Great Basin Climates in Relation to Human Occupance*

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The concept of the Great Basin enjoys an attractively precise areal definition as the great assemblage of contiguous areas of interior drainage in Western North America. Even this definition weakens at the southern and western edges; the Southern San Joaquin Valley generally, and Coachella and Imperial Valleys frequently, are excluded from the region. Though topographic contours form the boundaries, clearly they can only be maintained by a distinctly subhumid climate. Evaporation must exceed precipitation for each of the major basin drainages or normal stream erosion would destroy their characteristic hydrologic pattern. Only minor basins in the Sierra Nevada and adjacent to the Wasatch mountains now depart from this pattern though in Pleistocene times there was much joining of what are now separate basins and at least some spill-over out of the region for short times from some of the component basins (Hubbs and Miller, 1948).

Thus a subhumid climate characterizes this vast region and must have characterized it for most of the long geologic time since tectonic forces erected barriers to the outflow of water.

I should like to examine here the present climate of the Great Basin in terms of modern meteorological concepts. It is my belief that this is an essential basis for any reconstruction of the sequence of climatic changes that geologic, and to some extent archeologic, evidence show have occurred. I am impelled to do this by a feeling that the sequence of Anathermal, Altithermal, and Medithermal, proposed and vigorously maintained by Antevs (1948, 1952, 1952a) has become a Procrustean bed into which some archeologists laboriously chop and fit their stratigraphic data. In terms of our present secure knowledge attempts to use Antevs' climatic scheme as the sole basis for dating such sites as Topanga and Farmington (Daugherty, 1953) can merit only the title of myth invention.

Antevs' scheme is based on a postulated world-wide contemporaneity of temperature changes, and its sequence ultimately rests on North European and Eastern North American pollen analyses and varved clay counts. A recent survey of the late glacial and postglacial climatic history of the Mediterranean region (Butzer, 1957) completely inverts the time period of Antevs' supposedly dry Altithermal (5000-2400 B.C.), and makes it a subpluvial. Both conditions may actually have obtained at the same time in the two regions, resulting from asymmetrical alterations of the atmospheric circulation in the Northern Hemisphere, but present theory does not explain them and has less worth in extending an understanding in areas when the

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data are even more fragmentary. Insofar as the Great Basin is concerned the terms Anathermal, etc., are especially unfortunate in that they suggest that temperature changes are the critical variable. This may be true in Scandinavia, but in the Great Basin variations in precipitation are of vastly greater importance. In this region I shall try to show that low temperatures may well be inversely correlated with heavy precipitation.

While geological and even archeological evidence of past climates that differed greatly from present ones cannot be ignored, a satisfactory understanding of the sequence and temporal position of these climates can only be achieved if the spotty geological data is coordinated with a general theory of atmospheric circulation. The earth's atmosphere is a single heat exchanging engine. Any changes in its circulation at one place will have repercussions throughout the system. If a firm understanding of the present atmospheric circulation can be obtained, there is a possibility of predicting, though only within fairly broad limits, how a known change at one or two places will be paralleled by changes in other parts of the system.

A few postulates about paleoclimates must be expressed. (1) In the first place, glaciers, pluvial lakes, or extensive deserts are caused by climates. While the presence of great ice masses or vast lakes will have a modest effect on local climatic conditions, particularly temperature and relative humidity, these topographic features are the products of air masses which originated far away and the atmospheric movements that brought them over the area in question are the immediate cause of increases or decreases in temperature and precipitation. (2) Pluvial and even glacial conditions in the Great Basin might be obtained either from an increase in precipitation or a decrease in evaporation; the latter phenomenon is rather closely correlated with temperature. It is entirely possible to get a rise in lake levels associated with rising temperatures if the increase in precipitation is sufficient, and in this connection it is pertinent to remember that warm air carries, and consequently can precipitate, more moisture than cold air. (3) While the atmospheric circulation at the height of the Mankato glaciation and earlier may have included some elements basically different from those that occur today--even this is far from certain--it is likely that post-Mankato climatic fluctuations are the product of synoptic weather patterns which recur at the present time. The humid and arid sequences of years involved no kinds of weather not now known; only their frequencies varied (Thornthwaite, Sharpe and Dosch, 1942). Further, geologists seem agreed that no tectonic movements capable of changing atmospheric circulation patterns significantly have affected the Great Basin in the last 25,000 years. Many climatologists believe that the most promising line of investigation directed toward understanding the causes of glaciation involves learning why particular kinds of weather occur with greater or lesser frequency in certain years or sequences of years, but this is not the subject of this paper.

On the above grounds I should like to examine the present climates of the Great Basin from two standpoints. In the first place, what is the static climatic record? On the average, how are precipitation and temperature geographically and seasonally distributed over the region?[1] Secondly, what are the specific weather patterns which, combined over many seasons, produce this climatic record? Working from this base we should be better able to evaluate the real nature of the climatic fluctuations that seem to have occurred in the Great Basin over the last 10,000 to 12,000 years.

Various parts of the Great Basin experience extreme temperatures, and these are correlated closely with the widely variant latitudes and altitudes of the region. The whole region is one of great diurnal temperature range, a product of low humidity, clear skies and, for much of the area, considerable elevation. The highest temperatures of the hemisphere have been recorded at Death Valley, and nights in Central Nevada can be almost as cold as any in the United States, though average temperature values are generally intermediate. Temperature minima occur near the winter solstice rather than in January or February as is characteristic of the Eastern United States. Clearly, they are primarily the product of radiation cooling of stagnant air rather than the invasion of the area by rapidly moving polar air masses. From the human standpoint, this means that at certain times of the year effective shelter and fuel are needed to maintain human life in all but the lower southern deserts. Furthermore, even if average temperatures were to rise or fall by as much as 10° F. the same situation would prevail. Thus temperature changes themselves are a very minor factor in modifying the attractiveness of the region for human occupation.

Figure 1, taken from Leighly (1956) with the outline of the Great Basin overlaid, is about as good a representation of regional precipitation distribution as can be obtained for an area with such broken topography and a loose network of weather stations, many of them providing only very short records. The basic data are obvious. Precipitation is closely correlated with elevation and the rain shadow effect is pronounced to the east, the lee side, of major mountain ranges. Extreme drought is experienced in the south where cyclonic storms are fewer and elevations are generally lower. Only at the extreme west and east do mountainous areas receive enough precipitation to provide sufficient runoff to support large permanent lakes, but each of the ranges in Central Nevada and many of those in Eastern California do get enough rain to support permanent springs and short streams (Hubbs and Miller, 1948).

A few points less evident from the map may be noted. Northeastern Utah is relatively humid. The Northern Wasatch range is lower than many of the ranges of Nevada, but collects far more precipitation, and the zone of heavier rainfall extends into the Salt Lake Lowland far west of the range,

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1. The basic source for climatic data is the "Climatic Summary of the United States," Bulletin W and Supplement. United States Weather Bureau 1932 and 1954.

an area with slightly lower elevation than the exceedingly dry Bonneville Desert near the western border of the state. This contrast is almost certainly not the result of evaporation from the Great Salt Lake. It appears to result from a concentration of cyclonic paths over Northeastern Utah, especially in late winter and spring, combined with an increase in the incidence of convectional summer storms toward the east.

As is characteristic of dry regions, annual precipitation tends to vary tremendously from year to year in the Great Basin. A typical station with an average annual precipitation of 10 inches may record less than 2 inches in one year and over 20 inches in another. The longer the record, and to some extent the drier the station, the wider this range is likely to be. The northeast corner of the Great Basin, however, shows an atypical stability in its rainfall pattern. A 56 year record for Salt Lake City shows an average annual precipitation of 16.26 inches with the driest year receiving 10.33 inches and the wettest 23.67 inches; comparable figures are characteristic for Northern Utah and adjacent areas. I can suggest no obvious physical reason for this local climatic feature, but the secure though not abundant rainfall is of great importance to the present development of the region, and must have been an attractive environmental feature to the Indian population as well. One would expect a hunting and gathering population to stabilize at a relatively high level rather than being kept well below its normal ecological potential by recurring drought and famine years.

The extreme variability of precipitation over short distances, from less than 5 inches to more than 20 inches, must be considered when we attempt to assess the ecological effects on non-agricultural human societies of post-glacial climatic fluctuations. Most of the surface area of the Great Basin cannot now support humans. It can be inhabited at all only because there are local concentrations of water, vegetation, and animal life. These include springs and meadows below them, piñon forests on the higher, wetter ridges, etc. Among these richer spots the nomadic hunting and gathering Indians of historic times wandered, as bands or as families, exploiting piñon nuts in the fall, meadow grasses in the spring and early summer, fish in the few streams and ponds, and local concentrations of other animal life at various times and places (Steward, 1938, pp. 14-44). Archaeological evidence suggests that this type of economy was followed in the Great Basin for almost all of human time.

If the average annual precipitation were to be doubled at all stations, a climatic fluctuation almost certainly greater than any that has occurred since glacial times, and perhaps greater than at the Pluvial Maximum, the same thing would be true. There would be more oases suitable for habitation and a greater total population could be supported, but vast areas of true desert would remain. Conversely, if the annual precipitation at all points were halved there would still be foci suitable for settlements, few in number, and smaller, but scattered throughout the Great Basin. The piñon forests, and other plants restricted to the moister parts of the Great Basin, survive in isolated spots near the crests of various mountain ranges. Their present existence demonstrates that they could withstand all postglacial

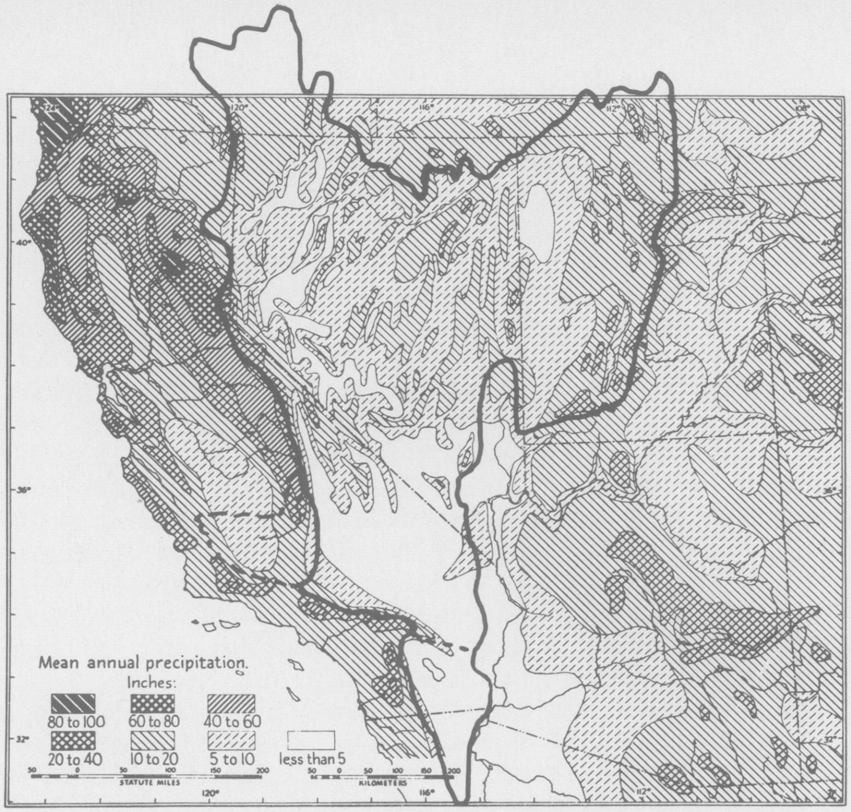

FIGURE 1. MEAN ANNUAL PRECIPITATION. (AFTER LEIGHLY)

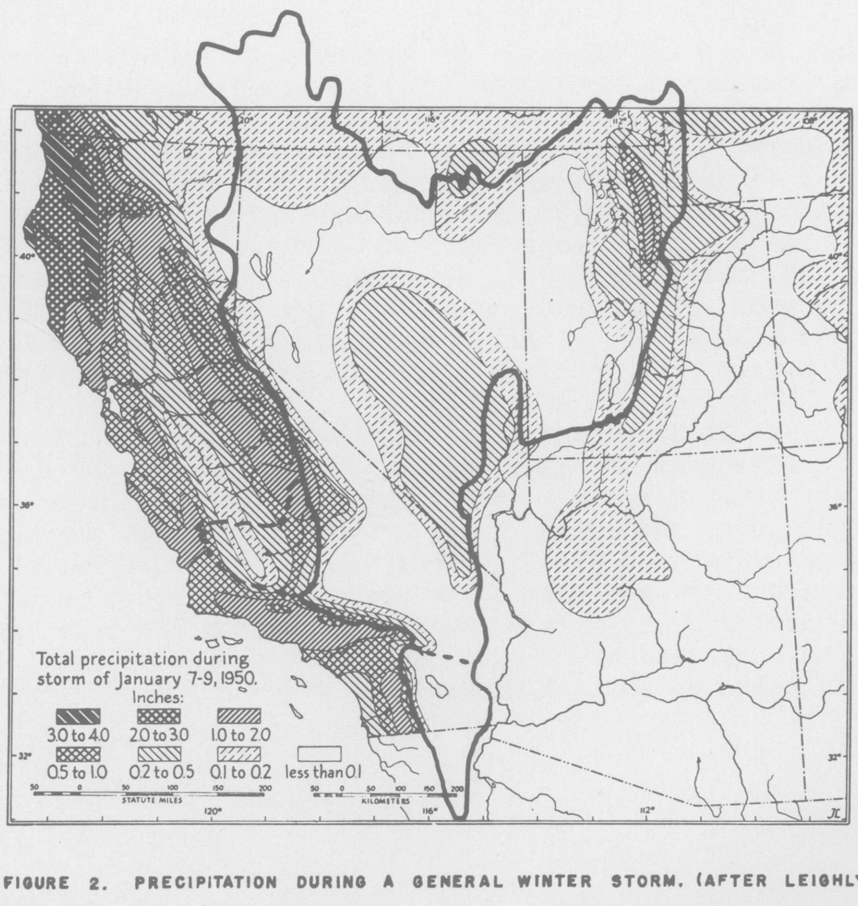

FIGURE 2. PRECIPITATION DURING A GENERAL WINTER STORM. (AFTER LEIGHLY)

droughts. It seems unlikely that postglacial dry cycles forced man to abandon completely vast areas of the desert West. Certain sites were abandoned, surely; particular ecologic adaptations or economies may have failed; and cultural phenomena depending on sizable concentrations of population with substantial food surpluses may have disappeared. But if man had the tools and techniques needed to enter the Great Basin and maintain himself 10,000 years ago, he could continue to do so ever since.

When we examine the climate of the Great Basin in terms of the specific storms that produce the region's precipitation it is evident that these storms are of two distinctive sorts. The better known type is the mid-latitude cyclone which enters the region from the west or northwest. These are winter storms though they affect the northern edge of the Great Basin well into the spring. Figure 2 (Leighly, 1956) shows the way in which the precipitation from a single large cyclonic depression was distributed over the Southwestern United States. The coastal regions of California and the mountains behind them caught most of the rain. Much of the Great Basin's share fell on the eastern slopes of the Sierra Nevada in California. Precipitation on the highlands of Central Nevada was modest though the mountains of Central Utah, especially the Wasatch Range in the north, received enough snow to produce substantial spring runoff. The rain shadow effect in the lower parts of the Great Basin is obvious.

Though the illustrated storm is typical, the precipitation product in the Great Basin of other storms could be distributed differently. Storms later in the spring are likely to produce more precipitation in North Central Nevada; but almost invariably the mountains receive several times as much as the lowlands.

Though the polar Pacific air mass that brought the storm produced relatively cool weather in California, it was associated with rising temperatures in the heart of the Great Basin. There the normal winter weather pattern involves a high pressure cell centered over Utah. With rapid radiation from the high ground this continental air mass is chilled at the base so that even in the valleys temperatures fall below 0° F. on most mornings. The longer the continental air mass persists the colder the mornings are likely to become. The cyclonic depression that displaces this air mass with air from the sea will tend to raise the temperature. The more frequently the continental air mass is displaced, the milder the average temperature for a particular month or season will be.

An average of ten cyclonic storms affect the southern part of the Great Basin during the winter half-year. Perhaps twice as many affect the northern part, most of the difference resulting from their beginning earlier in fall and continuing later in spring. During mid-winter each station in the Southwestern United States is likely to experience a drought lasting for a few weeks. These droughts result from the persistence of a cold dry continental air mass over the station, and produce a slight statistical reduction in the rainfall curve for the first two weeks of January at almost all stations (Leighly, 1956, pp. 34-35). A more humid climatic phase thus might involve a more frequent passage of winter cyclones and warmer winter temperatures in the Great Basin. Greater persistence of the normal high pressure continental air masses in winter would result in a colder, drier climate.

A completely different sort of storm provides rainfall during the summer, especially to the eastern half of the Great Basin. Although at the surface a thermal low pressure center persists north of the Gulf of California almost all summer, changes in the weather seem to result from variations in the atmospheric circulation aloft, especially at the 700 and 500 millibar levels (about 10,000 and 19,000 feet, respectively). When there is a moderate high pressure cell aloft, centered roughly over Southern Colorado, the clockwise flow of air around it brings air from the Gulf of Mexico over West Texas, New Mexico, Arizona and Utah. As this air moves into higher latitudes it becomes conditionally unstable. A small local convection, resulting from differential surface heating, can produce condensation aloft and violent afternoon thunderstorms when it pushes into the unstable air above the 700 millibar level. Such a system of storms moves slowly from southeast toward the west and north over a period of several days. The rain falls as local showers, usually only in the afternoons, but these can be widespread, and as illustrated in Figure 3 (Leighly, 1956), a single sequence can produce substantial amounts of rain over wide areas of Arizona and Utah, and to some extent in Eastern Nevada and Southeastern California. Summer rains in the Sierra Nevada are more likely to result from weak cyclonic circulations from which only this major mountain range can extract moisture. Although elevated areas in Utah and Arizona tend to get more rain from these summer thunderstorms than do lowlands, the contrast is not so great as in winter. Thus the lower areas of Utah and Nevada tend to get a larger fraction of their rains from the summer storms than they do from the winter ones (see Figure 4).

Although the maximum daily temperature is reduced by the afternoon cloudiness associated with a summer thunderstorm, this is a hot weather phenomenon. The warmest temperatures in Nevada are likely to occur while the unstable air is moving slowly westward over New Mexico and Eastern Arizona, in other words a day in advance of the thunderstorms there. A summer rich in such storms would not be a particularly cool one. In an occasional year this circulation of Gulf of Mexico air aloft is reinforced and has its influence extended to the western part of the Great Basin by the passage of a tropical cyclone, known locally as a Chubasco, up the Gulf of California and into the Great Basin. Over land this circulation is weakened, but it adds to the instability of the whole air column and can result in especially heavy local convectional rains. Imperial Valley gets heavy rains of this sort about every other year. They occur in the three months centering on September. Farther north such storms arrive less frequently (Thornthwaite, Sharpe and Dosch, 1942, Fig. 6).

It should be emphasized that the moisture that supports both the summer and the winter storms in the Great Basin is evaporated from distant

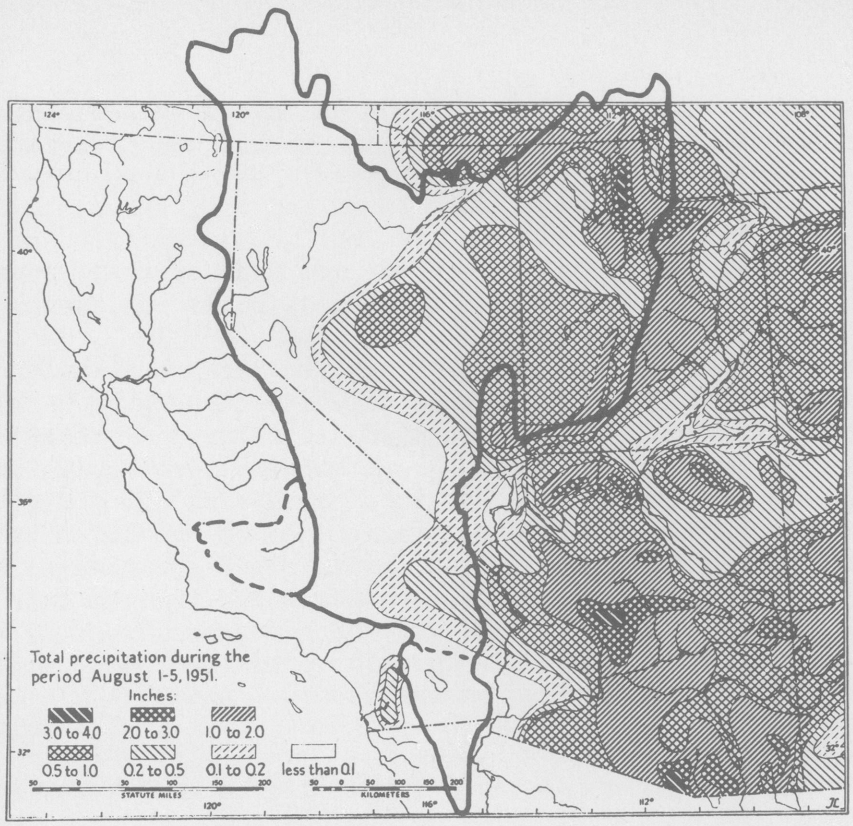

FIGURE 3. PRECIPITATION DURING A SUMMER RAINY SPELL IN THE SOUTHWEST. (AFTER LEIGHLY)

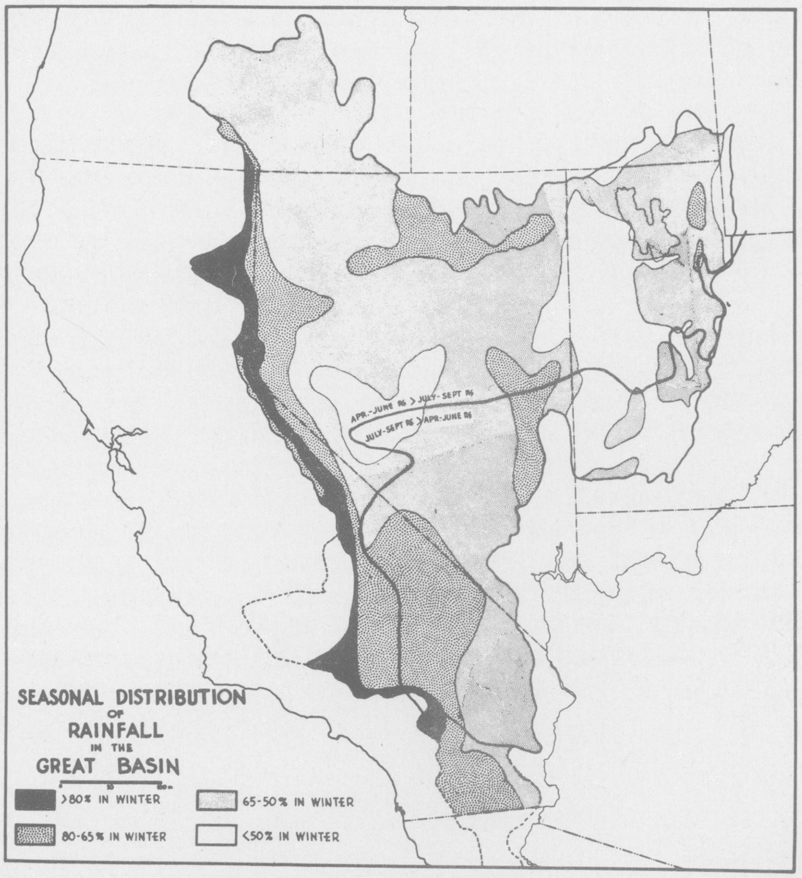

FIGURE 4. SEASONAL RAINFALL DISTRIBUTION.

ocean surfaces. Evaporation within and from lands adjacent to the Basin makes a minor contribution, and the maximal pluvial lakes are not likely to have made much more. The recent expansion of the Salton Sea and the irrigation of the Imperial and Coachella valleys have had no perceptible affect on local rainfall, just as the Gulf of California modifies little the desert lands on both its sides. Rainstorms in this region are dependent on upper air circulations that bring about instability aloft.

Another aspect of the precipitation pattern of the Great Basin is illustrated by the map (Fig. 4) showing the seasonal distribution of rainfall. Summer is treated as the April through September period and winter the rest of the year. Actually, in the northern part of the region, April and May rains are likely to be of the winter cyclonic type while October rains may be of the summer pattern in the south and east. Clearly, the western edge of the Great Basin receives the bulk of its precipitation from winter storms; the western areas receiving most of their rain in summer are in the drier lowlands (cf. Fig. 1), illustrating the greater effect of mountains on winter storms. In the eastern half of the Great Basin summer storms and winter storms provide roughly equivalent amounts of precipitation.

The heavy line across Figure 4 permits a further characterization of the Great Basin climate and one which applies directly to ecology. To the south and east of the line the late summer and early fall rainfall exceeds that which falls in the late spring and early summer. There is a remarkable coincidence between the greater part of this line and the northern and western limits of prehistoric agricultural settlements. This is clearly related to the requirement of the Indian crops, particularly maize, for moisture relatively late in their growing season (cf. Kroeber, 1939, pp. 207-212). The almost miraculous ability of the Hopi to get a maize crop from very little rainfall stems from the rain's regular occurrence at just the right time in the plants' development, and we may assume that the occurrence of these late summer rains was a necessary condition for the attempts at agricultural settlement to the west and northwest of the Central Pueblo area. Most students date these attempts early in the second millennium A.D. when the Anasazi-type economy was undergoing its greatest geographic expansion.

Another ecological tie-in may be noted. The students of tree rings state that the size of the tree ring increments on coniferous trees in the Southwest correlates best with the amount of winter precipitation (Antevs, 1948; Schulman, 1951; Glock, 1941). On the other hand the ability of such trees to survive in localities with minimum rainfall and high evaporation seems to be enhanced by the occurrence of a large fraction of that rainfall in late summer. Specifically, the arid timberline for piñon and yellow pine is notably lower in Northern Arizona and Southern Utah, where the summer rains are regular and fairly abundant, than in Central Nevada where they are scarce. The Nevada uplands get as much rain, and with higher latitude presumably are cooler at the same elevation.

The basic points in this discussion of the climate of the Great Basin are: (1) The amount of precipitation in a given year is very poorly correlated with temperature. Because of greater cloudiness a rainy summer is likely to be cooler than a dry one. Since the clouds form in an upper air mass, however, relative humidity and hence rate of evaporation would not be significantly lower at the surface except when it is actually raining. Conversely, a rainy or snowy winter, with its frequent breakdown of the continental high pressure cell, would be warmer than a dry one. In these terms, Anathermal, Altithermal and Medithermal are irrelevant to the critical moisture variable in the climate. (2) The two weather patterns which, in all but the western fringe of the Great Basin, produce roughly half of the annual precipitation each are of completely different origin and character. There is no reason in terms of our present knowledge of the general circulation of the atmosphere why variations in the two circulations should be coordinate. They could both be productive, and often are, resulting in a very wet year, or both inactive, producing a dry one, or drought in one season could cancel heavy precipitation in the other. Fluctuations in summer rain are likely to be more effective in altering the climate in the eastern part of the Great Basin and winter rains more effective in the western part.

In attempting to relate the present climatic pattern to variant conditions of the past, it is clear that we are on firmest ground when we work with the recent past for which the most direct evidence is available. Instrumental records go back about 100 years at a few stations and these correlate reasonably well with the tree ring record. Unfortunately that record is not yet developed for most of the Great Basin, and extending the Southwestern sequence of climatic events beyond Southern Utah is probably fallacious. Beyond this (roughly 2000 years), the geological evidence of minor climatic fluctuations is singularly difficult to interpret. Radiocarbon dates clearly associated with climatically characteristic geological or cultural events might permit correlations across extensive areas so that a feature that might be the product of local conditions, for example, the draining of a marshy district by the normal progress of headward erosion of an arroyo, could be distinguished from more widespread changes which must have a climatic cause. Unfortunately, few of the radiocarbon dates for the past 10,000 years permit clear climatic characterizations.

Sorts of geologic evidence which may relate to alterations in the general climatic pattern and thus be applicable over wide areas, are:
1. Glacial moraines occurring beyond the limits of present glaciers. These may indicate either a cooler or a moister climate or some combination of both. In the Great Basin they almost certainly mean an increase in winter precipitation. One limitation on this kind of evidence is that ordinarily it can only refer to the last glacial advance of a given extremity. In rugged areas subsequent ice advances almost always destroy the earlier moraines they override.

2. Shore features indicating higher stands of water in enclosed lake basins. A rise in lake level in the Great Basin might result from an increase of either winter or summer precipitation, quite different climatic events, or at the western and northeastern periphery from a rise in temperature which melted extensive mountain glaciers in the Sierra Nevada or Wasatch Mountains, respectively. The extent of the shoreline terraces or the size of deltaic or tufa deposits may suggest a duration for the high stillstand. Evidence of long-enduring high water levels may survive a subsequent greater rise and later a decline in lake level. Two caveats are appropriate concerning this kind of evidence. (a) A correlation in time between separate basins should rest on independent evidence such as radiocarbon dates. The early Danger Cave date at a low level in the Bonneville Basin (Jennings, 1953) should illustrate this point. (b) Even very minor and frequently occurring topographic changes such as stream captures, landslides, or the opening of springs along a fault line can produce notable changes in the supply of water for a particular lake basin. The repeated filling and drying of the Blake Sea in the Imperial and Coachella Valleys as a result of shifts of the lower Colorado River on its delta is only a spectacular example of this; others are likely to exist.

3. The salinity of lakes, evaluated in terms of the duration of input of soluble matter, has permitted some extraordinary conclusions to be drawn (e.g., Jones, 1925). At present there seem to be too many unknowns involving the chemical dynamics in saline deposits, variability of salt sources in the drainage basin, separation of saline beds by impervious mud layers, and removal of salts by the wind from dry playa surfaces (the ability of the wind to do this certainly varies from playa to playa, and a really salty playa surface such as that at Searles Lake is almost impervious to wind action) to give this kind of evidence much independent stature.

4. Pollen diagrams have been worked out in some detail to my knowledge only on the northwestern edge of the Great Basin (Hansen, 1946). In the grossest sense they suggest the expected warming and drying of the climate since Pleistocene times. Because they can be arranged in linear columns that show sequent expansions and contractions, pollen diagrams have an especial attractiveness for the archeologist. The climatic evidence they present, however, is of the most indirect sort. In the first place, it is unlikely that the rate of deposit in the marshes where pollen grains are preserved is uniform so that relative depth even within a single column provides only an ordinal indicator of age. Secondly, the pollen of trees can and does come from great distances; changing wind directions and velocities may have more to do with what pollens are deposited than the character of the local flora. As pollen students recognize, the ecological succession following an extensive fire might produce the sorts of changes in pollen frequency noted in most of the Columbia basin records by Hansen. Finally, the pollen of only a few kinds of plants can be identified so the sample is not randomly selected, and the difference between a 10 and 30 per cent occurrence of one of five broad classes of plants is of dubious statistical significance. If the changes recorded in pollen pro-

files are not gross, their interpretation from the standpoint of climatic change is risky indeed.

5. Finally, we come to cave deposits which involve several classes of phenomena. Many of the caves around Great Basin lake shores do provide a terminus post quem since all deposits have to be later than the time when the lake rose above the cave mouth.[2]

Widespread bat guano deposits separated by dust deposits are often taken to indicate wet and dry periods respectively. The rationale that bats and their insect food need lots of water and that the dust comes from dry lake beds is reasonable. But it is far from conclusive. Bats just do not occupy all suitable caves at any one time, and there is no reason to assume that they did not occupy, abandon, and reoccupy a particular cave while the local environment remained effectively constant for them. Bat guano accumulates faster than dust, so a marked dust layer may merely mean that no bats occupied the cave during the period when it was deposited. Chemical analysis of the dust within and apart from the guano, showing the high salinity content of dry lake beds and a lower content within the guano would be relevant, but I have found no record that such analyses have been made. Bat guano itself is subject to radiocarbon dating, and the dates from it diverge only moderately from those for the cultural materials found in it.

The accumulation of dust in caves, while not likely in a heavily forested area under truly humid conditions, cannot have been halted in the Great Basin by any conceivable post-Pleistocene increases in precipitation. If these desert valleys received enough additional rainfall to become steppes, perhaps twice as much as they now get, they would still experience the dust-raising winds over nearly bare surfaces in early spring as even the least dry districts do today.

Other coprolites, particularly those of large herbivorous mammals, afford a better index of the flora, and possibly, depending on the mobility and eating habits of the animal, these can be related to the climate. The ground sloth dung of Gypsum Cave is notably indicative (Laudermilk and Munz, 1935). Human feces and kitchen refuse, while they provide valuable cultural, and with C-14 temporal, data are less suitable indicators of the general flora and climate because of man's dietary selectivity and his mobility and tendency to carry food long distances into camps for preparation and eating.

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2. Phil C. Orr, in an oral communication, states that he has detected evidence of a rise in the level of Lake Lahontan, covering cultural materials in the caves in Pershing County, Nevada. Curiously, such evidence has not been noted before, but if it is substantiated such flooded cave sites will form a wonderful new basis for determing and correlating climatic events in the distant past.

Other materials resulting from human occupance, both in and out of caves, are more difficult to use as an indicator of climate. The cultural prism dominates the scene. Fishhooks in a desert might be prized ornaments. While a major climatic change in the Great Basin might increase or reduce the carrying capacity of the region as a whole, and permit or prevent occupance of particular sites, full scale abandonment was not necessary. The Leonard Rock Shelter (Heizer, 1951) and Danger Cave (Jennings, 1953) finds should finally quiet the myth of the uninhabitability of the Great Basin during the Altithermal or "Long Drought." Even the discovery of living sites far from any present water source does not require a climatic change. Springs in dry lands are remarkably mobile as I have learned in Central Baja California by comparing mission descriptions with the present scene in localities which have not been occupied since mission times. Changes in the phreatophytic vegetation, erosion down to ground water table, or alluvial covering of springs, as well as the most minor movements along fault lines can result in the appearance or complete disappearance of a spring at a particular locality. A non-agricultural group requires only one tiny spring.

In climatic terms alone, what can be stated definitely about climatic change in the Great Basin in postglacial times? Beyond this what inferences are particularly reasonable? The clearest record is from the extreme ends of the time scale. Truly glacial conditions must have been characterized by more frequent cyclonic storms and heavier winter precipitation. Winter temperatures, except adjacent to the Sierra Nevada, need not have been much lower, and the very small ice sheets within the Great Basin could not in themselves have had much effect on summer temperatures. The end of glaciation undoubtedly had a climatic cause. Fewer and weaker cyclones did not provide the winter snows to nourish the glaciers. If maximum lake stages occurred while the glaciers were in retreat, and though this should be subject to demonstration by stratigraphy I have found the literature equivocal, we might postulate that summer rains became more abundant, both contributing moisture and accelerating the melting of the glaciers. Without this the lakes probably receded as the glaciers melted, suffering the same lack of nourishment as the glaciers. The relatively low stand of Lake Wendover in the Bonneville Basin about 9500 B.C. (Jennings, 1953) would suggest that the latter situation existed. Similarly, I find no real support for the statement that the climate was cooler and moister in the material taken from the roughly contemporaneous lowest occupation level of Fishbone Cave (Orr, 1956). The cactus thorns from Crypt Cave, which Orr, on the grounds of topographic position and artifact typology, believes to be even older than the occupation of Fishbone Cave, would appear to suggest a warmer climate than the present one if anything.

At the recent end of the time scale, the modern instrumental records for stations in and near the Great Basin do not show significant trends in either annual precipitation or temperature. These conditions have fluctuated tremendously, but in a random fashion, a very dry or warm year often being followed by a very wet or cool one, or vice versa (Thornthwaite, Sharpe and Dosch, 1942). With this random sort of variation it should not be surprising that a decade of drought or of unusually moist conditions would occur during any hundred year period. This being the case the Great Drought of 1276 to 1299 and other dry periods of comparable extent during the last two millennia in the Colorado Plateau would be expectable phenomena over the longer time span. A recent study in New Mexico (Leopold, 1951), however, has turned up an interesting climatic fluctuation that involves a longer period and has interesting implications for culture history. At Santa Fe from 1849 to 1939 the annual rainfall totals varied but at random. On the other hand in the first half of the period (1849-1895) there was a higher proportion of heavy rain from summer storms and fewer light rains from winter storms than in the more recent period. Analysis of similar records for Albuquerque and Las Cruces produced results that are statistically significant between the one percent and five percent levels, and all show a change in the same direction.

Leopold would attribute this secular climatic fluctuation to some change in the general circulation of the atmosphere, and he considers it potentially competent to effect a change in the erosional epicycle. The eastern Great Basin is affected by the same two rainfall-producing atmospheric circulations as New Mexico. In particular, here we have a possible cause for the occupation and later the abandonment of the agricultural settlements in Southern Utah and Eastern Nevada (Rudy, 1953; Jennings and Norbeck, 1955). With its peculiar dependence on summer rainfall, maize might be quite successful during a fifty year period when such rains were relatively abundant and impossible if they were reduced for a similar period. And all this could happen while the average annual rainfall and general ecological conditions remained essentially uniform. In any event, this is objective and instrumental evidence that a moderate term secular climatic variation is now occurring in the Southwest; it is reasonable to expect that similar and longer term variations in the proportions of winter and summer rains have occurred during the last 11,000 years.

For the period from 9000 B.C. to the beginning of the Christian era I have tried to check the radiocarbon dated finds in the Great Basin and adjacent areas for data that can be clearly associated with climatic change. This has not been very successful. The long record for Danger Cave provides nothing since the first human occupation that demands a different climate for its explanation. The typical random wet year is a sufficient condition for all the visits to the cave.

The sloth dung at Gypsum Cave (Laudermilk and Munz, 1935) of about 8500 B.C. is a particularly awkward bit of data. I could certainly be happy to think it some thousands of years older. Regardless of whether these remains can be associated with man, we can be sure that ground sloths did not travel 40 miles to defecate. The Agave, Yucca and juniper materials in the dung, which currently grow only at 3000 feet greater elevation in the Clark mountains, are true climatic indicators. The other materials could come from the surrounding area. There are hills in the immediate vicinity that come within 1500 feet of the elevation of the present habitats of these plants so we need not assume a climatic change involving a reduction in temperature or increase in precipitation equivalent to a 3000 foot rise in elevation, but the minimum estimate would call for a drop in temperature of 5° F. or a proportionate rise in precipitation. The cattails in the dung also imply standing water, something not now available locally but which may have disappeared as the result of erosional activity rather than climatic change.

This then suggests a distinctly cooler and moister climate, specifically more winter cyclonic activity. The later date from near the top of the sloth dung pile (Sample C-222 ca. 6600 B.C.) is even more troublesome. It is surprising that if ground sloths survived into such recent times more remains do not show up at other radiocarbon dated sites, particularly in view of their affinity for caves.[3] From the climatic standpoint it would be easier to assume contamination and a much greater age for all this dung. The much more recent age for the top of the pile would support the notion of contamination from downward seeping water.

Though they occur far to the southeast of the Great Basin, the very early (2000 to 6000 years ago) finds of maize and other domesticated plants in Bat Cave, New Mexico, Coahuila and Tamaulipas are suggestive of a somewhat different climatic structure, as is the undated Mimbres florescence. All these localities today are marginal or submarginal for maize because of drought, and the wide range of dates from various levels in the column at Bat Cave would suggest interrupted occupation. The manioc from Southern Tamaulipas,[4] even if the plant grew a considerable distance away, suggests a far more tropical climate, that is, a greater inflow of moist air from the Gulf of Mexico during the summer over Northern Mexico and the Southwestern United States under conditions of instability, with relatively heavy summer precipitation. Such conditions may have prevailed for fifty years or a century, improving the environment from the standpoint of the cultivation of the New World crops, possibly accelerating the melting of mountain snow fields and glaciers, but not altering the basic semi-desert characteristics of much of the lowlands.

The evidence for the so-called Altithermal from 5000 B.C. to 2000 B.C., when the Great Basin was supposed to be uninhabitable, I find lacking. On Meighan's correlation chart of May, 1955, the period is as well-documented with dated sites as one would expect considering its temporal remoteness. Some of these sites, notably Danger Cave, and the Leonard Rock Shelter, are in particularly dry localities, localities where today it would be difficult for a hunting and gathering group to maintain itself for more than a few weeks following a season of heavy precipitation.[5]

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3. See, however, A. J. Jelinek, Pleistocene Faunas and Early Man. Papers Michigan Acad. Science, Arts and Letters, Vol. 42, pp. 225-37, 1957 [Ed.].
4. Oral communication from Alex D. Krieger. The find was made by Richard S. MacNeish.
5. This statement hardly holds for the lower Humboldt Valley where Leonard Rock Shelter is situated. For the local environment see Univ. of California Publs. Amer. Arch. and Ethnol. Vol. 47, No. 1, pp. 1-190, 1956 [Ed.].

In sum, then, the search for evidence of widespread and long term postglacial climatic changes in the Great Basin does not produce much that will help the archeologist who seeks a date for his site. Few of the changes in character of the stratigraphic columns require a pronounced climatic change for their explanation. It would appear that during the last 10,000 years the annual climate has varied greatly, as it does now. Dry or wet periods lasting a decade or so have occurred frequently. While the Antevs system of three major distinctive climatic units, Anathermal, Altithermal, and Medithermal, is a comfortably simple system with which to match a stratigraphic sequence, its simplicity does violence to the climatic fluctuations that have occurred in postglacial times.

During the recent past only the proportions of summer and winter rain seem to have varied over periods long enough to have affected human cultures and the migrations of people. This variation might have some worth as a tool for evaluating the temporary occupation of the southern and eastern Great Basin by farming groups.

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