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Geologic and Climatic Inferences from Surficial Deposits of the Colorado Plateau and Great Basin

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ABSTRACT.—The relatively unconsolidated deposits that lie upon the bedrock formations in the Colorado Plateau and the Great Basin are of interest not only to geologists but also to soil scientists, anthropologists, biologists, engineers, ranchers, and farmers. These deposits are mostly intimately associated with specific landforms, such as lake beds and shoreline features, river terraces, pediments, alluvial fans, debris slopes, sand dunes, and valley fill. These landforms are related directly to the geologic agents which shaped them and the effectiveness of these agents in shaping the land and distributing weathered products is in turn dictated mainly by climatic influences.

It is proposed that the climate of the American Southwest has shifted generally toward increasing coolness and aridity during the late Cenozoic. The basic influences have been the same in the Great Basin and Colorado Plateau, but the effects have been quite different, chiefly because the Plateau has external drainage while the Basin has internal drainage. It is assumed that during the middle Tertiary both provinces were at about the same elevation, had a fairly humid climate and a deep stable regolith. Later, perhaps in the early Pliocene, came a distinct shift toward aridity. At this time great quantities of material loosened by earlier weathering were stripped from the higher ranges and scarps to create extensive alluvial fans and pediment surfaces throughout the Southwest. Aridity continued to intensify so that the middle and late Pliocene appear to have been the dryest parts of the Cenozoic. Little sediment was produced or moved during this interval.

The oscillations of Pleistocene climates were superimposed upon the general trend so that at times increasing precipitation brought lakes to the interior basins and produced greater runoff generally. During humid intervals alluvium filled many secondary valleys and canyons in the Southwest. With shifts into dryer cycles this material was subject to rapid removal. Several periods of alluviation and erosion are associated with the aboriginal settlement of the Southwest, and a period of severe erosion commencing about 1850 seems to coincide with Caucasian settlement.

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INTRODUCTION

The ubiquitous symbol *Qal* (Quaternary alluvium), which geologists have applied liberally to hundreds of maps of the Southwest is a complex and fascinating unit. Understandably, most field geologists have been more concerned with the solid bedrock than with the surficial cover, which they may regard as either a curse or a blessing—the former if it obscures essential geologic clues, the latter if it saves them the trouble of mapping or explaining something they haven't time to deal with. On many, if not most, geologic maps the yellow patterns, which ultimately appear, do little more than provide an attractive background for the more dramatic bedrock colors.

Only a small percentage of the loose surficial material mapped as Quaternary alluvium in the arid west is "soil" in the classical agricultural sense. That small percentage has been modified and is amenable to cultivation or is otherwise of value to man because of the growth of plants which it sustains. Because most of the surficial material of arid and semi-arid lands is not cultivated and is essentially without vegetation, it becomes a matter of semantics whether or not it is properly called "soil." But even the loose material on the surface of the moon and Mars is being referred to as "soil," so perhaps we must allow the term more than one usage. Nevertheless, a real need exists to distinguish the bedrock from the non-bedrock, regardless of what the non-bedrock may be.

While the soil scientist, like the geologist, feels impelled to leave no surface unmapped, it is certain that he follows his trade with much more confidence in the corn fields of Indiana than in the wastelands of the Colorado Plateau. In direct contrast with the geologist, the soil scientist may regard the bedrock outcrops simply as troublesome nuisances that interrupt or obscure the soils, which are his main concern. To view a geologic map side by side with a soil map of the same region reveals, perhaps better than anything else, that there are more ways than one of looking at a particular surface.

Although most modern ranchers and farmers have a working knowledge of soil maps, they are not as interested in the niceties of scientific classification as they are in the crops and animals they can harvest from the land. Only when sterile subsoil or bedrock appears in their fields or when gullies cut into their grazing lands do landowners think much about what lies beneath the plow mark. But destruction of the surficial material is of more than usual interest in the Southwest. Agriculture and ranching in that region have proven to be precarious occupations, as attested to by thousands of abandoned farms and homesteads. By contrast with areas where the soil has supported continuous tillage for hundreds of years, the duration of cultivation and grazing on many sites in the Southwest has proven to be a one- or two-generation affair. The fragile lands have not proven suitable for the sustained cultivation or grazing to which modern methods have subjected them.

Biologists, too, have a vested interest in surficial material. Soil and vegetation are companion terms, linked together in any discussion of the physical geography of a region. The intimate relationship between the soil and plant life brings yet additional disciplines into consideration. All phases of botany from simple systematics to environmental relationships have a fundamental basis in the historical development of the environment.

Somewhere between the soil scientist and the geologist in his interest in the subsurface is the anthropologist. He is concerned with the bedrock only as far as it furnishes a setting for aboriginal cultures and with the soil chiefly because it must be excavated to reveal what he seeks in the layers beneath. Because so much of his work is based on excavations, his results are generally presented more in terms of cross-sections than in terms of maps. The anthropologist has contributed a great deal, perhaps more than the geologist, towards an understanding of the surficial materials of the Southwest. Unfortunately, his interest ceases when traces of man can no longer be found. Below this level, however, the vertbrate paleontologist has a valid interest, but bony remains are so scarce and scattered that little has been contributed here.

Certainly not to be overlooked are the interests of engineers in the soil and subsoil. Man's disturbance of the earth has carried him ever deeper and deeper below the surface. Shallow excavation has become probably the greatest engineering concern of modern time. Vast systems of roads that no longer follow the surface contour and that have their foundations far below the superficial soil are everywhere. Foundations for great buildings and even for entire self-contained communities must be cleared and landscaped. Strip-mining, now feasible to depths of over 100 feet, by its very nature involves chiefly the section above the solid bedrock. Unfortunately, the engineer has no time to actually study more than the engineering properties of the materials with which he deals. Soil and geological maps do him little good. The archaeologists and fossil hunters who follow his activities like gulls behind the plow may prove to be expensive nuisances if they spot a supposed treasure that must be salvaged at all costs. Certainly geologists have missed something by not being more concerned with the practical needs of engineers for more information on surficial materials of the earth. They have even harmed themselves by failing to impress engineers with the scientific importance of what may be uncovered in their operations.

If the foregoing paragraphs seem to belittle the interests of geologists in non-bedrock materials, it is to make a point and not to criticize. After all, whatever may be said about the shortcomings or omissions of geologists may be applied to soil scientists, botanists, anthropologists, and even agriculturalists, who must also concentrate on their own specialities and who cannot be expected to be skilled in all areas.

In any event, the *Qal* of the geologist represents a true meeting ground of many disciplines, and even though opportunities for cooperative studies or for the application of diverse approaches have been utilized by a few investigators, much remains to be done.

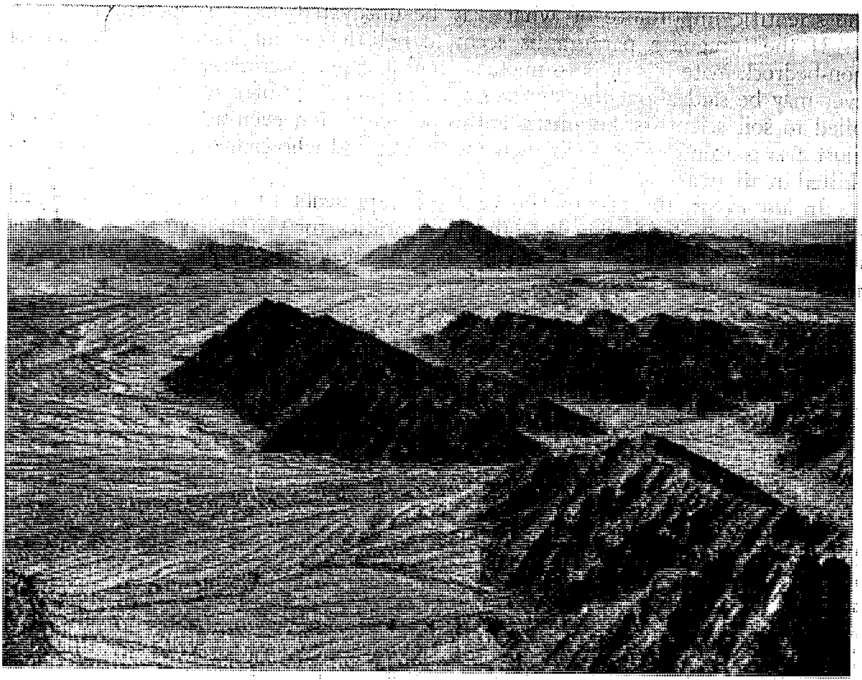
What follows deals with the surficial deposits of the Colorado Plateau and the Great Basin from a geological viewpoint but is intended to show how these deposits are best interpreted as products of long-term climatic change. In addition an attempt is made to correlate events that occur in the two extensive regions, events usually treated by geologists and geographers as distinct entities.

THE GREAT BASIN

The Great Basin is that part of the much larger Basin-and-Range geologic province which has exclusively internal drainage. The absence of through-flowing streams insures that erosion products, with the exception of the fraction removed by wind, remain near their sources in the form of alluvial or lacustrine deposits. Numerous relatively long and narrow ranges outlined by faults or fault-line scarps and separated by broad alluvial valleys are characteristic of the Great Basin. The combined action of erosion and deposition is working to eliminate extremes of topography; hence, a large percentage of the province lies between 5,500 and 6,500 feet elevation. Climates range from arid in the south to humid in the north with many internal variations.

In a structural sense the Basin and Range including the Great Basin shows evidence of decreasing age from north to south. In other words, the faulting responsible for creating the characteristic structure and physiography began in the Mexican sector and has progressed northward. As a result, the uplifted blocks have undergone progressively less erosion northward and therefore occupy more of the total surface in that direction. Alluvial valleys dominate in the south; mountains, in the north. Western Utah and central Nevada show approximately equal areas of bedrock and alluvium.

To the south, in southern Nevada, bare rocky ranges predominate. In these, soil and vegetation are scanty to lacking, and the sedimentary strata are clearly exposed. The name *skeletonized* may be used in designating this type of exposure. Farther north, in central Nevada, the ranges have a mixed character: bare rock exposures at the base and thicker soil and vegetation, including stands of conifers, at higher elevations. Examples that the writer has personally traversed are the Snake, Schell Creek, and Cherry Creek Ranges. In Utah the Deep Creek and Wellsville Ranges have this mixed character. Of course, the effects of glacial erosion and the lack of much vegetation above the tree line must be taken into account. Continuing northward into southern Idaho, the proportion of bedrock exposures is very small. Most of the ranges, for example, the Black Pine Range, the Arbon Range, and the Bannock Range are mantled with soil and vegetation including forests. In summary, it is possible to find a complete gra-



TEXT-FIGURE 1.—Barren, rocky outcrops of the tilted fault-block Tule Mountains, southwestern Arizona. Erosion products are being deposited in the near vicinity of their source in the "skeletonized" ridges. Although powerful sporadic rain is clearly needed to create the drainage patterns and land forms, the area is one of general aridity.

Photo Courtesy National Park Service

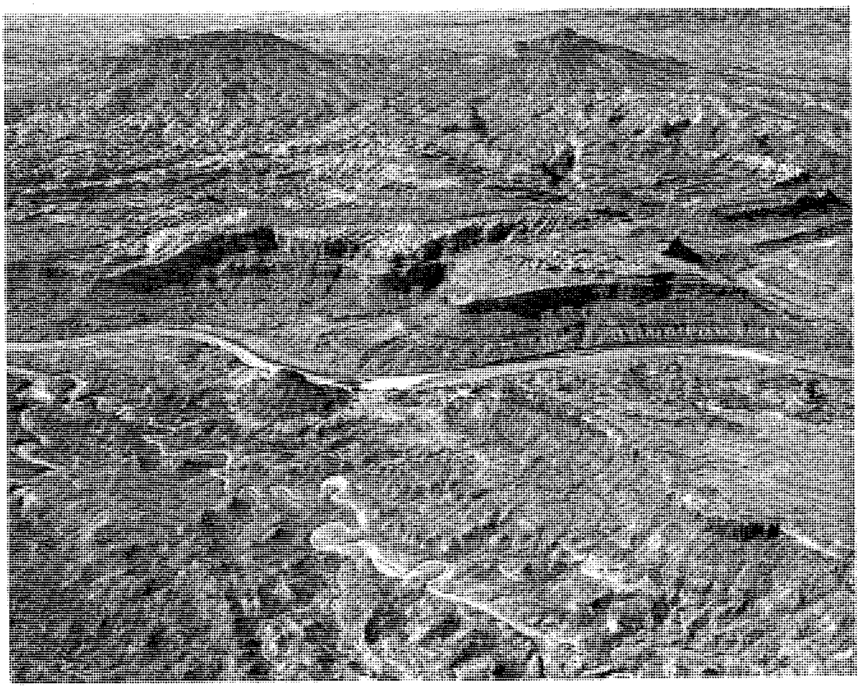
dation from thoroughly denuded, almost lifeless, rocky, skeletonized ranges to those that are heavily forested with practically no exposures of bedrock.

THE COLORADO PLATEAU

The Colorado Plateau is an area of relatively undeformed sedimentary rocks almost completely surrounded by higher, more complex mountains or plateaus. The average elevation is about 6,500 feet, and the climate is classified as semi-arid. The region has been deeply eroded by the Colorado River and its tributaries, the greatest effects being along and adjacent to the main rivers. Around the periphery, plateau remnants and basins are in process of erosion.

The Colorado Plateau is unusual in displaying evidence of long continued uplift with little internal deformation. This tectonic reaction has been attributed to the overriding of and the incomplete fusion of plates of lighter rocks through a westward movement of North America.

Except at higher elevations, bare rock outcrops dominate the landscape. Cliffs, badlands, pediments, and other types of barren surface are the chief land forms. The production of sediment has been and still is relatively great, but because the material loosened and released by weathering is removed almost immediately by erosion, soil is rare and transitory or immature in nature. As



TEXT-FIGURE 2.—The southern group of the Henry Mountains intrusives and surrounding territory, south-central Utah. With minor exceptions, the entire region is eroded to the bedrock. Any loose debris is quickly removed by tributaries of the Colorado River, which crosses the view from right to left.
Photo Courtesy Bureau of Reclamation

in the Great Basin, progressive stages of denudation are seen but they are more evident with changes in altitude than with changes in latitude. The Grand Canyon is a classical example of a so-called vertical desert with extreme aridity at the bottom and coniferous forests on the rim, 5,000 feet above. A number of mountains and plateaus in and adjacent to the Colorado Plateau have been glaciated, and these reveal significant details of past climatic changes.

THESIS

The foregoing brief descriptions of the Great Basin and the Colorado Plateau are given as a basis for introducing and developing a particular argument; namely, that a long-term, secular trend toward increasingly dry and cool climates provides a valuable basis for geomorphic interpretations and correlation in the southwestern United States. Although the basic framework is tectonic, the details—including the surfaces upon which man lives—have been determined by climatic factors which have been operating with some degree of consistency over the entire area. Climatic trends and oscillation have certainly provided the conceptual framework for studies of the last few million years of geologic time; and with increasing evidence that short-term climatic effects can apparently be correlated from continent to continent and from ocean basin to ocean basin, it seems safe and reasonable to seek for correlations over distances of only a few hundred miles.

Deliberately minimizing the drastic and perhaps atypical effects of the Pleistocene Ice Age, it may be said that the cooling and drying trend in the American Southwest over the past 60 million years has been due in part to progressive uplift of western North America which in turn stems from forceable reactions between the American and Pacific lithospheric plates. Along with this tectonic effect there has apparently been a general cooling of the Pacific Ocean that has cut down evaporation and hence precipitation. Accentuated seasonality probably accompanied the general trend to create relatively rigorous climates.

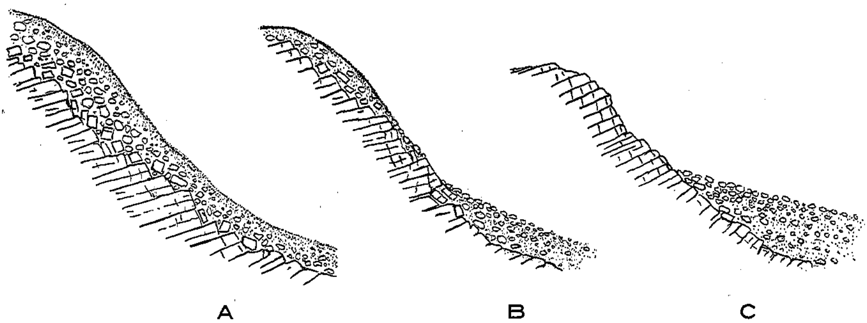
Analysis of the general trend is difficult because of the perturbations of the glacial-interglacial stages of the Quaternary ice age. At times, because the short-term trends neutralized or even temporarily reversed the major trend, ice caps, extensive lakes, and heavier vegetation prevailed. At the other end of the cycle the general trend toward dryer and cooler conditions was accentuated. The following brief review will examine the hypothesis that climatic influences are useful in correlating the geologic record of the Colorado Plateau and that of the Great Basin.

CHARACTER OF THE DATA

It is an obvious fact that land forms as well as deposits created by many specific geological processes linger on after the agents which produced them have ceased to operate. This is particularly true of the Pleistocene Ice Age. From abandoned terraces, spits, and bars the vanished lakes of arid regions can be outlined. Moraines, cirques, and lake basins permit accurate reconstruction of bodies of glacial ice. In the Southwest, Pleistocene ice and water bodies have been ephemeral things, and an investigator must travel elsewhere to see ice and glacial lakes creating their typical land forms at the present time.

But there are less obvious climate-controlled processes still in operation which may be studied in a before-during-and-after sequence within the present confines of the region. These are the weathering and erosion effects of climates that range from hot and dry at low latitudes and elevations to moist and cool at higher latitudes and elevations. Aside from soils which must become integral parts of the stratigraphy to be preserved, there are also erosional and depositional features that tell of past climatic influences: badlands, stripped surfaces, cliffs, alluvial fans, pediments, playas, gullies (arroyos), and varied types of sand dunes. All are observable in process of formation, in stable condition, and in stages of disintegration. To put it simply: an observer studying any given landscape or land form in the Southwest need only to look downward and/or southward to learn what the conditions of his area will be in the future and to look upward and northward to see what it has been in the past. For plants and animals this relationship has long been recognized and utilized. The living biota of the Southwest is being superimposed on or is replacing one with colder and generally moister requirements. For an excellent summary see Malde (1964).

We have, in effect, a geomorphic equivalent of Walthers Law in stratigraphy, which states that within a given sedimentary cycle the same succession of facies that occurs laterally is also present in vertical succession.



TEXT-FIGURE 3.—Diagrammatic cross-sections, showing progressive changes in the relationship of bedrock and regolith with increasing aridity: *A.* Continuous soil and thick blanket of loosened bedrock fragments under humid conditions; *B.* Soil and regolith in process of rapid removal when moisture is insufficient to maintain a stable cover; *C.* Bare rock exposure with little or no cover under conditions of extreme aridity.

EARLY TERTIARY (PALEOCENE-EOCENE)

During the early Tertiary, extensive lakes occupied the Uinta and Green River Basins and lesser ones were present in central Utah. The elevation of the lake surfaces is regarded as having been below 2,000 feet (Bradley, 1948). The extensive fauna and flora known from lacustrine and fluvial sediments of this interval indicate semi-tropical, humid climates over much of what is now the central and southern Colorado Plateau where lakes were also probably present, but no sediments remain (Hunt, 1956). By contrast, very little Eocene sediment is preserved in the Great Basin, and the vertebrate record is practically nonexistent. Paleobotanical studies by Axelrod (1968) indicate that northwestern Nevada supported hardwood and coniferous forests at altitudes ranging from 1,000 to 4,000 feet. Central and southern Nevada and southwestern Arizona appear to have been lower and warmer.

Both the Colorado Plateau and the Great Basin must have been well drained, but routes of the major rivers are not known. The Sierra Nevada Range evidently had little or no climatic effect. No erosion surfaces of proven Paleocene or Eocene age are known in the region.

MIDDLE TERTIARY (OLIGOCENE-MIOCENE)

No extensive sedimentary deposits of Miocene or Oligocene time are known in the Colorado Plateau. The last significant deposits of the Uinta Basin are those of the Duchesne River Formation, latest Eocene. General degradation of the area began very late in the Eocene or early in the Oligocene. The precise geological processes and reactions that affected the Colorado Plateau during this interval must be inferred from indirect evidence.

Although not really abundant, the middle Cenozoic record of the Great Basin is far better than that of the Colorado Plateau and is sufficiently complete to allow paleogeographical reconstructions. The Oligocene is known to have been a time of intensive volcanic action (Mackin, 1960), and fossils are very rare. Practically no Oligocene vertebrates are known in either Utah or Nevada. Paleobotanical evidence begins to be reasonably abundant at about mid-Miocene and is very important. About a dozen vertebrate sites positively datable as Miocene are known in Nevada, but there are none in Utah. From these scattered sources it is inferred that previous subtropical floras were replaced during middle Tertiary time by a more temperate flora (Axelrod, 1957). The reference just cited contains a rainfall map of Mio-Pliocene time showing a pattern of decreasing precipitation from generally 15-20 inches in southern Nevada, southeastern California, and southwestern Arizona to 25-30 inches in northern Nevada and northern Utah. Most of the areas being discussed in this paper are shown as having 20-30 inches (p. 36). Somewhat higher values probably prevailed in the early Miocene, but this same area today has generally less than 10 inches of precipitation annually.

Axelrod (1957, p. 32) describes the dominant Great Basin flora of Mio-Pliocene time as a forest of deciduous hardwoods and conifers and compares that flora with the present flora of eastern North America.

Considering the known floras and faunas and the inferred climatic elements, particularily the rainfall, it is assumed that weathering penetrated deeply and produced a thick mantle of soil and loose rock over the entire area. This store of loosened material was destined to be of great importance in later physiographic developments.

PLIOCENE

Datable sediments of Pliocene age are also rare in the Colorado Plateau. Significant exceptions are (1) the Bidahochi Formation, which has yielded fossils as old as early Pliocene, and (2) the unfossiliferous Geyser Basin Formation near the La Sal Mountains, also considered to be of Pliocene age (Carter and Gualtieri, 1965). The Bidahochi is an erosional remnant of a once more widespread formation thought by some to predate the cutting of the Grand Canyon of the Colorado.

Although Pliocene faunas and floras are known in the western Great Basin, it is probably safe to say that this epoch is the least well represented by sediments of all Tertiary divisions in the Utah-Nevada region. Geomorphologically, however, it may be the most important. All lines of evidence strongly suggest that the driest continental climates of the Tertiary came in the mid-Pliocene. In west-central Nevada the floras show a decrease of precipitation from 25-30 inches in the Mio-Pliocene to 15 inches in the middle Pliocene. This brought a change from woodland and forest to semi-arid savanna and grassland (Axelrod, 1957, p. 41) and this trend toward aridity probably had even greater effects in areas of the eastern Great Basin and the Colorado Plateau where no records are preserved. Translated into probable geomorphic effects I would characterize the late Pliocene as the time of the "great disintegration." Secular trends toward drying had reached a climax, and the aridity was severe enough to destroy former forests, and perhaps even grasslands, over extensive areas. With the breakdown of vegetative cover and effective soil structure, a tremendous amount of material became vulnerable to erosion. The regolith on the ranges of the Great Basin and the ridges, scarps, and valley sides of the Colorado Plateau was probably several hundred feet thick. Glaciation was not yet a factor, and running water had unlimited opportunity to act on the surface. With the decline of vegetative cover a change in the precipitation patterns which favored thunderstorm precipitation over the more evenly distributed "general" rain and snowfall might be expected. As has been pointed out many times, the erosive effects of precipitation depend much more on the distribution pattern than on the total quantity. Maximum effects are experienced under thunderstorms or "cloudburst" regimes in areas where the regolith is unprotected by soil or vegetation. This is the situation that began to be effective in the Middle Pliocene and continued to be operative into the present time, with intensity varying with the glacial-interglacial climates.

If the foregoing analysis is correct, a great deal of the landscape of the Great Basin and the Colorado Plateau originated in late Pliocene time. But because of the lack of fossils and the scarcity of accessible superimposed sedimentary sections, the evidence must be chiefly geomorphic. Looking first at the former basins of Lake Bonneville, one is struck by what is revealed by the relationships of shoreline features and underlying material. In the first place it is obvious that the major, massive accumulations of fan or pediment material achieved their present status before any of the terraces of Lake Bonneville or its predecessors were formed. Striking examples are seen on the east flanks of the Pilot Range, the west side of the Terrace Mountains, the southeast portion of Salt Lake (Jordan) Valley, and the northeastern flanks of the Stansbury Range. The major alluvial fans or pediments derived from these ranges clearly antedate the incisions made by the lake levels. The depth to which the terraces have been excavated and the size of bars and spits constructed from the material removed depends largely on the size and durability of the fragmental material already in place. In general, the larger blocks come from the Precambrian quartzites, and the smaller blocks from the Oquirrh Formation or the Park City Group. Here and there superimposed upon the abandoned terraces are bouldery deposits of post-lake origin that retain their original form and distribution. These are merely the latest local veneers upon the massive older deposits, from which they differ in no essential way except in age. Any deposits brought down during the high stages of the lakes would have been absorbed near the shore lines and mostly obliterated by wave action.

From these observations it is concluded that a major denudation of Great Basin Ranges preceded those Pleistocene lakes which left the terraces commonly referred to as belonging to Lake Bonneville and Lake Lahontan. Relatively little sediment has been yielded by these ranges since the lakes disappeared an estimated 16,000 years ago. Undoubtedly, careful mapping would reveal the effects of intense local floods during the high stands of the lakes, but there is no obvious indication that the high stands coincided with periods of greater erosion in the ranges. Whether or not this constitutes some sort of contradiction is not clear.

PLEISTOCENE

Geologic evidence bearing on pre-Wisconsin glacial events in the Great Basin and Colorado Plateau is either lacking or poorly known. The much-studied deposits and shoreline features of Bonneville and Lahontan lakes pertain chiefly to the Wisconsin stage. Almost certainly a significant record of the older glacial stages is preserved in subsurface sediments of the numerous intermountain valleys of the Great Basin. As a matter of fact, the Pleistocene sediments of the larger depressions (such as that of the Great Salt Lake) may retain one of the world's most complete Pleistocene records. However, the exploration of the valley sediments of the Great Basin has been very spotty.

I am indebted to Dr. A. J. Eardley for the use of an unpublished preliminary manuscript on a paleomagnetically dated 1,005-foot core from near Burmester on the southern shore of Great Salt Lake. This virtually uninterrupted core provides a remarkable record of alternating periods of lake deposition and subaerial weathering. Seventeen lakes, indicating 17 climatic cycles, have been recognized by Eardley and his co-workers within the upper 360 feet. The 360-foot level is interpreted to coincide with the middle of the Jaramello paleomagnetic event dated at about 900,000 years. Below this, approximately 68 additional wet-dry cycles are recognized, beginning about 3.4 millions years ago. Two key beds of volcanic ash are recognized: one at 202 feet is the Pearlette "O" fall, dated elsewhere at 600,000 years; and the lower one, at 317 feet, is the Bishop ash, dated at about 700,000 years. The well-known Lake Bonneville and its predecessor, Lake Alpine, are lakes I and II respectively in Eardley's scheme of nomenclature. Apparently all the lakes before number VIII were shallow and were exclusively freshwater. Soils formed between lacustrine intervals are generally regarded as being of arid to semi-arid origin.

The significance of this core in the present context is that only the last few lakes since Lake VIII that have occupied this part of the Bonneville Basin were deep and left salty sediments while the great majority of older ones were relatively shallow and exclusively freshwater.

The broadest climatic generalization that can be made is that the late-Pliocene-middle-Pleistocene climate was much more arid than the late Pleistocene or Wisconsin interval, because the former produced shallower and shorter-lived lakes. It is inferred that this lengthy arid period produced not only less water but also less sediment. The five latest lakes were deeper and produced 160 feet of sediment, while the preceding 80 lakes produced only 850 feet. These climatic implications are based on the assumption that tectonic activity in the basin has not been such as to totally disrupt and obscure the climatic influences.

Evidence suggests that the late Pliocene and the earlier two-thirds of the Pleistocene were relatively arid as compared with the later Pleistocene, particularly the Wisconsin, when Lake Bonneville overflowed.

In the absence of any significant evidence to the contrary, it is assumed that the relatively arid conditions recorded in the Burmeister core are probably responsible for the paucity of sedimentological record in the Colorado Plateau, including the lack of any glaciations older than those recorded in the Harpole Mesa Formation of the La Sal Mountains.

TABLE 1
GEOMORPHIC AND CLIMATIC CORRELATIONS BETWEEN THE COLORADO PLATEAU AND THE GREAT BASIN

Time Spans	Colorado Plateau	Great Basin
Historical Period	Onset of extensive gullying about 1850; steady removal of valley fill and some denudation in higher elevation.	Fluctuations in levels of existing lakes; much destruction of vegetation and soil cover under intensive grazing by domestic animals.
Recent and Near-Recent	Previously deeply eroded tributary canyons alluviated, reexcavated, and refilled several times; human occupancy begins about 15,000 B.C.; climates generally oscillating but arid.	Fluctuations of lake levels; very surficial erosion and deposition; gradual cooling and drying as shown by succession of human cultural remains found chiefly in caves.
Middle and Late Pleistocene	Sparse sedimentary record, including glacial deposits in the La Sal mountains; minor modification of land forms; drainage probably integrated.	Extensive surficial deposits and land forms associated with lakes of varied sizes, some over 1,000 feet deep; fair paleontological and geosol record; numerous wet-dry cycles.
Late Pliocene and Early Pleistocene	Practically no dated deposits; probably extensive bedrock erosion by secondary and tertiary streams.	Probably considerable volume of sediment laid down in deeper parts of trenches and valleys; practically no datable surface deposits; no positive evidence of large lakes; probably arid.
Early and Middle Pliocene	Scanty sedimentary record includes Bidahochi formation (Arizona); drainage patterns mostly unknown; general disintegration of weathered regolith with increasing aridity.	Sparse paleontological evidence and few proven sedimentary deposits; general denudation of ranges and building of alluvial fans with increasing aridity.
Oligocene-Miocene	Scanty record; no extensive deposits; drainage pattern unknown; laccoliths intruded; Green River captured.	Fair sedimentary record; much igneous material; general subsidence; deciduous hardwood forests; humid climate; deep weathering.
Paleocene-Eocene	Great downsinking in Uinta-Piceance basins, producing extensive lake systems at elevation 1,000-2,000 feet; humid climate; external drainage, but routes unknown.	Relatively higher elevation than surrounding areas; sparse paleontological and sedimentary record; drainage both eastward and westward.

The position of the Pearlette ash is most significant in this reconstruction. By a quirk of geology it was trapped and preserved in the alluvial fill of Fisher Valley in the middle member of the Harpole Mesa Formation, second oldest in the series of nine glacial formations of the La Sal Mountains (Richmond, 1962). The great bulk of sediments in the Fisher Valley fill post-dates the ash bed. In the Burmeister core the Pearlette is 202 feet below the surface in what is regarded as Lake XII.

Insofar as the Colorado Plateau is concerned, dated deposits of the pre-Wisconsin glacial stages are practically nonexistent. The only significant soils and constructional features adequately known are those of the La Sal Mountains. Destructional features are another matter, and they are difficult to date. Present erosional land forms are but end results of long-continued destructive processes and must be attributed to the whole interval of formation, not just the current phase. In this light, the Colorado River, its major tributaries, and most of its secondary branches must be regarded as products in part of early- and middle-Pleistocene erosion. If there were cyclic effects such as the speeding up or the slowing down of erosive processes or alternations of cutting and filling, these effects have not been recognized. Certainly many subsidiary pediments and their cover, certain of the higher gravel-capped stream terraces, and certain alluvial fills such as that of Fisher Valley belong to the early and middle Pleistocene.

If there is any significant sedimentary paleontological data for the interval between the Bidahochi and the Jeddito in the Southwest, it must be of small volume and isolated occurrence. This would seem to imply either that conditions were stabilized or that erosion has destroyed the evidence. In any event, there is a long gap in the record which would seem to span essentially the middle and late Pliocene and most of the Pleistocene.

In the Great Basin a different situation is found. Here the sediments and the shoreline features of Pleistocene water bodies such as Lake Bonneville and Lake Lahontan are almost continuous records for the Wisconsin stage. A review of the complicated histories of Lake Bonneville and Lake Lahontan need not be given here. An excellent summary with references is that of Morrison (1965).

RECENT AND NEAR-RECENT

Anthropologists have had to come to grips with the problems of Recent and near-Recent sedimentation and erosion in the Southwest in connection with their studies of the aboriginal inhabitants. Scores of small settlements and many large communities are known to have been established on or adjacent to the alluvial fill of the canyons or upon the higher intervening mesas of the Colorado Plateau. The inhabitants lived exclusively upon local products, and their fortunes waxed and waned according to the productivity of their surroundings.

Intensive human colonization of the Southwest began about A.D. 600 and reached a climax probably around A.D. 1000. After about A.D. 1300, the area was almost completely abandoned, and except for the Pueblo communities, the rest of the area was utilized by only nomadic travelers.

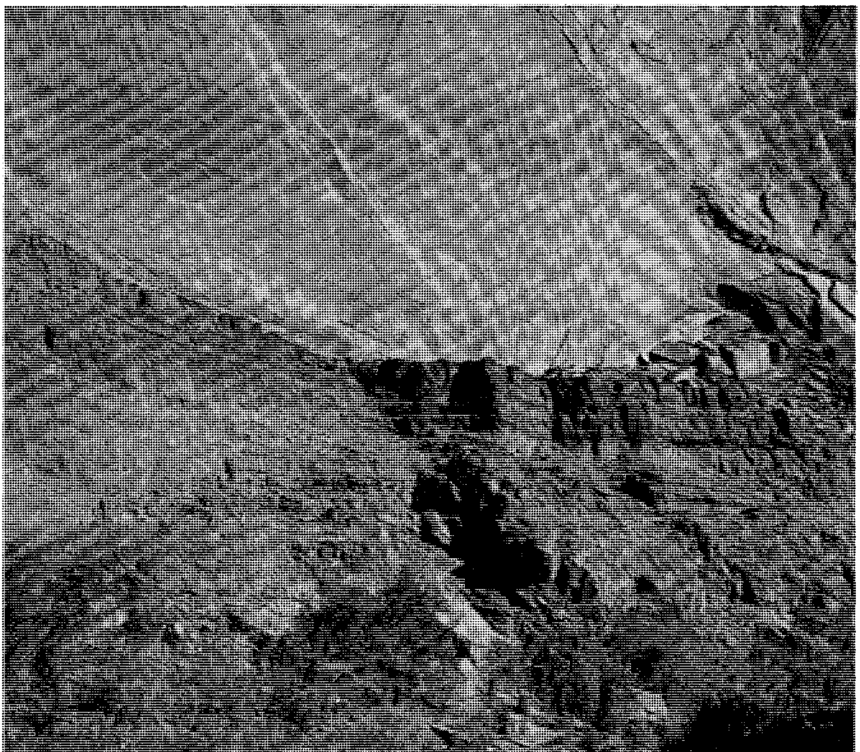
Conditions which encouraged a settled, semi-civilized existence but which seem to have been insufficient for continuous settlement have been studied extensively by anthropologists. Few have doubted the basic importance of climatic influences, but there are differences of opinion as to how these have operated.

In a pioneer study, Hack (1942) recognized three chief periods of alluviation with intervening erosion. The earliest deposit is the Jeddito Formation, which holds the remains of large extinct mammals and probable traces of early humans. After the Jeddito was terminated by erosion and downcutting, the Tsegi Formation was deposited. Remains of basketmakers and early Pueblo cultures are associated with the Tsegi, which is judged to have accumulated between about 1000 B.C. and A.D. 1200. The subsequent erosion of the Tsegi is a manifestation of events of critical importance to the human inhabitants, who deserted most of their previously held territory and never resettled it. It is thought by many that the severe drought in the thirteenth century (inferred from dendrochronological evidence) is a correlative and causative event.

Deposition 3 of Hack is the Naha Formation, dated as having accumulated between about A.D. 1300 and A.D. 1850. Final evidences of the Pueblo culture and artifacts associated with the modern Navajo and Piute peoples are found in it. The final erosional episode, generally believed to have commenced about 1880, is still going on.

The most comprehensive and integrated archaeological study of any region of the Colorado Plateau yet completed is that of the University of Utah Glen Canyon Project. Surveys were conducted, not only along the main stream, but along all important tributaries. Although the chief interest was archaeological, due attention was given to the total ecological situation, including climate and soil. Jennings (1968, p. 11) has written:

> All the canyons have often been more productive than now. As recently as A.D. 1915 in some cases, these deep narrow canyons contained



TEXT-FIGURE 4.—Moqui Canyon, a tributary of the Colorado River, San Juan County, Utah. View shows the solid walls of Wingate Sandstone, a crumbling embankment of alluvium in process of removal, and the boulder-strewn stream bed, which may be not far above the original bedrock floor of the canyon.
Photo Courtesy University of Utah, Dept. of Anthropology

rich sediments as deep as 90 feet, across which the clear streams meandered. With the high water table and the broad flood plain extending from cliff to cliff, each canyon supported the same varied fauna and flora but in larger quantity than now occurs. While today's streams all flow on bedrock between sheer rock walls, in every canyon the remnants of the earlier valley fill form crumbling earthen cliffs beside the stream. Some of the narrower channels have been flushed out entirely by local floods, and stains alone attest to the earlier deep sediment. Aboriginally, then, the canyon floors were fertile soil contrasting greatly with the present scene.

The Glen Canyon project failed to prove any well-marked correlation of events among the various sites and canyons but did show a progressive series of depositional and erosional events recorded in deposits ranging from those with a large extinct fauna to those produced by the present intensive erosion. Maurice E. Cooley, who has studied the stratigraphic and geomorphic implications of the Glen Canyon Project, reports that Recent time is represented by five alluvial units and by two prominent and two secondary cycles of erosion and arroyo formation (Cooley, 1962). The subdivisions cannot be said to correlate exactly with Hack's scheme, but neither do they deny its essential harmony with the overall trend. What seems to be proven is that a repetition of climatic conditions has taken place which has favored the alternate alluviation and erosion of valleys in the Southwest.

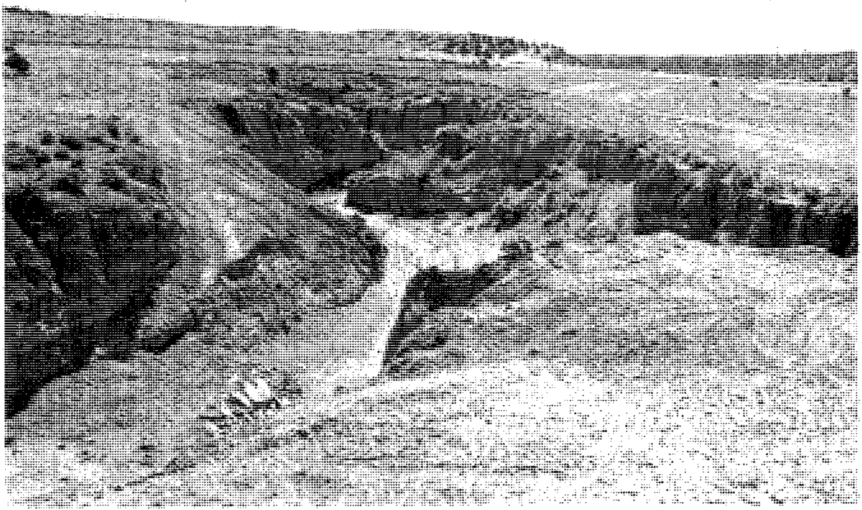
HISTORICAL PERIOD

The settlers of the American West long believed that water follows the plow. The truth—and the falsity—of this belief are nowhere better illustrated than in the settlement of southern Utah by the Mormon pioneers. The history of the town of Escalante is typical. Settlement began in 1875 on the banks of the Escalante River, which flowed as a clear stream through a series of grassy meadows. For a while things went very well indeed; even the water in the river increased several fold, an occurrence that the settlers attributed to the prayers of their leaders. But a series of floods, chiefly during the 1890s, created a huge gully with an average depth of 35 feet and a width of 69 feet that extended throughout the length of the Upper Valley area and past Escalante.

The experience of Escalante can be duplicated at many places in the Southwest within the last few decades of the nineteenth century. The initial increase in runoff was described as follows by Powell in his epoch-making report on the lands of the arid regions (Powell, 1879 p. 91-92):

> The increase is abundantly proved; it is a matter of universal experience. The observations of the writer thereon have been widely extended. Having examined as far as possible all the facts seeming to bear on the subject, the theory of the increase of rainfall was rejected, and another explanation more flattering to the future of agriculture accepted.

Among the items Powell listed as tending to increase runoff were the "cropping of grasses and treading of the soil by cattle; the destruction of the beaver dams, causing a drainage of the ponds; the clearing of driftwood from streams channels; the draining of upland meadows; and many other slight modifications. . . ."



TEXT-FIGURE 5.—Gully erosion of historic time; Sheep Flat south of Cannonville, Utah. Photo Courtesy Soil Conservation Service

Powell seems to have been much too optimistic about the end results judging by his conclusions that, "the changes are chiefly advantageous to man in arid regions where agriculture is dependent on irrigation for here the result is to increase the supply of water."

There are many other versions of cause and effect: according to Navajo legend, the Tsegi region was "bewitched" in 1884 when the farm lands were cut out, and the lakes vanished (Gregory, 1917, p. 130). Here not even temporary benefits were enjoyed. After the passage of three-quarters of a century, the cutting of washes or arroyos must be judged as a tragedy. A great many pioneer settlements had only a temporary existence before being rendered uninhabitable through the erosion of their agricultural lands. A few settlements in alluvial valleys have maintained a precarious existence, but the bright promises of early prosperity have long since vanished in devastating floods. Thus have the ranchers and farmers added their share to the "ghost towns" of the west.

The rapid destruction of alluvial lands by the arroyo cutting over the entire Southwest seems to have followed so closely on the heels of settlement that a cause-and-effect relationship is commonly assumed. The introduction of huge herds of cattle and sheep with resulting overgrazing is held by some to be the primary cause of the trouble. If this assumption is correct, those who owned and profited from the flocks and herds could be "blamed" for a great wrong. However, many of the supposed culprits had acted innocently and ignorantly. Certainly few were anxious to accept any blame for the outcome: cattlemen blamed sheepmen and vice versa. And of course the Indians blamed white men, while the different groups of Caucasians blamed each other. But generally, those who suffered most blamed a "change of climate," which is the interpretation most geologists are inclined to favor as the ultimate, but not necessarily the immediate, cause of the historic arroyo cutting. The long-term trends cannot be overlooked or ignored. Geologists know better than most that the chain of cause and effect which produced the present landscape is very long indeed.

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