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SOIL PHENOMENA AS EVIDENCE OF CLIMATIC CHANGES.

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ABSTRACT. The study of composite or polygenetic soils provides a promising though as yet little used method for investigating climatic changes of recent geologic time. Climatic variations in the factor of moisture are particularly effective in producing changes in the chemistry and mineralogy of the subsoil. Where these changes are not so great as to obliterate older soil profiles, the complex soil thus produced assumes the nature of a rough climatic record. Optimum conditions for the development of such soils are found in semi-arid country along the belts separating the soils with zones of iron enrichment from those with zones of lime enrichment.

At Praesum, in the Davis Mountains of western Texas, is a complex soil that permits of two climatic interpretations. Both of these indicate that the climate of this area has fluctuated between the relatively wet and the relatively dry. The more elaborate interpretation would indicate three stages of dryness with two intervening moist intervals. This is in harmony with the known record of Pleistocene erosion and deposition in the same area which likewise indicates three dry and two moist stages of which the most recent dry stage is the one in progress.

INTRODUCTION.

THE modern view on the genesis of soil is that five factors are responsible: 1. parent material; 2. climate; 3. biologic activity; 4. relief; 5. time (Thorp 1941). The principal differences in soils are "zonal," that is climatic, as climate controls and influences the biologic as well as the chemical and most of the physical processes in soil formation. The differences due to factors other than time or the influence of man's activities are of relatively minor importance.

This viewpoint rests on a series of generalizations which may be briefly summarized. Soils consist of layered masses of mineral and organic matter graded downward from the surface of the ground into the "parent material," a somewhat weathered surface portion of the "rock" as defined by geologists. Soil-making or soil-formation is the change of the parent material by a complex of processes mostly biochemical but partly mechanical. A portion of the changed material is lost from the surface by erosion and a portion is transferred mostly in a downward direction from one layer of the soil mass to another. The change in the original rock by which the "parent material" is produced is a part of this process although usually not discussed by soil scientists. Under this concept of soil formation the perfectly developed or mature soil can form only on relatively flat land with gentle slopes because on steeper slopes the surface layer is removed so rapidly that the soil is perpetually immature. On slopes that are too flat the land is water-logged, and special types of soil develop.

The moisture supply, the range of temperature and other factors related to climate, influence the chemical processes of soil making. But climate has a still more important effect because it determines the character of the vegetative cover. The cover influences and in fact determines the biologic complex, both living and dead, within the soil and hence influences the chemical processes. Thus the complex of bio-chemical processes operating in the soil is largely a function of climate. One of the major objectives of Soil Science is the definition and complete understanding of the process of soil formation. This detailed study is an elaboration of studies of weathering, as defined by the geologist. Mineralogical and chemical studies of great future importance are being made. That these studies are as yet incomplete and that many products of soil-making are imperfectly understood does not prevent an interpretation of the larger features of the soil as a reflection of the dominant soil-making process at any given place or in any given time.

The proof of this set of generalizations lies in the discrimination of types of soils marked by recognizable and characteristic layers or soil profiles. These types are distributed in the major climatic regions and occur on parent materials of diverse chemical and mineralogical composition. Immature soils not uncommonly carry these distinguishing characters, although imperfectly. Waterlogged soils, alluvial soils and other minor kinds provide numerous exceptions to the general rule that the boundaries of major climatic zones correspond to the boundaries of the great soil groups. Furthermore, certain rock types are so resistant to soil-making processes as to provide soils anomalous in type to those otherwise climatically dominant.

The foregoing generalizations, first made by the Russian Dokuchaiev and enlarged by his followers, are now generally admitted to be true, and the general correlation of the great soil groups with the major climatic regions is being continually confirmed. However, the doctrine requires that climate shall be sufficiently constant so that the climatically determined bio-chemical processes may produce a characteristic result—the mature soil. In other words the factor of time in Thorp's summary is assumed to operate with climate a constant.

In an attempt to lay a broadly philosophical base for soil science, Nikiforoff (1942) discusses these matters with penetration. He raises the question of change in climate through time and notes that "the steady state" of a mature soil depends on the maintenance of climatic stability. If climate changes, the original soil is altered by an "evolution of the soil" to be distinguished from "soil development" under an unvarying climate. In Nikiforoff's terminology this paper deals with variations from one "steady state" to another and with seemingly abrupt changes because of the loss of the upper layers of the soil by erosion between one recorded period of soil-making and another.

On many lines evidence is being brought forward that the climates of the not distant past were different from those of the present. Is the time interval, in which the present climate has existed, sufficiently long so that a soil profile compatible with the present climate might develop? Are the existing soil profiles in part the record of climatic conditions which have passed into history?

The soil profile, particularly the chemical and mineralogical properties of the sub-soil or B-horizon should provide the answer to these questions. The deeper zones of the soil carry the identifying marks of the great soil groups.[1]

Thus in humid climates enrichment of the lower zones in clay and iron oxide occurs. In cool and temperate areas the subsoil is brown or rusty with limonite and organic compounds. In warmer areas red and yellow subsoils prevail. In the tropics reddish limonite passes over into hematite and great changes occur in the clays to form "lateritic" subsoils. In the arid regions on the other hand calcium carbonate forms in the subsoil. A change in climate from humid to arid would produce the most marked mineralogic and chemical change in the subsoil.

[1] These soil groups are discussed in textbooks on soils: Jenny, H.: 1941, Factors of soil formation: McGraw-Hill. Kellogg, C. E.: 1941, The Soils that support us: Macmillan. Robinson, G. W.: 1936, Soils, their origin, constitution and classification, 2nd ed., T. Murby, London.

A change from cold humid to warm humid would result in a change in color of the iron hydroxides—an important difference but not a change of the essential chemical character of the soil.

The present surface of the Earth for the most part dates from fairly late in Pleistocene time. As emphasized by Brooks (1926) mild and subtropical climates prevailed over most of what are now the temperate regions in Tertiary time. The soils of the Tertiary have for the most part been eroded. The Pleistocene including the present has been colder with rapid fluctuations from very cold climates to climates as warm or only a little warmer than the present. It is therefore hardly to be expected that within the central area of the major climatic zones that these climatic fluctuations would change the chemistry of the subsoils. There may have been periods of intensification of process, but the kind of result remained the same. On the borders of the zones in particular between the arid and humid zones, the fluctuations of Pleistocene climate should have been effective.

It should be expected that with a changed climate on such border zones that old profiles would be modified to conform with new conditions. The soil should bear a record of the change until the transformation is complete. If, however, the time interval is too short for a complete transformation, the new profile would be superimposed on the old and the double impress should be detectable.

If a soil is matured in a single period having a relatively uniform climate, there results the normal soil familiar from textbook description. It is a monogenetic soil. If, however, two time intervals of differing climate are involved so that one type of profile is superimposed on another, or if more than two time intervals are involved, the soil is polygenetic. As the physical evidence is definite whereas the interpretation of such soils is debatable, the kind of soil involving the superimposition of one profile on another might best be considered complex, as compared to the simple or normal soil. Many obscure phenomena, not well explained, arise from the penetration of soil phenomena through one "parent material" into different and lower "parent material." Such soils might be designated by the term, composite.

Complex soils require no special conditions of preservation. All that is required is that the climatic change be adequate to impart new characters on an older profile but not so strong nor so long continued as to wholly destroy the earlier characters.

The term "fossil" is applied to soils that have been buried and preserved more or less intact. In such a soil the bacteria and animal life presumably died almost instantly. The organic matter has been somewhat modified. Slow changes in mineralogy and gradual consolidation or even complete recrystallization may have occurred so that the soil profile may have been profoundly modified. On many old erosion surfaces preserved as unconformities or disconformities, most of the 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 are preserved. Such phenomena have been reported by many geologists, but have rarely been analyzed in the light of modern soil science.

The present paper is concerned chiefly with soil phenomena in Trans-Pecos Texas, where complex and composite soils occur in a semi-arid region along the general border between climatic regions having iron and lime subsoils and thus in an area peculiarly favorable for climatic change.

The observations here recorded are by-products of an investigation on the geology of archaeological sites which, in 1938, were being excavated by the Sul Ross-Peabody Museum Expedition (Kelley, Campbell and Lehmer, 1940). Most of the geological findings have already appeared in an earlier paper (Albritton and Bryan, 1939) which contains maps and figures that will serve to illustrate this report. We thank Dr. James Thorp and Prof. H. J. Lutz for helpful and generous criticism of the manuscript, but they are not to be held responsible for the opinions expressed. The geological work was financed by a grant from the Penrose Bequest of The Geological Society of America. To the Society, and to our co-laborers and assistants elsewhere named, we again give thanks.

Pedologic Approach to Paleoclimatology

previous interpretations.

Polynov (1927) has discussed the problems here considered under the term, Paleopedology. He divides the phenomena involved into four classes: 1. secondary soil formation, 2. two-stage soils, 3. fossil soils, 4. products of ancient weathering. Under the first class he includes the "degraded chernozems" and some of the gray forest loams of Russia which are regarded as soils originally developed as chernozems, when the steppe extended further north. They have been modified by podsolization as the forest moved southward. As the reader will note, these soils lie on the boundary of two climatic zones. This boundary has been shifted in relatively recent time, presumably since the Post-glacial Optimum of 5,500 to 7,500 years ago. Polynov also raises the question whether some of the soils have not been subject to more than one such change in climate and in vegetation, but criteria for indicating these probable changes are still lacking. He also includes soils changed by a raising or a lowering of the water table, particularly the soils of the terraces of Russian rivers. As the terraces are the result of changes in stream gradients, connected with glacial events and therefore with climatic changes, these soils should prove a fertile field for study.

Two-stage soils are defined as those whose upper horizons constitute a soil normal to the region, but which have in their lower horizons traces of more ancient soil formation. Russian scientists have described steppe and podsol soils developed on red residuums of weathering. Interpretation of these phenomena has led to controversy as to the significance of the underlying red material.

Fossil soils are defined as soil profiles developed on a surface subsequently buried. The fossil soils of the loess of Russia and particularly the Ukraine have been much studied. Some doubts as to the significance of these horizons have arisen by reason of inadequate preservation and limited exposure of the horizons. Polynov includes here the peat profiles which have been studied by means of the method of pollen analysis. Under ancient weathering products, Polynov discusses a wide variety of phenomena occurring in a equally wide group of geological formations. In each instance attempts have been made to define the climate of the time by a consideration of the chemistry and mineralogy of the weathering product. If this product represents part (usually the deeper part) of a surface soil, the principles of soil formation indicate that it should reflect the climate. The method is sound, but the difficulties of carrying it to a successful conclusion are great.

It is obvious that the term complex or polygenetic soil as here defined, applies to the first two groups of Polynov's classification. The last two groups are fossil and are distinguished from each other only by the circumstance that the upper horizons of the soil are preserved in the group called "fossil soils." They are easier to interpret than the group of "weathering products" but both are buried and fossil.

Veatch (1938) has discussed some of the pedologic criteria of climate, and has described bodies of mature Prairie soil of Michigan which are azonal [Intrazonal?] in the surrounding forest soil. He considered them "relicts" of the once widespread prairies of the Midwestern forested regions. Such a prairie period, warmer and dryer than the present, has long been postulated on botanical grounds (Gleason, 1923). Veatch also cites Podzols on dry sites, in areas where Podzols now form only on wet sites, as relicts of the still earlier cold climate of ice retreat.

In south-central Minnesota, Bryan, Retzek and McCann (1938, pp. 125, 130-133) found subsoils on both till and gravel marked by a strong limonitic strain which is at the present time being penetrated and displaced by calcium carbonate. Obviously there has been a change from a condition in which iron hydroxide was deposited in the subsoil to one in which calcium carbonate is normal. This relation they interpreted according to current theory as due to a change in climate from relatively humid to relatively dry. As south-central Minnesota lies in the prairie near the border between the arid and the humid, it is a locality at which such changes would be most marked.

These two papers utilize soil phenomena as indicators of climatic change. Veatch used the method of "relicts" which is not only effective in ecology, but has already been used by the several German geologists who have cited the existence of soils, weathering phenomena, land forms, etc., as "Vorzeitformen" attributable to a pre-existing climate. Harrasowitz (1928) describes the fossil soils of the Oligocene and Miocene land surfaces of Germany and Bohemia. These soils were once laterites formed under a tropical climate, that according to Harrasowitz had a strong seasonal change from wet to dry. In localities where these laterites are exposed they have been changed to "Red Earths" by the soil processes of a later non-tropical climate. Further modification by burial in loess and a strong mechanical movement and the formation of involutions with loess occurred under periglacial conditions during the Ice-Age. These deposits are both complex and composite soils. They record not less than three earlier climates and are polygenetic. Presumably other climatic changes, well-known on other criteria, occurred, but have not been identified by soil changes. Somewhat similar methods are used by W. H. Bryan (1939) in his discussion of the "Red Earths" of south-eastern

Queensland. Because these soils occur on dissected remnants of an old erosion surface, they are attributed to the period when the surface was formed, and thus to Pliocene time. Their most significant character is the presence of limonitic nodules and their red color. The color is, however, in places modified by the soil-forming processes of the present day which lead to Podzol types, and thereby they are bleached to light, almost white colors. In these areas the soils are complex and polygenetic according to the foregoing definitions.

The use of laterites and silicified soil zones (duricrust) as indicators of an ancient tropical climate is common practice in the desert parts of Western Australia (Woolnough, 1918, 1927, 1930; Carroll, 1939) Thorp (1941) has shown that for the formation of true laterite a high water table as well as a tropic climate is required.

Red color of the gravel and other materials of early Pleistocene terraces in Burma is attributed by de Terra (1938, p. 294) to a moist climate and consequent laterization which prevailed at the time of formation, as such colors cannot now be produced in the existing dry climate. In a consideration of the Pleistocene of China, de Terra (1941) advocates the hypothesis, foreshadowed by earlier workers, that the "Red Loams" of China are loesses deposited in a cool, dry climate that extended into South China during periods of ice advance in the mountains of Asia. Originally gray or yellow in color the loesses have been modified to a red color by the succeeding interglacial periods when warm, moist climate extended northward even into North China. This hypothesis has been elaborated much more fully by H. L. Movius, Jr., in a forthcoming publication (1943?). Movius introduces the term, rubification, for the process of making a material red during a period of warm, moist climate.

The recognition of ancient land surfaces with accompanying zones of weathering, now buried under later deposits, is a commonplace of geology. These are the true fossil soils. On the foregoing argument they present climatic data on which the climate of the time of their formation may be interpreted.

Fossil soils of interglacial age, the so-called gumbotils, buried beneath later glacial deposits have formed the basis for a climatic interpretation of glacial sequences (Kay, 1929). Also the depth of solution and oxidation, which are phenomena of the lower horizons of the soil, have long been used as criteria of the length of exposure to weathering of glacial deposits (Kay, 1929 and Leighton, 1937).

An early glacial deposit exposed in the middle western United States to all the vicissitudes of climatic fluctuation in the interval intervening between its deposition and the present might, in theory, retain a record of these fluctuations, but Kay and Leighton have shown conclusively that its antiquity is related to the total depth of chemical alteration of the original material. These data were gathered well within the humid region, whereas the boundaries of the great soil groups and of the concomitant climatic zones are obviously the favorable places in which the composite character of the deeper soil horizons will be revealed by tangible mineralogic or structural clues.

In spite of the very considerable body of data accumulated on the subject of paleopedology, adequate recognition of the influence of the soil-making process in the past or of the effect of changing climates on the soil-making process has not been attained. An adequate set of terms seems to be required in order that clarity may be attained. The terms here used and defined, or restricted, are a relatively formidable list. In the opinion of the authors, they are, however, justified by the intricate and numerous distinctions that need to be made. They are summarized in the following table:

Terminology of Types of Soil Applicable
in Paleopedology.

Descriptive term	Genetic term	Character of profile
Normal	Monogenetic (developed in one climatic regime)	simple profiles
Complex	Polygenetic (developed in more than one climatic regime)	modern soil profile superimposed on the relics of one or more older profiles
Composite	Monogenetic or polygenetic	Soil profile extends downward through two or more "parent materials." Each parent material may have preserved all or part of an earlier soil profile.
Fossil	Monogenetic or polygenetic	Complete profile or only the lower part of the profile ("weathering products" of Polynov) may be preserved.

Complex Soils of Trans-Pecos Texas

GENERAL STATEMENT.

The work already cited is sufficient to indicate that Soil Science or Paleopedology may supply useful clues leading to the recognition and interpretation of past climates. It is instructive, however, to test this method in a region such as Trans-Pecos Texas, where a climatic chronology for the late Quaternary has already been formulated.

Trans-Pecos Texas is a great area of mountain, plateau, and plain, largely a part of the Mexican Highland and Basin-and-Range provinces. The plains are for the greater part erosional surfaces or pediments cut on bed rock, but partly covered by alluvium. The soils of the plains are developed from alluvial material which may be a thin or a thick mantle over the rock. On the mountain slopes, soils are absent or quite immature except in localities of little relative area that have a colluvial cover.

The soils of the area may be somewhat arbitrarily divided into two broad types: (1) those developed on igneous rocks, largely Tertiary lava flows and intrusives, or on alluvium composed largely of fragments of these rocks, and (2) those developed on sedimentary rocks, mostly calcareous, or on alluvium derived from such rocks.

Examples of complex soils have been found in both types, and such soils bear evidence of climatic changes in relatively recent geologic time. This evidence permits of an interpretation that is consistent with a climatic chronology, already postulated on the evidence of Quaternary alluvial formations.

Complex Soils from Igneous Sources.

At the railroad station of Praesum, southwest of Alpine, Texas, a cut along the Alpine-Marfa line of the Southern Pacific Railway exposes a section of colluvial material derived from an adjacent outcrop of andesitic lava. The slope which shows in profile at the top of the cut is sufficiently inclined so as to cause good drainage, but not so steep as to cause rapid removal of soil by slope-washing or gullying. Here the profile is as follows (Bryan, 1940, p. 101):

Soil Profile at Praesum, Texas.

	Thickness (inches)
1. Humus soil, brown, with semi-columnar jointing	15.0
2. Chestnut brown clay; contains cracks filled with illuvial clay	4.5
3. Gray-brown sand with angular fragments; contains small veins of newly deposited calcium carbonate, also holes from which concretionary calcium carbonate has been dissolved ..	11.0
4. Sand with angular rock fragments, the whole strongly cemented with calcium carbonate so as to form a hard mass; small solution pits and channels appear at the top	120.0+

The upper humus layer is typical of the grassy plains of the area, and approaches in texture and structure the Chernozem type. The next layer is the upper part of a B-horizon of such a soil, which has a considerable accumulation of illuvial clay. This zone extends into the underlying layer, number 3, by the accumulation of calcium carbonate in thin films and veins. It is obvious that in unit 3 solution has resulted in destroying caliche nodules and has left holes. It is not a process of the present, but must be attributed to an earlier more humid time interval during which active solution of calcium carbonate occurred. The lower layer, 4, contains the typical caliche of the Southwest—a material thoroughly impregnated with calcium carbonate. Evidence of a long interval of relative dryness is provided by this mass of caliche, and the solution pits and channels along the top record a succeeding more humid interval during which carbonates were being dissolved.

Granting that caliche was deposited in the soil at Praesum under conditions of relatively arid climate something like the present and that this secondary calcium carbonate was dissolved during intervening stages of relatively humid climate, the record of climatic changes recorded in this soil may be interpreted in at least two different ways, either of which is consistent with the data at hand. The two interpretations are compared in the following table:

Alternate Climatic Interpretations of the Soil at Praesum.

Interpretation 1.		Interpretation 2.	
Climate postulated	Events	Climate postulated	Events
Relatively arid (present)	Deposition of caliche films and veins in unit 3	Relatively arid (present)	Deposition of caliche films and veins in unit 3

Interpretation 1.		Interpretation 2.	
Climate postulated	Events	Climate postulated	Events
Relatively humid	Solution of caliche nodules in unit 3, leaving holes	Relatively humid	Solution of caliche nodules in unit 3, leaving holes and at the top of unit 4, leaving pits and channels
Relatively arid	Deposition of caliche nodules in unit 3	Relatively arid	Accumulation of main caliche mass in unit 4 and of caliche nodules in unit 3
Relatively humid	Solution of top part of caliche in unit 4		
Relatively arid	Accumulation of caliche in unit 4		

The fundamental difference between these interpretations lies in whether it is assumed that the main mass of caliche in unit 4 and the caliche nodules which were formerly present in unit 3 were deposited at the same or at different times. If they were deposited during the same interval of relative aridity their partial or complete solution was probably effected during a single succeeding interval of relative wetness; thus the soil records three climatic conditions: one of the present and two of the past. If they were deposited at different times, during two intervals of relative aridity separated by an interval of relative wetness, the soil then records five climatic conditions: one of the present and four of the past. The question of interpretation cannot now be settled, although consideration of the Quaternary erosional and depositional history as given in a following section of this report will shed some light on it.

Complex Soils from Sedimentary Sources.

The terranes of sedimentary rock flanking the Davis Mountains to the east are on the whole considerably more calcareous than are the igneous terranes of the Davis Mountains themselves. Wide belts of limestone and calcareous shale occur along the Del Norte Mountains and in the Marathon Basin (Albritton and Bryan, 1939, Pl. 1) and the soils developed on these rocks or their alluvial derivatives contain in their subsoils greater quantities of calcium carbonate than do the soils developed in igneous rocks.

In the areas of limestone and its derived alluvium the subsoil contains zones of carbonate enrichment appearing as solid beds two to four feet thick, generally called caliche. Where bed rock is close to the surface, plates of caliche extend into the cracks and fissures so as to cement the subsoil and the bedrock into a firm mass. This mass is penetrated, however, by cracks and fissures opened by solution and generally filled by fine sand washed down from above. In most localities an early stage of calichification and a later state of solution can be detected.

It is obvious that the main accumulation of caliche is a process of the past and that the caliche has undergone solution since the time of its formation. In this regard the evidence is in harmony with that at Praesum, except that at the latter. locality there is evidence for two and perhaps three stages of calichification. In the presence of abundant calcium carbonate from sources in the sedimentary rock, however, the overlying soils become so highly impregnated with caliche that evidence of any previous solution of the carbonate has been obliterated. The climatic record preserved in such soils therefore tends to be less complete than in soils which have a less readily available supply of carbonates.

The use of complex soil profiles as indicators of climate in the Davis Mountain area is hampered by incompleteness on the part of some of the soil records and ambiguity on the part of others. Furthermore, the soils present evidence only of a succession of climatic fluctuations, and nothing on the dates of the climatic episodes that appear to be recorded. The time might be approximated by reference to some general chronology of climatic fluctuations as attempted by Veatch. However, in the Davis Mountain area a local chronology can be utilized as brought out hereafter.

Alluvial Plains.

The soil-making processes in the alluvial plains of the Davis Mountain area are obviously carried on under conditions quite different from the production of soils on slopes. Whereas on slopes there is a nearly continual removal of the finer soil particles, on the alluvial flats there is a strong alternation between violent and catastrophic removal of the soil and deposition of new material laid down almost as suddenly and equally violently. Whereas also in a semi-arid country of this type, the soils on slopes are dried out almost completely between the infrequent rains, the alluvial flats may be saturated or partly saturated with water for considerable periods of time. They also gradually dry out for even longer time intervals.

The alluvial plains are plains cut on rock or pediments. In the axial portions of the larger areas the alluvium is 20 to 30 feet deep. On the borders it may be only one to three feet thick.

In areas of thin alluvial cover, below a few inches of uncemented, humus-stained alluvium, is a hard compact iron-stained alluvium. The uncemented alluvium is an incipient chernozem with faint films of calcium carbonate at the base, but the compact alluvium below was cemented when it formed the deeper horizons of a humid type soil. Thus the thin alluvial cover is a composite soil of polygenetic type.

In areas of thicker alluvium, waters spread widely. The whole body of alluvium is saturated for days or weeks, as this water drains off by lateral flow down valley and also toward the principal and deeper channels. There is also loss to the air so that a large part of the contained salts remain. The salts of alkalies being easily soluble are likely to be redissolved and carried off by the next flood whereas calcium carbonate remains.

The deposition of calcium carbonate takes place in two locations: (1) within the alluvium and (2) near its surface. Within the alluvium there is not only downward movement of dissolved salts but also lateral flow. Deposition takes place in the locus of greatest flow or in other terms in the more permeable beds. (Frazer, 1935). Thus the gravelly beds tend to be cemented and in places are hard conglomerates. At the surface and near the surface the calcium carbonate is deposited in concretionary masses and as seams and veins in the soil cracks. Here it may form a mere stain or a hard compact mass of caliche comparable to the caliche on areas of slight slope outside the flood plains.

There is, however, a further aspect of flooding. The saturation of the ground even though it is temporary and sporadic in occurrence promotes the growth of vegetation and particularly of the grasses to a luxuriance unknown on the hillsides of the area. Thus soil formation is promoted and may be carried to a kind of precocious maturity in a relatively short time particularly in broad, grassy areas adjacent to main channels. Here strongrooted perennial grasses, *Tobosa* and like types, form a nearly complete plant cover that during floods strains out the finest silt and much organic trash. The growth and decay of grass roots and general soil-making processes break up the laminations induced by sedimentation and produce in these grassy areas dark humus zones with a strong vertical structures. These pseudo-soils or precocious soils, formed largely by deposition, are only incipient if considered from the standpoint of the chemical or mineral changes of soil development. However, at depth they produce secondary characters because between rains the alluvium dries to great depths and cracks develop which, on renewed flooding, fill with colloidal clay.

Correlation of Geologic and Pedologic Data.

Most of these major streams in the broad-alluvium floored valleys of the Davis Mountain area have recently incised their channels into gullies or arroyos. The walls of these arroyos reveal complex stratigraphical relationships that are elsewhere concealed beneath the smooth flood plains. Three alluvial formations separated from each other by disconformities can be identified. Each successive stage of alluviation was followed by an interval of erosion similar to that in progress at present. These formations, previously described in detail by the authors (1939, p. 1423-1474), are named the Neville, Calamity and Kokernot, in order from the oldest to youngest.

The Neville alluvium is distinguished from the younger formation by its higher content of clay and ferruginous materials, its abundance of secondary calcium carbonate in the form of caliche nodules and crusts, and by its content of numerous horse and elephant bones representing extinct species. During its deposition the valley flats must have been covered with vegetation sufficiently luxurious to sustain such "gross feeders" as the mammoths, in numbers such as could not live in this region under the present climatic regime. Thus the climate during Neville time is presumed to have been more humid than that of the present.

Conditions were thus favorable for soil formation. It must be supposed that the slopes which supplied the materials for the Neville were mantled with a soil containing more secondary clay and iron hydroxide than the present soils. The derived alluvium was more clayey and iron-stained than that carried by streams of the present. The rate of soil formation on the alluvial flats was also more rapid than at present. Iron was released in the soil of the grassy areas to a greater extent and with the subsequent loss of humus gives the formation as a whole a reddish color. Compact, reddish clayey silts which were the original humic zones or "precocious soils" are fairly common. In these zones and below them cracks filled with reddish-brown colloidal clay are common. These cracks are indicative of prolonged drying out, although other characteristics testify to a wetter climate. In a few localities the top of the formation is exposed. It is marked by a fine-grained dark-brown to black layer grading down into a structureless compact reddish and clayey silt. It appears that near the close of the period of deposition the surface was in places stabilized and soils of the pedalfer type were developed to a state near maturity.

The caliche in the Neville occurs as fillings in old root holes and worm borings, as concretions scattered throughout the clayey matrix, as cementing material in the gravelly layers, and as thick crusts such as might have formed in subsoil zones. Much of it was formed after the greater part of the formation had been deposited and prior to the post-Neville pre-Calamity interval of erosion as the basal layers of the younger alluvial formations commonly contain fragments of caliche reworked from the Neville. Also the zones of caliche in the Neville do not extend across erosional disconformities into the younger alluvium of the Calamity or Kokernot.

The Calamity formation contains at several horizons humic zones or precocious soils in various stages of development. The best developed is generally at the top of the formation and extending downward from it are veinlets of illuvial clay which are likewise dark with humus. In the Calamity-Sheep Creek Valley (Albritton and Bryan, 1939, Pl. 1) some of these veinlets extend down across the Calamity-Neville contact and several feet into the red clayey silts of the Neville formation. These veinlets have been figured by the authors in an earlier report (1939, Pl. 6, Fig. 1). In places they parallel or cross older seams of reddish illuvial clay which are confined to the Neville and which are truncated at the Neville-Calamity contact. The clay seams are instructive in that they show how subsoil characteristics of one stage may extend across an erosional unconformity to form a composite soil of polygenetic character.

The Calamity and Kokernot formations both contain humic zones and calcium carbonate stains and veins. They also contain artifacts, indicating that man inhabited the valley flats during the two stages of alluviation. The inferences that during these stages the flats were covered with vegetation and attracted settlement by the Indians indicate that the climates of both Calamity and Kokernot times were humid relative to the present.

On the other hand, there is evidence that the two erosional intervals represented by the disconformities between the three formations coincided with relatively arid times. Rock shelters and caves in pre-Quaternary rocks along the sides of the valleys commonly contain quantities of reddish or yellowish wind-blown dust. The color and texture of the dust strongly suggest that it was derived from the Neville, and archaeological evidence indicates that most of it is older than the Calamity (Kelley and Campbell, 1940, p. 88). Thus it was in all probability stored in the shelters by the wind during a dry stage that corresponded to the post-Neville pre-Calamity erosional interval. Wind-polished rocks in areas where the wind is not now an effective agent of abrasion attest former times of dryness, and the evidence at hand points to this same erosional interval as the time of most active wind abrasion (Bryan and Albritton, 1942, p. 1411-1414).

The alternating stages of erosion and deposition in valley flats of the Davis Mountains seem thus to have reflected alternations in climate from the relatively moist to the relatively dry, alluviation having occurred during the moist times and dissection during the dry. Hack (1942) who has described a similar sequence of Quaternary alluvial formations in the Jeddito and other valleys of the Hopi country in Arizona, has found good evidence for a like control of erosion and deposition by climatic changes.

The time involved in the deposition of these formations can be approximated. The Neville formation has some antiquity as it contains the bones of extinct species of elephants and horses. It may represent more than one horizon, but as a whole it seems likely that, with other beds containing the remains of elephants, it belongs to the Late Pleistocene.

The upper part of the Calamity formation contains numerous artifacts including points of the Pecos River Type. These belong to a cultural complex which Setzler (1935) tentatively dated at about 700 A. D. The lower part of the formation contains artifacts of as yet unknown antiquity. In certain localities an unconformity exists between the Upper and Lower Calamity. It can not be readily traced by geologic means but may represent a period of erosion and drier climate within the Calamity interval as discussed by Bryan and McCann, 1943.

There is as yet no archaeological evidence to give a sure date for the formation in years. Deposition of the Kokernot, as indicated by its contained artifacts, was presumably under way prior to 1200 A. D., although Kelley and Campbell (1940, p. 160-161) admit the "somewhat remote possibility" that its deposition may have begun as late as 1400 A. D. This latest stage of alluviation ended with the cutting of the present arroyos, a process that began in the decade 1880-1890, but which was most effective in this region after 1900 (Campbell, in Kelley and Campbell, 1940, p. 42).

If as the evidence at hand appears to indicate, the alternating stages of sedimentation and erosion in valley flats of the Davis Mountain area have been initiated by changes in climate, an opportunity is afforded for correlating the geologic and pedologic records in this area. Such a correlation is given in the following table, where the more extended interpretation of the Praesum profile is chosen for comparison. For obvious reasons this correlation must be regarded as tentative, but it is nonetheless suggestive that polygenetic complex soils and Late Quaternary alluvial bodies may preserve duplicate records of climatic changes for a given region.

Correlation of Geologic and Pedologic Events, Davis Mountain Area.

Climate	Geologic Events	Pedologic Events (Praesum)	Time
Relatively arid	Dissection of valley flats by the present arroyos	Deposition of caliche 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 1880-90 A. D.

Climate	Geologic Events	Pedologic Events (Praesum)	Time
Relatively arid	Dissection of valley flats; erosion of Calamity and Neville formations	Deposition of caliche nodules in unit 3	? (Possibly in progress 1200-1400 A. D.)
Relatively humid	Deposition of the Calamity formation	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 the Neville formation	Formation of parent soil	? (Possibly 8,000 - 25,000 years ago)

The humic silt zones or "precocious" soils of the alluvial formations were formed with great rapidity. Those of the Kokernot formation began to be formed at sometime between 1200 and 1400 A. D. The length and the antiquity of the Neville formation is not well known, but the length of time available can be estimated as several thousand years. When it is realized that two or three of these humic zones occur in the Calamity formation and that all were formed in the relatively short interval, probably no longer than 1,400 years, the rate is rapid.

If the correlation between the soil section at Praesum and alluvial chronology as shown in the table is correct, one must believe that visible films of calcium carbonate have formed at Praesum since 1880 A. D. Although there exist no data on the time required to form such films, the time interval seems too short. The correlation may be defective. It is possible that the deposition of caliche nodules in unit 3 took place in the mid-Calamity erosion interval and that solution of these nodules occurred during Upper Calamity and not Kokernot time. From this point of view the caliche films and veins of unit 3 may have begun to form in the Calamity-Kokernot erosion interval and continued to form throughout Kokernot time to the present.

Such a correlation would assume that the relatively humid Kokernot time was too feeble or too brief to affect the soil-making processes.

Further investigation may reveal a method by which a firmer correlation can be made between the several periods of soil formation revealed in the complex soils of this region and the sequence of geologic events that have been in part dated in years.

Summary of Conclusions.

The technique of using complex soils to interpret past climatic changes has proved generally successful in the relatively few instances where it has been used. In the interpretation of complex soils, however, it should be remembered that only those climatic changes which were sufficiently pronounced to alter one or more soil properties will be recorded. On the other hand the changes must not be so long continued as to obliterate older soil profiles. Complex soils will therefore be best developed in areas on the margins of the great soil groups where relatively small changes in one soil-making factor will produce relatively great structural or chemical changes. In particular the boundaries between the humid and semi-arid climatic belts are areas where the alternate accumulation of lime and iron hydroxide in the subsoil are likely to be preserved. Within the humid regions the fluctuations of climate characteristic of the Pleistocene presumably lead to successive periods of intensification and of weakening of soil making processes. No change in the chemistry of the subsoil is necessarily involved.

Composite and polygenetic soils in semi-arid lands which may reveal the greatest amount of climatological data are likely to be found on slopes that are sufficiently inclined to be well drained, but not so steep as to allow for rapid wasting by erosion. They are not likely to develop along the floors of valley-flats where the soil-forming processes normal to a region are modified by special conditions of flooding, of deep drainage and of plant growth. The humic silt layers or "precocious soils" of such areas although they are imperfect soils, may produce parallel chemical and mineralogic changes in beds below them which can be interpreted in the light of information gained from the true soils on slopes. Soils that have their sources in limestone or other rocks rich in carbonates are likely to record climatic changes imperfectly, such large quantities of carbonates are deposited that the effects of previous climatic regimes may be obliterated. In calcium-poor rocks, however, the release and hence the accumulation of carbonates proceeds more slowly and is less likely to obscure in short lengths of time the effects of previous climatic change.

A complex soil near Praesum, in the Davis Mountains, seems to satisfy the requirements for providing a large amount of paleoclimatological data. According to one interpretation, this soil records three stages of relative aridity during which caliche was deposited in the subsoil, and two intervening stages of moister climate during which the previously deposited caliche was partially or entirely dissolved. This interpretation is in harmony with the climatic evidence in the adjacent valley flats, which are underlain by three bodies of alluvium separated by erosional disconformities. On the evidence of the alluvium itself, it had already been postulated that deposition took place during relatively humid times, whereas erosion of the valley flats in gullies now identifiable in the surfaces preserved along disconformities occurred during relative arid times. The pedologic and geologic records seem therefore to be in harmony with each other, although the correlation here tentatively proposed should be tested in the light of further work on the soils of the Davis Mountain Area.

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