Jon formation (SJ) at the San Jon site. BS indicates Basal Sand. For location see figure 4.

Fig. 1. (left): Highest terrace deposits of the Wheatland formation filling channel cut in Basal Sand at the San Jon site. For location see figure 4. Fig. 2 (right): Small cliff formed by soil developed at top of old wind-blown sand and covered by modern blown sand. (K, fig. 1.)

40 feet thick. The equivalent reddish alluvium to the south may be somewhat thicker. Although exposures do not exist because the modern arroyos do not cut to the extreme southern edges of the basin, the San Jon formation presumably thins to nothing in this direction.

Near the center of the depression the first deposit of zone 1 is a layer of limonite and manganese oxide. It varies from a paper-thin film to a crust of botryoidal, crystalline iron-manganese oxide 2 to 6 inches thick but in a few places reaches 3 feet in thickness. Over it lies a bleached gray-white sand with layers of red and green clay at the top. This zone is in places 4 feet thick but elsewhere is missing. Laterally to the south the crust and the bleached sand grade into, and are replaced by, 5 to 8 feet of reddish laminated clay and silt. This zone is stained to a greenish tint by green clay films which occupy strong vertical joints in the clay, and near the center of the basin penetrate downward from the top of the clay into the Basal Sand. Fragments of proboscidian teeth and a bison scapula have been taken from the top of these laminated clays at a locality in the first gulch west of area 2. (See profile A-A′, fig. 7, and profile of area 2, fig. 8.) Toward the south these laminated clays grade in turn into a compact reddish alluvium with clay zones.

Near and at the top of the clay are discontinuous bodies of fine gray-white tuff which constitute zone 2 of the San Jon formation. Where present this tuff zone is a distinctive horizon. It is composed of minute fragments ranging in size from 0.005 mm. to 0.15 mm. in diameter. There is no apparent uniformity in the shape of the individual shards. Some are the angular fragments of shattered vesicle walls; others are lathlike in shape, and still others are vesicular. Approximately 95 percent or more of the tuff is made up of a glass having an index of about 1.500. Small phenocrysts and some isolated crystal fragments of orthoclase and, to a lesser extent, of sodic feldspar and quartz constitute the balance of the ash. Some finely disseminated calcite and some iron staining has been introduced after the deposition of the tuff. Other bodies of tuff are known in the region and are mentioned in subsequent pages.

Swineford and Frye (1946) distinguish between the Pliocene and Pleistocene volcanic-ash beds of western Kansas on stratigraphic position as well as on the optical and physical properties of the individual shards. The bulk of the Pleistocene ash deposits described by them is assigned to the Pearlette ash, which occurs in discontinuous beds from western Texas to Iowa in deposits of late Kansan and Yarmouthian age (Frye, Swineford, and Leonard, 1948). Although the ash at the San Jon site exhibits petrographic similarities to the Pearlette ash its stratigraphic position indicates it to be late Pleistocene in age. The nature of the phenocrysts within the San Jon ash may eventually serve to distinguish it petrographically from the mid-Pleistocene Pearlette ash.

The limonite crust appears to have been deposited in an open body of water in which its botryoidal top could freely form. The laminated clay is also a deposit of standing water. It is presumable, therefore, that zone 1 of the San Jon formation was deposited in a fairly deep pond. The clay settled out on the southerly portion of the bottom of this pond, whereas the central portion was relatively free of silt and here chemical precipitation of limonite took place.

Limonite is commonly deposited in waters that are slightly acid in reaction by the intervention of the iron bacteria, nonspecific bacteria, and other microorganisms (Starkey, 1945). The acid reaction arises by reason of decaying vegetation and most of such deposits are in lakes or swamps in cool temperate climates. The mere presence of a permanent pond in this region in a watershed as small as that involved implies a climate somewhat cooler and moister than that of the present. Toward the close of deposition of the red-green clays this water body dried up, presumably more than once, and the deep cracks were formed. Clay was washed into the cracks. The cracks extend into the Basal Sand previously described and near the center of the basin the Basal Sand is lime-bearing and has a vertical columnar structure. These phenomena seem to be related to the presence of the pond and to its subsequent drying toward the end of deposition of zone 2. As this was presumably a slow process it is inferred that the pond formed and reformed.

The discontinuous small bodies of tuff came in at this time. This fine volcanic ash was derived from an ash shower of a distant volcano. Within the basin its thickness ranges from paper thinness to 1.5 feet. Elsewhere in the region bodies of tuff of similar character and presumably due to the same ash fall reach 4 to 12 feet in thickness. If at the time of the ash shower the tuff at the site was thicker and more continuous than now, it has been eroded and carried away by the wind during the periodic drying-up of the pond.

Above the volcanic-ash horizon and near the center of the basin, zone 3 is a hard, compact, columnar-jointed, blue clay which passes laterally into a sandy, greenish clay. Both the blue and green clays grade upward and laterally into a reddish sand, which is also silty, compact, and vertically jointed, containing here and there clayey beds. Southward from the center of the basin red and green clays or reddish alluvium make up both zones 1 and 3 and are indistinguishable unless separated by lenses of the tuff which constitutes zone 2.

Rounded iron-manganese nodules averaging one-quarter of an inch in diameter are common throughout zone 3 and in the clayey and silty portions of zone 1. They are hard, pitted pellets where exposed to the air but slightly softer on fresh exposure. Calcite concretions and plates are also characteristic of the same horizons. The plates occupy vertical joints and horizontal bedding planes. Within the clay and alluvium and lying between the bedding planes and in the joint system are roughly round concretions ranging from one-eighth to one-half inch in diameter. In places the calcite penetrates cracks and breaks in the iron-manganese pellets and plates. Thus the calcite is obviously later in time than the iron manganese. Both the calcite plates and concretions are hard and when broken with the hammer exhibit a fibrous structure. The large amount of calcite and its hardness is a distinguishing feature of the San Jon formation. Shells of *Helisoma tenue sinuosum* (Bonnet) are common.

The San Jon formation was laid down in a pond that became increasingly smaller until it had dried completely, except in its central portion where the blue clays were probably always wet during the period of deposition. The iron-manganese oxides were presumably precipitated when the pond was relatively deep. The calcite was deposited at a later date.

SAND CANYON FORMATION [8]

The Sand Canyon formation overlies the San Jon formation unconformably. It lies in broad and, in most places, flat-bottomed channels, which lead northward to the canyon (pl. 3; pl. 4, fig. 2). Much of the deposit has been removed by the cutting of the existing arroyos which tended to follow these old channelways. Presumably there once existed a broad area of the formation just south of the head of the canyon, but all this material has been removed by erosion.

The thickness varies from a thin cover over the San Jon formation to 20 to 30 feet in the axes of the channels. At one locality the formation is 50 feet thick. On the south near the heads of the gullies the Sand Canyon overlaps the alluvial beds of the San Jon in an indistinguishably thin sheet.

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[8] The name "Sand Canyon formation" is proposed for those deposits hereinafter described. It derives its name from Sand Canyon, a local designation for the dissected depression containing the San Jon site. Exposures there developed are considered to represent the type exposures.

The Sand Canyon consists of a reddish-brown alluvium with beds and laminae of sand, humic and silty clay ranging from paper thinness to 2 or 3 feet in thickness. The clayey layers have a strong vertical jointing such as develops in grassy places along streamways today.

Iron-manganese nodules are common, but calcium carbonate exists only in small tubules and along the joints in the formation. There is much less lime than in the San Jon formation, a distinguishing criterion. It is possible that the iron-manganese nodules are secondarily derived from the underlying San Jon formation.

Bones of *Bison bison,* the modern species, and associated "Collateral" Yuma-type projectile points have been found near the base of the formation.[9] A Clear Fork (?) point, also in association with modern bison, was found at a slightly higher level in the same formation. The shells of *Helisoma tenue sinuosum* (Bonnet) are found throughout the formation.

WHEATLAND FORMATION [10]

The present aspect of the arroyos and gullies of the site suggest rapid and extraordinary erosion beyond the gloomiest dreams of the soil conservationist. Inspection demonstrates, however, that these gullies, reaching in places 100 feet in depth, have developed over a considerable period of time and with successive stages of reversal of erosion and effective alluviation.

These stages are shown by terrace remnants which occur as scraps or fragments hanging on the walls of the gullies or on the points between gullies (pl. 3; pl. 5, fig. 1). The terrace sediments comprise the Wheatland formation. Each of these terrace remnants consists of a fine basal gravel, mostly of fragments of concretions from the Ogallala sandstone, and of sand. The sand and gravel layer is 1 to 3 feet

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[9] Roberts (1942) originally suggested that these points showed affinities to the Eden Valley Yuma. In a personal communication, however, dated March 16, 1948, he writes: "Since writing my report [Roberts, 1942] and seeing Howard's later article in American Antiquity [Howard, 1943] I am doubtful as to whether this type should be called Eden Valley Yuma. It unquestionably belongs in the category formerly called Collateral, but possibly should be considered as Scottsbluff rather than Eden." The points are hereafter referred to in this report as "Collateral" Yuma.

[10] The name "Wheatland formation" is here proposed to include those strata at the San Jon site hereinafter described and the exposures at the site are considered as type exposures. The name is derived from the town of Wheatland 4½ miles south of the site. (Figs. 1, 5.)

thick and overlies an irregular surface cut in the older formations. In places, a rubble of clay fragments takes the place of the basal gravel, and 5 to 15 feet of gray sand and silty sand which at the top is a dark, grass-covered soil, overlies the basal gravel and represents aggradation of the stream channels.

The highest terrace has a base 20 to 25 feet above the grade of the streams at points nearest the head of the canyon. The base rises rapidly and near the heads of the gullies is 60 to 70 feet above the grade of the arroyos. In these southerly localities this terrace occupies considerable areas.

The two lower terraces have bases at 8 to 10 feet and 1 to 5 feet above present grades. When fully developed they were confined to narrow areas along the gullies.

Each terrace records a downcutting of streams through the Sand Canyon and older formations with a stabilization of grades and a later slight alluviation. This episode was repeated three times before the present stream grades were established. At places in the highest terrace, bones of *Bison bison* have been excavated. These bones give no critical evidence as to the time interval separating this terrace deposit from the present. The dates of the episodes of erosion and sedimentation involved in the three terraces fall within the interval spanned by the Wheatland formation and estimated in a subsequent section.

RELATION OF CULTURAL AND FAUNAL MATERIAL TO THE DEPOSITS

Extensive archeologic excavations at the San Jon site by Roberts during the summer of 1941 (Roberts, 1942) and test trenches by Hibben in 1940 have produced a sequence of cultural material associated with the bones of animals, some of them now extinct. Although the amount and variation of the material are disappointingly small, enough information has been gained to demonstrate four distinct cultural horizons. These horizons can be tied to the deposits of the site as diagrammatically suggested in figure 9. The stratigraphic position of the material is in accord with the conclusion of the archeologist that it includes four different time horizons separated by intervals of varying duration.

The oldest cultural horizon is represented by a single point, called by Roberts (1942, p. 8 and fig. 2a) the San Jon point. It was found in area 2 in association with the heavily mineralized bones of an extinct bison, probably *Bison taylori* (Roberts, 1942, p. 8 and ftn. 2). The point and the bone were embedded in a clayey-silt bed near the

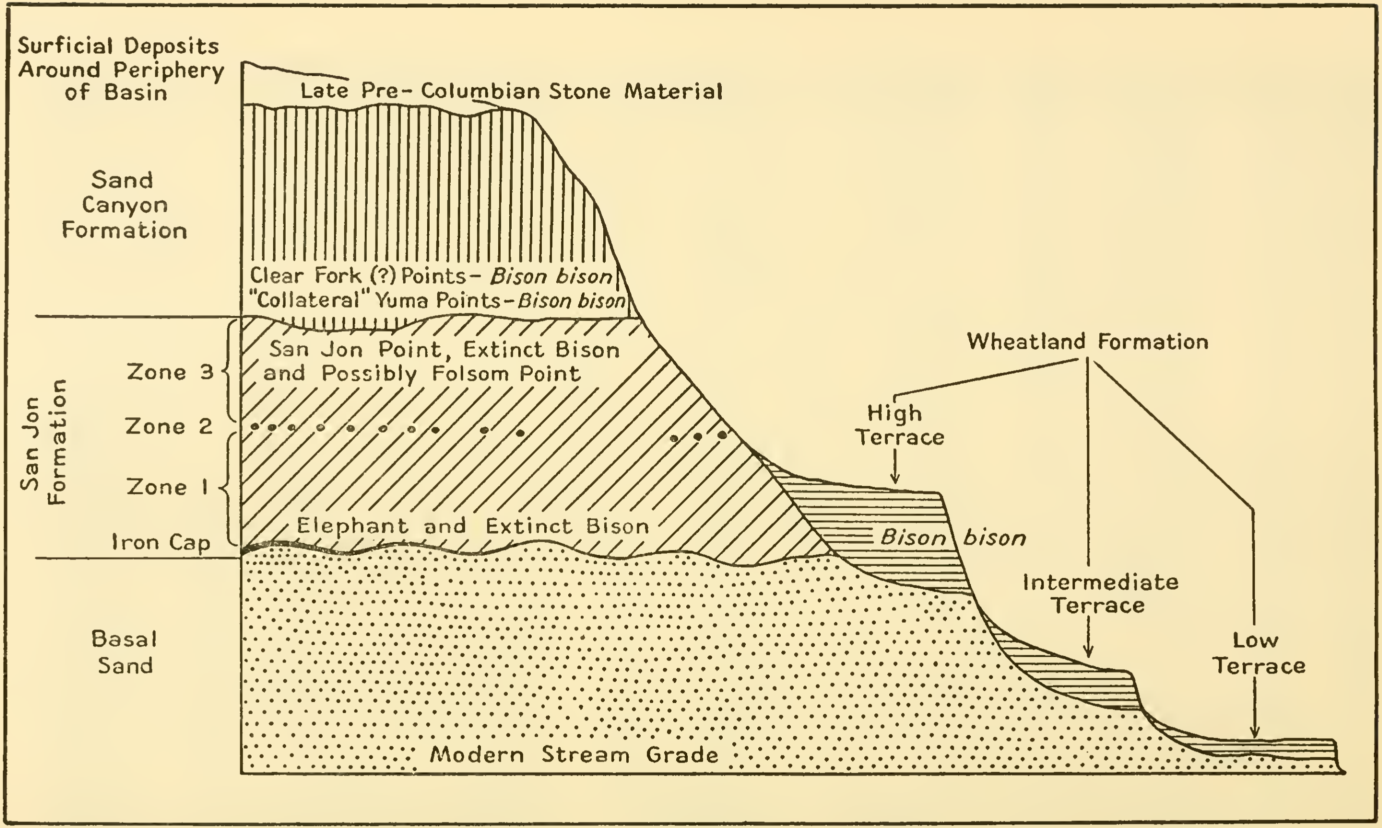

FIG. 9.—Diagrammatic sketch to show relation of cultural and faunal material to late Pleistocene deposits at the San Jon site.

top of zone 3 of the San Jon formation (figs. 8 and 9). The upright position of articulated leg bones within the deposit suggests that the animals died after miring in a shallow pond. The almost complete absence of all but leg bones further suggests that the bulk of the carcasses were removed by scavenging animals or by man (Roberts, 1942, p. 8). A true Folsom point was found on the surface along a ridge 500 feet to the north as indicated in figure 4 and plate 3. Although this point was not found in situ it appeared to be raveling out of clays belonging to the same horizon as that containing the San Jon point. The horizon also contained fragments of bone similar in amount of mineralization to that associated with the San Jon point.

The second horizon recognized contains the "Collateral" Yuma points in association with the slightly fossilized bones of *Bison bison* excavated in the Hibben dig area. These points have been obtained by both Roberts and Hibben and are also included among the points collected by Keith Martin, discoverer of the site, and turned over to the Museum of Anthropology at Santa Fe. The points and bones occur in the base of the Sand Canyon formation. The amount of time involved between the end of San Jon time and the beginning of Sand Canyon time was of considerable extent and will be considered later at some length.

The third horizon also occurs within the Sand Canyon formation but at a slightly higher stratigraphic position than do the Yuma points. It is represented by a point bearing some similarities to the Clear Fork types of west Texas (Roberts, 1942, p. 10). The bones of *Bison bison* were found with the point, but they were slightly less mineralized than were those found with the Yuma points.

Shallow trenches along the eastern slopes of the depression produced stone material obviously of a comparatively late culture, probably slightly pre-Spanish in age. The artifacts were found just below the grass roots within surficial deposits equivalent in age to some phase of terrace formation within the site itself during Wheatland time.

No artifact material has been removed from the Wheatland formation represented by the terrace deposits although the bones of modern bison have been found within the highest terrace as previously noted.

CONCLUSIONS

The sequence of beds at the San Jon site presents problems that require further discussion and amplification. Nevertheless simple inferences can be made from the material thus far presented.

1. A depression, to be the future location of the San Jon site, was formed in the Ogallala formation by alternate leaching and deflation. This depression was formed during some portion of Pleistocene time as climate alternated between moist and arid or semiarid. This depression was bottomed by the Basal Sand.

2. In this depression of the Plains underlain by the Basal Sand a pond existed and gradually became shallower and less constant as the San Jon formation was deposited. A volcanic-ash shower occurred while this deposit was being laid down. During the latter part of this period the people who made the San Jon points, and possibly also a true Folsom people, occupied the area. Proboscideans were present during the early stages of deposition, and extinct bison watered here during human occupation of the late stages of depositions.

3. Following the deposition of this formation the depression was breached and was dissected by broad channels.

4. In these channels the Sand Canyon formation was deposited partly as alluvium and partly in temporary evanescent ponds along the streamways. During this period the people who made the "Collateral" Yuma and the Clear Fork (?) points occupied the area. By this time the modern bison had replaced the large bison and the elephant was probably extinct.

5. Erosion then began on the present drainage lines and the existing deep arroyos were cut in stages represented by three terraces, the sediments of which are termed the Wheatland formation. During these time intervals the area was occupied, but the sequence of cultures is as yet indefinite.

6. The human occupation at the San Jon site is correlated with a series of events which are reflected in the local deposits and erosional intervals.

7. The human occupation is also closely related to one of the depressions of the Plains. Before discussing the geographic extent of the events recorded at the site it is fitting to consider the role of the depressions and human occupance of the Plains.

DEPRESSIONS AND OCCUPANCE OF THE PLAINS

The history of human occupance of the Plains has been dominated in large part by the depressions. This dominance is less apparent today than it was 50 years ago or when aboriginal peoples roamed the Plains. It is still important, nevertheless, for here man has found water not only in the lakes but also in shallow wells, which tap soft water at economical depths. Most of the pasture land of today surrounds these depressions.

The Indians, recent and ancient, were of necessity more sensitive to their environment than are modern men. When on the Plains they depended almost entirely on these shallow lakes for water. Moreover, the game on which they lived watered here, and a mired buffalo or elephant was easy prey for a hungry Indian. The more prominent of the sand hills east of the lakes provided still another attraction for the migrant hunters of the past. These hills offered them not only a commanding camp site from which they could see for great distances in all directions, but they were also well drained. On all the higher hills examined by the writer, evidence of Indian occupation is present. The depressions drew the Indians to them not only during the moist periods of the past but even during the dry periods, although presumably the population of the Plains was smaller than during the periods of more effective rainfall.

Unfortunately, our knowledge of cultural successions on the Plains is as yet incomplete. As that knowledge expands, however, it should key to, and be explained in large part by, the depressions of the Plains and the variations in climate from dry to moist. The San Jon site contributes a few facts to this picture. The people who made the San Jon point, and probably the Folsom point, hunted around the small lake which once occupied the now-dissected depression. The mere presence of the lake suggests a climate moister than the present. Whether these peoples camped around this lake is not known. Certainly the lake's strategic position with respect to the Valley Plains of the Canadian to the north and the High Plains to the south, along with water and game, would provide a logical setting for a camp site. If one or more camp sites once existed they were either destroyed by erosion or lie buried under more recent deposits. One would expect that primitive hunters would not camp directly on the lake margin but on higher, better-drained ground to the east and south of the lake where a commanding view of the surrounding country could be obtained. If this be true then the camp sites have been either destroyed by erosion or mantled by subsequent eolian deposits.

Following the occupation by the San Jon–Folsom people, a period of erosion occurred during which the depression was breached, the lake drained, and the basin partially dissected. As will be discussed later, this stage is thought to coincide with a dry period. Whatever the climate, we have no cultural record from this interval, perhaps because people were absent from the area, but more probably because no deposits representing this interval have been found.

The next record of human occupance is that of the people who made the "Collateral" Yuma points, closely followed by people using points having affinities to the Clear Fork complex of Texas. The conditions of burial indicate that these people enjoyed a climate moister than the preceding dry period and probably moister than that of the present. The camp sites of these peoples are also unknown. No longer was there a lake to attract man but small pools or *charcos* must have existed along the drainageways. If the Yuma and Clear Fork (?) peoples maintained camp sites here they are now destroyed or as yet undiscovered.

The more recent history of the San Jon site is recorded by remnants of three terraces. These periods of alluviation were interrupted by progressive downward cutting of the streams until the modern drainage was established. What relation human occupance of the site bears to these periods of alluviation and erosion is not clearly understood. Roberts (1942, pp. 10-12) reports the presence of a comparatively late culture from shallow sites around the peripheries of the basin. What relation the physical events at the site bear to this culture is unknown.

SUMMARY

The Pleistocene deposits of the San Jon site lie within a depression now breached and partially dissected. As shown by an examination of this site and of other breached depressions along the northern escarpment and confirmed by studies of undrained depressions on the Plains, these depressions were formed by the deflation of locally leached areas of the Ogallala formation. Deflation has been in progress intermittently since the beginning of the Pleistocene. The depressions were excavated in warm, dry periods, and deposition occurred in cool, wet periods. The depressions have been important geographic factors in the utilization of the Plains by aboriginal peoples. Furthermore, they contain deposits which duplicate in part the events recorded from the San Jon site. This duplication is important for it permits the assertion that the deposits at the San Jon site do not represent locally restricted and unique events, but rather events which have some geographic extension on the adjacent High Plains. This extension of the San Jon sequence to the adjacent Plains is considered below.

PLEISTOCENE STRATIGRAPHY IN THE VICINITY OF THE SAN JON SITE

GENERAL STATEMENT

In addition to the deposits at the San Jon site the writer has studied in some detail the Pleistocene stratigraphy of the surrounding area. This area, although ill-defined, extends in a general way from the

Texas–New Mexico line on the east to a line approximately 5 miles west of Tucumcari and from the Canadian River on the north to Grady on the south. The northern escarpment of the Llano Estacado divides the area into two irregular portions, a section of the Southern High Plains to the south, hereafter referred to as the Plains, and a large segment of the Valley Plains of the Canadian River to the north, termed the Valley in subsequent pages.

The various phases of the late Pleistocene stratigraphy, lacustrine, alluvial eolian, and erosional, are listed chronologically in table 2, a condensed presentation of late Pleistocene geologic history. The deposits described from the San Jon site have their counterparts throughout the area and are identified in the field on the basis of lithology, fossil and artifact content, and stratigraphic position. Furthermore, the disconformities recorded at the site are represented elsewhere not only by erosion but by wind activity and the accumulation of eolian deposits. Certain other events, such as the deposition of fresh-water limestone, the formation of the "cover" of the Plains, and the planation of pediments in the Valley, antedate the oldest Pleistocene deposit of the San Jon site. However, the position of these older events within the late Pleistocene is poorly defined. Therefore the most complete part of the record begins with San Jon time and continues to the present. This is the period spanned by the so-called "Alluvial Chronology" (Bryan, 1941), a sequence of events and time intervals now established in many parts of the Southwest and thus of utmost importance to this discussion. The recognizable fragments of this sequence, now exposed at various localities on the Plains and in the Valley are described in the pages immediately following. From the description and discussion of this sequence, summarized in table 2, it will be evident that there has been an alternation of deposition in ponds and streams, with erosion of channels, deflation of depressions, and accumulations of eolian deposits. A detailed consideration of the implications of the "Alluvial Chronology" is given in a later section.

CHARACTERISTICS OF LATE PLEISTOCENE FORMATIONS

SAN JON FORMATION

The lacustrine phase of the San Jon formation is predominately clayey in texture and may be blue, red, green, or brown. The fluvial deposits are sandy to silty alluvium, red to brown. The deposits of both phases are extremely compact and in most instances impossible to crumble between the fingers. They are characterized by a well-developed joint system along which have been deposited alluvial clay. Lime carbonate forms nodules independent of the joint system and

Table 2.—*Correlation of the various phases of late Pleistocene stratigraphy in eastern New Mexico*

	AGE	LACUSTRINE & ALLUVIAL PHASE OF THE PLAINS	ALLUVIAL PHASE OF THE VALLEY	EOLIAN PHASE	EROSION PHASE
"ALLUVIAL CHRONOLOGY"	1900 TO DATE	DEPOSITION IN MODERN EPHEMERAL PONDS	—	MODERN DUNES	CHANNEL CUTTING ON MANY STREAMS
	WHEATLAND 1400 A.D.± -1900	LOOSE SEDIMENTS IN PONDS, ON SLOPES OF DEPRESSIONS AND IN CHANNELS IN SHORT STREAMS NEAR ESCARPMENT.	LOOSE ALLUVIUM OF WHEATLAND FORMATION IN CHANNELS.	DEVELOPMENT OF SOIL ZONE	—
	1300± - 1400± A.D.	—	—	FORMATION OF DUNES	DEFLATION OF DEPRESSIONS. EROSION AND CHANNELING OF SAND CANYON (B) FORMATION
	SAND CANYON (B) IN PART POST 1 A.D.	COMPACT, SOMEWHAT LIMY SEDIMENTS OF SAND CANYON FORMATION DEPOSITED AS ABOVE. AT SAN JON SITE CLEAR FORK ? AND "COLLATERAL" YUMA POINTS WITH MODERN BISON NEAR BASE.	COMPACT, SOMEWHAT LIMY ALLUVIUM OF SAND CANYON (B) FORMATION	DEVELOPMENT OF SOIL ZONE	—
	DATE ?		—	SOME WIND ACTIVITY	SOME EROSION AND CHANNELING OF SAND CANYON (A) FORMATION
	SAND CANYON (A) 3500-2000 B.C.± TO?		COMPACT. SOMEWHAT LIMY ALLUVIUM OF SAND CANYON (A) FORMATION	DEVELOPMENT OF SOIL ZONE	—
	MEGATHERMAL PHASE 5400±-2000± B.C.	—	—	FORMATION OF DUNES	DEFLATION OF DEPRESSIONS. EXTENSIVE EROSION AND CHANNELING OF SAN JON FORMATION. BREACHING OF SAN JON SITE AND OTHER DEPRESSIONS
	SAN JON PRIOR TO 5400 ± B.C	COMPACT, LIMY SEDIMENTS OF SAN JON FORMATION DEPOSITED AS ABOVE AT SAN JON SITE CONTAINS SAN JON POINT, PROBABLY FOLSOM POINT, MAMMOTH AND EXTINCT BISON.	VERY COMPACT LIMY ALLUVIUM OF SAN JON FORMATION. CONTAINS MAMMOTH HORSE AND SLOTH.	DEVELOPMENT OF SOIL ZONE PLAINVIEW POINTS IN THIS SOIL ?	—
	UNDIFFERENTIATED LATE PLEISTOCENE PRE - SAN JON IN AGE	LACUSTRINE DEPOSITS, LARGELY LIMESTONE UNDIFFERENTIATED	—	FORMATION OF PART OF "COVER" OF THE PLAINS.	DEFLATION OF DEPRESSIONS: DISSECTION OF LOW PEDIMENT AND ESTABLISHMENT OF MODERN BEDROCK GRADE CUTTING OF LOW PEDIMENT DISSECTION OF HIGH PEDIMENT CUTTING OF HIGH PEDIMENT

up to 1 inch in diameter. In some exposures, particularly of the lacustrine phase, pellets of iron-manganese oxide about one-quarter of an inch in diameter are characteristic. Volcanic ash is present at several localities, and mammoth, horse, and giant bison are found in some exposures. Mollusca are common but not diagnostic. Nonpottery cultures are related to the upper part of the formation. The formation may form a terrace within depressions and along streams.

SAND CANYON FORMATION

Good exposures of the lacustrine phase of the Sand Canyon have not been seen. The fluvial phase, however, is a red to brown sandy or silty alluvium containing distinct humic zones of darker tone. In the Valley a set of two humic zones tends to be characteristic. The formation is jointed but not to the same degree as is the San Jon formation. Although calcium carbonate has collected along the joint planes and filled root tubules and worm burrows, it does not form concretions independent of these structures. No extinct animals are known from the formation, and *Bison bison* is characteristic of this and the later Wheatland formation. No pottery has been found in the Sand Canyon but is to be expected from its upper part. Mollusca are again undiagnostic. Along streams it may form a terrace intermediate between terraces of the San Jon and Wheatland formations.

WHEATLAND FORMATION

Exposures of lacustrine deposits of Wheatland age are not known. The fluvial phase consists of a gray, sandy, friable, unjointed alluvium very low in calcium carbonate. It contains *Bison bison* and traces of pottery cultures. Mollusca are present but undiagnostic. It occupies channels cut in the older formations and at favorable localities is preserved as a low terrace a few feet above the modern stream.

SUMMARY OF LATE PLEISTOCENE STRATIGRAPHY OF THE PLAINS

Exposures of Pleistocene beds, although rare within the undrained depressions, are present in fortuitous artificial cuts. Beds of this age are, however, more completely exposed in the breached and dissected depressions along the escarpment.

The following sections and figures summarize the late Pleistocene stratigraphy of selected localities in the vicinity of the San Jon site:

TIPTON CANYON

Immediately southeast of the San Jon site along an abandoned wagon trail into Tipton Canyon (A, fig. 5) the following section is present:

	Feet
San Jon formation.—Sandy to clayey, reddish, compact alluvium. Calcium-carbonate and iron-manganese nodules. Midway in section thinly laminated volcanic ash 4-6 feet thick, petrographically similar to volcanic ash at Son Jon site	50
———disconformity———	
Leached Ogallala formation.—Grades laterally into unaltered lime cemented Ogallala formation. Lower contact obscured	15

GRAPEVINE CANYON

Grapevine Canyon is located about 6 miles southeast of the San Jon site (B, fig. 5). In a gulch on the western side of the Canyon the following section is present:

	Feet
Wheatland formation.—Gray, friable, stream deposits in channels cut into Sand Canyon formation. Little calcium carbonate. Contains *Bison bison*	0–5
———disconformity———	
Sand Canyon formation.—Reddish alluvium occupying channels cut in San Jon formation. Crumbled with difficulty between fingers. Calcium carbonate along joint planes and in root tubules. Scattered charcoal and fragments of charred bone in upper few inches	0–10
———disconformity———	
San Jon formation.—Well-compacted clay sand, silt, and gravel predominately lacustrine. Calcium carbonate locally in concentrations 1 foot thick. One of these contains volcanic ash similar to that of San Jon site. Pellets of iron and manganese oxides $\frac{1}{4}$ inch in diameter	0–40
———disconformity———	
Pleistocene "cap rock."—Fragments of Pliocene "cap rock" recemented by the calcium carbonate	2
———disconformity———	
Leached Ogallala formation.—Buff unconsolidated sand derived by leaching of Ogallala sandstone in place. Lower contact not seen	ca. 100
———angular unconformity———	
Purgatoire formation.—(Cretaceous).	

DEADMAN'S CANYON

At head of Deadman's Canyon which is located between Tipton and Grapevine Canyons (fig. 5) lies a small breached depression. The section is given below and illustrated in figure 10.

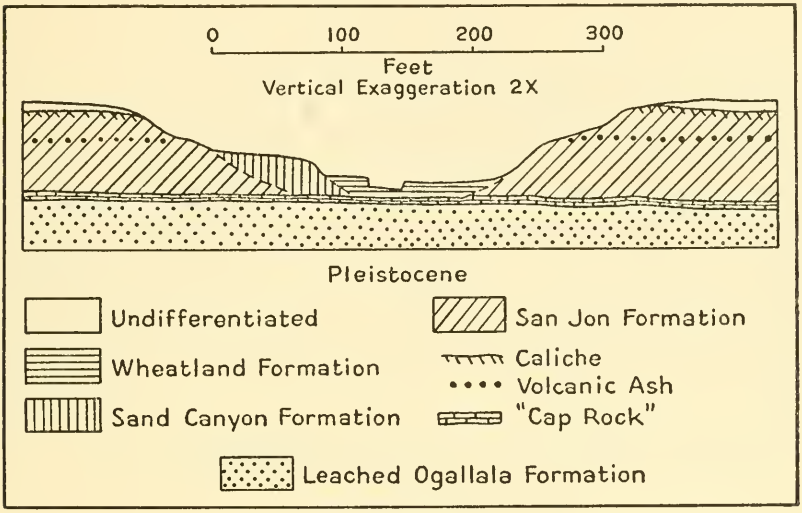

FIG. 10.—Section showing relation of late Pleistocene formations to the Pleistocene "cap rock" and leached Ogallala formation at Deadman's Canyon.

	Feet
Wheatland formation.—Low terrace 3-5 feet above modern grade. Gray friable alluvium, little lime carbonate. Lies in channels cut in Sand Canyon formation	0–5
———disconformity———	
Sand Canyon formation.—Terrace 8-12 feet above modern grade. Reddish alluvium, some lime carbonate. Lies in channels within San Jon formation	0–12
———disconformity———	
San Jon formation.—Terrace 25-28 feet above modern grade. Basal 15 feet red, jointed, compact, stream-laid alluvium with many lime-carbonate nodules up to ½ inch in diameter. Iron-manganese oxides stain joint planes. Upper 10-12 feet somewhat sandier with caliche zone of over 1 foot at top. Lower and upper zones separated by 5-6 inches of volcanic ash similar to that of San Jon site........	0–28
———disconformity———	
Pleistocene "cap rock."—Rubble of fragments from Pliocene; rubble overlain by 1 foot of gray platy limestone as much as 25 feet below general level of "Pliocene cap rock"........	3
———disconformity———	

Leached Ogallala formation..	40

———angular unconformity———

Purgatoire formation.—(Cretaceous).

PUERTO CANYON

Within the reentrant marked C in figure 5 a well-developed Pleistocene "cap rock" crops out from 20 to nearly 50 feet below the general level of the "Pliocene cap rock." At lowest point it is a gray, platy limestone 3 feet thick which grades downward into a massive caliche which in turn overlies 10 feet of unstratified gravels composed chiefly of rounded fragments of "Pliocene cap rock" with a few silicious pebbles from the Ogallala which have wind-fashioned surfaces. This Pleistocene "cap rock" was deposited in a depression now breached. It predates the terrace deposits in Puerto Canyon at the headwaters of Barranca Arroyo described below and shown in figure 11.

	Feet
Wheatland formation.—Deposits of gray friable alluvium, low in calcium-carbonate accumulation and 5-10 feet above modern grade...........	0–5

———disconformity———

Sand Canyon formation.—Deposits of reddish, jointed alluvium with powdery lime carbonate along joint planes. More compact than Wheatland deposits. Forms terrace 30-35 feet above modern grade........	0–10

———disconformity———

San Jon formation.—Deposits forming a terrace about 100 feet above modern grade. Extremely compact, well-developed joint planes stained by iron-manganese oxides. Lime-carbonate nodules $\frac{1}{4}$ inch in diameter in basal section..	0–25

QUEEN CANYON

At point B, figure 1, is a small depression breached and partially dissected by the retreating headwall of Queen Canyon. Within this depression are fluvial deposits thought to be of Sand Canyon and Wheatland age and possibly of San Jon age. Outside of this depression in short drainageways to Queen Canyon three terraces are thought to represent, from highest to lowest, the San Jon, Sand Canyon, and Wheatland periods of alluviation. These relations are shown diagrammatically in figure 12.

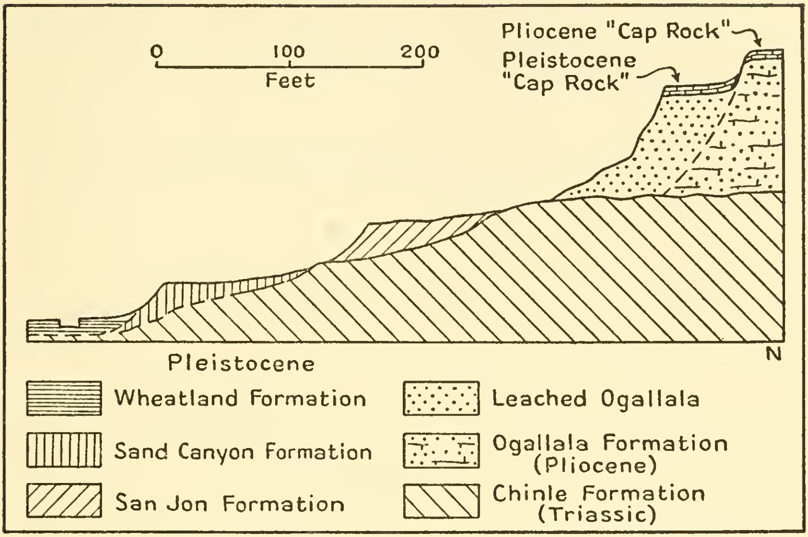

FIG. 11.—Section showing relation of late Pleistocene formation to the "cap rock" and leached Ogallala formation at Puerto Canyon.

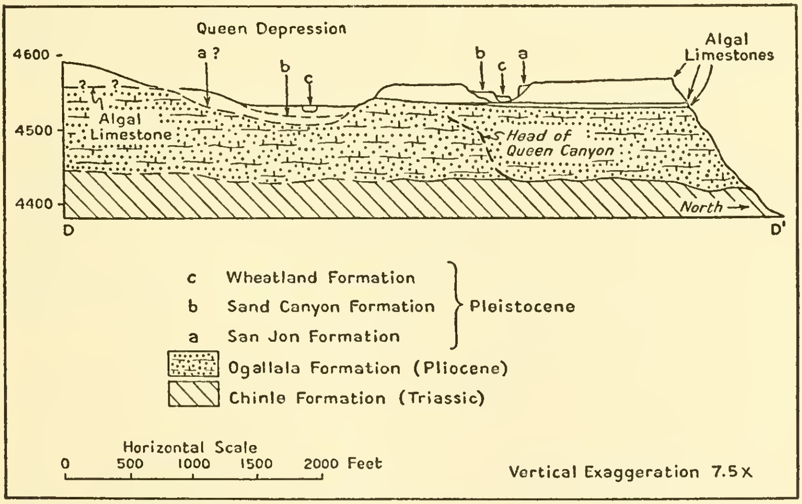

FIG. 12.—Section showing relation of multiple "cap rocks" and late Pleistocene formations to breached depression at the head of Queen Canyon.

LANDRIGAN CANYON

Near the head of Landrigan Canyon at point C, figure 1, 200 yards west of the New Mexico–Texas State line is a small, breached, and partially dissected depression.

	Feet
Wheatland and Sand Canyon formation.—Deposits not present in the depression but found as scattered exposures of stream deposits in the canyon below level of depression.	
———disconformity———	
San Jon formation.—Compact sand and jointed sandy alluvium and clay. Iron-manganese oxides along joint planes. Lime-carbonate nodules up to 3 inches in diameter..	0–27
———disconformity———	
Leached Ogallala formation.—Buff, unconsolidated sand. Upper 12 feet stained with limonite..	75
———angular unconformity———	
Chinle formation.—(Triassic).	

HATFIELD LAKE

West of Grady lies a large elliptical depression having a maximum width of over 4 miles. This major depression, which is over 50 feet in depth, contains three smaller depressions occupied by wet-weather lakes. The largest of the lakes is Hatfield Lake, which covered approximately one-quarter square mile in 1947 and had an elevation of about 4,615 feet. During the exceptionally rainy summer of 1941 the lake spread over an area approximately one-half square mile and rose to a level of approximately 4,625 feet. On the other hand, during the dry years of the 1930's the lake disappeared completely. To the east of Hatfield Lake lies double-crested Delaney Hill, the largest hill within the area mapped. It reaches an elevation of nearly 4,700 feet or about 80 feet above the 1947 level of Hatfield Lake.

During 1947 State Highway 18, which previously crossed the extreme southern portion of the lake on a low viaduct, was rerouted around the southern side of the lake as indicated in figure 13. In so doing several borrow pits and a drainage ditch were opened and an opportunity afforded to examine some of the water-laid deposits around the southern edge of the present lake. Furthermore, a sand pit in the western crest of Delaney Hill exposed eolian deposits considered to represent the erosion intervals separating the beds within the depression.

"Cap rock."—Exposures of "Pliocene cap rock" are present at various points around Hatfield Lake as indicated in figure 5. The limestone varies in elevation and appears to slope toward the center of the depression from all sides. At a locality marked A in figure 13 a quarry exposed "Pliocene cap rock" with a maximum thickness of 3 feet. A platy, almost pure limestone, brown to pink in color, with a botryoidal upper surface and internal concentric banding, overlies a massive sandy caliche not over 2 feet in thickness. One and one-half

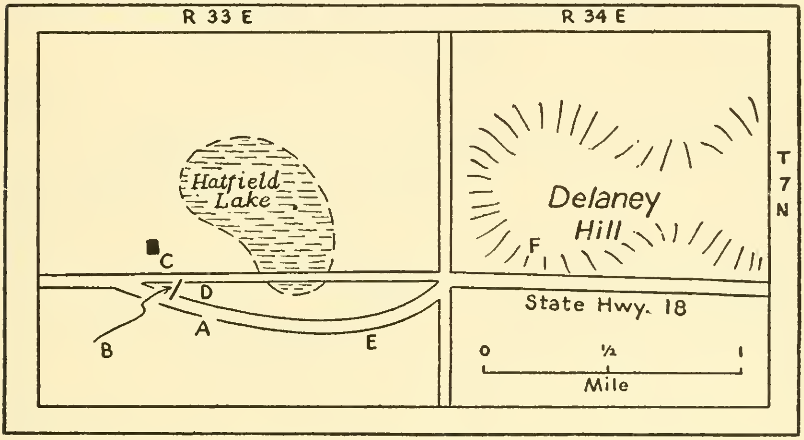

FIG. 13.—Sketch map of Hatfield Lake. Letters refer to localities mentioned in text.

to three feet of sandy, finely laminated and vertically jointed caliche overlies this "cap rock." The caliche contains gray and red irregular blotches, low in calcium carbonate. They have an upper maximum dimension of 2 feet and narrow downward in a manner suggesting solution from above. A gray, friable alluvium 18 to 24 inches thick overlies this caliche. Point A, figure 13, marks the farthest extent of the "cap rock" into the depression. Elsewhere on the slope around Hatfield Lake fragments of "Pliocene cap rock" ravel out on the surface but no vertical sections are present.

Pre-San Jon deposits of Pleistocene age.—Along the line B in figure 13 a run-off ditch from the new road exposes gravel, sand, and clay of Pleistocene age which is overlain by later deposits of the San Jon and Sand Canyon formations as shown in figure 14.

Stream-laid sand and gravel forms the floor of the ditch midway along its length. The gravel ranges in size from one-quarter of an inch to 3 inches in diameter and is composed entirely of rounded fragments of the "cap rock." Some coarse sand and a small percentage of silt-size particles are mixed with the gravel. The deposit was excavated to a depth of 6 feet without reaching its lower limit. Test holes in the immediate vicinity show that the gravel has no great areal extent and suggest that it represents a discontinuous channel deposit. Southward along the trench as shown in figure 14, a heavily calichified sandy clay reaches 7 feet in total exposed thickness. The gravel appears to be laid within a channel cut into this deposit but the relations are obscure.

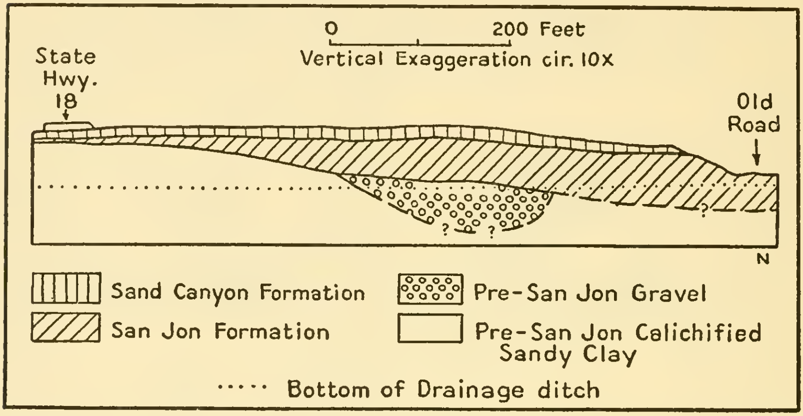

FIG. 14.—Section showing relations of Pleistocene deposits along drainage ditch southwest of Hatfield Lake (B, fig. 13).

San Jon formation.—Disconformably overlying the preceding deposits a greenish clay ranges up to 7 feet in thickness. As shown in figure 14, these beds pinch out to the south. The clay is compact, jointed, and grades upward into a black soil zone 18 to 24 inches thick. Clay films coat the joint planes and calcium-carbonate nodules reach three-quarters of an inch in diameter and are independent of the joint system. Lime carbonate is also present along the joints and in root tubules. Similar deposits were exposed during road construction at points D and E of figure 13. At E, 8 inches of powdery lime carbonate containing volcanic ash and fine sand is present near the base of the exposure. The beds here are about 4 feet thick and overlie a "cap rock." No fossils were found but at point C in figure 13 elephant bones were uncovered several years ago during the excavation of a trench for a water pipe. Additional elephant bones are reported to have been found within the depression approximately 2 miles to the north in beds no longer exposed. These deposits, one of which contains volcanic ash, resemble other lake beds of the San Jon formation with which they are correlated.

Sand Canyon formation.—The Sand Canyon formation is the topmost deposit exposed in the trench at B, figure 13. It averages 2 feet in thickness, as shown in figure 14, and is reddish brown, darkening toward the top. The upper 6 to 8 inches has been disturbed by the plow. The Sand Canyon formation is also present in the trench at locality E, figure 13, where it is 18 inches thick.

Wheatland formation.—The Wheatland formation is present as a thin layer 6 to 18 inches at localities A and E. It is a gray, friable alluvium containing little lime carbonate and in both instances forms the modern surface.

Eolian deposits of Delaney Hill.—Excavations of a sand pit in 1947 in the eastern crest of Delaney Hill (F, fig. 13) showed that Delaney Hill is composed of a series of wind-blown sands separated by soil zones and overlying "Pliocene cap rock." These sands represent periods of deflation within the basin to the west. They were removed from the depression by strong westerly winds during successive arid periods of the past and dumped here to form Delaney Hill. The intervening moist periods during which fluvial and lacustrine deposition in the basin curtailed deflation are recorded in the soil zones at the top of each sand body. The relation of these sand bodies and their capping soils to the deposits within the depression is shown in table 3.

Two feet of black, sandy to silty sand overlies the "Pliocene cap rock," and the weathering which produced this soil is correlated in time with the San Jon formation. Disconformably over this sand lies 17 feet of buff-colored sand. The lower 9 feet of this deposit contains little lime carbonate. Above this are 8 feet of sand high in lime and containing local patches of lime-cemented sand 1 foot in diameter. This zone also exhibits a columnar jointing which becomes more prominent upward. The upper 2 feet of this limey sand changes gradually from buff to red and finally to a dark gray. This is the soil zone equivalent in age to the Sand Canyon formation. The sand on which it is developed represents the arid period intervening between San Jon and Sand Canyon time.

Over the buff limy sand and the soil developed upon it was laid additional eolian material. This is a buff to reddish sand, $1\frac{1}{2}$ feet thick, containing little lime carbonate. At its top it is gray, and this portion is a remnant of an immature soil. In this upper zone artifacts have been found which point to a relatively recent Spanish or immediately pre-Spanish age for the soil. This soil is correlated, in table 3, with the Wheatland formation and the sand on which it is developed with the interval between Sand Canyon and Wheatland time.

A thin skin of loose, unconsolidated, buff to gray sand, 2 to 5 inches thick, lies disconformably above the soil of Wheatland age. This sand is very recent and was blown in part from plowed land to the west and in part from the dried bed of Hatfield Lake and its environs during the "dust bowl" days of the 1930's.

TABLE 3.—*Correlation of soils and wind-blown sand in Delaney Hill with fluvial and lacustrine deposits in Hatfield depression*

Delaney Hill	Hatfield depression	Climate
Modern sand	Deposits of Ephemeral Lake	Dry
Soil	Wheatland formation	Moist
Sand	Erosional disconformity	Dry
Soil	Sand Canyon formation	Moist
Sand	Erosional disconformity	Dry
Soil	San Jon formation	Moist

COVER OF THE PLAINS

The soils and sand deposits of Delaney Hill lie above the "Pliocene cap rock." As such they form a portion of the "cover" of the Plains. Other hills such as those east of Watkins, Best, Owens, Rush, Big Beef, and Big Smith Lakes are similar to Delaney Hill in form and relation to neighboring depressions. They also form a part of this "cover" and probably have histories closely analogous to that of Delaney Hill. In addition to these "sand" hills lying east of the depressions there is an extensive blanket of material which mantles the "Pliocene cap rock." It lacks distinctive physiographic expression but is not uniform in thickness. Data from well logs show that the mantle is almost universally present and ranges up to 40 feet in thickness above the "cap rock." At localities where exposures are available this deposit consists of highly calichified sand with a large percentage of particles of silt and clay size. Distinctive horizons within this "cover" have not been recognized, nor does surface expression assist in a detailed geomorphic evaluation. It seems reasonable, however, to infer that the "cover" of the Plains is largely eolian in origin, that it is post-"cap rock" and Pleistocene in age. One can also infer that it has a long and complex history involving accumulation during periods of aridity and weathering during moist periods and that in general it antedates the late Pleistocene deposits already discussed in some detail.

STRATIGRAPHY OF THE VALLEY

The broad Valley Plains of the Canadian have been described as butting abruptly against the northern escarpment of the Llano Estacado. This Valley, in places 50 miles wide, was cut during the Pleistocene epoch by the Canadian River and its tributaries. The detailed record of valley development is fragmentary, however, and includes only the most recent events in an otherwise long time interval. These events are represented by remnants of gravel-covered pediments lying between the ephemeral streams tributary to the Canadian River, by bodies of stream-laid sediments along these drainages, erosional intervals, and by deposits of wind-blown sand.

The stream-laid deposits repeat in major outline the late Pleistocene stratigraphy already described from the Plains. In general, water-laid deposits of the Valley are the result of alluviation in streams having exterior drainage, whereas on the Plains correlative deposits have been laid down in undrained depressions or in short streams near the escarpment. The deposits of the Valley are more continuous than those of the Plains and exposures are better and more frequent.

PEDIMENTS

Two gravel-topped surfaces are developed across the Triassic Chinle formation, which almost everywhere underlies the Valley. The lower surface, or pediment, forms large segments of the present floor of the Valley, and the modern streams flow within narrow channels carved to a depth of as much as 40 feet below the general level of the pediment.

The higher pediment is preserved along the interfluves of the modern streams and particularly toward the escarpment of the Plains. It has an elevation of 50 to 80 feet above present stream grade, as indicated in figure 15, and is covered by up to 5 feet of gravel derived from local Mesozoic and Pliocene beds. The upper surface is in many places partially obscured by more recent eolian deposits and soils. No attempt has been made to map this pediment or to analyze the nature and pattern of the drainage system which formed it. Nevertheless, the surface represents a long period of planation during which the Canadian River and its tributaries were stabilized at a level much higher than the present. The gravel veneer was deposited by these streams during the final stages of erosion.

The second and lower pediment is approximately 25 to 40 feet above modern stream grade (fig. 15). It has been widely developed at the expense of the higher pediment. This surface marks a second planation when local streams were graded to a level higher than the present but below that of the higher pediments. It, too, is capped by a gravel cover up to 5 feet in thickness which represents the closing stages of planation.

Comparatively narrow inner valleys and canyons have been cut into the lower of the two pediments and form the modern bedrock grades. The Canadian River itself flows in a bedrock gorge incised in places to a depth of 200 feet below the general grade of these tributary valleys. Figure 15 illustrates the relation of the modern bedrock channels of a tributary stream to the remnants of the higher and lower pediments.

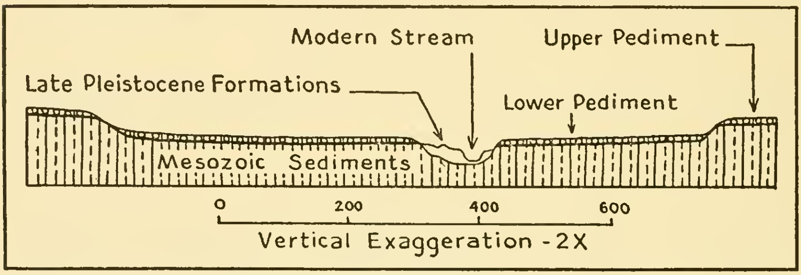

Fig. 15.—Diagram showing relation of pediments and late Pleistocene formations to the modern stream grade in the Valley.

SEDIMENTATION AND EROSION IN THE VALLEY

Within the bedrock channels cut into the lower pediment successive periods of fluvial sedimentation have left their record. The alluvium thus laid down can be divided on the basis of stratigraphic position, lithology, and content into the San Jon, Sand Canyon, and Wheatland formations, bounded in time by epicycles of erosion. During these erosive intervals wind activity was prominent, and today at favorable localities eolian material exists which has been trapped between successive bodies of fluvial deposits. Elsewhere wind-transported sand mantles the interfluves and testifies to the effectiveness of wind action during the epicycles of erosion. These events of sedimentation and erosion correlate with similar events at the San Jon site and elsewhere on the Plains and fall within the time represented by the "Alluvial Chronology" (table 2). Summaries of selected localities are presented below.

FIREPIT ARROYO

In 1941 Roberts carried on excavations in the banks of a small stream just north of the San Jon site in SE¼ sec. 21, T. 9 N., R. 34 E. The stream, here called Firepit Arroyo for the deeply buried hearths there found, is tributary to Sand Canyon which drains the San Jon depression.

	Feet
Wheatland formation.—Gray, friable alluvium, thickest in channel filling in Sand Canyon formation. Little lime carbonate. Wood ash and charred bone and wood in deposit but no artifacts found............	0–6

———disconformity———

Sand Canyon formation.—Reddish-brown sandy and silty alluvium, some gravel lenses. Alluvium compact, jointed and with lime carbonate along joint planes and in root tubules..............................	0–12

Equivalent deposits in nearby Sand Canyon Arroyo contain mollusks identified by the late Frank C. Baker as follows:

Fresh-water species	Land species
Helisoma tenue sinuosum (Bonnet).	*Pupoides marginatus* (Say).
Stagnicola bulimoides cockerelli (Pilsbry and Ferriss).	*Heliodiscus singleyanus inermis* (Baker)
Helisoma plexatum (Ingersoll).	*Succinea grosvenori* Lea.

Two humic zones present here and throughout deposits of this age in the Valley vary between 18 inches and 3 feet in thickness. They are dark brown to black silty to clayey zones with gradational contacts above and below. Locally they contain wood ash and evidence of human occupation. Near site of archeological excavations channel cutting has occurred at some time between the deposition of the two humic zones (see fig. 16). At the archeological site this erosion is represented by blown sand within the formation and between the two humic zones (see fig. 17).

A single projectile point of unknown affinities was found in the lower humic zone with bones of modern bison, antelope, and deer. (Roberts, 1942, p. 12, fig. 2d; pl. 3, fig. 2.)

———disconformity———

San Jon formation.—Discontinuous bodies of a red, extremely compact alluvium, correlated with beds of San Jon age......................	0–3

———disconformity———

Chinle formation.—(Triassic) on which are developed two pediments, one 25 feet and the other 50 feet above modern grade (see fig. 18).

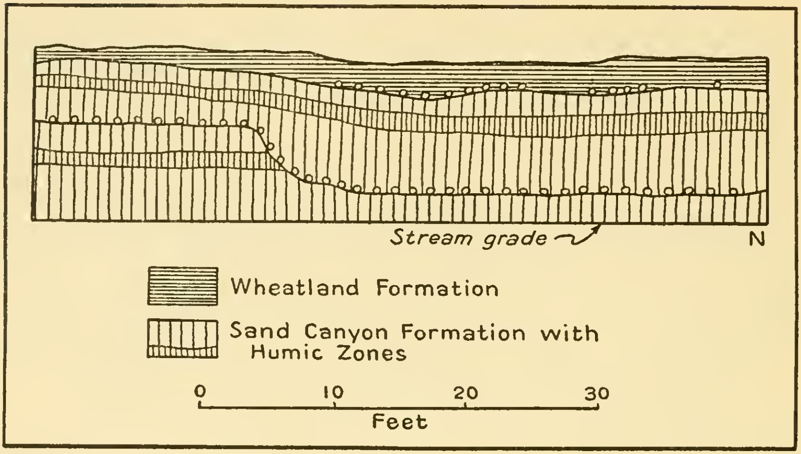

FIG. 16.—Section showing channel cutting intervening between upper and lower members of the Sand Canyon formation in Firepit Arroyo.

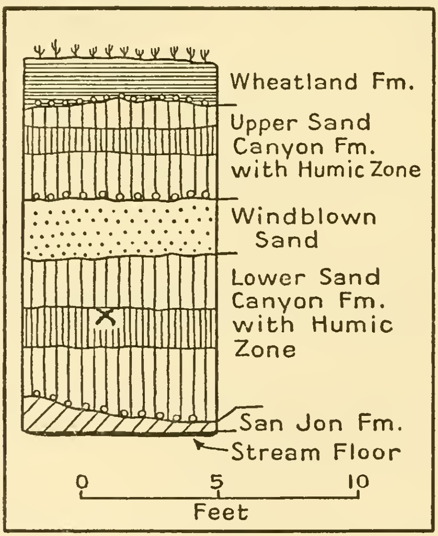

FIG. 17.—Section showing sequence of deposits at the locality of archeologic investigations in Firepit Arroyo. "X" indicates position of artifact and bone material.

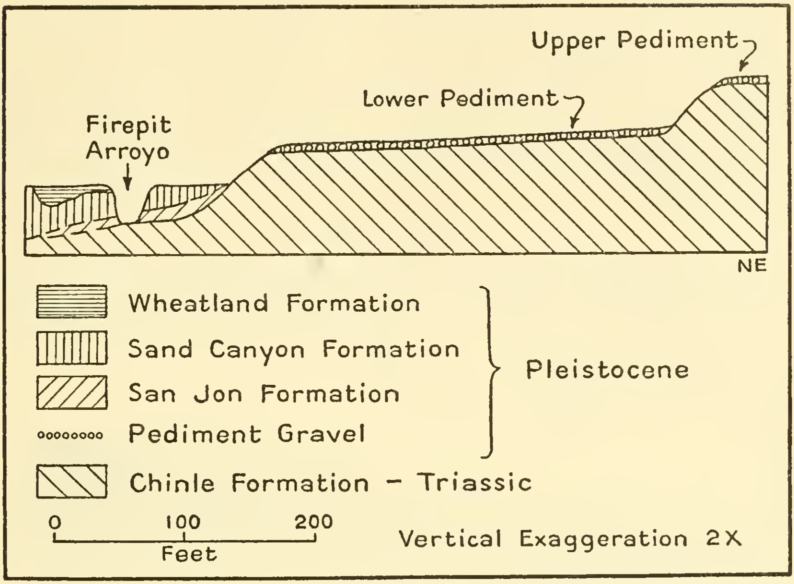

FIG. 18.—Section showing relation of pediments to late Pleistocene formations at Firepit Arroyo.

HODGES SITE

The Hodges site, consisting of two rock shelters, is located along Plaza Larga at point D, figure 1. The geology of the site is reported by Judson (in press) and the archeology by Dick (in press). Here deposits of wind-blown sand are trapped between deposits of Wheatland and Sand Canyon age.[11] This sand represents the erosional interval between Sand Canyon and Wheatland time. Pottery in the sand is dated by Dick (in press) as having a maximum range of A.D. 1150 to 1300.

MESA REDONDA

Excellent exposures of the San Jon formation are present along the eastern foot of Mesa Redonda, an outlier of the plains. They are found in sections 35 and 36, T. 9 N., R. 31 E., along small streams tributary to Barranca Arroyo (see E, fig. 1). The formation is a brick-red, very compact, well-jointed alluvium. Clay films are found along joint planes. Lime carbonate also found along joints as well as root tubules and as nodules averaging one-half inch in diameter.

[11] The San Jon, Sand Canyon, and Wheatland formations are referred to by Judson (in press) as fills No. 1, 2, and 3, respectively.

Deposits are terrace remnants up to 30 feet above modern grade. Bones of extinct animals occur in SW¼NE¼ sec. 35. Nelson J. Vaughan, collecting in 1930 for the Colorado Museum of Natural History, removed parts of several mammoths (4 juveniles and 1 adult), ground-sloth teeth, and the lower jaw of a horse.[12] No evidence of associated human activity was reported by Vaughan or seen by the writer.

BARRANCA ARROYO

Late Pleistocene deposits are well displayed along this arroyo, but the best single cut seen by the writer was found on a small tributary

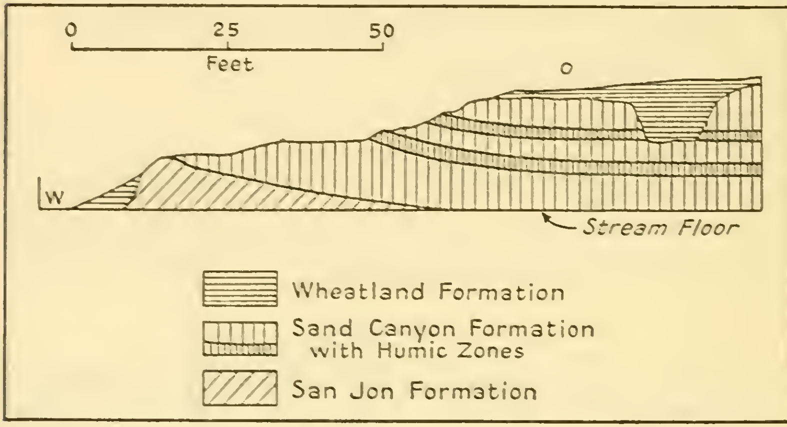

FIG. 19.—Section showing relations of late Pleistocene formations at point F, figure 1.

to the Barranca just north of the escarpment in SE¼ sec. 16, T. 8 N., R. 32 E. (F. fig. 1). The relations of the deposits are shown in figure 19.

	Feet
Wheatland formation.—Gray friable alluvium occupying erosion channels in the underlying Sand Canyon formation	0–10
———disconformity———	
Sand Canyon formation.—Buff to reddish alluvium more compact than Wheatland deposits and has some secondary lime. Two humic zones indicate that upper and lower members are present	0–20
———disconformity———	
San Jon formation.—Brick-red, very compact alluvium. Blotches of secondary calcium carbonate	0–10

[12] Personal communication from H. C. Markham, Colorado Museum of Natural History, dated August 12, 1941.

TUCUMCARI MOUNTAIN

Between Big and Little Tucumcari Mountains (G, fig. 1) the San Jon formation crops out in a low terrace about 15 feet above the present stream grading eastward to Plaza Larga. The terrace is present at various localities along the drainage in which deposits younger than the San Jon are not exposed because of lack of dissection.

The locality is of interest because of the archeological material raveling out of a veneer of wind-blown sand and dust 1 to 2 feet thick which caps the terrace. A large amount of stone material is present. Dr. Frank Hibben, University of New Mexico, has found here both stemmed and barbed points of uncertain affinities.

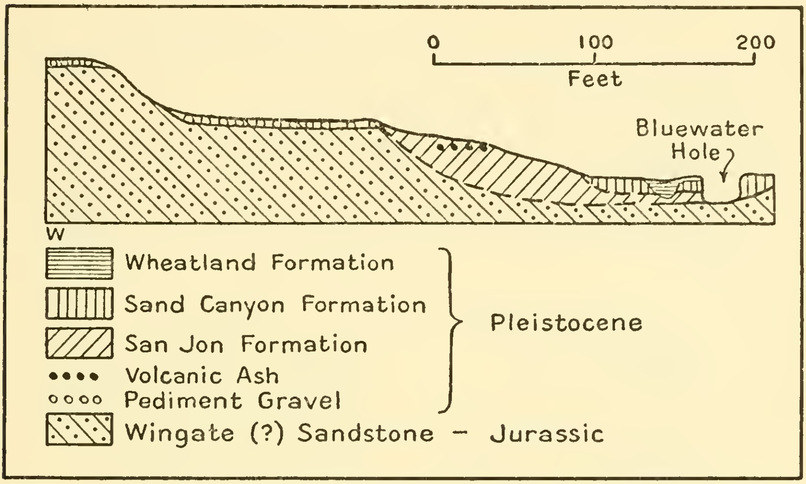

FIG. 20.—Section showing relations of pediments and late Pleistocene formations at Blue Water Hole (H, fig. 1).

BLUE WATER HOLE

Blue Water Hole is located west of Tucumcari (H, fig. 1) along a tributary to Pajarito Creek. The locality is of interest not only because of the presence of two pediments and three late Pleistocene formations but also because of the occurrence of beds of water-laid volcanic ash similar to that described from that of the San Jon formation as shown in figure 20.

	Feet
Wheatland formation.—Gray friable alluvium as fillings of channels cut in the Sand Canyon formation. A single pottery fragment identified by Roberts as "Rio Grande glaze or Kidder's glaze I or Mera's Group A"[13] and dating from the late 14th to early 15th century was found at this locality....................................	0–10

[13] Letter to Kirk Bryan dated October 7, 1942.

Feet

———disconformity———

Sand Canyon formation.—Buff to red, sandy to silty, jointed alluvium. Lime carbonate along joints and root tubules. Two humic zones are present and locally contain wood ash but no artifacts were found. Lower humic zone locally missing suggesting erosion between upper and lower members at this place. Fragments of secondarily derived volcanic ash are present.. 0–15

Mollusks from the formation were identified by the late Dr. Frank C. Baker as follows:

Fresh-water species	Land species
Helisoma anceps (Menke).	*Succinnea avara* (Say).
Sphaerium, valves.	
Pisidium, valves.	

The above forms are to be expected from the area today.

———disconformity———

San Jon formation.—Brick-red, very compact, well-jointed alluvium with lime-carbonate concretions independent of the joint system up to 1 inch in diameter.. 0–?

Mollusks collected from the deposit and identified by Baker are as follows:

Fresh-water species	Land species
Sphaerium, valves.	*Pupoides marginatus* (Say).
Pisidium, valves.	*Gastrocapta cristata* (Pilsbry and Ferriss).
Helisoma anceps (Menke).	*Valonia gracilicosta* Reinh.
Fossaria sp.	*Succinea grosvenori* Lea.

The above represent species to be expected in the area today.

On west side of stream about 30 feet above stream grade is a deposit of white, fine-grained, well-bedded volcanic ash partially cemented by calcium carbonate and reaching 8 feet in thickness. Petrographically similar to the ash at type section at San Jon formation. Here it dips up to 10° SW., which may be original or induced by later subsidence because of evaporite solution at depth. No secondary ash in San Jon deposit along modern stream. Although relations are obscure it is thought that the ash fall was probably during San Jon time.

———disconformity———

Pediments.—Two gravel-topped pediments, one 40 feet the other 80 feet above modern grade, are present as shown in figure.

———angular unconformity———

Wingate (?) sandstone.—A sandstone thought to be Wingate forms the bed rock at Blue Water Hole.

NORTHWEST OF SAN JON

Four and one-half miles northwest of San Jon, U. S. Highway 66 crosses a small valley one-quarter mile in width (I, fig. 1). On the eastern side of this valley is a succession of alluvial and eolian de-

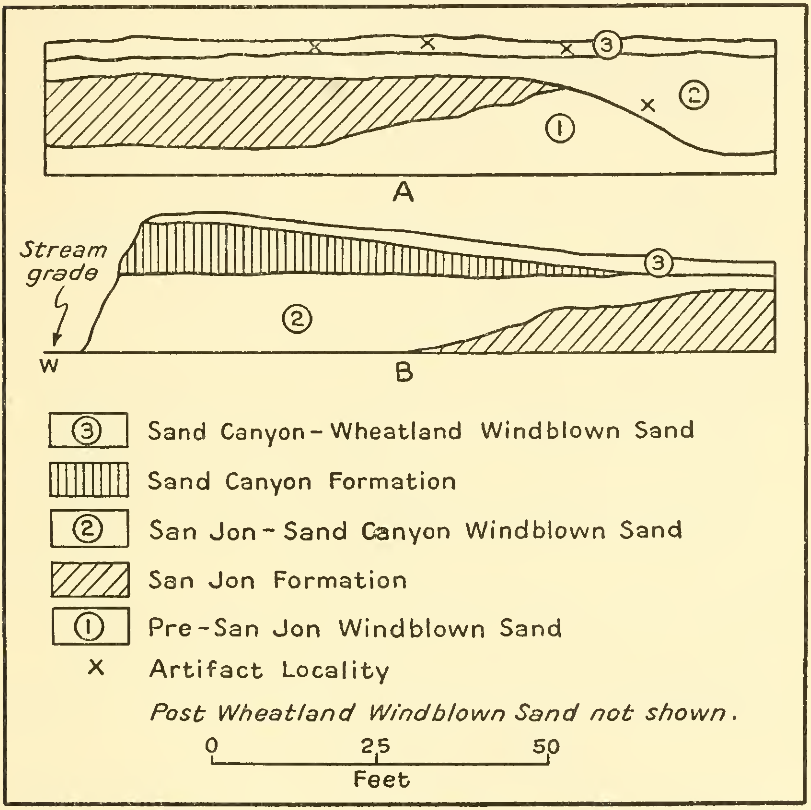

FIG. 21.—Sections showing relations of late Pleistocene deposits at point I, figure 1. A, immediately north of Highway 66; B, 300 yards south of Highway 66.

posits containing both bone and artifacts. The succession is complex and in places obscure. Although the sections presented in figure 21 are believed to be essentially correct, time may produce new exposures which will clarify the interpretation given below and in figure 21.

	Feet
Wheatland formation.—Discontinuous bodies of gray friable alluvium along the modern stream grade. In sections of figure 21 it would be represented as thin gray soil on blown sand #3	0–5

Feet

———disconformity———

Wind-blown sand #3.—Buff-colored loose sand disconformably overlying the Sand Canyon formation and wind-blown sand #2. Thin, immature soil at top represents Wheatland time. Some undiagnostic artifacts from this sand and soil. A small triangular unnotched projectile point of white quartzite not found in place may originally have come from this sand or soil.. 0–3

———disconformity———

Sand Canyon formation.—Reddish compact alluvium with lime carbonate along joint planes and root tubules. Lies disconformably above wind-blown sand #2.. 0–10

———disconformity———

Wind-blown sand #2.—Buff-colored sand laid along eroded surface of San Jon formation and wind-blown sand #1. Sand becomes red toward upper surface. Top 2 inches a soft calcareous sandstone north of highway (section A, fig. 21). Mineralized bone and undiagnostic scrapers found in the sand as indicated.......................... 0–15

———disconformity———

San Jon formation.—Brick-red, jointed, compact alluvium with nodules of lime carbonate up to ½ inch in diameter. Lowest 10 feet of the deposit is clayey alluvium, above this more sandy. North of Route 66 it lies over the wind-blown sand #1. Bases of two projectile points not found in place may have come from upper contact of San Jon with wind-blown sand #2 where some chips were found. One base is Plainview in aspect, the other Scottsbluff-Yuma.................... 0–15

———disconformity———

Wind-blown sand #1.—On the north side of the highway a wind-blown sand lies beneath the San Jon formation. It is red in color, contains a few stringers of clay, and is partially cemented by lime carbonate. Base not seen.. 0–10

EOLIAN MATERIAL UNRELATED TO ALLUVIUM

In the above discussion bodies of wind-blown sand intimately related to the late Pleistocene fluvial deposits have been described. In places this sand intervenes between the fluvial formations and represents part of the wind work during the periods of erosion which separate the periods of alluviation. Wind-blown sand in such position is, however, rare. The great bulk of wind-transported material occurs in dune fields and as a discontinuous veneer on the interfluves. Most of the sand actually moving today is located along the eastern side of stream channels and in scattered patches in the largely stabilized dune fields. Modern sand movement in the dune fields is largely due to activation of old sand dunes by injudicious attempts at farming.

Near the streams, however, sand is blown out of dry channels and piled along the lea or eastern banks. The supply of sand thus derived is renewed by each of the floods of the stream. Only renewed aggradation and filling of the channels with alluvium will diminish the supply of sand and provide opportunity for vegetation to stabilize the dunes. Not only does this sand move onto the interfluves and their sandy cover, but it also reactivates old dunes both by smothering vegetation and erosion of the old dunes because of grain-to-grain impact of the new sand on the old. The sand of the recent geologic past must have been derived also from dry stream beds, and this sand must have assisted in the activation of previously formed dunes.

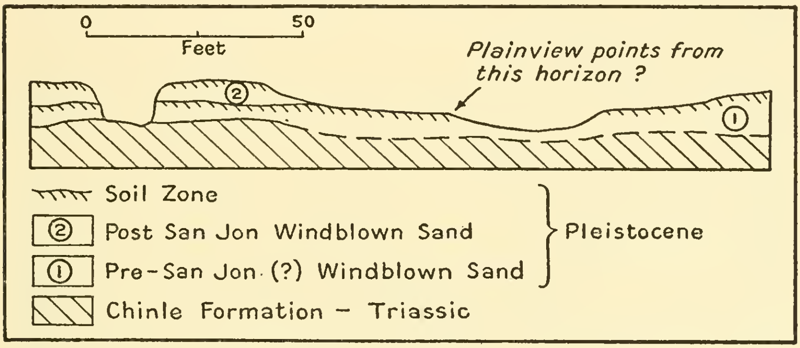

FIG. 22.—Section showing relations of wind-blown sand deposits and soil zones at Gibson ranch (J, fig. 1).

The fact that there are dunes now moving and also stabilized dunes indicates at least two periods of sand movement. The partially dissected dunes have a complex internal structure consisting of bodies of sand capped by soil zones. Thus stabilized dunes were formed in more than one period.

Gibson site.—On the ranch of Roy Gibson, approximately $3\frac{1}{2}$ miles northeast of San Jon are several blowouts in a large dune area which show this complex internal structure (J, fig. 1).

In a blowout one-quarter of a mile east of the Gibson ranch house are two sands each with a soil zone at their upper surface. The oldest sand overlies red Triassic shale of the Chinle formation and forms the floor of the blowout. It has a known thickness of 5 feet. The sand is red, contains lime-carbonate concretions 1 inch in diameter, and carries a brown to black soil zone 2 to 3 feet thick at its top as shown in figure 22. Gibson has found three points identified by Roberts [14] as Plainview, raveling out of this old soil. A careful

[14] Personal communication dated February 13, 1948.

examination of the blowout produced no additional artifacts of similar type, although a few fragments of mineralized but unidentifiable bone were found in the soil horizon.

Over the lower sand lies 2 to 8 feet of buff to brown sand comparatively free of lime. It grades upward into a darker red at its top, a change in color undoubtedly due to soil-making process and indicating an old surface of stabilization. Spread over this upper sand is a discontinuous blanket of buff to white sand up to 12 inches in thickness.

Additional artifacts described by Roberts [15] as of comparatively recent age or of undiagnostic nature have been found in the blowout.

Eastward from this locality for about 2 miles are several additional blowouts which contain old bodies of wind-blown sand and each with a soil zone at its upper limit.

Blowout north of San Jon.—Two and three-quarter miles north of San Jon (K, fig. 1) State Highway 39 skirts a blowout in which are exposed two bodies of wind-blown sands. On the west side of the road there is exposed a buff to red sand 1 to 5 feet thick. It has a high lime-carbonate content, a considerable content of silt, and is capped by a lag gravel a few inches thick and composed of ironstone, quartzite, and sandstone pebbles. Above the lag gravel lies a sand of reddish color and small calcium-carbonate content. Its top supports a 12-inch zone of gray to black humic sand, an old soil zone, which is in turn overlain by recently deposited sand. On the east side of the highway, in the main excavation of the old sand, the blowout exposes this upper sand and its soil stands as a small ledge below the modern sand as shown in plate 5, figure 2. Presumably the lower sand was deposited in the San Jon–Sand Canyon interval and the upper sand in the Sand Canyon–Wheatland interval.

Other localities.—Two wind-blown sands predating the present have been seen at several other localities. Along Sand Canyon Arroyo (SE¼NE¼ sec. 17, T. 9 N., R. 34 E.) a gray to white unconsolidated sand 5 to 7 feet thick overlies 3 feet of reddish silty sand. The older sand supports a vertical bank and at its top is a soil zone. The upper sand has a soil zone which carries the modern vegetative cover. Multiple eolian deposits are also present in the dune field east of Tucumcari Lake, east of Logan on the north side of the Canadian River and in various road cuts along U. S. Highway 66 as far east as Oklahoma. In none of these localities are there criteria by which the ages of the wind-blown sands may be determined.

[15] Idem.

Five miles east of San Jon on the Gilstrap ranch (NE¼SE¼ sec. 8, T. 10 N., R. 35 E.) pottery has been found in a modern blowout. This pottery, according to Roberts, probably dates from the late fourteenth or early fifteenth century. It may date from the deposition of the sand but more probably is correlative with the gray to brown soil developed at the top of this sand after its deposition and during Wheatland time.

SUMMARY

The foregoing discussions and summary tables of Pleistocene stratigraphy demonstrate that the sequence described from the San Jon site has a geographic extension well beyond the boundaries of the site. Although the deposits of a basin like that of the San Jon site are limited in area and cannot be traced outside the basin in which they were deposited, they reflect events which were neither singular nor unique but which obtained over a large area of the High Plains and the Valley Plains of the Canadian. Similar events in the same time intervals are recorded throughout the Southwest.

Fresh-water limestone and the formation, in part at least, of the "cover" of the Plains antedate the oldest Pleistocene horizon at the San Jon site. Pre-San Jon events in the Valley include the formation and dissection of a pair of gravel-covered pediments. Because these events cannot be fixed in time precisely and because they do not bear directly on the antiquity of the site, they will not be further considered.

The "Alluvial Chronology," which begins with San Jon time, is more important, however. A reexamination of table 2 will serve to fix it more firmly in the mind. In the Valley successive periods of alluviation in stream valleys are represented by the San Jon, Sand Canyon, and Wheatland formations. On the Plains lacustrine deposits of equivalent age collected in undrained depressions while alluvial phases of these deposits were laid down around the peripheries of these basins and in short streams draining to the escarpment. These periods of sedimentation were separated by epicycles of erosion. Valley streams incised their channels into previously deposited alluvium and took on an aspect very similar to the modern arroyos. Concurrently winds whipped sand and dust from the dry stream beds to form dunes on the interfluves and to reactivate stabilized dunes existing from an earlier time. Deflation predominated in the depressions of the Plains and loose material was piled up east of the depressions, and either added to the featureless "cover" of the Plains or removed entirely from the area. Where short drainages flowed to the escarpment events duplicated on a small scale those of the Valley.

THE "ALLUVIAL CHRONOLOGY"

The brief events of the "Alluvial Chronology," mere incidents in earth history, are unspectacular when viewed against the immense span of geologic time. Nevertheless, they coincide with the human occupation of the area from the time of the Paleo-Indian to the present. As such, these various events of the chronology are of intimate concern to the archeologist and demand a more careful examination. Thus it is important to consider the cause of alternate sedimentation and erosion and their wide distribution in the Southwest, and to discuss the relative age of the sequence of episodes.

CAUSES OF ALTERNATE SEDIMENTATION AND EROSION

The steep-walled, sandy-bottomed gullies of the ephemeral streams tributary to the Canadian River have characterized the Valley for the last half century. Previously, however—that is, from the time that the Spanish first crossed this country almost to the arrival of the first homesteaders—these streams had a much different aspect. Where today the deep gullies of the modern streams scar the valley floors, there were once smooth, grassy flood plains marked by shallow stream channels or quiet water holes, the *charcos* [16] of Spanish days. Vertically walled gullies, scarcely passable by foot, much less by horse or mule, today lie across the old Spanish trail which led from Santa Fe to San Antonio and crossed the streams of the Valley just north of the escarpment (fig. 1). In 1853 an exploratory survey seeking a route for a railroad to the Pacific and led by Lt. A. W. Whipple, U.S. Army Corps of Topographical Engineers, followed this trail quite closely. Whipple (1856) states that the "Arroyo de Barrancas" was a "flowing stream" and that "the water, tinctured with red marl, was about two feet deep and six feet wide." He also reports the presence throughout the Valley of springs, pools of water, and stream bottoms bordered by groves of trees and green meadows, but no gullies are mentioned. In 1885 George Kilgore settled in the Valley before any gullies marked the tributary streams of the Canadian.[17]

[16] *Charco,* meaning stagnant pool of water, is still the name applied to a stream, tributary to the Plaza Larga, which must have been named by the Spanish before its present channel was scoured out. Arroyo Charco no longer has a *charco.*

[17] The writer is indebted to Wayne H. Miles of the Soil Conservation Office, Tucumcari, for the information on recent channel cutting gathered by him from the first American settlers in the area.

In January 1903, the *Quay County Democrat,* a weekly paper published in the vigorous frontier town of Tucumcari, eulogized "springs and pools of water" along the valleys which drained to the Canadian "across a billowy meadow unending." [18] But this eulogy was truly funereal for a wave of erosion was already sweeping over the "billowy meadow" and leaving deep, red, ugly gashes as it went. T. L. Reid passed through the country in 1902 and found that the Plaza Larga was channeled west of what is now Highway 18 and that Charco Arroyo, a tributary, was cut to a distance of 3 miles beyond this point. Returning in 1905, Reid found that the Charco had been channeled for another 9 miles upstream, and he reports that by 1910 the gully had reached the escarpment, 8 miles farther. According to Robert Abercrombie, the Barranca Arroyo was badly eroded when he arrived in the Valley in 1904, but local stockmen told him at the time that a few years previously it was unchanneled. Bull Canyon, a tributary to the Pajarito west of Tucumcari, began to cut its channel in 1908 or 1909. Fifty years ago Ute Creek, entering the Canadian from the north, was a permanent stream. According to Mosé Romero, who has lived his entire life in the area, the Ute was rapidly eroded and became intermittent in flow about 1904. Specific information is lacking for many streams. But, in general, rapid erosion swept up the major tributaries of the Canadian sometime around 1900, slightly earlier in some instances, and a bit later in others.

The cause of this sudden change in stream regime is in dispute. It of course could be effected by a change of gradient through tilting of the land downstream. Huntington (1905) and Hack (1942) have pointed out that orogeny so nicely adjusted to the drainage pattern is inconceivable and that it is completely unacceptable as a prime cause of erosion. Nor is it possible to believe that periods of sedimentation were the result of the reversal of such warping. Furthermore, sedimentation and wind erosion within the depressions on the Plains and correlative in time with filling and trenching in the streams of the Valley can in no way be explained by differential warping of the land.

As pointed out by Hack (1942) the explanation of the steepened stream gradients necessary to produce erosion must be a result of a change in the transporting power of the streams because of an increased rate of discharge. He further argues that this increased discharge is due not to increased precipitation but to a decrease in the effectiveness of the vegetative cover. Thus rate of run-off is increased by a thinned and weakened plant cover and erosion follows.

[18] *Quay County Democrat,* vol. 2, No. 19, p. 1, Saturday, January 16, 1903.

Disagreement arises as to the manner in which the vegetation is weakened. A change in climate toward the dry to a degree sufficient to decrease the amount of grass would in itself start an erosion interval. On the other hand, it is argued that overgrazing and improper cultivation of the land is a more reasonable cause of erosion than a change in climate (Antevs, 1952). This second argument can be applied with some justification to the Valley. The modern epicycle of erosion began just before a wave of homesteaders displaced large herds of longhorn cattle. Erosion continued while these same homesteaders overworked land holdings too small for their needs. The apparent cause-and-effect relationship between injudicious land use and erosion is very persuasive and climatic change as a cause of gullying in this area might be logically untenable were it not for the record of the past.

The climate during San Jon time was moister than it is today. The very presence on the Plains of lakes of some permanence points to either increased precipitation or decreased evaporation. Even the existence of large and now-extinct animals indicates a better vegetative cover. It is inconceivable that a mammoth could survive on the meager vegetation and surface water of today, and its presence in San Jon time indicates a lusher plant cover thriving in a climate effectively "moister" than the present. The subsequent epicycle of erosion was obviously drier, for wind-blown sand dates from this period and an old dune system thought to be of equivalent age is found throughout the area.

It has been shown that the depressions of the Plains are excavated by deflation during periods of aridity and that these dry periods are separated by moist periods during which lakes exist in the basins. Deflation of the basin containing Hatfield Lake occurred both during and after the deposition of the Sand Canyon formation. It must be assumed that a moist climate obtaining during Sand Canyon time was preceded and followed by a more arid climate. In the Valley deposition in Sand Canyon time healed the old channel scars and presumably occurred in a moister climate than that of the preceding erosion interval.

Douglass's tree-ring chronology, as summarized by Schulman (1938), shows four major droughts since A.D. 11. The greatest of these occurred between A.D. 1276 and 1299, or immediately preceding the epicycle of erosion separating the Sand Canyon and Wheatland formations. It seems logical to presume that this drought precipitated the erosion which spanned most of the fourteenth century.

The same tree-ring record shows that a fifth drought, perhaps of major proportions, began in 1880, and Bryan (1925) has shown that the last half of the nineteenth century was unusually dry and culminated in the present epicycle of erosion everywhere in the Southwest after 1880.

More recently Leopold (1951) has analyzed the frequency of rainfall as recorded at long-record weather stations in New Mexico. He has shown that, although the variation in the total annual rainfall has been slight during the last 100 years, the variation in the frequency of rains of differing sizes has been significant. Thus in the early part of the last 100 years New Mexico experienced a low frequency of small rains. Such rains provide the main moisture for grass growth. Therefore a low frequency would tend to weaken the grass cover and make the ground susceptible to erosion.

During the last half of the nineteenth century the frequency of rains of intermediate size was slightly higher than the present and the frequency of large rains about the same. These are the rains that, because of rapid run-off, promote erosion. They would be most effective during periods of low frequency of small rains. Here then is a factor that would encourage erosion which began in this area about 1900 and elsewhere in the Southwest about 15 years previously.

Thus the immediate geologic past has been marked by periods of erosion during dry climates and by intervening periods of more effective moisture during which sedimentation occurred. The modern epicycle of erosion, while perhaps abetted by misuse of the land, has probably been largely conditioned by increasing aridity. In all likelihood man has merely hastened an inevitable period of stream channeling.

In the preceding discussion aridity has been correlated with erosion and increased moisture with sedimentation. During the latter half of the "Alluvial Chronology," however, it is quite probable that variation in the frequency of rains of different sizes as well as increases in evaporation rates due to rising temperatures did more to promote aridity and hence erosion than did decreases in the total precipitation. On the other hand, the San Jon formation, as will be seen later, is correlated in part with glacial advance in more northerly latitudes. Under such conditions the belt of cyclonic westerlies must have been displaced southward by a more southerly polar front than now exists. The now arid and semiarid Southwest may very well have enjoyed a greater actual precipitation as a result.

DATING THE EVENTS OF THE "ALLUVIAL CHRONOLOGY"

The Sand Canyon–Wheatland epicycle of erosion, the Wheatland formation, and the modern channel cutting can be dated by archeologic and historical methods. Thus the modern gulches date from the turn of the last century. The Wheatland formation has yielded a single fragment of late fourteenth- to fifteenth-century pottery, and pottery thought to come from a soil equivalent to the Wheatland is of the same age. Pottery and artifacts dated as falling somewhere between A.D. 1150 and 1300 have been found in eolian deposits of the Sand Canyon–Wheatland interval. Probably the erosive interval occupied the greater part of the fourteenth century, and the Wheatland formation began to collect about 1400. Alluviation was initially rapid until the old channel was filled and the stream reached grade. Thereafter, and until the onset of the modern erosion, sedimentation was for all practical purposes nonexistent. The Sand Canyon–Wheatland interval also provides an upper date for Sand Canyon time, A.D. 1300. The upper part of the Sand Canyon formation, therefore, must have occupied a part of the Christian era.

The artifacts and fossils from the Sand Canyon and San Jon formations are of little help in precise dating. The hope is that eventually the artifacts, at least, will be well enough defined to serve as definite time markers. Until then the earlier events of the "Alluvial Chronology" must be dated by some other means. Included would be the use of the climatic argument, pollen analysis, and the newly developing technique of dating by radiocarbon. These three approaches are used in the following discussion.

The climatic argument is based on the assumption that the deposits containing evidence of man's presence reflect events which have a wide geographic extension related to world-wide climatic fluctuations which in themselves can be assigned dates in terms of actual years.

It has already been seen that the "Alluvial Chronology" is developed throughout the area here studied and that the sequence at the San Jon site is related to it. This same chronology is reported across the Southwest from the Big Bend of Texas to the Hopi Country of Arizona, as shown in tabular form in table 4. The climatic pulsations represented by these various periods of sedimentation and erosion can be tied by argumentation to the already dated events of glacial advance and retreat in North America and Europe. Such a correlation involves the following assumptions: (1) That late Pleistocene climatic fluctuations are world-wide and synchronous, and (2) that they are expressed in the geologic record. The discussion to date has demonstrated that man at the San Jon site is related to a local sequence and that this sequence has climatic implications and a wide geographic extension. It is assumed from this point that the local record and its southwestern equivalents are correctly interpreted and reflect world-wide and synchronous climatic changes susceptible to a dating in terms of years. What, then, are the phases of this world-wide chronology, what are the dates, and how do they relate to the "Alluvial Chronology"?

In general and oversimplified terms the last major advance of continental and mountain glaciers throughout the Northern Hemisphere has been followed by an increase in heat to a maximum well in excess of our present temperatures. From this point of maximum warmth temperatures dropped, a trend which has continued, with minor interruptions, to the present.

The central section of this climatic curve, the period of great warmth following upon the last deglaciation, occupies a key position in dating the "Alluvial Chronology." This intensification of heat, this Megathermal Phase, is recorded throughout Europe and the United States and is the "Postglacial optimum" of many writers.[19]

Dates are assigned the Megathermal Phase by pollen analysis, salt concentration of southwestern lakes, and the newly developing method

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[19] "Postglacial optimum," although widely used, is not a satisfactory designation for this time period. "Postglacial" is obviously inappropriate because we are still in the Pleistocene, an epoch characterized by recurrent glacial advances and retreats. "Optimum" here refers to the most favorable growth conditions for a temperate flora. As such it is applicable to much of Europe where increased temperature combined with greater moisture. Throughout the United States, however, and probably throughout much of the rest of the world, the increase in warmth was not accompanied by increased moisture. In the American Southwest increased temperature produced aridity, and conditions favoring a temperate flora were at a minimum. Furthermore, "optimum" is a superlative and implies a single point in time and we wish to designate a period of time which includes this point.

An acceptable term, therefore, would eliminate the concept of "Postglacial," would include the fact that increased heat is the only universally present climatic change, and would avoid the use of a superlative.

Antevs (1948), in discussing this problem of nomenclature, has suggested "Altithermal" to replace "Postglacial optimum" and his old "Middle Postglacial" (Antevs, 1931). It is here suggested that "Megathermal" would be more correctly derived, having both roots in Greek (μεγα = great or large, and θερμός = heat). For a period or periods of minimum heat Oligothermal (ὀλιγο = least, and θερμός = heat) is immediately available.

Megathermal is used below combined with "Phase" to avoid the obvious inappropriate use of "age" or "period."

TABLE 4.—*Correlation of the "Alluvial Chronology" and human cultures from selected localities in the Southwest*

EVENTS	EASTERN NEW MEXICO JUDSON		HIGH PLAINS OF WEST TEXAS HUFFINGTON & ALBRITTON (1941) EVANS & MEADE (1945) †		BIG BEND. TEXAS ALBRITTON & BRYAN (1939) KELLEY, CAMPBELL & LEHMER (1941)		HOPI COUNTRY, ARIZONA HACK (1942.1945)		WHITEWATER DRAW, ARIZONA SAYLES AND ANTEVS (1941) ▲●	
EROSION AND WIND ACTION *	MODERN DUNES MODERN CHANNEL CUTTING	SINCE 1910 SINCE 1900	MONAHANS FM. (UPPER PART) MODERN CHANNEL CUTTING O	PRESENT ACTION PRESENT ACTION	MODERN CHANNEL CUTTING	SINCE 1885 ?	MODERN DUNES MODERN CHANNEL CUTTING	PRESENT ACTION SINCE 1910 +	MODERN CHANNEL CUTTING	SINCE 1885 ?
DEPOSITION NO. 3	WHEATLAND FORMATION	AFTER 1400 ± A.D.	LOW TERRACE O AND RECENT FILL		KOKERNOT FORMATION	CHISOS FOCUS 800 – 1400 A.D.	NAHA FORMATION	AFTER 1300 A.D.	DEPOSITION OF UPPER SILTS	POTTERY CULTURE AFTER 1300 A.D.
EROSION AND WIND ACTION	CHANNEL CUTTING ON STREAMS DEFLATION OF SOME DEPRESSIONS	PROBABLY 1300 – 1400 A.D. HUNTING-GATHERING CULTURE	MONAHANS FM. (MAIN BODY) CHANNEL CUTTING O		CHANNEL CUTTING	LIVERMORE FOCUS	EROSION AND POSSIBLY SOME WIND ACTION	AFTER 1200 A.D. BEFORE 1500 A.D. PROBABLY ABOUT 1300 A.D.	BROAD CHANNELS CUT	AFTER 1200 A.D. POTTERY
DEPOSITION NO. 2B	UPPER SAND CANYON FORMATION	IN PART LATER THAN 1 A.D.	INTERMEDIATE TERRACE O AND RECENT FILL		UPPER CALAMITY FORMATION	PECOS RIVER FOCUS ?—?—?—?	TSEGI FORMATION (B)	OCCUPATION OF UNKNOWN AGE	CLAY AND SAND	SAN PEDRO STAGE 2463 ± 310
EROSION AND WIND ACTION	CHANNEL CUTTING WINDBLOWN SAND ×	DATE UNKNOWN			EROSION ?		POSSIBLY EROSION	2000 B.C. ± ?	BROAD CHANNELS CUT	
DEPOSITION NO. 2A	LOWER SAND CANYON FORMATION	CLEAR FORK (?) "COLLATERAL" YUMA — AFTER 3500 - 2000 B.C.			LOWER CALAMITY FORMATION	SANTIAGO COMPLEX	TSEGI FORMATION (A)		CLAY AND SAND	CHIRICAHUA STAGE 4006 ± 270
EROSION AND WIND ACTION	CHANNEL CUTTING SAND DUNES DEFLATION OF DEPRESSIONS	OCCUPATION OF UNKNOWN AGE BETWEEN 5400 AND 2000 B.C.	JUDKINS FM. O CHANNEL CUTTING (MEGATHERMAL PHASE)		WIND ACTION BROAD CHANNELS CUT (MEGATHERMAL PHASE)	MARAVILLAS COMPLEX	DUNES CHANNEL CUTTING	"POST-GLACIAL OPTIMUM" (MEGATHERMAL PHASE)	BROAD CHANNELS CUT (MEGATHERMAL PHASE)	
DEPOSITION NO. 1	SAN JON FORMATION	BEFORE 5400 - 5000 B.C. SAN JON POINT FOLSOM POINT ? PLAINVIEW POINTS? *ELEPHAS, BISON TAYLORI, EQUUS.*	HIGH TERRACE O LATE PLEISTOCENE FILL TAHOKA CLAY	PLAINVIEW △ POINTS *ELEPHAS, BISON TAYLORI, EQUUS.*	NEVILLE FORMATION	NO KNOWN OCCUPATION *ELEPHAS, EQUUS.*	JEDDITO FORMATION	PRIOR TO 6000 B.C. ? NO KNOWN OCCUPATION *PROBOSCIDEA*	CLAY SILT SAND AND GRAVEL	SULPHUR SPRINGS STAGE 6210 ± 450 7756 ± 360 *EQUUS, ELEPHAS, CAMELOPS, ETC.*

† IN PART REINTERPRETED * LACUSTRINE DEPOSITION CONTINUES WITHIN UNDRAINED DEPRESSIONS O ALONG EASTERN MARGIN OF PLAINS

× NOT REFLECTED AT SAN JON SITE △ SELLARDS ET AL.. (1947) ▲ IN PART REINTERPRETED ● RADIOCARBON DATES FROM LIBBY (1952) of radiocarbon. The pollen method needs no amplification here. Two studies are of prime importance, however. Both claim an absolute value in terms of our calendar. In 1938 Fromm was able to tie his pollen study to Liden's varve sequence in Lake Ragunda in Sweden and thus construct an absolute chronology extending from 6700 B.C. to A.D. 900. He considered that the Megathermal Phase began about 5000 B.C., reached a peak about 4200 B.C., and ended with a degeneration of climate commencing about 3500 B.C. Welten (1944) has studied the pollen in a Swiss bog that contains annual laminations from 7550 B.C. to A.D. 1920. His pollen profile shows a Megathermal Phase extending from perhaps 5400 B.C. and certainly 5000 B.C., reaching a thermal maximum at 4300-4200 B.C., and ending about 3200 B.C.

Van Winkle (1914) concluded that certain undrained lakes in the Great Basin came into existence about 2000 B.C. Antevs (1948) arbitrarily adds 500 years to this figure and considers that 2500 B.C. is terminal for the Megathermal Phase.

The development of the radiocarbon technique holds great promise of adding exactitude to dates in the late Pleistocene throughout the world. Numerous radiocarbon dates have already been released (Libby, 1952). The writer is not in a position to evaluate the exactitude of the dates or the method. Undoubtedly future work will refine the method and encourage more accurate and extensive collection of usable material. Several dates are referred to below with the realization that additional work may demand their revision.

Of the radiocarbon dates thus far available a single determination applies directly to the Megathermal Phase. A peat sample from this horizon at Shapwick Heath, Somerset, England, gave an age of $6{,}044 \pm 380$ years before the present. This agrees with the dates reported by Welten and Fromm.

The epicycle of erosion separating the San Jon and Sand Canyon deposition is the most extensive erosional in the "Alluvial Chronology." The evidence also indicates it to be the warmest and incidentally the driest in the chronology. Therefore it is correlated with the Megathermal Phase.

The Megathermal Phase precedes Sand Canyon time and defines its lower limit. We have already seen that Sand Canyon time ended with an erosional interval which occurred in the fourteenth century A.D. Therefore Sand Canyon time, and hence the Sand Canyon formation, must have begun as temperatures fell from their highest during the Megathermal Phase and continued to the fourteenth century A.D. The lower limit of Sand Canyon time corresponds to the end of the Megathermal Phase, a date which is as yet unfixed and probably varied from place to place. The dates given in a preceding paragraph suggest that it ended between 3500 and 2000 B.C.

The "Alluvial Chronology" of southeastern Arizona has been reported by Sayles and Antevs (1941). Radiocarbon dates have since been obtained within this chronology. The San Pedro cultural stage reported by Sayles and Antevs is here considered in part contemporaneous with Sand Canyon time. A single radiocarbon date in this cultural stage is listed as 2,463±310 years (Libby, 1952). This is within the limits suggested above for Sand Canyon time. A radiocarbon date from the Chiricahua cultural stage is listed as 4,006±270 years. The Chiricahua stage is stratigraphically below the San Pedro and is separated from older beds by a well-marked erosional interval here presumed to represent the Megathermal Phase. Thus the Chiricahua stage is considered to fall within Sand Canyon time. The radiocarbon date is within the limits previously suggested for Sand Canyon time.

It has been shown that the Sand Canyon formation is double and that a period of erosion splits the formation. An erosional interval of deposits here correlated with the Sand Canyon formation is reported from southeastern Arizona (Sayles and Antevs, 1941), from northeastern Arizona (Hack, 1942), from western New Mexico (Leopold and Snyder, 1951), and from Trans-Pecos, Texas (Albritton and Bryan, 1939).

One of the difficulties arising in considering the age of the San Jon formation is the lack of adequate exposures. No guarantee exists that the sediments assigned a San Jon age do not actually represent several stages of alluviation separated by intervals of erosion. In any event the end of San Jon time has been defined by the beginning of the Megathermal Phase or between 5400 and 5000 B.C. Lacking definite evidence to the contrary, San Jon time is considered as uninterrupted by epicycles of erosion.

San Jon time was relatively cool and moist. Because of this and because it preceded the Megathermal Phase it is correlated in part with a time when glacial climate obtained to the north. It is reasonable that this time was marked by either the Corral Creek or Long Draw substages of the Rocky Mountains (Bryan and Ray, 1940) and represented elsewhere on the North American continent by the Late Mankato (St. Johnsbury) or Cochrane (?) substages, respectively. The writer knows of no evidence in eastern New Mexico or elsewhere in the Southwest which would indicate with which substage the earliest formation of the "Alluvial Chronology" is correlative.

Very probably, however, San Jon time covers both glacial substages and the climatic oscillation which separated them is not reflected in the "Alluvial Chronology."

Radiocarbon dates of the Two Creeks forest beds, Wisconsin, average 11,404±350 years (Libby, 1952). This forest bed is of the same age as the advance of the Valders (Mankato) ice at Two Creeks about 100 miles north of its terminus near Milwaukee. Therefore its maximum stand is younger than the Two Creeks forest bed by some unknown amount. Because the Valders ice produced no marked terminal moraines or outwash plains it is not thought to have stood long at its maximum advance (Thwaites, 1943). The exact age of its maximum advance, however, does not affect this discussion. San Jon time includes the advance, maximum, and retreat of the Mankato ice and the Cochrane stand up until the beginning of the Megathermal Phase between 5400 and 5000 B.C.

Furthermore, a radiocarbon date from a horizon near Lubbock, Tex., regarded as Folsom by E. H. Sellards, Grayson Meade and Glen L. Evans, is given as 9,883±350 years (Libby, 1952). This date falls well within the interval suggested for San Jon time and is about 1,500 years younger than the arrival of the Valders ice at Two Creeks, Wis. This ice continued another 100 miles to the south before reaching its greatest advance.

Radiocarbon dates from the Sulphur Springs culture of southeastern Arizona (Sayles and Antevs, 1941) are given as 7,756±370 and 6,210±450 years. The sediments in which the culture is entombed are here considered correlative with the San Jon formation. The latter date seems a little young. If correct, it points to a somewhat later beginning for the Megathermal Phase than here suggested.

In the preceding discussion the Sand Canyon formation is considered to represent a slightly cooler and moister time following the Megathermal Phase, and San Jon time to represent a cool, moist period preceding this Megathermal Phase and spanning both the Mankato and Cochrane ice maxima of the north. Another possibility exists, namely, that the San Jon formation is correlative with the Mankato ice advance, the Sand Canyon formation is equal in time to the Cochrane advance, and the erosive interval separating them reflects withdrawal of ice between Mankato and Cochrane advances. Future work may prove such a correlation but on the basis of the evidence now at hand, it is discarded because: (1) The interval separating San Jon and Sand Canyon time was marked by great aridity, wind action and erosion; (2) this desert climate was so marked that it seems doubtful that it is a reflection of the minor climatic oscillation separating the Mankato and Cochrane ice maxima, but only of the major increase in warmth during the Megathermal Phase; (3) certain facts suggest that the Sand Canyon formation lies at least partially in the Christian Era; and (4) the time from the Mankato climax to the present is best filled by considering the Sand Canyon formation as deposited after the Megathermal Phase.

The dates of the various events of the "Alluvial Chronology" in eastern New Mexico are included in table 2. The events in eastern New Mexico are correlated in table 4 with similar events elsewhere in the Southwest.

GEOLOGIC ANTIQUITY OF THE SAN JON SITE

GENERAL STATEMENT

The discussion contained in the preceding section, although detailed and laborious, has set the stage for a consideration of the antiquity of the San Jon site. Archeologic investigations by Roberts (1942) established four distinct cultural levels at this site. From oldest to youngest these contain: (1) A point termed San Jon in association with extinct bison; (2) points called "Collateral" Yuma having affinities to both Eden and Scottsbluff-type Yuma, but in association with modern bison; (3) points related perhaps to the Clear Fork type of West Texas and also associated with modern bison; and (4) an obviously more recent group of artifacts with associated pottery. The relative stratigraphic positions of these four levels as set forth by Roberts is confirmed by geologic methods. More precise ages for the three earlier levels than can be inferred from their cultural and faunal content are suggested below.

THE SAN JON LEVEL

The single San Jon point was found near the top of the San Jon formation. This formation reflects a cool, moist climate partially correlative in time with the presence of glacial ice in northern United States and southern Canada. Its deposition began with the first stages of Mankato ice advance. San Jon time continued to the beginning of the Megathermal Phase at 5400 to 5000 B.C. and perhaps slightly later.

Because the San Jon point comes from a level high in the formation, it is probably late in San Jon time. Because it was found in deposits indicating continuing moisture it is probably older than the stage immediately preceding the Megathermal Phase. A classic-type Folsom point was discovered at the site raveling out of a level correlative with that in which the San Jon point was found and is thus similar in age to the San Jon point. This San Jon point lies in time between the Two Creeks forest bed, 9454 B.C. ± 350 years (11,404 ± 350 years before the present), and 5400 to 5000 B.C.

The Plainview points found on the Gibson ranch in the Valley bear an uncertain relation to the San Jon point. They are said to have come from a soil zone which is developed on wind-blown sand. This soil may have formed in San Jon time, in which case the Plainview points could be more or less contemporaneous with the San Jon point. In this regard it is appropriate to note that the Plainview points at the type locality (Sellards et al., 1947) are found in association with extinct bison and at the top of a fluvial deposit correlated with the San Jon formation. (See table 4.)

"COLLATERAL" YUMA LEVEL

A long period of time separates the people who made the San Jon point, and presumably the Folsom point, from those who fashioned the "Collateral" Yuma projectiles found in the next youngest cultural level. During this period the climate of San Jon time became increasingly warmer and drier, until it ended with the beginning of the Megathermal Phase between 5400 and 5000 B.C. This phase was a time of great aridity in which moving sand was common throughout the area and stream erosion was rampant. At the site the depression containing the lake sediments of San Jon age was breached by a stream eating headward into the escarpment from the valley below and broad channels were carved in the San Jon formation. At some time between 3500 and 2000 B.C. the Megathermal Phase ended and the deposits of the Sand Canyon formation began to fill the old stream channels at the site. The giant buffalo, failing to survive the arid Megathermal Phase, was replaced by the smaller modern bison. A people using "Collateral" Yuma projectile points hunted this new arrival and the points are found associated with the bones of *Bison bison,* in the earliest deposits of Sand Canyon time. The occurrence of the "Collateral" Yuma points indicates a maximum age of between 3500 and 2000 B.C. for the people who made them. Whatever the exact age it must lie early in Sand Canyon time shortly after the end of the Megathermal Phase.

The above dates are assigned on the assumption that the Sand Canyon formation was deposited subsequent to the Megathermal Phase. If, as previously discussed, the Sand Canyon formation antedates the Megathermal Phase, then a much earlier date for the

"Collateral" Yuma points is indicated. The same is true in relation to the Clear Fork (?) points discussed below.

CLEAR FORK (?) LEVEL

In deposits of Sand Canyon age but at a level stratigraphically higher than that containing "Collateral" Yuma points are projectiles bearing affinities to those of the Clear Fork complex of West Texas. They must be younger than the "Collateral" Yuma and older than the end of Sand Canyon time, i.e., A.D. 1300. A more precise age is difficult to determine. The break in Sand Canyon time recorded in the Valley below is not reflected at the site, or, if it is, has not been identified. Therefore, the Clear Fork (?) cannot be placed in relation to this horizon. Furthermore, Kelley's review of the Clear Fork (1947) indicates that it occurs throughout deposits correlative with the Sand Canyon formation. The Clear Fork (?) points, therefore, are younger than the "Collateral" Yuma points. They are older than A.D. 1300 by an unknown interval of time.

POTTERY LEVEL

The stone cultures associated with pottery were found in trenches excavated in the gentle slopes east of the deep gullies of the San Jon site and cannot be directly tied to the "Alluvial Chronology." Roberts (1942), however, dates the pottery as late as the fourteenth or early fifteenth century A.D. On this basis the material is probably of early Wheatland age.

GENERAL CONSIDERATIONS

The single most interesting fact gleaned from the geologic investigation is the relatively late date of "Collateral" Yuma and its relation to the much older San Jon and Folsom levels. Sellards has reported (1950) that the Yuma points of the Clovis–Portales region 45 miles south of San Jon are stratigraphically above the true Folsom and the Clovis-fluted points. The Yuma points found at the San Jon site are of a younger age than that usually assigned to this type of projectile. Radiocarbon, for instance, dates the Yuma of the Horner site, near Cody, Wyo., as $6,867 \pm 250$ years (Libby, 1952). Moss (1951) states that at the Eden site, Wyoming, the Yuma predates the Megathermal Phase. On the basis of the available evidence there is little doubt, however, that at San Jon they postdate the Megathermal Phase and are separated by a considerable time span from the earliest cultural level at the site.

The physical evidence also tends to demonstrate that if this Yuma evolved from one or more of the earlier stone cultures then this evolution has not been accomplished in the vicinity of the site. The break in time between San Jon and Yuma peoples is too great. Furthermore, it is marked by extreme aridity which both man and beast must have found inhospitable. We do not know whether man roamed the deserts which intervened between San Jon and Sand Canyon times, but if he did it is safe to assume that his numbers were small. Certainly the giant buffalo did not survive the interval and was replaced by the modern, smaller form. The horse and mammoth, also present in San Jon time, were extinct by Sand Canyon time.

Dates have been applied to the prepottery cultures of the San Jon site with the full realization that they lack precision. This inadequacy is due in part to the uncertain nature of the dates of the late Pleistocene climatic fluctuations, and in part to the lack of distinctive intraformational horizons in San Jon and Sand Canyon time. Nevertheless, these dates seem of the correct order of magnitude, and the relative chronologic positions of the various cultures appear firmly established.

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