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ALLUVIAL CHRONOLOGY OF THE TESUQUE VALLEY, NEW MEXICO¹

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ABSTRACT

Two Recent alluvial terraces are well developed along Rio Tesuque downstream from the limits of the Sangre de Cristo Range. The high terrace, which stands 18-20 feet above the present stream, is a prominent surface $\frac{1}{4}$ - $\frac{1}{2}$ mile wide. The low terrace, which stands 8-10 feet above the stream, occupies a narrow strip adjacent to the channel. Charcoal from a depth of 13 feet in the high-terrace alluvium yielded a radiocarbon date of $2,230 \pm 250$ years. Deposition of high-terrace alluvium had ceased by A.D. 1200-1250, as indicated by the presence of datable pottery in the upper portion of the alluvium and by the dates of Pueblo sites built on the high terrace. Computations based on this chronologic information suggest that rates of sediment production during the period of high-terrace deposition were similar in magnitude to modern rates in this area.

INTRODUCTION

Beginning about 1880, many alluvial valleys in the arid and semiarid portions of the western United States experienced a period of accelerated erosion. According to eyewitness accounts, spectacular incision and lateral cutting by streams produced wide, deep trenches or arroyos where a short time previously there had been arable floodplains traversed by stable channels carrying perennial flow.

It was only natural that the serious economic consequences of this sudden erosion should lead to investigations aimed at an understanding of the causative factors involved, such information being an obvious prerequisite for sound planning of remedial measures. The present consensus of opinion seems to be that the accelerated erosion which began about 1880 was caused in part, and perhaps wholly, by poor land management, especially overgrazing and deforestation. The approximate coincidence of erosion with settlement might lead to the reasonable conclusion that misuse of the land was the sole cause, were it not for the fact that this same recent phase of erosion exposed a stratigraphic record interpreted by several geologists as indicating earlier periods of erosion and deposition. Because these earlier events clearly could not have been related to agriculture and other human activities, a more general explanation of

erosion and deposition based on natural causes is required.

Attempts to evaluate the relative magnitudes of natural versus human agencies as causative factors in the alluvial histories of western valleys led to a controversy that is still unresolved. The considerable differences of opinion which exist are partly due to variations in interpretation of the same information and partly the result of different philosophic approaches to the problem. One group (Bryan, 1925, 1941; Hack, 1942; Judson, 1953; Leopold and Miller, 1954; etc.) believes that the stratigraphic evidence indicates as many as three periods of deposition, separated by intervals of erosion. Furthermore, the deposits themselves and their contained flora and fauna, plus the approximate synchronism of erosional and depositional events over a tremendous area, seem to require an explanation involving fluctuations in climate. However, this group admits that the latest episode of erosion probably was "triggered" by misuse of the land. The opposing group (Bailey, 1935, 1941; Thornthwaite *et al.*, 1942; and others) emphasize the role of human activities in causing accelerated erosion since 1880. This group does not find conclusive evidence in the alluvial deposits for earlier distinct periods of erosion and deposition. Rather, they believe that deposition and erosion occurred more or less simultaneously in restricted valley segments, through formation of fans composed of sediment eroded from

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discontinuous gullies immediately upstream. Furthermore, erosion and deposition are believed to have occurred under conditions which included climatic fluctuations of no greater magnitude than those experienced today.

This report describes alluvial deposits in the Tesuque Valley near Santa Fe, New

Mexico. Archeologic investigations which preceded construction of a new segment of highway (the so-called "Tesuque bypass") led to discovery of a site (designated as LA-3297) where hearths and associated artifacts were buried deep in the alluvium. As will be shown by subsequent discussion, archeologic materials from this site and

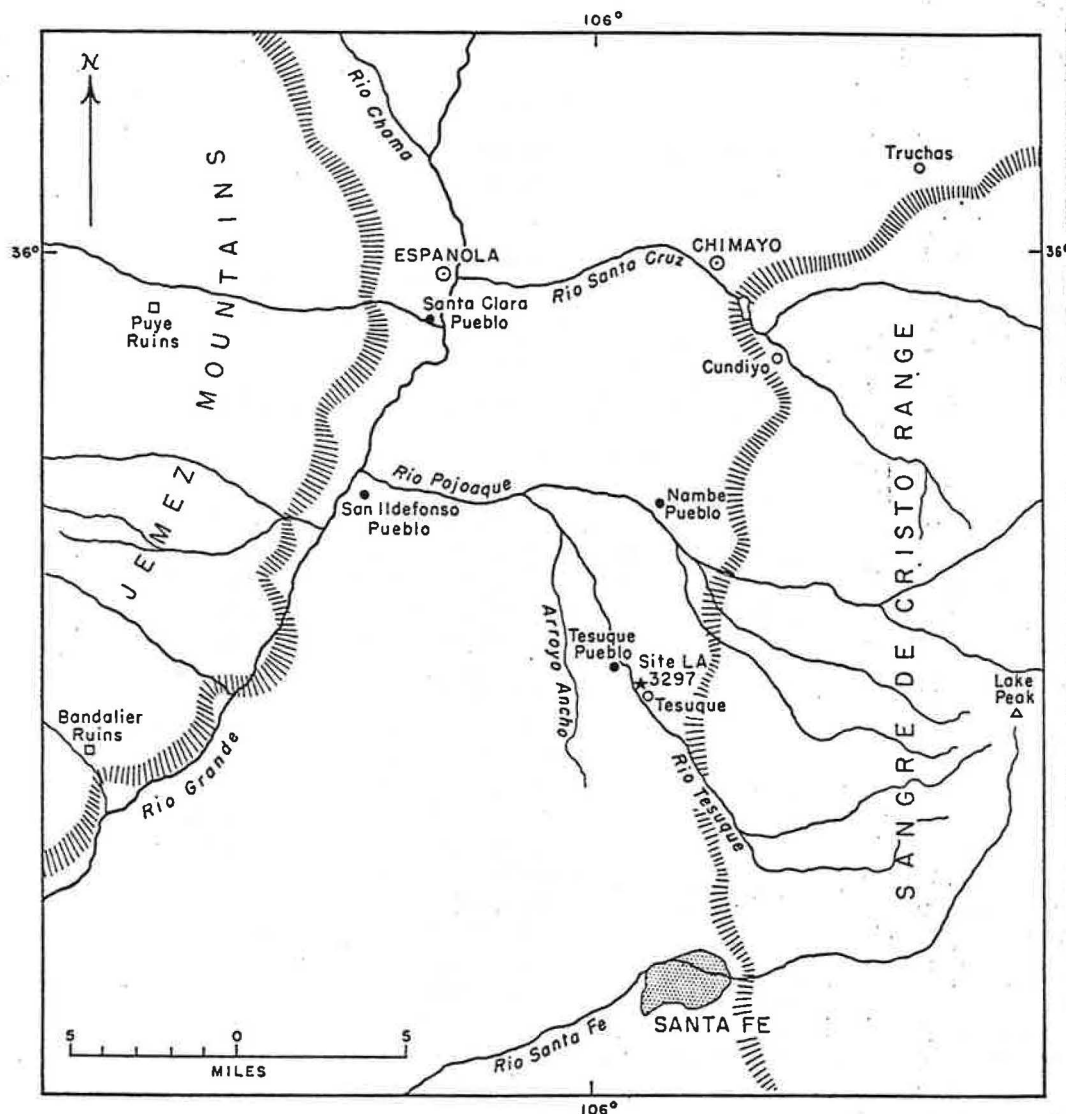


FIG. 1.—Location map, showing relation of the Tesuque Valley to geographic features of the region

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others nearby provide the principal basis for establishing rather precisely the alluvial chronology of the entire valley.

PHYSICAL SETTING

The Tesuque Valley is located in north-central New Mexico a few miles north and northeast of the city of Santa Fe (fig. 1). Rio Tesuque heads on the western slope of the Sangre de Cristo Range and flows into the Pojoaque River, which, in turn, is tributary to the Rio Grande. Topographic maps of the Rio Tesuque drainage basin (on a scale of 1:24,000 with 20- and 40-foot contour intervals) include the following 7½ minute quadrangles: Aspen Basin, McClure Reservoir, Tesuque, Santa Fe, Cundiyo, Horcado Ranch, and Espanola.

In the area considered here, the Sangre de Cristo Range dominates the landscape and presents a striking contrast to the adjacent lowlands of the Rio Grande depression. Viewed from a distance, the mountains appear to form a steep, nearly straight escarpment, rising abruptly above an extensive plain which slopes gently toward the Rio Grande. Actually, the mountain front is quite irregular in plan-view, but it is sharply defined topographically by low hills, which rise from the 7,500–8,000-foot level. Eastward the mountains rise gradually to altitudes of nearly 13,000 feet. The lowland at the foot of the mountains is not a smooth plain but rather is laced by a close network of deep stream channels and in places has typical "badlands" topography.

Boundaries of the Sangre de Cristo Range and the Rio Grande depression are well defined geologically as well as topographically. This portion of the range is underlain by granite of pre-Cambrian age, whereas slightly consolidated silt, sand, and gravel deposits of the Miocene-Pliocene Santa Fe formation underlie the Rio Grande depression.

The drainage basin of Rio Tesuque is divisible into two roughly equal parts, characterized by strikingly different properties which are related to both topographic

and geologic factors. The upper portion of Rio Tesuque is a typical high mountain stream flowing in a deep, narrow canyon. At the mountain front, the character of the stream and its valley changes markedly. The deep canyon ends abruptly at the limits of the granite bedrock, and changes in the stream channel are no less striking. Over a distance of only 1–2 miles, there is a transition from perennial flow in a channel only 10 or 15 feet wide to an arroyo more than 100 feet wide.

The alluvial deposits, which are the subject of this report, are confined almost entirely to the lowland portion of the valley. Either deposition did not occur in the narrow canyons of the upper valley, or subsequent erosion has removed all traces of alluvium.

The climate of the Tesuque Valley is generally similar to that in other portions of the southern Rocky Mountains, in that its most striking feature is variation with altitude. During summer, hot days and cool nights are the rule in the lowlands; temperatures in the mountains are lower by amounts which depend on altitude. Precipitation exceeds 30 inches in the mountains, but averages 15 inches or less in the low country. Slightly more than half of the total annual precipitation occurs during the summer rainy season, generally as brief, though intense, afternoon thunderstorms.

Vegetation in this area reflects especially the effects of climatic zonation and to a lesser extent the effects of bedrock geology. The mountainous portion of the Rio Tesuque drainage basin is covered with forest trees, mostly pine at intermediate altitudes and aspen-fir-spruce at the higher levels. In the lowland part of the valley (underlain by the Santa Fe formation) the natural vegetation consists of piñon, juniper, sage, cacti, and grasses, which make only a sparse cover. Large cottonwood trees grow at several places along the banks of Rio Tesuque.

The Tesuque Valley is one of the many localities in the northern Rio Grande Valley

occupied by Pueblo peoples for hundreds of years. As can be seen in figure 1, Tesuque Pueblo is only one of several modern pueblos in this area.

ALLUVIAL DEPOSITS AND TERRACES

Throughout its length downstream from the mountain front, Rio Tesuque is flanked by terraced alluvial deposits which occupy a valley $\frac{1}{4}$ – $\frac{1}{2}$ mile wide. Plate 1, *A*, shows typical relations of alluvial features to the modern arroyo. The broad terrace surface shown in this photograph can be traced along the valley with no discontinuities, and there is also a lower terrace which is not obvious in plate 1, *A*. The alluvium is well exposed, both in the nearly vertical terrace escarpments along Rio Tesuque and in the cut-banks of numerous minor tributaries.

Description of alluvium.—The alluvial deposits in Tesuque Valley are composed largely of light tan silt and sand, with scattered lenses and stringers of gravel. A typical exposure along Rio Tesuque is shown in plate 1, *B*. Locally, there are bands of silty clay which in most cases are dark gray in color; however, such bands extend laterally only a few hundred feet. Almost everywhere the alluvium is highly calcareous and effervesces freely with acid. At most places, however, blotches and nodules of caliche are not readily apparent.

The alluvium resembles the Santa Fe formation closely enough that in places there is some difficulty in locating the contact between them. These two units are almost identical in color, but the Santa Fe formation contains more gravel layers and generally is more consolidated than the alluvium.

An unconformity separates the high-terrace deposits from those which underlie the low terrace. A definite cut-and-fill relationship can be seen at many places along the valley (see pl. 1, *B*). The low-terrace alluvium is considerably coarser than that of the high terrace.

Soils on both terrace surfaces are skeletal in character, columnar structure being the only indication of profile development. No evidence of buried soil profiles was found anywhere in the valley.

Terraces.—An alluvial terrace is a remnant of a former floodplain; its origin involves deposition at a time when the stream flowed at a higher elevation than at present, followed by later downcutting. Several periods of alternate erosion and deposition may produce a great variety of stratigraphic and topographic relationships (see Leopold and Miller, 1954, p. 4–6).

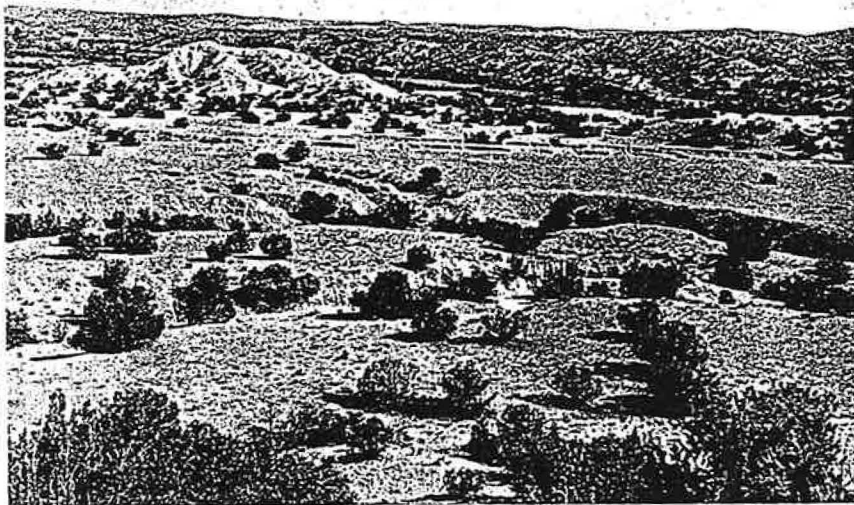
Identification of two terraces in the Tesuque Valley is a very simple matter because the terrace surfaces can be traced along the length of the stream with practically no breaks in continuity. Furthermore, exposures are sufficiently numerous that stratigraphic relations of the deposits underlying different terraces can be seen clearly.

The high terrace in Tesuque Valley stands 18–20 feet above the present channel, and the low terrace 8–10 feet above the present channel (fig. 2). The high terrace is by far the more prominent of the two, not only because of its greater height but also because of its much larger areal extent (see cross section, inset of fig. 2). The low terrace occupies a narrow strip on either side of the present channel. Using the terminology of

PLATE 1

A, Tesuque Valley near Camel Rock, approximately 4 miles downstream from Site LA-3297. High-terrace surface in foreground is cut by numerous deep gullies. Low hill in left middle ground is a residual of Santa Fe formation completely surrounded by alluvium. The channel of Rio Tesuque is to the right of this hill. The brush-covered area in the background is the Santa Fe formation. A lower terrace not seen in this view is present near the stream channel.

B, Alluvial terraces in Tesuque Valley approximately 5 miles downstream from Site LA-3297, showing cut-and-fill relation between the coarse, sandy alluvium of the low terrace and the silty, banded alluvium of the high terrace.



A



B

Tesuque Valley

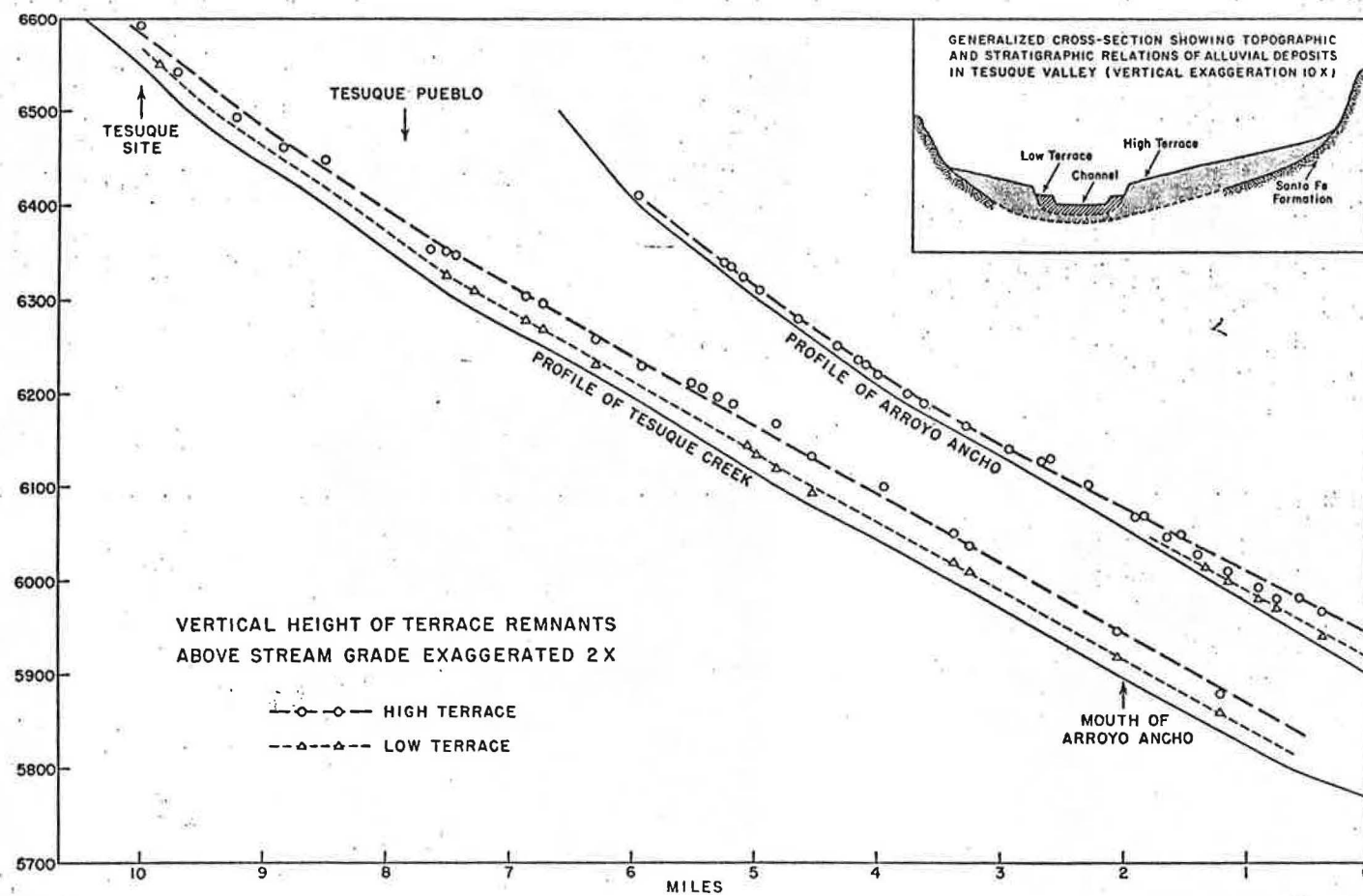


FIG. 2.—Profiles of alluvial terraces in the Tesuque Valley. Plotted points are field measurements of terrace height

Leopold and Miller (1954), this is a two-fill, two-terrace alluvial valley, with the younger fill having an inset relation to the older fill.

Arroyo Ancho, the only major tributary of Rio Tesuque which drains an area entirely in the lowlands, also shows two terraces. As indicated in the profile of figure 2, these terraces can be traced to a junction with their counterparts along Rio Tesuque. However, both terraces, decrease in height upstream, and the low terrace extends only 2 miles above the mouth of Arroyo Ancho.

As shown in the cross section (*inset*, fig. 2), the high terrace has an appreciable slope toward the valley axis, which apparently is the result of slope wash from the nearby hills. The effects of a sloping terrace surface are readily apparent in the profile (fig. 2), on which field measurements of terrace height are plotted. The departures from a constant, uniform height above the present stream are the result of differences in channel width. Obviously, the wider the channel cut into a sloping terrace surface, the greater will be the terrace height. However, the approximate altitude of the stream during a period of deposition can be reconstructed by projecting the sloping terrace remnants on either side of the valley to the point of intersection. It should be noted in figure 2 that the low terrace along Rio Tesuque, which does not slope toward the valley axis, stands at a uniform height above the present stream.

Terraced alluvial deposits in the Tesuque Valley indicate the following sequence of events: (1) deposition of the high-terrace fill, (2) erosion, (3) deposition of the low-terrace alluvium, and (4) modern erosion.

CHRONOLOGY OF THE ALLUVIAL SEQUENCE

Artifacts and other evidences of occupation by man provided the essential data for establishing chronologic relations of alternate erosion and deposition in the Tesuque Valley. Most of the known archeological remains are pithouse villages and pueblos located on the surface of the high (18-20-foot) alluvial terrace or on the crests of nearby hills underlain by the Santa Fe

formation. Several of these sites have been excavated, and, although the final reports of the findings are not yet published, they have been summarized by Stubbs (1954), Wendorf (1954), and Wendorf and Reed (1955). From these excavations and others conducted in adjacent valleys, the sequence of occupation has been reconstructed.

Pottery occurs generally as broken fragments, both on the surface and buried at the various sites, and provides more definite chronologic information than other kinds of artifacts. Through many years of study it has been possible to classify Pueblo pottery into several reasonably distinct types and to estimate rather accurately the period of manufacture of each type. Dates are derived from tree-ring methods for the older types and from historical records of various kinds for the more recent types. The beginning and terminal dates of the period of manufacture of decorated pottery found in the Tesuque Valley can be placed fairly accurately, that is, within 50 years or less. The approximate time ranges of the various types are listed in the accompanying table.

	A.D.
Kwahe's Black-on-white.....	950-1200
Santa Fe Black-on-white.....	1200-1300
Wiyo Black-on-White.....	1275-1400
Abiquiu Black-on-white (Biscuit A)....	1350-1450
Bandelier Black-on-white (Biscuit B)...	1425-1625
Sankawi Black-on-cream.....	1500-1625
Tewa Polychrome.....	1625-1700

With this kind of information it is possible to date the occupation of a particular site if an adequate sample of decorated pottery can be collected. Thus, the 54 known sites in the Tesuque Valley can be arranged in chronological order, as shown in figure 3.

The locations of village sites in the Tesuque Valley have significant bearing on the chronology of the alluvial sequence. All the sites which contain Kwahe's Black-on-white and therefore presumably dating before A.D. 1200, are located on outcrops of the Santa Fe formation, either on hills of this material adjacent to the valley or on isolated erosional remnants which stand

slightly above the level of the high terrace in the valley proper. These locations might be an expression of a preference for height and view, but several of the lower remnants are only a few feet higher than the surrounding terrace surface. It seems likely that these higher areas were selected for building sites

primarily because the adjacent terrace surface was subject to periodic overflow.

While deposition of the high-terrace alluvium was occurring, the floodplain of Rio Tesuque would have been an excellent area for the practice of floodwater farming (Bryan, 1929). The numerous villages

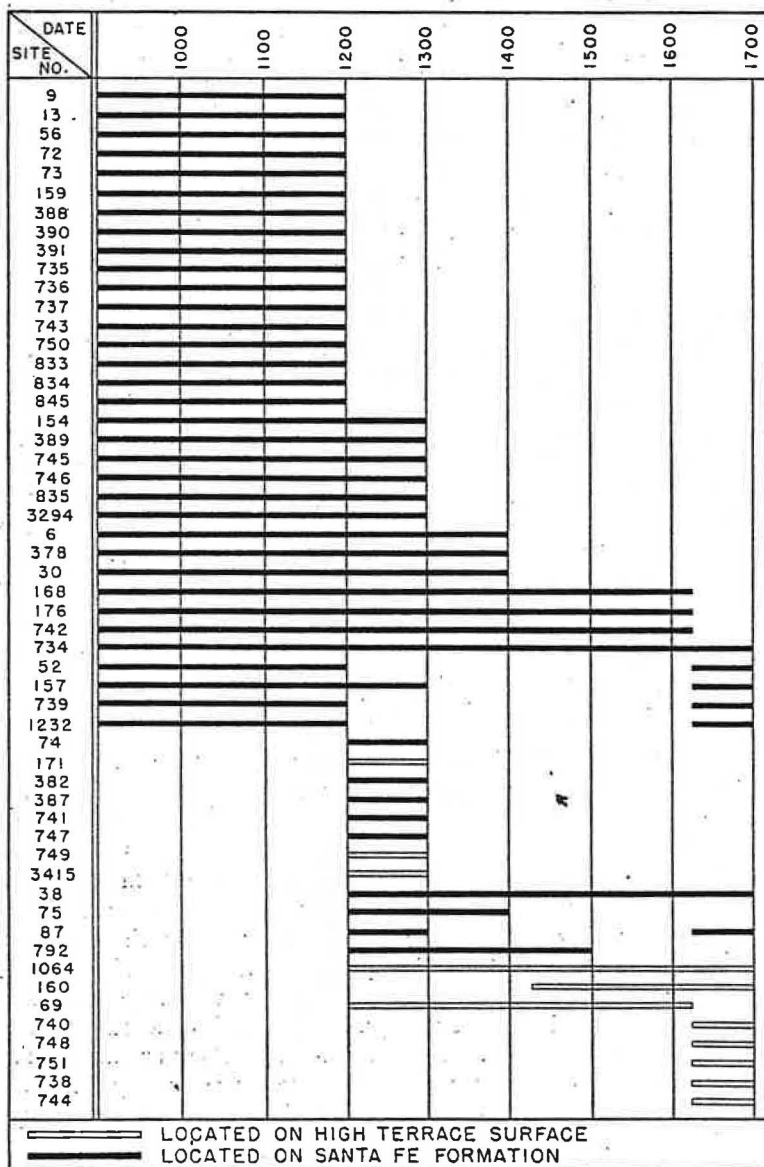


FIG. 3.—Pottery chronology of known archeologic sites in the Tesuque Valley as related to geographic location of the sites.

located by the archeologic survey indicate that the valley supported a large population during this period. Later, when the high terrace was trenched by erosion, the area suitable for floodwater farming was greatly reduced. Although the high-terrace surface could have been utilized for agriculture, irrigation canals would have been required.

Some of the villages occupied after 1200 are also located on Santa Fe formation hills, but several others are on the surface of the high terrace. Site LA-3415 at Cuyamungue, 4 miles downstream from Tesuque, is of special importance in this regard. It is a small adobe and stone-wall pueblo of 10 to 15 rooms built on the top of the high terrace. A nearby arroyo has exposed a cross section through the terrace, so that it is possible to trace the various layers of alluvium throughout the distance from the pueblo to the terrace escarpment. It is clear in this case that the aggradation of terrace fill had ceased by the time the pueblo was built (between 1200 and 1250). The occupation of this site was brief, certainly less than 75 years and probably less than 50 years, for all the decorated pottery found is a stylistically early variety of Santa Fe Black-on-white. It may be concluded, therefore, that the accumulation of the high-terrace alluvium probably ceased by 1200 and definitely before 1250.

Pottery of the type manufactured in the 1100's (Kwahe's Black-on-white) should be present in the upper part of the high-terrace alluvium, but none has yet been found *in situ* along the main stem of Tesuque Valley. However, several sherds were found on the upper slopes of the terrace scarp, apparently where they had recently eroded from the alluvium. Scattered sherds of Kwahe's Black-on-white, together with abundant culinary types and other associated midden debris, were found exposed in a vertical cut 1-3 feet below the surface of the high terrace of Arroyo Ancho, 4 miles upstream from its junction with Rio Tesuque. This material further indicates that the upper portion of the high-terrace alluvium

was deposited during the interval of the Kwahe's occupation (950-1200).

Cultural materials which were excavated at Site LA-3297 near Tesuque (see maps on figs. 1 and 4) provide considerable additional information about the chronology of alluvial events. The artifacts were exposed in the scarp of the high terrace. Figure 4 shows topography and geology in the vicinity of the site, with contours drawn as they were before construction of the new highway. Details of the alluvial stratigraphy at the site are presented in figure 5. Except for a disconformity at about 90 inches below the surface, the sequence of alluvial deposits is typical of the high terrace throughout the area. No particular significance is attached to this disconformity because it is not apparent elsewhere in the valley and, in fact, extends only a few feet laterally from the site.

The position of cultural remains in the alluvial deposits at Site LA-3297 is shown in figure 5. Two loose accumulations of charcoal (juniper and piñon), ash, and fire-cracked rocks are interpreted as hearths. The stem of an obsidian point was found with the lower hearth and a larger fragment of an obsidian point with the upper hearth. In addition, a score or more small flakes of chert and obsidian were recovered.

Only one of the projectile fragments is complete enough for positive identification. It is a thin, bifacially flaked, leaf-shaped blade with a hafting stem set off by deep diagonal corner notches (fig. 6). When complete, it probably measured between 1½ and 2 inches in length. The other fragment appears to be the stem portion of a point closely similar to the first. These points are similar in style to those found in certain prepottery Basket Maker sites in the San Juan area, which have been dated by tree-ring methods from about the time of Christ to A.D. 500. They are also similar to some of the points reported by Campbell and Ellis (1951) from undated prepottery sites near Albuquerque. However, such points are known to occur, generally as rare pieces, in ceramic sites of the Tesuque Valley. Thus,

FIG. 4.—
low terrace

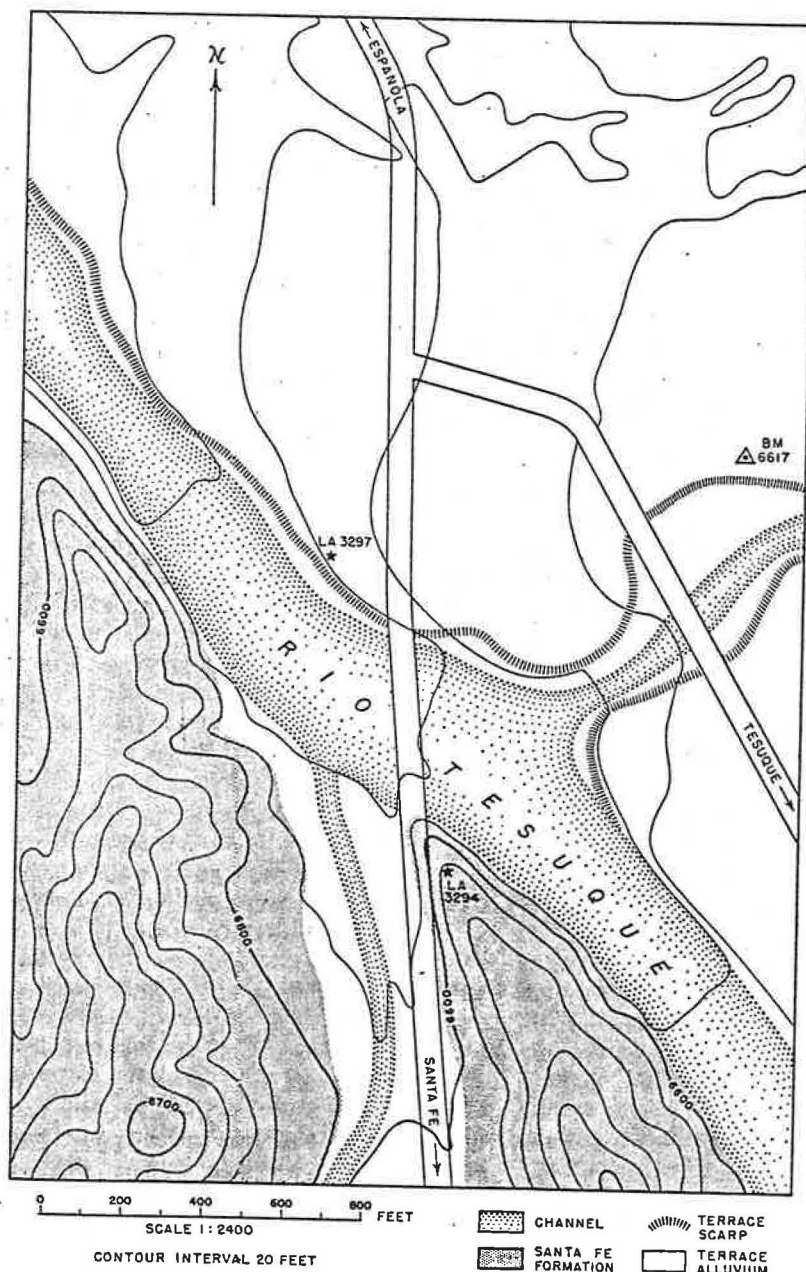


FIG. 4.—Topography and geology in the vicinity of Site LA-3297. Scarp of high terrace is indicated; the low terrace occupies a very narrow belt between the channel and the high terrace.

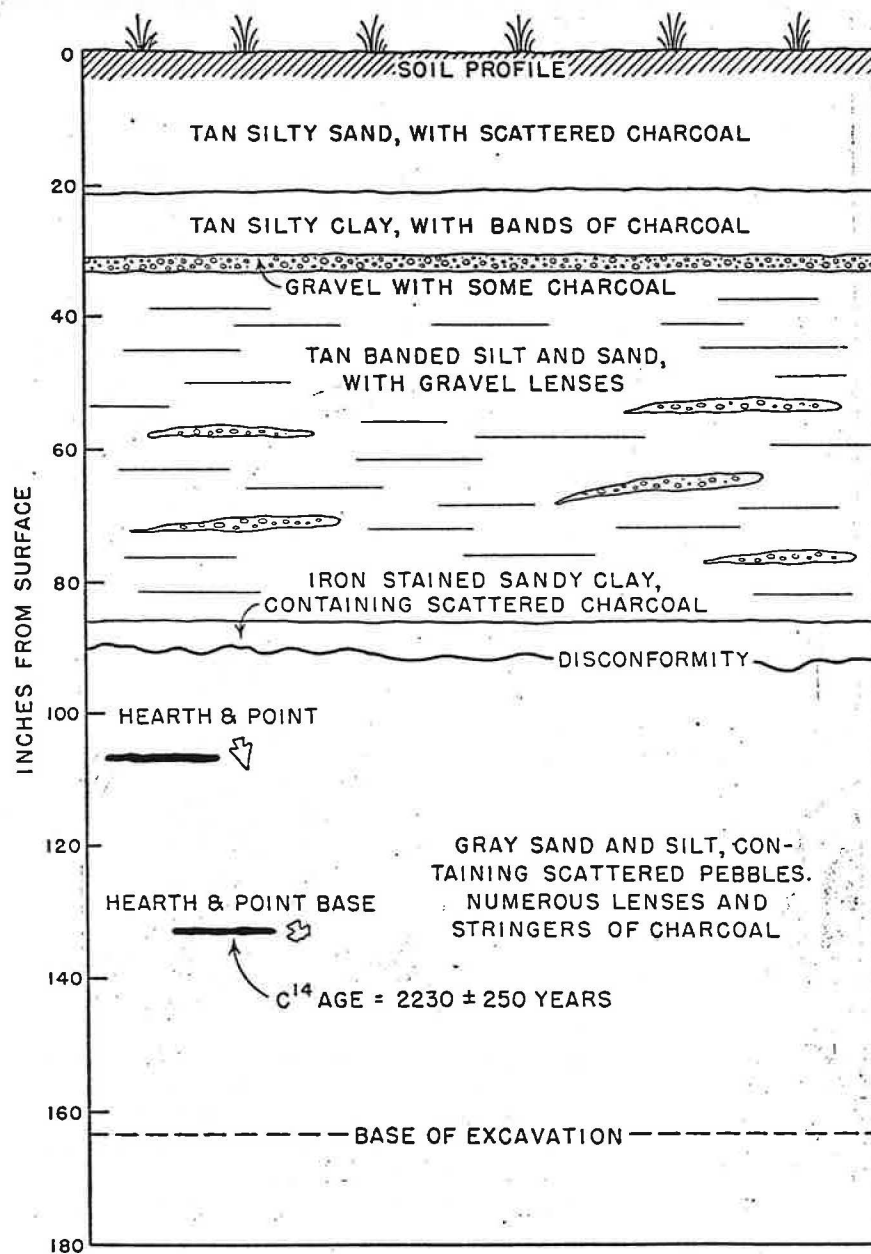


FIG. 5.—Stratigraphic section of high-terrace alluvium at Site LA-3297

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although points of the type found are most common in preceramic sites, they cannot be considered very reliable indicators of cultural chronology.

A sample of charcoal large enough for radiocarbon determinations was collected from the lower hearth. Through the cooperation of Dr. James B. Griffin, it was submitted to the Phoenix Memorial Radiocarbon Laboratory at the University of Michigan (sample no. M-511). An age of 2230 ± 250 years (275 B.C. $\pm$ 250 years) was obtained.

At Site LA-3297, there are scattered lenses of charcoal and fire-cracked rocks above the two hearths discussed previously, but no tools or identifiable artifacts were recovered in place. A sherd of Kwahe's Black-on-white was found on the floor of a small tributary wash, but its source could not be determined. Scattered pottery also occurs on the surface of the high terrace, but no definite pueblo could be located. Identifiable decorated types include Santa Fe Black-on-white and Tewa Polychrome.

In summary, evidence from cultural materials permits construction of a partial chronology of the high-terrace depositional history. Exactly when deposition began is unknown, but it was occurring in 275 B.C. ($\pm$ 250 years) and continued until A.D. 1200-1250.

There is no way of determining exactly when deposition of the low-terrace alluvium began, for no artifacts or other datable materials have been found in it. Present knowledge permits only the statement that, sometime after 1200-1250, channel trenching occurred, and subsequently deposition of the low-terrace fill commenced. Likewise, it is not known when this second phase of deposition ceased, but 1880 is probably a maximum terminal date because accelerated erosion in the Santa Fe area began at about that time.

REGIONAL CORRELATION

On the basis of reconnaissance studies, it is believed that the alluvial chronology described for the Tesuque Valley applies to

the Santa Fe area in general. The next step is to compare alluvial events in this area with those in other parts of the West. Several authors have presented summary accounts of the alluvial chronology (Bryan, 1941; Judson, 1953; and Leopold and Miller, 1954). The reader interested in a detailed discussion of problems associated with regional correlation of alluvial deposits is referred to these papers.

Table 1 is a correlation table which includes only those localities in the Southwest for which at least part of the alluvial se-

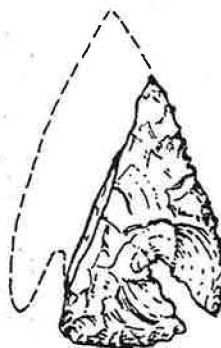


FIG. 6.—Drawing of projectile point from upper hearth (9-foot depth) in high-terrace alluvium at Site LA-3297.

quence is dated rather precisely. The general designations of alluvial fills used here were proposed by Bryan (1941) and subsequently adopted by most writers on this subject. The dates in table 1 followed by plus or minus figures were obtained by radiocarbon methods, and all the others were from artifacts (mainly pottery) which have been dated by tree-ring methods.

The chronologic relations of the alluvial sequence, and especially the high terrace, in the Tesuque Valley seem to be somewhat more precisely established than in most other areas studied previously. In order to emphasize this fact, a brief summary of the evidence used for obtaining dates in each of the various areas is presented below.

San Jon Site, New Mexico (Judson, 1953).—Wheatland formation yielded one fragment of late-fourteenth- or fifteenth-century

TABLE 1
CORRELATION OF THE ALLUVIAL SEQUENCE IN TESUQUE VALLEY WITH SELECTED LOCALITIES IN THE SOUTHWEST

EVENT	NEW MEXICO				ARIZONA		TEXAS
	Tesuque Valley (Miller and Wendorf)	San Jon Site (Judson, 1953)	Chaco Canyon (Bryan, 1941, 1954)	Gallup (Leopold and Snyder, 1951)	Hopi Country (Hack, 1942)	Whitewater Draw (Sayles and Antevs, 1941)	Big Bend (Albritton and Bryan, 1939; Kelley <i>et al.</i> , 1941)
Erosion and wind action	Since 1880	Since 1900	Since 1860	Since 1860	Since 1880-1910	Since 1885	Since 1880?
Deposition no. 3	Low-terrace alluvium After A.D. 1200-1250	Wheatland formation After A.D. 1400 $\pm$	Channel deposit After A.D. 1200	Late fill in channels	Naha formation After A.D. 1100-1300 until 1700 later	Upper silts After A.D. 1200-1300 until 1540 or later	Kokernot formation Upper part, A.D. 1100-1400
Erosion and wind action	After A.D. 1200-1250	After A.D. 1150-1300	After A.D. 1200		After A.D. 1100-1300	After A.D. 1200-1300	After A.D. 900-1300
Deposition no. 2B	High-terrace alluvium, upper part, A.D. 1200-1250; lower part, 2230 $\pm$ 250 years	Upper Sand Canyon formation	Main fill A.D. 500-700 to A.D. 1200 or later	Upper Nakaibito formation, A.D. 900-1100 (lower part)	Tsegi formation (B) Before A.D. 1100-1300	San Pedro II 1762 $\pm$ 370 San Pedro stage 2463 $\pm$ 310 2450 $\pm$ 300	Upper Calamity formation
Erosion and wind action							
Deposition no. 2A		Lower Sand Canyon formation		Lower Nakaibito formation	Tsegi formation (A)	Chiricahua stage 4006 $\pm$ 270 4508 $\pm$ 680	Lower Calamity formation
Erosion and wind action							
Deposition no. 1		San Jon formation (extinct fauna)		Gamerco formation	Jeddito formation (extinct fauna)	Sulphur Springs stage 6210 $\pm$ 450 7756 $\pm$ 360 (extinct fauna)	Neville formation (extinct fauna)

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pottery (type not stated). Eolian deposits of the Sand Canyon-Wheatland interval yielded pottery and artifacts (not described) dated between A.D. 1150 and 1300. The Sand Canyon and San Jon formations contain no artifacts or fossils which can be dated precisely. No radiocarbon dates have been obtained.

Chaco Canyon, New Mexico (Bryan, 1941, 1954).—The main fill contains Basket Maker III pottery (A.D. 500–700). The channel in the main fill was formed after completion of Pueblo Bonito (after A.D. 1167), and contains Pueblo III pottery (A.D. 1100–1300). No radiocarbon dates have been obtained.

Gallup area, New Mexico (Leopold and Snyder, 1951).—The lower part of the Upper Nakaibito formation yielded two potsherds, one is Pueblo I and the other Pueblo II (A.D. 900–1100). No artifacts or fossils which can be dated precisely have been found in the Gamarco formation or the late fill. No radiocarbon dates have been obtained.

Hopi country, Arizona (Hack, 1942).—A tree-ring date of 1700 was obtained for wood from the top of the Naha formation. Pueblo III pottery (1100–1300) and Pueblo IV pottery (1300–1600) occur in the Naha formation. During the Tsegi-Naha interval, Pueblo II sites on top of the Tsegi formation were eroded. Pueblo II sites (900–1100) and Pueblo III sites occur on top of the Tsegi formation. The Jeddito formation contains no artifacts or fossils which can be dated precisely. No radiocarbon dates have been obtained.

Whitewater Draw, Arizona (Sayles and Antevs, 1941).—Upper silts contain domestic horse and cow (post-1540) and are underlain by potsherds (not described) of unknown age but estimated to date 1200–1300. Deposits of the San Pedro, Chiricahua, and Sulphur Springs stages contain no artifacts or fossils which can be dated precisely. Radiocarbon dates (charcoal) obtained thus far are listed in table 1.

Big Bend area, Texas (Albritton and Bryan, 1939; Kelley et al., 1941).—The upper part of the Kokernot formation contains El Paso polychrome pottery dated 1100–1400.

The Calamity-Kokernot interval contains midden (not described), dated 900–1300. The Calamity and Neville formations contain no artifacts or fossils which can be dated precisely. No radiocarbon dates have been obtained.

It should be noted in table 1 that the alluvial sequence of Tesuque Valley lacks deposits assigned to Depositions 1 and 2A in certain other localities. Possibly, the disconformity in the stratigraphic section at Site LA-3297 (fig. 5) marks the boundary between Depositions 2A and 2B. If this is true, then the artifacts and dated charcoal are in the upper part of Deposition 2A instead of the lower part of Deposition 2B, as indicated in table 1. This alternative interpretation is rejected because of the exceedingly local character of the disconformity. As shown in figure 5, there are several feet of high-terrace alluvium below the dated portion of the section at site LA-3297. Although no widespread disconformity is recognized, a portion of this deposit may be equivalent to Deposition 2A.

Apart from any uncertainty about the disconformity, it seems obvious that both the high-terrace and the low-terrace alluvial fills in the Tesuque Valley have counterparts of approximately the same age in other parts of the Southwest. It is unlikely that such a degree of synchronism of alluvial events over so large an area could be a fortuitous coincidence of completely independent local conditions. Rather, some over-all control, probably climatic in character, seems to be required.

CAUSES OF EROSION AND DEPOSITION

Available stratigraphic information, including that from the Tesuque Valley, supports the view that roughly synchronous periods of erosion and deposition have occurred during the last few millennia. Except for the recent period of erosion, there seems to be convincing evidence that the alteration of erosion with deposition is related to changes in climate. Antevs (1952, 1955) has recently summarized various aspects of this viewpoint.

Climatic fluctuations toward more humid or more arid conditions are believed to affect the regimes of streams indirectly through their effects on vegetation. Greater aridity is supposed to decrease the vegetative cover, thus permitting more rapid runoff and causing erosion. Conversely, more humid conditions would improve the cover of vegetation, and during such periods of less rapid runoff deposition would occur. No change in total annual precipitation is necessarily involved in such a fluctuation. As suggested by Leopold (1951), a decrease in the frequency of small rains and increased frequency of large rains would weaken the vegetative cover and favor erosion.

ever, it is possible to arrive at some rather definite conclusions about paleohydrology at various times in the past and from this information to draw certain inferences about climate. This argument will be presented in the following section.

SEDIMENTATION RATES IN THE TESUQUE VALLEY

At Site LA-3297, charcoal buried 135 inches below the surface of the high terrace yielded a radiocarbon date of 2230 ± 250 years before the present. Pottery from the uppermost part of the terrace is considered to date from 1200-1250. Taking into account the ranges for both dates, the average

TABLE 2
COMPUTATION OF VOLUME AND WEIGHT OF ALLUVIUM IN HIGH-TERRACE
AND LOW-TERRACE FILLS, RIO TESUQUE, IN REACH BETWEEN
ARROYO ANCHO AND MOUNTAIN FRONT

	High-Terrace Alluvium	Low-Terrace Alluvium
Average depth (feet).....	11*	9
Average width (feet).....	2000	500
Cross-sectional area (square feet).....	2.2×10^4	4.5×10^3
Channel length (miles).....	13	13
Volume of alluvium (cubic feet).....	15.1×10^8	3.1×10^8
Drainage area (square miles).....	67	67
Volume of alluvium per square mile of drainage area (cubic feet).....	2.25×10^7	0.46×10^7
Weight of alluvium per square mile of drainage area (tons)†.....	9.58×10^5	1.96×10^5

* Thickness of dated portion only.

† Specific weight = 85 pounds per cubic foot.

At many locations in the Southwest the alluvial deposits themselves contain convincing evidence of climatic change. Flora and fauna, along with such physical features as buried pond deposits, clearly indicate deposition under conditions more moist than at present. On the other hand, erosion intervals were accompanied by eolian activity and development of pedocalic soils. Furthermore, combining the known dates of alluvial events with "dendroclimatic" information (Schulman, 1956) shows general coincidence of erosion intervals with dry periods and deposition with moist intervals.

Direct evidence for climatic fluctuation; as indicated by the character of deposits and their contained flora and fauna; is exceedingly sparse in the Tesuque Valley. How-

deposition rate at the site was 0.0064-0.0096 foot per year. Stated another way, each foot of deposition of high-terrace alluvium required, on the average, 104-156 years. Probably deposition did not occur at the average rate during most years but ranged from none to several times the average amount, depending on runoff conditions. Furthermore, it seems likely that the average deposition rate computed here is somewhat too low because the disconformity at Site 3297 (fig. 5) represents local erosion during a period of unknown duration.

The rate of deposition in Tesuque Valley as a whole can be estimated by using a method similar to that of Leopold and Miller (1954, p. 68-75). This computation refers to the segment of valley extending from the

junction of Arroyo Ancho to the mountain front, a distance of about 13 miles. This particular segment was chosen so as to eliminate the problem of estimating volumes of sediment in tributary valleys.

Cross-sectional dimensions used for computing volumes of high-terrace and low-terrace alluvial fills are shown in table 2. The estimates of width are based on measurements made in the field and on topographic maps. The values given for depth do not represent the entire thickness of either the high-terrace or the low-terrace al-

after 1300-1400 (see table 1). Deposition of low-terrace fill ceased by 1880, at which time accelerated erosion in the Santa Fe area began. Values of annual deposition rates listed in the accompanying table were

	Rate of Deposition (Tons/Year/Sq. Mile of Drain- age Area)
High-terrace alluvium	
2230 $\pm$ 250 B.P. (275 B.C. $\pm$ 250)	
to A.D. 1200-1250 = 1175-1775	
years.....	540-816
Low-terrace alluvium	
A.D. 1250-1400 to 1880 = 480-630	
years.....	311-408

TABLE 3
SUSPENDED SEDIMENT PRODUCTION IN BASINS OF STREAMS TRIBUTARY TO
MIDDLE AND UPPER RIO GRANDE

Stream and Station	Period of Record	Drainage Area (Sq. Miles)	Av. Annual Suspended Load (Tons/Sq. Mile)
Rio Santa Cruz at Cundiyo.....	1929-41	92	1,011
El Rito Creek near mouth.....	1937-41	121	489
Rio Ojo Caliente near mouth.....	1937-38	515	507
Rio Chama near Abiquiu*.....	1949-52	2,170	507
Rio Chama near Chamita.....	1937-42	3,200	1,534
Rio Chama near Chamita*.....	1948-52		554
Rio Galisteo at Hwy. 85.....	1937-40	697	855
Rio Galisteo at Domingo*.....	1949-52	640	1,736
Jemez River at San Ysidro.....	1936-41	854	726
Jemez River at Zia Pueblo.....	1936-41	979	951
Jemez River near Bernalillo*.....	1949-52	1,040	496
Arroyo Salado at San Ysidro.....	1937-40	125	734
San Jose River at Hwy. 66.....	1937-41	2,765	425
Chico Arroyo near Guadalupe*.....	1949-52	1,390	1,074
Rio Puerco below Cabezon*.....	1949-52	420	1,598
Rio Puerco at Rio Puerco.....	1937-41	5,160	2,340
Rio Puerco at Rio Puerco*.....	1949-52		783
Rio Puerco near Bernardo*.....	1948-52	5,860	605
Rio Puerco at Hwy. 85.....	1937-41	6,092	2,178
Rio Salado near San Acacio*.....	1949-52	1,380	1,074
Rio Salado at Hwy. 85.....	1937-41	1,434	730

* Compiled from U.S. Geological Survey Water-Supply Papers. Other data in this table are taken from Brown (1945), based on Soil Conservation Service and Corps of Engineers records.

luvium. The thickness used for high-terrace alluvium refers to only the dated portion, and in the case of the low terrace the figure given refers to exposed thickness.

By using the dates discussed previously, the annual rate of deposition of the high-terrace alluvium can be computed. Unfortunately, age relations for the low terrace are not known accurately. Pottery data indicate that deposition of low-terrace alluvium in the Tesuque Valley could not have begun before 1250. At several other places in the Southwest this phase began

computed from the data in table 2 by taking into account the ranges in estimated duration of deposition intervals. According to these computations, the rate of deposition of the high-terrace alluvium was at least twice the rate for the low-terrace fill.

Computed values of deposition rates in Tesuque Valley can be compared with available data on modern rates of suspended sediment production in the drainage basins of streams tributary to the middle and upper Rio Grande (table 3). For example, if during deposition of the high-terrace alluvium in

Tesuque Valley all the sediment derived from the basin was deposited, the rate of sediment production required by the volume of alluvium present is at least half as great as the modern rate for Rio Santa Cruz (15 miles north), at least one-third as great as the modern rate for Rio Galisteo (40 miles southwest), and at least one-fourth as great as the modern rate for Rio Puerco, which carries the largest load of any stream in the Rio Grande system. These fractions are minimum figures because it is not reasonable to suppose that all sediment derived from the basin of Rio Tesuque was deposited in the terrace fill.

Adequate data for estimating the fraction of total suspended load which may be deposited under conditions of aggradation are not available. The only studies of modern valley sedimentation in this region are those in the middle Rio Grande Valley, where both deposition rates and suspended load have been measured for more than 40 years. About a third of the suspended sediment produced in the basin and carried into this segment of the valley during the period of record has been deposited. If the same ratio is applicable to alluvial deposits of the Tesuque Valley, then rates of sediment production during the past periods of deposition were not greatly different from those of the present, as is shown in the accompanying table. Computations based on less satis-

	Tons/Year/Sq. Mile
High-terrace deposition.....	1,620-2,448
Low-terrace deposition.....	933-1,244
Upper and Middle Rio Grande tributaries (modern).....	425-2,340

factory chronologic information lead to a similar conclusion for alluvial valleys in Wyoming (Leopold and Miller, 1954).

Judging from modern conditions, it seems reasonable to suppose that the rate of sediment production in the area underlain by the slightly consolidated Santa Fe formation has always greatly exceeded that in the mountainous portion of the Rio Tesuque drainage basin which is underlain by granite. Hence the rate of sediment production com-

puted for the basin is the average of a high rate and a low rate for these two areas of different geology.

If the assumptions underlying the computation of rates discussed above are valid, sediment production during periods of deposition was of the same magnitude as at present. This does not necessarily mean that climatic conditions were similar to those of the present because the modern rate of sediment production is supposedly greater than the geologic norm, owing to accelerated erosion induced, at least in part, by the activities of man. It is not known whether rates of sediment production equal in magnitude to those of the present, but due entirely to natural causes, would require climatic conditions appreciably different from those which prevail at present. However, it will be argued here that past periods of erosion and deposition may have resulted from climatic fluctuations which produced only slight changes in sediment production.

The ephemeral character of Rio Tesuque and other arroyos on the Santa Fe formation is due more to the permeable nature of the unconsolidated deposits than to the semiarid climate. Because of the appreciable depth to the water table, a very large increase in precipitation would be required to yield perennial flow in such streams.

During flow under present conditions, water is lost by percolation, with the result that suspended sediment concentration increases downstream (Leopold and Miller, 1956). If a sufficient decrease in the water-sediment ratio occurs, the load can no longer be transported. Whether or not this happens depends primarily on the magnitude of discharges involved. Runoff insufficient in volume to flow the entire length of the channel results in deposition, whereas large discharges may scour the channel throughout most of its length.

Climatic fluctuations consisting only of variations in the ratio of small rains to large rains, without any over-all change in total precipitation, would probably be adequate to account for the known periods of alternate erosion and deposition. A greater pro-

portion of deposition downstream. Further, of precipitation have the erosion during rains would interfluvial sediment material as decreased. The erosion of Tesuque climate presence of in the vegetation depositional generally.

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portion of small rains would cause general deposition along the channel because of downstream loss of water by percolation. Furthermore, the more frequent occurrence of precipitation would favor development of vegetation along the channel, which would have the twofold effect of reducing channel erosion and causing deposition of sediment during large flows. Although more small rains would also increase the grass cover on interfluvies, it is doubtful that the rate of sediment production from such erodible material as the Santa Fe formation would be decreased appreciably.

The argument that both deposition and erosion of alluvium have occurred in the Tesuque Valley without major changes in climate gains some support from the presence of juniper and piñon wood and charcoal in the high-terrace alluvium. Apparently, vegetation in the area during a period of deposition more than 2,000 years ago was generally similar to that of the present.

CONCLUSIONS

Using pottery chronologies and the radio-carbon method, deposits underlying the higher of two alluvial terraces in the Tesuque Valley have been dated rather precisely. Chronologic relations of alluvial events in this area are similar to those of other dated sequences in the Southwest. Approximate synchronism over so large an area suggests that climatic fluctuations were the basic causes of alternating periods of erosion and deposition during the last few millenniums. Evidence from the Tesuque Valley does not

seem to require any major change in the amount of precipitation during this period. Estimates of sediment production indicate that rates approximately the same as at present prevailed even during periods of deposition. Although the exact mechanisms required for initiating periods of erosion and deposition are unknown, it is argued that variations in the proportion of small rains without change in the total precipitation may be adequate to account for the known alluvial history. Probably, climatic variations of this character would not greatly affect the rate of sediment production from such erodible material as the Santa Fe formation.

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