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Post Pluvial Climates
of the
Southwest United States

Master's Thesis

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Introduction

In this paper we will consider that space of time in the Pleistocene that has been called Post glacial time. We will be concerned with the fluctuations of climate that have occurred in the Southwestern United States since the maximum of the last Wisconsin ice sheet and in dating these fluctuations as accurately as possible.

In speaking of the Pleistocene, Flint's (27) definition is adhered to. The Pleistocene is separated from the Pliocene on the basis of climate and considered to still be in progress. It is that part of the late Cenozoic time, "which is characterized by repeated climatic cooling, involving repeated conspicuous glaciation in high and middle latitudes, and repeated world wide fluctuations of sea level." The intercontinental migrations of the horse, camel, mammoth, and man also mark the Pleistocene.

This definition eliminates the Recent as a normal stratigraphic subdivision, and Flint decides to use it like the term postglacial is used, in an informal sense without an exact stratigraphic definition.

The Pleistocene epoch is subdivided into ages, which are the major glacial and interglacial periods with the stratigraphic equivalents of stages. The term postglacial, however, can be applied to only one locality or district at a time. Events that took place while the district was last covered with ice are referable to glacial time and subsequent events are postglacial time. Since the removal of the ice cover was progressive, it follows that postglacial time began for some districts much earlier than for others. The term postglacial is sometimes applied to events in regions that never were glaciated but in which the indirect effects of glaciation are clearly marked, as for example the valleys of large streams whose headwaters drain glaciated regions. The cessation of outwash deposition and the beginning of trenching of the outwash by nonglacial runoff is an event that can be definitely recognized and that can with propriety be considered as marking the transition from glacial to postglacial time in a given valley or valley system, (as described in the Cache la Poudre River section below).

Where there is no direct connection, such as is afforded by outwash, between a glaciated and nonglaciated district, the term postglacial is hardly applicable to any feature in the non-glaciated district. For the desert regions of the western United States, where Pleistocene features record alternating episodes of moisture and dryness, terms such as Pluvial and Post Pluvial are sometimes used, and seem best for this report.

The sources of data for a Post Pluvial chronology of the Southwest have been compiled from data on soil phenomena, cave and dune deposits, terraces of lakes and rivers, migrations of ancient peoples, and analyses of tree ring structure and tree growth.

The tree rings have provided a chronological picture of the variations in climate; they also provide a source quite independent of geological factors. In a number of cases, the dating of artifacts found in certain deposits assists in estimating the year of deposition of the strata.

Post Pluvial dating, however, must begin from a definite date to provide a point from which to work backward or forward. The first section of this paper discusses this date as set forth by a number of geologists working in the northwestern United States.

The states of Arizona, New Mexico, Colorado, Nevada, Utah, and California are the setting for the paper. Two score papers or so have been published on the climatic oscilations in these areas of the Southwest by Bryan, Albritton, Kelly, Campbell, Ray, Hack and Antevs. Of these works, Bryan has done the most energetic job in attempting to correlate the fluctuations of each locality with one another. A complete chart showing the chronological correlation of all these areas within the Southwest has not yet been brought forth. It is the purpose of this paper to do so.

Each column in the accompanying chart represents a profile of the climatic conditions over at least a part of the last 25,000 years in a certain district as proposed by the worker in that area. The dashed lines between the columns indicate the correlated periods of humidity or aridity which, in some cases, have been dated differently by the various investigators.

The Pluvial Period

The climatic conditions in the Southwest during the Pleistocene have been influenced by the state of glaciation in western Canada and the United States. The Iowan stage of glaciation started in the mountains of Western Canada, probably as a result of a temperature lowering. Well started, the glaciation fed itself, the more snow and ice, the lower the temperature, and the longer the snow season.

The cooling ultimately effected, in a varying degree, the entire North American continent. When the ice sheets had become very large, the climatic conditions of summer in many respects resembled those of the modern winter. Thus, high pressure prevailed over the ice sheets most of the year. The Aleutian Low also persisted, and cyclonic storms traversed the States the year around. The sinking temperatures, the increasing precipitation, and the reduced snow melting and evaporation led to a marked growth of glaciers in the western mountains and of lakes in the basins.

Ultimately, the west Canadian ice sheets became so large, and the glacial anti-cyclone so strong that the storm tracks were pushed southward, and the heaviest precipitation occurred well to the south of the ice border. The resulting undernourishment together with increased ice-wastage caused retreat of the ice sheets, while the augmented precipitation to their south led to a maximum of the mountain glaciers and of the pluvial lakes.

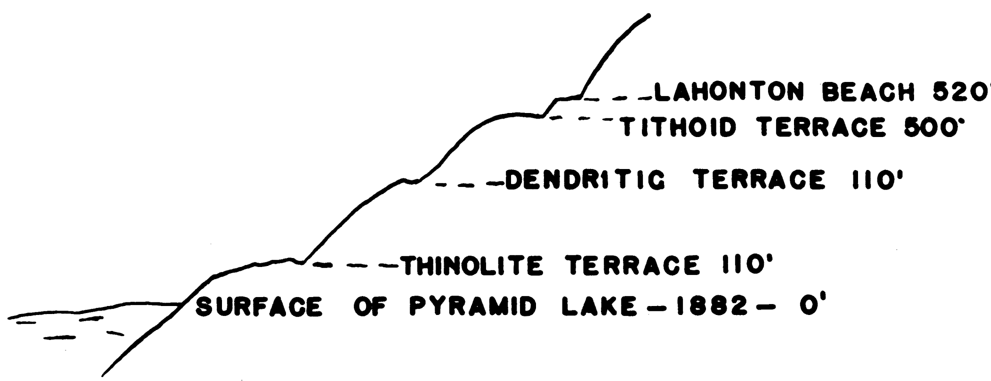
Later, when the western ice sheets had shrunk so that their anti-cyclone was weakened and the polar front moved northward, the precipitation over the ice sheets turned their retreat into advance. This led to the Mankato glacial period and the last glaciopluvial in the Southwest. (3a).

Data bearing directly on the climatic conditions in the Southwest are furnished in the first place by fluctuations of glaciers, snow lines, and lakes. The glacier variations have been studied by Blackwelder and Matthes, among others. In correlating the pluvial periods with lake fluctuations they found that the Iowan-Tahoe glacial may have been matched with the highest stages of Lakes Bonneville and Lahontan when Lake Bonneville overflowed and swept out its drainage channel. This moist age may be called the Bonneville Pluvial.

During the following interstadial, Lake Bonneville may have subsided to the level 350 feet above Great Salt Lake, judging from the profile in the Old River bed, described by Gilbert, and Lake Lahontan probably withdrew to the Thinolite terrace. (Figure 1.)

During the last glacio-pluvial, the lake in the north-western part of Utah rose to the overflow channel and recorded the Provo Pluvial. (Tables 1 and 2.) The lowering of the snow line during this period suggests that the summer temperature then was 8 degrees Fahrenheit lower than the present. (3A)

After the glacio-pluvial maximum some 23,000 to 20,000 years ago, the climate of the Southwest grew warmer and drier, and roughly 10,000 years ago, it was as it is today.



RUSSELL, "GEOLOGY OF LAKE LAHONTON"

FIG. 1

Table 1a

Bonneville Deposition and Erosion*

Recent - Great Salt Lake Stage
Stansbury - Wisconsin Glacial Stage.
Provo Stage - Iowan Glacial Stage.
Illinoin glacial stage not recorded.
***Bonneville Stage (Second high water stage) Kansasan.
**Inter-Bonneville Stage (First low water stage) Altonian interglacial stage.
*Lower Bonneville stage (yellow clay corresponding to 1st high water stage) Nebraskan.
Pre-Bonneville Epoch of low water. Pliocene.

*Antevs and Jones, "Quaternary Climates" <u>Carnegie Institute of Washington</u> No. 352, 1935' The Great Basin'. pp. 137-154.

Table 1b

Colorado River, Arizona. *

* 1. At the beginning of the Pleistocene there was an uplift of the Colorado plateau, which brought about the cutting of the Grand Canyon to a depth of 5,000 feet or more. During this time the Colorado flowed through the Sacramento Valley, eroding it deeply. This course of the river is from 15 to 40 miles east of the present one.

** 2. Some change occurred which caused the Colorado to deposit sand and gravel from the mouth of the Grand Canyon to the Gulf of California. In the Detrital-Sacramento Valley gravels were laid down to a depth of perhaps 2,000 feet. At the same time there were eruptions of Basalt. The Temple Bar Conglomerate. **

*** 3. Increased activity of the streams-excavation 2,000 feet.

4. Deposition of gravels

5. Humid

Table 1b continued.

6. Recent times river has been building up flood plains.

*corresponding times of deposition and erosion.
Lee, (40)

Table 2 *

1. Pre-Lahontan arid Period
    Probable Climatic conditions
        A time of aridity; precipatation small with large evaporation and rapid; high temperature.

    Results - Small lakes at times dry; Mountains free from glaciers.

2. First rise of Lake Lahonton
    Probably Climatic conditions:
        Precipitation moderate; evaporation decreased; temperature low.

    Results - Large lakes in the valleys and glaciers in the Mountains.

3. Inter Lahonton arid period.
    Probable climatic conditions;
        Decreased precipitation; evaporation rapid; temperature high.

    Results - Smaller lakes that at present and at times possibly dry; glaciers contracted and possibly completely melted.

4. Second rise of Lake Lahontan
    Probable climatic conditions.
        Precipitation moderate, probably more copious than during the first rise; evaporation decreased; temperature low.

    Results - Broad Lakes and large glaciers.

5. Post Lake Lahontan arid period
    Probable climatic conditions;
        At times of great aridity; precipitation and small mean temperature higher than at present.

    Results - Lakes desiccated and glaciers melted.

6. Present time - precipitation small; evaporation rapid; mean temperature 50 degrees F.; Country arid; rivers small and fluctuating; lakes and glaciers small.

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* I.C. Russell, "Geology of Lake Lahonton", U.S.G.S. Mon.11, 1885, p. 254-268

III.

The Post Pluvial

In the Post Pluvial, comprising the last 10,000 years, three main climatic ages may be distinguished.

The early Post Pluvial was characterized by a humid climate and one which became progressively warmer as the glaciers waned.

The middle Post Pluvial was distinctly warmer and drier than the present, and was clearly the correlative of the warm middle Post Pluvial of the glaciated region which is dated at 5,000 to 2,000 B.C. by Antevs (3A) and from 6,000 to 4,000 B.C. by Flint. (27). It is recorded by arroyo cutting, wind, erosion, desiccation of lakes, and extinction of the glaciers.

From the late Post Pluvial, the last 4,000 years, briefer and less pronounced climatic variations are known to have occurred. The first half was more moist than the present, and later wide spread droughts enable a further division of time as well as dating of beds and of records left by man.

The dating of the climatic optimum in the western part of the United States has predominantly come about through the work of Blackwelder and Matthes who have noted that the present glaciers of the northwest United States are receding, and thus, being so delicately adjusted to climatic fluctuations could not have endured the numerous oscilations of climate since the last of the great glacial periods. The moraines of these glaciers, too, are of such a small amount of material, that it would hardly have taken 10,000 years to accumulate.

As the glacial periods are known to have coincided with the pluvial periods in the basins of the west, it is probable that the present glaciers came into being sometime after the last desiccation of the Pleistocene lakes. The glaciers of the Sierra Nevada, for instance, provide water for lake Owens in California. It has been estimated by Antevs that the lake was completely dried up about 4,000 years ago. Thus, the present glaciers of the Sierra Nevada must have come into existence after this date.

There remains the question, how long ago the cool and humid period began that brought with it the mild recrudescence of glacial conditions of historic times?

The figures by pollen analysis (21,44,17), vary considerably and in themselves afford no really conclusive answers. They range all the way from 1,000 to 4,000 years. Some of the analyses do not show any definite evidence of a return to cooler conditions, and a variety of local factors can be surmised as the means.

According to Antevs, the Europeans now generally regard 4,000 years as a rough estimate of the time that has elasped since the warm period came to an end. (3). The year 2,000 B.C., therefore, commonly appears in their writings as the approximate date of the transition. However insecure these figures for the duration of the cool period may seem, it is probably no coincidence that closely accordant figures are indicated by calculations based upon entirely different classes of materials.

For instance, the Bear River, at the head of the Portland

Canal in British Columbia, has built a small delta which is largely composed of glacial silt derived from several small glaciers at the head of Bear River. From measurements of the rate at which the frontal margin of the delta advances from year to year, as the result of continual deposition, it has been calculated that the entire delta was built in about 3,600 to 4,000 years. The glaciers are, therefore, not remnants of the Pleistocene glaciation; but came into existence after the Climatic Optimum. (33) Antevs work on Owens lake, as mentioned above, also points to cooler and more moist conditions about 2,000 B.C.

Also, the salt content of Albert and Summer Lakes in southern Oregon is estimated to be much to small to represent a concentration due to the progressive evaporation of the large lake of the Pleistocene. They are pools of relatively recent origin that were formed after a prolonged period of desiccation, during which the salts precipitated from the ancient lake and later became buried under the alluvial material. From the present salt content of these lakes, taking into consideration the quantity and quality of the inflowing waters and the rate of evaporation, it has been estimated that the lakes came into existence about 4,000 years ago.

To Matthes it seems probable that all the cirque glaciers of the ranges of the Rocky Mountains within the United States belong to the modern generation. Only the main glaciers on the Peaks such as Mt. Olympus, Baker, Rainier and Glacier Park are probably survivors of the major glaciation. If so, however, they must have shrunk greatly during the Climatic Optimum and rejuvenated during the following cold period.

The above will, therefore, make it reasonably sure that the Climatic Optimum ended about 4,000 years ago, followed by a maximum in cold, humid weather about 2,000 B.C. These two divisions in paleoclimatology would correspond to the Suboreal and Subatlantic periods of the Blytt-Serander hypothesis and to the main divisions of the Von Post scheme based on the vegetal growth. (17,45). From this it seems we have enough information for a footing in time.

The recent recession of the glaciers has been in progress for approximately the last five or six decades, and this recession is prevalent throughout the northwest United States. It will be seen from further investigations into areas of the non-glaciated territory that a period of warmth, dryness, and erosion began about 1880 and is still in progress today.

Deposition and Erosion as Indicators of Climate

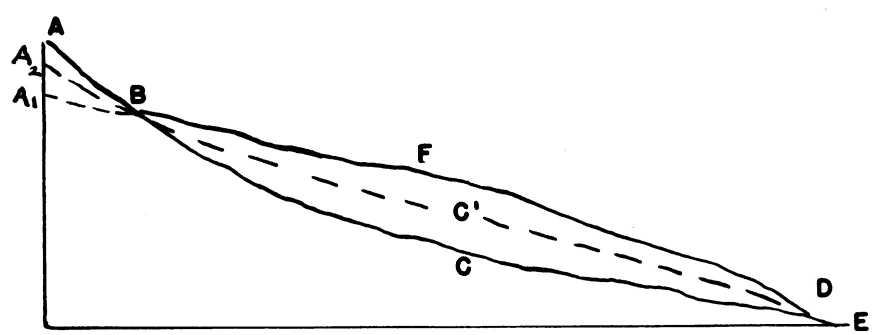
It is a generally accepted theory that in times of humidity deposition takes place in the higher reaches of a stream and that in times of aridity the predominant agent in these areas is erosion. In other words the result of an epicycle of erosion is to steepen the average gradient of the streams, entrenching the streams along their courses and moving the place of deposition downstream.

The same change could be brought about by the tilting and warping of the earth, but as Huntington and Hack (35 and 31), argue, it is improbable that one valley will be tilted one way, another another way, and a third still another. And it is also improbable that just the right amount of warping would take place to start erosion and thereafter be reversed.

The explanation which must be resorted to is that the steepening of the stream channels is the result of the increase in the average transporting power of the streams due to i ncrease in the rate of discharge. The increased rate of discharge must be due to an increased rate of runoff at the headwaters. Such a concentration of runoff is likely to be the result of a change of the vegetative cover which has been sharply reduced due to arid conditions.

Figure 2 demonstrates the changes in stream profiles due to a fluctuation of climate from moist to arid and back to moist conditions. The profile from A, the highlands, to C,

FIG.2



PROFILE OF CLIMATIC TERRACE.

HUNTINGTON, PAGE 33

the lowland, and to E, the ocean is the typical concave curve during moist conditions.

With a change to an arid climate, the profile runs from A' to B in the highlands, B to F in the lowlands and on the D and E and the ocean. Erosion has taken place from A' to B and the place of deposition has been moved downstream to B through D. The profile is concave from A' to F and convex from F to D.

Upon the return of moist conditions erosion once more takes place from B to D in the lowlands and there is deposition from B to A_2. The deposition probably takes place in the highlands because the stream channels are full of water while in arid times they are usually dry and subjected to wind erosion. With the streams full, vegetation most likely grows in the shallow water and impedes the stream load from being carried downstream.

Terraces of the Streams in the Hopi Country

Hack (32) in his study of the stream valleys of the Hopi Country was able to draw up a chart (Table 3), using the system described above. This, with the aid of artifacts of the Pueblo period and dates proposed by Fromm and Antevs, enabled him to attempt a correlation with the West Texas area studied by Bryan and Albritton. (12)

The soils of the Jeddito formation show that it was deposited in a climate more humid than that of today. The subsequent period of erosion was clearly drier than the present climate, for great sand dunes mantled the region. The Tsegi formation shows two periods of deposition or humidity with a period of erosion between.

The Naha formation was dated by archaeological evidence as having been deposited between 1300 and 1700 A.D. There is no direct geological evidence of the climate drying during the deposition of the Naha formation, but the study of the annual tree rings and the analysis of archaeological findings show that the Pre-Naha period was a time of erosion and drought. The greatest break in the history of the Pueblo people occurred at the end of the Pueblo III (around 1250-1300 A.D.), and many migrations occurred at this time. The entire 13th century is thought to have relatively climate.

That the present cycle of erosion may be due in part to climatic causes is shown by the fact that the latter half of the 19th century was abnormally dry. The culmination of a

Table 3

Hopi Country	West Texas	Time in Yrs.	Climatic Interpretation Fromm 1939	 Antevs 1938
Naha Fm. After 1300 A.C.	Kokernot Fm., 1100- 1400 A.C.			Late Post Pluvial
Erosion About 1300	Erosion, 900- 1300 A.D.	1,000 A.C.	----	Moist
Tsegi Fm. (A) Occupation no date.	Calamity Fm. (A)?700 A.D.?	0	Increas- ing cold	
		1,000 B.C.	---Cool---	
----------	----------	2,000 B.C.	----Warm	----------
				Mid
Tsegi Fm (B) or erosion?	Calamity Fm. or erosion	3,000 B.C.	----Cool---	Post Pluvial
----------	----------	4,000 B.C.	Maximum Warmth	Warm & Dry
Erosion and formation of dunes	Erosion	5,000 B.C.		

----------	----------	6,000 B.C.	--Cool---	Early
Jeddito Fm.	Neville Fm.	7,000 B.C.		Post Pluvial
		8,000 B.C.	----------	----------
		9,000 B.C.		Pluvial Cool
		10,000 B.C.		& Moist

Hack, "Changing Physical Environment of the Hopi Indians", page 68.

drought in 1880, which may have been as severe as the Great Drought of the 13th century, and the recent epicycle of erosion began everywhere in the Southwest after 1880.

According to Antevs, the Post Pluvial period began about 10,000 years ago, and is divided into three parts, the early, middle and late Post Pluvial. These occurred from 8,000 to 5,500 B.C., 5,000 to 2,000 B.C., and from 2,000 B.C. to the present. After the Pluvial, again according to Antevs, the climate became warm and reached an optimum at about 5,500 to 2,000 B.C. The climate then became cooler and more moist. This evidence correlates with the pollen analysis of the north and eastern parts of the States. Hack, however, thinks that Antevs has made the fluctuations much too simple.

From the studies by Fromm in Sweden a cold period is shown about 6,000 B.C., a warm period about 4,500 B.C. (the post glacial optimum), another cold period in 3,000 B.C. which changed to one of warmth in 2,000 B.C. He pointed out a third cold period with a very low maximum at 1,000 B.C., succeeded by an uncertain period of fluctuating climate remaining about the same, but perhaps becoming colder by the year 1,000 A.D.

By assigning the pre-Tsegi erosion period to the time of the post glacial optimum from 5,500 to 4,000 A.C., the Tsegi formation was probably deposited between 3,000 B.C. and 1200 A.D. and there are, according to Hack, unrecorded periods of erosion within it corresponding to minor fluctuations.

Also, the Jeddito Formation was deposited before 5,000 B.C., probably about 10,000 years ago (perhaps during the Wisconsin 4 and correlating with the deposits of Sandia cave and of the Lindenmeier site). "Of course, "says Hack, "it may represent alternate stages of erosion and deposition, and still more ancient deposits of Pleistocene sediments may be buried in it, unexposed and therefore considered a part of it." (32)

Terraces of the Cache la Poudre

To continue with the evidence provided by terraces, another work by Bryan and Ray on the "Antiquity of the Lindenmeier Site" (14) comes to the fore. In order to place the site in a definite time in history, the authors of this paper proceeded in their investigations along these lines.

First, the cultural objects found at the site were associated with definite strata within the formation. The layer in which the archaeological remains were found was in the Lindenmeier Valley which retains part of its old floor, preserved as a terrace downstream.

Secondly, these beds are related to some geologic event in that the above terrace is evident in other streams of the region, and these in turn are tributaries of the Cache la Poudre River.

Thirdly, the geological event is related to some world wide geographic event in that the Cache la Poudre is a tributary of the South Platte River which drains most of the Colorado Front Range and the Colorado Piedmont and which rises in the Rocky Mountains, a recently glaciated area. Thus, the terraces of the Lindenmeier can be correlated with the glaciations of the Rockies.

Fourthly, the wide geographical event and correlated events were associated with some known geologic chronology, for in the inner canyon of the Cache la Poudre there are terminal moraines of three sub-stages of the Wisconsin, the Home, Corral Creek, and Long Draw substages. There is also evidence of a Pre-Home substage of the Wisconsin, and a Protalus Rampart on the valley of Corral Creek records a recent period of refrigeration too feeble to produce ice tongues which moved from the cirques of the region.

Similar features in other parts of the Southern Rocky Mountains are proof of a similar number of advances of the ice. On this account, the local stages of glaciation may be considered the records of climatic changes that were of wide extent and were not unique with the Cache la Poudre River.

A correlation is made between the substages of the last glaciation in the Rocky Mountains and those of the continental glaciers of North America and Europe. There is in this correlation a large uncertainty, but, if it is accepted, the writers maintain that the Corral Creek moraine, the Kersey Terrace of the river, and the old floor of the Lindenmeier

Valley formed approximately 25,000 years ago. The Long Draw moraine, the Kuner Terrace, and the dissection of the Lindenmeier Valley occurred approximately 10,000 years ago. It was sometime between these two stages that the Folsom culture began. According to Antevs these two stages occurred in the Wisconsin 3 and 4 substages. (Table 4).

Terraces of Copan, Honduras

Using the climatic origin of terraces as a premise, Huntington, (36) described the ruins of the city of Copan upon the terraces of the Copan River, a tributary of the Matagua River in northern Honduras. This section is included because Huntington found that the fluctuations of the Matagua River coincided fairly well with the history of the Mexican Lakes which in turn could be correlated to a fair extent with the records of the tree ring analyses of the trees of California and Arizona.

The ruins of this city stand upon a terrace about 18 feet above the present low water mark. They follow this mark very closely and were evidently built upon it. The conditions of deposition seem to indicate that when Copan was an inhabited city, the edge of the 18 foot terrace was washed by the river.

Just below this highest terrace lies another 12 feet above the low water mark, and today it is quite as good a place for houses as is the upper terrace; however, no trace of ruins is found on this 12 foot level. Today floods sometimes reach the 12 foot terrace but never rise higher. If the river

Table 4

Short designation	N. Eur. cont. subs.	Cache la Poudre Valley	Antevs generalized dating from 1900	North Amer. continental substages
	Post-glacial	Protalus rampart		
W_4	Fennoscandian	Long Draw	10,000	Cochrane (?)
	Scanian	?		?
W_3	Pomeranian	Corral Creek	25,000	Lake Mankato (St Johnsbury)
W_2	Weichel (Brandenberg)	Home	35,000	Tazewell-Cary (Harbor Hill)
W_1	Warthe (Flaming moraine)	Pre-Home		Iowan (Ronkonkoma)

Correlation and Dating of Rocky Mountain Glacial Stages - pp. 68, "Antiquity of the Lindenmeier Site", Bryan and Ray. Smithonian Misc. Col. Vol. 99, No. 2, Wah. Feb. 5, 1940.

should again proceed to deepen its channel the present flood plain would in turn become a third terrace. (Figure 3).

Huntington estimates that the city was built just before the time of Christ. Previous to that date the river had built up its flood plain approximately to the present 18 foot level. At this time, however, it probably was not aggrading its flood plain to any great extent for in that case, the town would have been flooded frequently. At any rate, the river rose quite high for on the outside of the walls it deposited materials within four feet of the level of the main terrace. Next, the river cut below the 18 foot terrace, then built up its flood plain and formed the 12 foot terrace. It later cut down, and once more laid deposits to form the present flood plain.

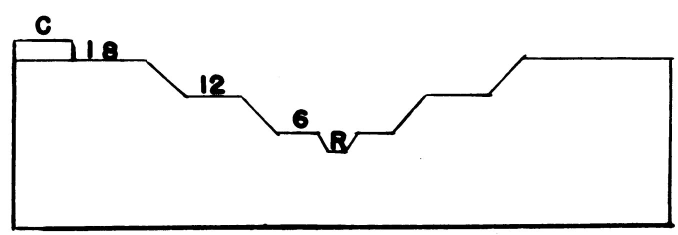
Thus, we have a history of the river and the climates of Copan that is somewhat like this:

Previous to 100 B.C. there was a period of aggradation and of increasing aridity antecedent to the building of Copan.

From 100 B.C. to 250 A.D. there was period when the river was at a high level but in which there was not much change in the flood plain. That is, there was a time when, although aridity was no longer increasing, there was no special tendency toward moisture. It was at this time that Copan was built.

From 250 to 700 A.D. there was a period of degradation or downcutting by the river to the edge of the 18 foot terrace. This was a time when the amount of rain and vegetation was increasing. The occupation of Copan was followed by a decline and

FIG. 3



RELATION OF TERRACES & RUINS AT COPAN, HONDURAS.

HUNTINGTON, PAGE 214-15.

a final abandonment.

From 700 to 1,000 A.D. there was a period of aggradation and of increasing aridity during which the river built up its flood plain to the 12 foot level.

From 1,000 to 1,300 A.D. there was a period of aggradation and of increasing moisture with a deepening of the river channel in such a way to form the 12 foot terrace. Then, from 1,300 to 1900 A.D. there were minor fluctuations of climate with alternate deposition and erosion, the present flood plain being approximately the mean level.

Soil as an Indicator of Climate

Of the factors of parent material, biologic activity, relief, time and climate, the last is perhaps the most influencial in the genesis of soils as it controls both the chemical and biologic factors. The climate dictates, to a large extent, the type of vegetal cover and this in turn determines the biologic complex. However, this doctrine requires the climate to be sufficiently constant so that the climatically determined bio-chemical processes may produce a mature soil.

The soils may depict any relatively abrupt change from one steady state of climate to another. The subsoil, or the B horizon, is the index zone for climatic pictures. In humid climates the subsoil gains clays and iron oxides. In cool and temperate regions the subsoil is brown or rusty with limonite and organic compounds. In the tropics the reddish limonite passes over into hematite and lateritic subsoils result. In arid regions, on the other hand, calcium carbonate forms in the subsoil. (12)

The change from humid to arid conditions produces a marked mineralogic and chemical change in the subsoil. The change from cold to warm climates results in a change in color or a change in the iron compounds. If the time interval from cold to warm, or vice versa, is too short for a complete transformation of the old profile to the new, the new should be detectable in the borders of the climatic zones, in particular between arid and humid zones.

The old mature soil of a single climatic period is a mongenetic soil, while if this soil is superimposed upon by one or more soils of different climatic intervals, it is a polygenetic soil. On many old erosion surfaces, preserved as uncomformities, most of the old soil was removed before the new deposit was laid down, but weathering phenomena of the lower part of the B horizon or of the parent material of the old soil are preserved.

Bryan's paper (12) discusses the soil phenomena in the Trans-Pecos region of Texas. There he found soils which occur in a semi-arid climate along the general border between climatic zones having iron subsoils and those containing lime subsoils. They were thus in an area favorable for recording climatic change. These soils make up the Neville, Calamity, and Kokernot formations which are found in the broad alluvial valleys of the Davis Mountain area. This region was recently cut by gullies and the stratigraphic sequence exposed for study.

The Neville is distinguished from the younger formations by a high content of clay and ferruginous materials and by bones of extinct horse and elephant. These facts, Bryan advocates, are indicators of a climate more humid than the present.

A layer of fine-grained, dark brown to black soil covers the formation where it outcrops. This fine-grained black soil grades into the compact red and clayey silt of the early Neville. This is indicative of a period of deposition when the soil reached maturity of the Pedalfer type.

Also in the Neville there is an abundance of Ca_2CO_3 in caliche nodules and crusts. As the caliche does not cross the erosional disconformities of the younger alluvial material of the Calamity and Kokernot, and as the caliche from the Neville is found in a reworked state in the Calamity, Bryan surmises that it was formed before the Post-Neville Pre-Calamity erosion. There are also many cracks in the Neville providing further evidence of a dry period during the formation of the strata.

In the Calamity Bryan found several horizons of humid zones in various stages of development, and throughout the formation there are several veinlets of illuvial clay some of which cross the contact between the Neville and Calamity. This is indicative of a humid period.

Upon studying the deposits found in a cave in the Davis Mountain area, Bryan found a yellow to red soil of the Neville texture. The soil was stored in the cave by the wind during the Post-Neville Pre-Calamity dry period. This sequence correlates with Hack's findings in the Hopi Country (32) where there is a like control of erosion and deposition by climatic changes.

The fossils of the Neville date it as late Pleistocene. The upper Calamity contains artifacts of a cultural complex dated as 700 A,D. In some localities there exists an unconformity between the lower and the upper Calamity indicating a dry climate. The lower Calamity contains artifacts but

Table 5

Correlation of Geologic and Pedologic Events, David Mountain Area, Bryan & Albritton*

Climate	Geologic events	Pedologic Events	Time
Relatively arid	Dissection of valley flats by the present arroyos	Deposition of caliche in films and veins in unit 3.	Beginning circa 1880-1890 A.D.
Relatively humid.	Deposition of the Kokernot formation.	Solution of caliche nodules in unit 3, leaving holes.	Beginning sometime prior to 1200-1400 A.D. continuing to 1800-90 A.D.
Relatively arid.	Dissection of valley flats; erosion of Calamity and Neville formations.	Deposition of caliche in nodules in unit 3.	?(Possibly in progress from sometime 1200 to 1400 A.D.)
Relatively humid.	Deposition of Calamity fm.	Solution of top part of caliche in unit 4.	(?Possibly in progress from sometime B.C. to 1200 A.D.)
Relatively arid.	Formation of caliche in the Neville, followed by extensive erosion of the formation by streams.	Accumulation of caliche in unit 4.	?(Possibly in progress 3500-5500 B.C.)
Relatively humid.	Deposition of Neville fm.	Formation of parent soil.	?(Possibly 8,000-25,000 years ago).

"Soil Phenomena as Evidence of Climatic Changes", Bryan and Albritton, Amer. Jour. of Sci., vol. 241, August 1943, p487 they haven't been dated.

The Younger alluvial member, the Kokernot, contains a humid zone dated at 1200 to 1400 A.D. by Bryan and artifacts of a date prior to 1200 A.D. (Kelly and Campbell believe that this formation may have begun as late as 1400 A.D.) (37). This period of deposition ended with the cutting of the present arroyos in 1880 or 1890. (Table 5).

The Sandia Cave Deposits

The deposits of Sandia cave in New Mexico have been investigated by Bryan (9) who has succeeded in correlating them with the Wisconsin glacial chronology. He found that the cave deposits could have been laid down only under the following circumstances: 1. Greater precipitation on the ridge above the cave; 2. Forest growth on the ridge; and 3. Pedalfer soils on the ridge to supply iron as well as calcium in the drip in the cave. ~~(Table 5).~~ A long humid period in the mountains of moderate altitude may well be the response to the climate of the Pleistocene glaciation.

There were three strong and two minor advances during the Wisconsin in the southern Rocky Mountains. Correlation is made easier by artifacts of the Folsom culture in the upper breccia of the cave deposits which has been correlated with the Corral Creek glacial stage (Wisconsin 3) along the Lindenmeier Valley.

The deposits probably represent the advance, climax, and waning of the Wisconsin 3 glacial period. The lower breccia, with evidence of increasing wetness, represents the oncoming of glaciation, while the yellow ochre depicts the climax of the Wisconsin 3, and the upper breccia, the period of glacial retreat.

Culture Patterns as Indicators of Climate

As to whether the supposed change of climates from the past to the present has been pulsatory or gradual, the evidence is not too strong. The terraces, and to a large extent, the lacustrine strands and gypsum dunes, seem to point to a pulsatory character but the human evidence is less conclusive.

Since the pre-columbian inhabitants of America first began their work, the course of history appears to have been characterized by three chief epochs. In the first epoch man spread over wide areas, lived peacefully in small, unsheltered communities, and apparently was not particularily disturbed as to his water supply. This population of early aborigines disappeared; how or why or when has not been worked out as yet. War, pestilence, or drought, or any of a dozen different disasters may have been the cause. Some of the tribes may have migrated at one time and the others centuries later. All that is known is that they went and were succeeded by people who lived a different sort of life.

At first these people may have been as peaceful and untroubled as their predecessors, but before they finally left their ruins they were forced to cluster around the main water supplies. They were compelled to build dams and reservoirs in large numbers, and they were sadly harassed by enemies. All the disasters which have been suggested as the chief source of their decline are the sort that would arise when the climate became dry, the crops failed, there was famine, disease had free rein, and war and plunder were rampant because of discontentment and suffering.

How many of these second type of people were displaced at one time, how long they were able to remain in one community before they were driven out, and how long they had previously dwelt in safety, again, is not yet known. Probably, however, they disappeared, or their villages had been abandoned and they had become mixed with the invading Pueblos at least two or three centuries before the Spaniards arrived about 1600 A.D., for otherwise the early explorers would have heard traditions of them.

Finally, the last type of aborigines, the Pueblo Indians, have had a history similar to that of their predecessors but on a much less extensive scale. They, too, in the early part of the 17th century seem to have been able to spread out into regions not now inhabitable, and they too suffered stress and were forced to give up their homes (36).

The above points to a gradual change of climates instead of a pulsatory one, which would seem logical when applied to a people, and on the whole demonstrates a much truer picture than that painted by geologic phenomena in relation to time. The times of transition were probably as long as the periods of maximum climatic conditions, and perhaps in some cases longer. The graph of the tree ring analysis will make this point even clearer (Chart), while parts of the chart and the tables included in this paper may give the impression of sudden change.

Anthropologists have been of great aid in dating many of the formations of the Southwest. The paper by Bryan and Toulouse (15) on the "San Jose Non-Ceramic Culture" offers an example of how the cultures of ancient peoples and the phenomena of the soil in which their artifacts and cultures are preserved, provide much of the data for working out both the chronology and climate of that area.

Tree Rings as Indicators of Climate

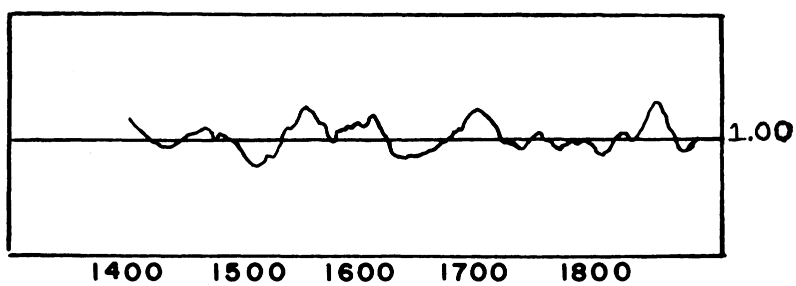
In 1901 A. E. Douglass (23,24,25,26) conceived the idea of the science of tree ring analysis or dendrology based upon the annual growth of trees. These rings are distinctly displayed by the trees growing in the regions characterized by regular seasonal changes of climate from dry to wet to warm to cold.

Douglass chose the yellow pine (Pinus Ponderosa) growing on the great plateau of northern Arizona at an elevation of 6,000 feet above sea level. These trees endured the vicissitudes of heat and cold, flood and drought in a climate that is subjected to a strong contrast between winter and summer and whose growing season is sharply limited to the warmer season.

As a rule the trees show one ring for each year; that is formed by the cambium which lies between the woody tissue of the previous growth and the bark of the tree. The rings measure the abundance of food supplied to the tree. This supply depends to a large extent upon the amount of moisture, especially where the quantity is limited and the life struggle is against drought rather than competing vegetation. On the advent of the growing season, large thick-walled cells are added to the wood and as the season advances toward the end of the growing period, the cells become increasingly smaller and thin-walled until they cease to grow at all. This is repeated the following year. (Figure 4)

Douglass went about his study by first preparing a curve

FIG 4



500 YR. CURVE OF TREE GROWTH
20 YR. MEAN

ANNUAL GROWTH OF TREES OF FLAGSTAFF FOR

1385 – 1900 A.D.

DOUGLASS, PAGE 117

of the tree growth, followed by an attempt at determining the connection between growth and precipitation. He then carried this correlation back over as long periods as possible to find whether the meteorlogical variations showed an association with any astronomical phenomena.

By drawing up a curve of the growth rings as determined by a cross section of the tree, the fluctuations of the local climate were deduced. Since the different trees of the same district showed similar influence, he counted backward in years, correlating the inside of the younger trees with the outer rings of the older ones. These variations were plotted on a graph to give the Skeleton Plot.

Cross dating of the trees is achieved by comparing the wide rings of one tree with the wide rings of the other and the narrow with the narrow. These sequences eliminate individual errors. The Standard Plot thus attained is typical of the area.

When Douglass carried this correlation back over long periods of time hunting for meteorological variations that might be associated with astronomical phenomena, he found that the trees of Arizona showed evidence of an 11 year cycle. From Clayton's studies (19) it was found that the sun spot cycle is of the same duration. The trees of Arizona show a double crested 11 year cycle, or Hellman cycle, while the Sequoias of southern California show the single crested cycle. (Figure 5). The difference lies in the fact that in Arizona the

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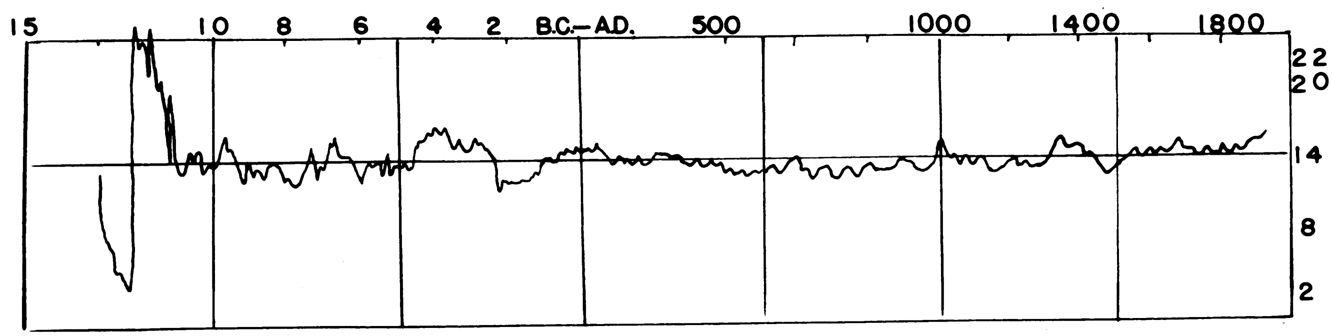

C U R V E O F G R. O W T H O F T H E S E Q U O I A I N C A L I F.

H U N T I N G T O N, "T H E C L I M A T I C F A C T O R" P A G E 1 5 3.

summers are extremely dry and two cycles appear.

It was found on the whole that the rings display the changes in rainfall and temperature. One other factor may be solar radiation, for the sun spot maximum increases the value of the solar radiation due to an increase in the radiation of ultra-violet, and its effect may be discernable in tree-ring structures.

Chart

The chart attempts a chronologic correlation of the areas discussed above. In some instances it was found that a very good correlation could be detected in all the columns, while in other cases there is a complete disagreement. The disagreement stems from divergent views on the chronology; the alternation of humid and arid periods does not vary, it is only a matter of properly dating the periods.

In all the regions it is fairly obvious that erosion has been in progress since about 1880 A.D. Then, too, a period of deposition is noticeable in each district anywhere from 1100 A.D. to sometime before 1500 A.D. The Kokernot and the Naha formations were deposited at this time in the Big Bend, West Texas, and Hopi areas. Whitewater Draw, Grants and the Davis Mountain regions show deposition, and a humid climate is indicated in the Flagstaff yellow pines and the California Sequoias. Erosion was predominant in the period before this, starting after 900 A.D. (Antevs and Hack; before 900 A.D., Bryan), and this is fairly evident in all the regions.

The opinions on the chronology of the previous series of deposition, erosion, deposition, bring about the main divergence in correlation. Bryan advocates that the Tsegi (A) was laid down before 900 A.D. and correlates this with the Calamity (A) and the first periods of deposition of this series in the Big Bend, Whitewater Draw and Grants areas. A period of possible erosion is agreed upon by most authors between Tsegi (A) and Tsegi (B) and the Calamity (A) and the

Calamity (B) and the contemporaneous deposits. Hack, correlating with the Antevs column of the Southwest, places these formations and intermediate periods of erosion from 4,000 B.C. to 1,000 A.D.

All the columns show a period of deposition about 10,000 B.C. The Neville and Jeddito fall into this time and the deposits of Sandia cave show a period of deposition. All the columns that extend as far back as 10,000 to 25,000 years show periods of deposition at the 10,000 year interval and at the 23,000 year interval. These periods of humidity correspond with the Wisconsin 3 and 4 substages as found in the Long Draw and Corral Creek moraines in the Cache la Poudre district, the yellow ochre and the equivalent of the Long Draw in Sandia cave, and the Provo and Stansbury shorelines of Lake Bonneville and contemporaneous strandlines of Lake Lahontan.

The period of erosion or aridity between the 10,000 year interval and the 25,000 year period is shown in the Big Bend, Hopi Country (Bryan), Whitewater Draw and Grants areas. This is also the period that caused the deposition of the upper breccia of Sandia cave.

It seems more plausible to the writer to date these fluctuations of climate in accordance with Antevs and Hack. The formations were probably laid down over a much longer time than Bryan's correlation will admit. Then, too, if the Jeddito and Neville formations proceed the Tsegi or Calamity formations with only a period of erosion between them, according to Bryan that period of erosion would have had to have been at least 9,000 years long, a length seemingly out of proportion with the time shown by each fluctuation of the rest of the chart. If it is true that variations in climate more or less follow a cycle which in a broad view would show an even, gradual change of climate, 9,000 years of erosion is tremendously out of proportion.

On the other hand, artifacts have been found with the formations, and in some cases they can be dated rather accurately. Also, it seems very likely that more research will reveal many fluctuations of climate not as yet observed.

Not one of the methods described above is infallible. In each, one discovers variables which demand readjustment of the methods' results. Bryan's work in soil phenomena is perhaps the most hopeful for this field where polygenetic soils are found. Tree ring analysis is the best method in use for dating periods of humidity and aridity and as these analyses become more abundant, the work of the geologist will become clearer.

Lake and river terraces are useful, especially in Pluvial times and glaciated areas. However, in the Southwest and in Post Pluvial times, the correlating of terraces of one region with those of another, must be done with caution and a third factor brought into the field of evidence as a check. The work done on the ancient saline lake basins of the Southwest may well prove to be a great impetus to the future, for, in some at least, there must be a complete, undisturbed record of deposits through the Pleistocene. Here again soil phenomena proves to be the most promising method of the field.

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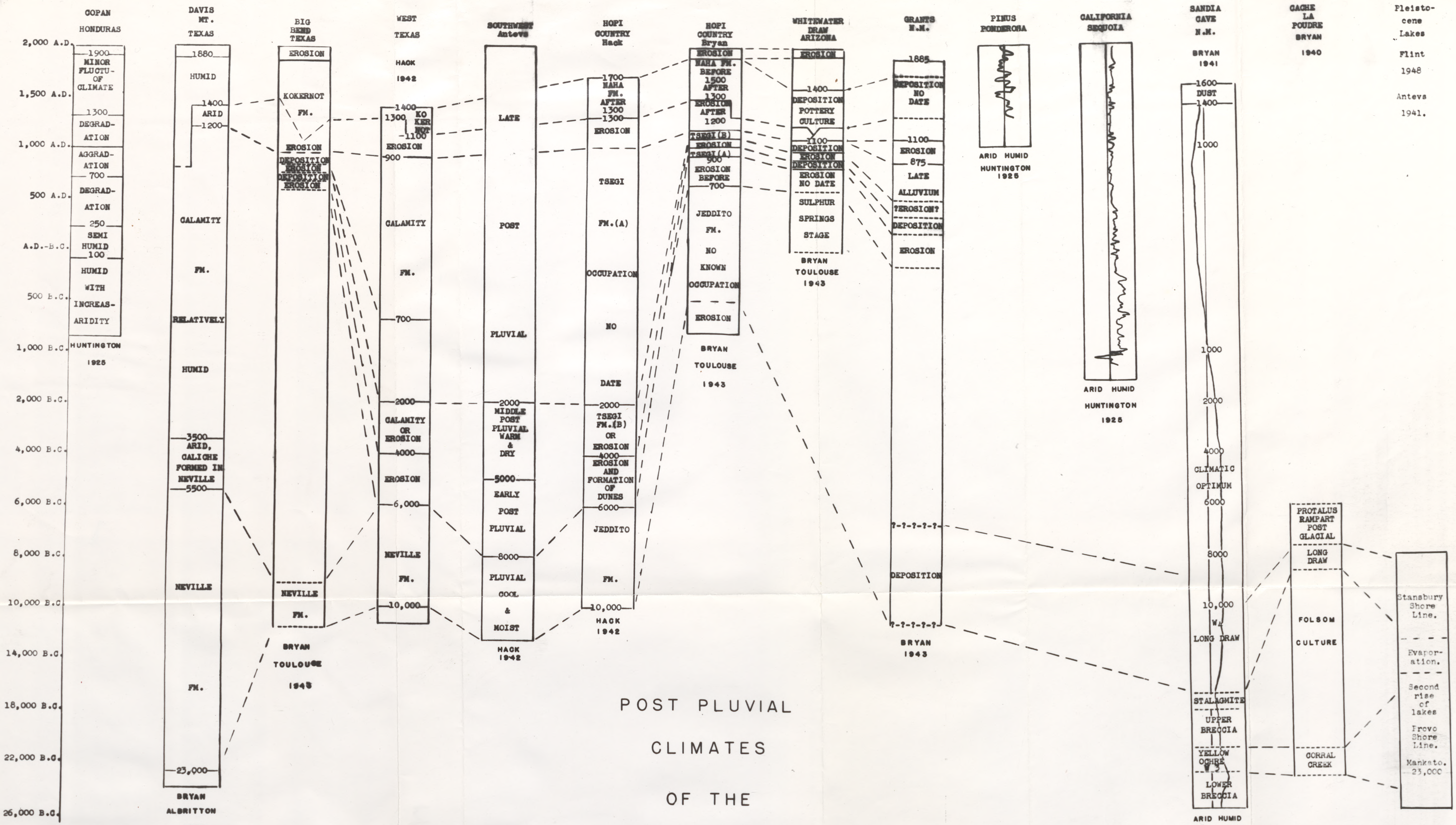

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BY ANN H. DAVIS, 1949

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