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PLIO-PLEISTOCENE SEDIMENTS AND CLIMATES OF THE SAN AUGUSTIN PLAINS, NEW MEXICO

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WITH A DISCUSSION

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INTRODUCTION

The floor of the intermontane basin called the San Augustine Plains lies at an altitude of 6,775 feet and is surrounded by highlands (erosional remnants of Tertiary volcanic rocks) which rise to heights of more than 12,000 feet. These rocks, flows, and tuffs range from rhyolite to basalt, and the allogenic sediments of the basin are all derived from this complex of lavas and their derivatives. The basin structure is considered by Stearns (1956) to be that of a graben, the age of which is not known but may be as old as late Pliocene.

During late Pleistocene time a lake occupied the basin. The lake—called Lake San Augustin—had a maximum area of 255 square miles. The present playa in which a 2,000 foot core-hole was drilled covers about 35 square miles at the west end of the plains. The drill site (altitude 6,790 feet) is near the central part of the playa about four miles from the bottom slopes of the nearest hills. This site was chosen in the hope that the core obtained would supply a composite of the sediments brought in by the streams entering the basin. The cores are believed to consist of sediments from a place in the basin where deposition was least rapid, where sediments are probably the finest grained materila carried into the basin at the time of deposition, and where deposition was under lacustrine conditions.

Table 1. — Macroscopic description of cores from the San Augustin Plains

0 - 47 feet	Silty clay	Zone I
47 - 210 feet	Allogenic sands with clay-silt horizons	Zone II
210 - 420 feet	Silty clay	Zone III
420 - 580 feet	Silty clay with authigenic calcite sands	Zone IV
580 - 950 feet	Silty clay	Zone V
950 - 1,070 feet	Silty clay with sand layers and a few pebbles	Zone VI
1,070 - 1,230 feet	Sand, grit, and pebbles	Zone VII
1,230 - 1,910 feet	Sand, breccia, and pebbles	Zone VIII
1,910 - 2,000 feet	Clay, silt, and sand	Zone IX

In 1955 drilling was carried to a depth of 645 feet. Sediments from this core have been analysed in considerable detail for pollen and other organic remains. Textural and petrographic studies as well as carbon dioxide analyses have also been done on many samples. Some of the results of this work are shown graphically in chart 1. Deeper drilling at a new site, a few feet from the first, was done in 1958-1959, and an almost continuous core has been obtained between the 600- and 2,000-foot depths. The lower 1,400 feet has been logged, photographed, and sampled. Some textural analyses and pollen studies of this interval have done, but these are not complete enough to give more than tentative ideas about conditions of sedimentation and vegetation of the region. A generalized picture of the entire 2,000 feet of section sampled by these cores is shown in table 1.

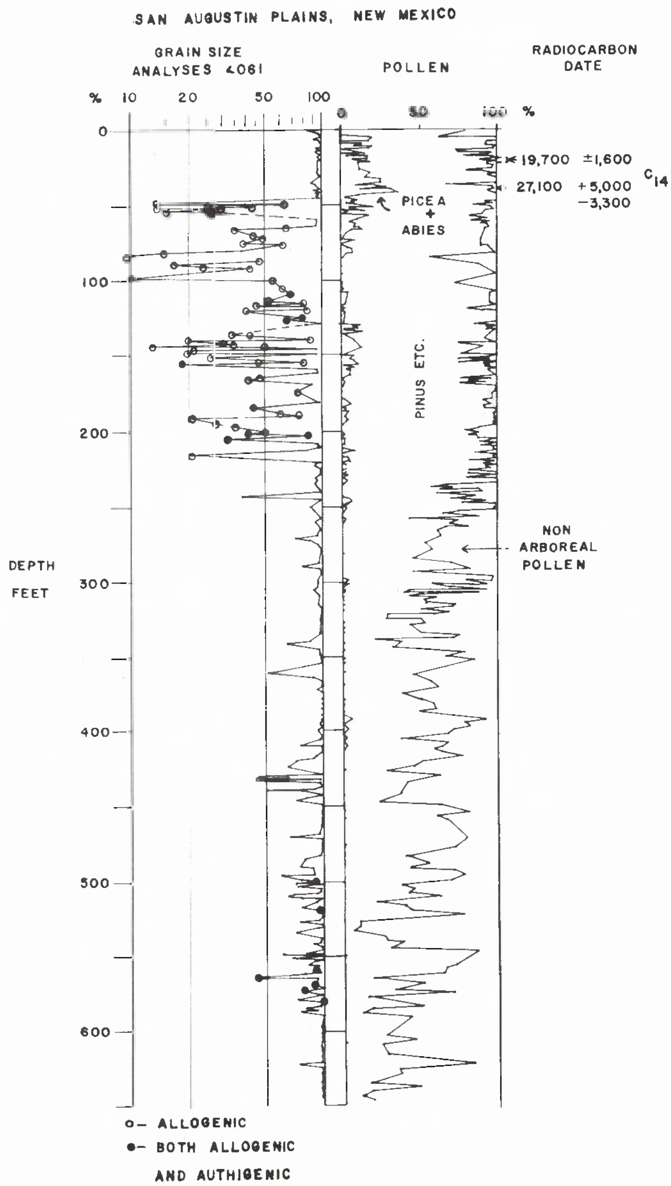

Chart 1.—Graph of results of textural, petrographic, and pollen studies of core in San Augustin Plains, New Mexico.

THE SEDIMENTS

Volcanic rocks surrounding the basin are nearly all porphyritic, and are generally microporphyritic with hypo-

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crystalline groundmass. Some groundmasses are holohyaline. Nearly all phenocrysts are less than ½ mm (millimeter) in diameter. Only a few phenocrysts (generally quartz and feldspar' from rhyolites) are larger than this, and even these are seldon caught on a 1 mm sieve. In the allogenic sediments of the cores, coarse sand and larger sizes are composed, almost without exception, of rock particles, whereas the fine sand and silt are mainly mineral grains which were originally phenocrysts in the lavas, although a few grains are rock particles. Quartz, feldspar, hornblende, biotite, and olivine are the only common mineral grains. These are either entire phenocrysts or cleavage fragments of phenocrysts. The feldspar grains are seldom weathered and the quartz grains almost never weathered. A few of the hornblende grains have hacksaw terminations and some of the olivine grains are rounded. The edges of mica flakes generally are stained and shredded. Thus, for the most part these minerals, except mica, are angular and fresh. The clays are derived almost entirely from the glass, microlites, and fine crystals of the mesostasis. This indicates that, where weathering has been severe in the upland, the allogenic materials are almost entirely microphenocrysts and clays, inasmuch as groundmass material weathers much more rapidly than the phenocrysts.

These allogenic materials can be divided into three groups which, for the most part, fall into three different textural types. As seen above the textures of two of these groups are related directly to textures of the parent volcanic rocks, whereas the texture of the third group was determined by the erosional and weathering history of these rocks.

Calcite ranging from coarse sand to clay sizes is the only common authigenic mineral. The sand sizes are either single crystals or aggregates. The single crystals generally are rhombs or prisms and may be clear to cloudy, and transparent to white. At some horizons oolites occur, and their presence is taken to indicate shallow turbulent water saturated with calcium carbonate. In some of the sediments analcite has been found in the silt and clay: The origin of the analcite is not known, but it is undoubtedly authigenic as it shows crystal outline and is concentrated at certain horizons.

The only common animal fossils are the valves of ostracods. These are most common in the upper sediments and are not found below 483 feet. They have not been studied in detail. The valves are sometimes fresh and unaltered, but at many horizons calcite has been deposited to such an extent that the valves appear as elongate oolites.

The sediments of the core (table 1) have been tentatively divided into nine zones chiefly based on textural variation and degree of consolidation. Zones have been numbered from I (top) to IX (bottom) because the base of the sedimentary section has not been reached to date. Because the lowest sediments are oldest, it is obvious that the history must begin at zone IX, but as noted above, no detailed work has been done on this part of the core and only a few tentative conclusions can be drawn from the lower 1,400 feet.

Zone IX is peculiar for two characteristics. It is not as well consolidated as the zone above and a higher proportion of the sediment is clay and silt.

Zone VIII is by far the thickest of all the zones, and it is well consolidated and is characterised by red and brown colors. Graded bedding is found at many horizons. Thickness of the graded units ranges from a few inches to more than five feet, but as no textural analyses have been run we cannot yet speculate on their origin. Pebbles to boulders, ranging in composition from rhyolite to basalt, are common. Some of these are weathered, others fresh; some are angular, others rounded.

Zone VII consists of partly-consolidated and partly crumbly sands, grits, and conglomerates. They are for the most part gray rather than red-brown, indicating less oxidation than that in zone VIII. This seems to be a transition zone in which the lower part is coarser and better consolidated than the upper, but as a whole the sediments are crumbly and have a wide textural range.

Zone VI is predominantly clayey silt, compact but not consolidated. There are some pebbles and coarse sand but these are for the most part weathered. Calcite has been deposited on the weathered surfaces and gives much of the core a whitish appearance.

Zone V is composed of compact silty clays and clayey silts 370 feet thick. These sediments without doubt represent a much longer period of time than does the 1,000 feet of sediments of zones IX through VI, and also seem to indicate very stable conditions, both on the uplands and in the lake itself. When these sediments are fresh the color is predominantly black to dark gray, but some portions are green and others almost white. These black, gray, and greenish colors turn brown when the material is exposed to the air and dried. The upper 650 feet (these have been studied in detail) carry considerable authigenic calcite. At some horizons calcite is more than one-third of the sediment, and the average calcite content as determined from 44 analyses is nearly 20 percent.

Zone IV is in some respects a continuation of zone V and could be included in this zone. However, the authigenic calcite in zone IV is usually in the medium to coarse sand sizes, whereas that of zone V is mostly in the fine sand and smaller size grades.

Zone III is composed of allogenic particles which are almost all silt and clay, black to dark gray when fresh. In most cases the authigenic carbonate is fine, but there are a few horizons of coarse authigenic calcite sand. A few horizons carrying ostracod valves are found in the upper part of zone IV, but they increase in frequency from the bottom of zone III upward and are common in the upper part of zone III.

Zone II is composed of sediments more than 200 feet thick. In these sediments allogenic sands, chiefly of fine textures, are common. At some horizons authigenic calcite sands predominate, but generally the allogenic grains give the sandy textures to this zone. The allogenic sands are, for the most part, grains of feldspar, quartz, hornblende, augite, mica, garnet, and olivine. They are invariably fresh-looking and usually angular, and generally have either crystal forms or cleavage surfaces although there are rare rounded and subrounded grains. Rock particles are found at some horizons but they are not common. The fine sandy layers are interspersed with clayey silts, but at some horizons sand predominates. Sandy zones at depths between 50 and 60 feet, 80 and 100 feet, and 135 and 160 feet are the aquifers tapped by the wells of local ranchers for watering their stock. Many horizons in zone II carry ostracod valves, and about one-sixth of those sampled carry oolites. The coarser texture of the sediments of this zone is interpreted as indicating a more rapid erosion of the uplands than during the previous three zones. Weathering evidently had altered the matrix of the exposed volcanics to hydrolysates but had no appreciable effect on the phenocrysts. Thus, the texture of the allogenic sands is determined chiefly by the original size of phenocrysts and not by their erosional history.

Zone I is another zone of silts and clays but, unlike zone III, it is predominantly gray. Some horizons are soft, poorly-compacted and easily crumbled. The few sand size grains are chiefly carbonate which is a mixture of calcite aggregates and ostracod valves, but contains no oolites. There are few allogenic minerals of diameter larger than fine sand.

There is a sudden change above the depth of 3.5 feet. Ostracods, which are common in the lower core, disappear and the sediment becomes even more crumbly and less compacted. This change is even more strongly reflected in the sudden disappearance of spruce and fir pollen and in a great increase of scrub pollen common to semi-arid climates.

INTERPRETATION

The bedrock floor of the basin has not been reached at a depth of 2,000 feet, and we must begin our interpretation with sediments that lie an unknown distance above it. The great thickness of clastics from the bottom of zone IX to the top of zone VI has not been studied in detail, but its character clearly differs from that of zones V through I. Zone IX, from the bottom of the core to about 1,910 feet, is relatively fine grained and little consolidated. In the interval from 1,910 to 950 feet (zones VII - VI), which is more than half of the present depth cored, sand, granules, cobbles, and, in places, boulders predominate. These indicate very different rates of erosion and deposition from those which prevailed later (zones V - I). In addition, this thick section (zones VIII - VI) is characterized by red-brown oxidation color and by frequent graded bedding.

It is possible only to suggest the conditions that give rise to this thick, coarse and oxidized detritus which often has graded bedding. The slopes and climatic conditions on the upland surfaces must have been such that both down cutting and oxidation proceeded rapidly. One would infer that slopes were steep, and that rainfall was plentiful but intermittent, possibly seasonal. The prevailing opinion today would be that the detrital materials were formed under warm moist conditions in which active tectonic movements were taking place. Detailed studies of the included pollen and of the sediments themselves may make these conditions clear.

The next 730 feet (zones V, IV, III) of black to gray to green beds of fine hydrolysates and authigenic calcite would indicate stable conditions of deposition in an alkaline lake. Reducing conditions were present at least in the bottom water of the lake. On the uplands, chemical weathering was dominant and only fine sediments were carried into the lake.

The abundant allogenic sand of zone II indicates that erosion was again more rapid. However, for the most part, only unweathered phenocrysts and weathered clays were carried into the lake. Weathering of the groundmass of the lavas (but not the phenocrysts) kept pace with erosion. Thus, deposition of sediments of zone II probably was more rapid than deposition of the underlying silts and clays (zones VI - III), but not nearly as rapid as the deposition of the lower 1,000 feet or so of sediments (zones VIII - VI).

The sediments of the uppermost zone (I) were deposited during a time of slow erosion and deposition. Clastics coarser than silt are almost completely absent. It is hard to imagine that decrease in slope of the streams would produce this abrupt change in the texture of the sediments. The pollen, on the other hand, with its abrupt increase of spruce pollen, does suggest that climatic factors are responsible.

THE POLLEN RECORD

The present vegetation of the plains drainage area has been studied by Potter (1957). The flora of the basin is now semi-desert, with soapweed - greasewood on the alkaline soils of the undrained plains. Atriplex and grasses grade upward into the woodland zone of pinyon pine and juniper. The ponderosa zone is still higher and farther away except where it descends locally in occasional canyons or on sandy soil. On the highest elevations, and in most canyons of the ponderosa belt, Douglas and white fir, limber pine, and trembling aspen form a dense cover. Spruce is confined to high altitudes beyond the limits of the basin drainage. Potter is preparing for publication a pollen study of the area which records the current distance of type transport and differential preservation of pollen.

Shifts from the present vegetative communities as indicated by the fossil pollen profile should be evidence of climatic change. Specifically, an increase in spruce pollen in the deposits would indicate low temperatures and greater available moisture than at present. In addition, the presence of ostracod tests and lacustrine algae indicate periods of precipitation sufficient to maintain water in the playa. During times of greater aridity such lakes would have become more alkaline and decreased in size or even dried up, resulting in an increase of alkaline scrub growth on the basin surface.

Although the upper 650 feet of the core has been analyzed in detail for pollen, only spot analyses have been made on the deeper sediments. Interpretation of the vegetative sequence of the latter must be tentative, subject to revision following close-interval pollen analyses. A provisional pattern of vegetation change as shown by the core is described below:

0'	- 3.5'	Pine woodland with semi-arid alkaline scrub.
3.5'	- 230'	Spruce-pine with recurring semi-arid alkaline scrub.
230'	- 470'	Mixed pine-spruce forest and pine-juniper woodland with grass-sage(?).
470'	- 950'	Grass-sage(?) (artemisia) community with recurring pine-oak-juniper woodland.
950'	- 2,000'	Relict Tertiary temperate forest of conifers and decidious hard woods.

The overall change or climatic trend seems to go from a relatively moist temperate climate, to a cool(?) semi-arid one, gradually changing to a cold moist climate.

Within this record of overall climatic change there are three major breaks in the significant pollen climatic indicators. The first historically, at about 950 feet, is the replacement of a relict Tertiary forest by a semi-arid steppe or chapparal plant community. Although this community was not static its general character persists to about 470 feet. Above this second break, woodland and forest assume increasing importance. The final major break, at about 230 feet, is marked by the sharp decline in sage(?) pollen, by a still greater importance of spruce, and by the appearance of allogenic sands.

Chart 1 shows that, during the time span involved in the accumulation of the upper 645 feet of basin sediments, the vegetation shifted from that of a grass-sage community to that of a montane coniferous forest. The tree pollen curve indicates a continuing decrease in temperature from the base of the core toward the surface, while the spruce curve furnishes evidence of fluctuating colder temperatures within the long-trend cooling stage.

If Pleistocene glacial stages were of approximately equal intensity and duration, then the spruce pollen curve for the San Augustin Plains should show similar maxima for each glaciation. Such a succession of maxima cannot, in fact, be identified. The spruce curve, although frequently changing from low to high maxima, exhibits a gradual increase from the 470-foot depth upward, reaching a principal maximum at 39 feet.

The climatic fluctuations recorded by pollen between 70 and 3.5 feet are comparable in number and magnitude to those which would ordinarily be ascribed to the last glacial stage. Evidence of earlier glacial stages must be sought in pollen indicators other than spruce.

CONCLUSION

Sedimentary and pollen profiles from ancient Lake San Augustin record a history of past climates, diastrophism, and erosion. This long record shows the relationship of climatic changes associated with pluvial and non-pluvial stages, shows temperature gradients, and locates levels of minimum and maximum temperatures.

The pollen curve is not commensurate with current theories of glacial climate, unless one attributes the gradual trend toward cooling to extensive regional uplift during much of the Pleistocene and/or Pliocene, or to reflections of the rather uniform continental glacial maxima by climatic changes of significantly different intensities in New Mexico. It is most unlikely, insofar as we now understand the history of the Pleistocene, that there was a single glacial maximum, as would be inferred from the over-all record of vegetative change culminating in the appearance and eventual maximum of spruce.

SELECTED REFERENCES

Clisby, K. H., and Sears, P. B., 1956, San Augustin Plains - Pleistocene climatic changes: Science, v. 124, no. 3221, p. 537-539.

Foreman, Fred, 1956, San Augustin Plains, - the sediments: Science, v. 124, no. 3221, p. 537-539.

Potter, L. D., 1957, Phytosocialogical study of San Augustin Plains, New Mexico: Ecological Monographs, v. 27, p. 113-136.

Stearns, C. E., 1956, San Augustin Plains - the geologic setting: Science, v. 124, no. 3221, p. 537-539.

DISCUSSION

The present core confirms our earlier conclusion that sediments beneath the San Augustin Plains occupy a basin, probably a graben, which is younger than any of the volcanic rocks exposed in surrounding highlands. The volcanic rocks cannot be dated securely on local evidence, but the still-recognizable form of some dissected lava domes implies that the youngest volcanics are no older than late Pliocene.

It has long been known that the San Augustin Plains, now dry, were occupied by an extensive pluvial lake. We have generally assumed that this and older lakes were coeval with one or more glacial stages, but that during interglacial times the plains were as dry as now. Essentially all the sediments described above are lacustrine. There is no clear evidence that the lake was ever fresh, and there is abundant evidence that during most of its recorded history the lake was alkaline. Possible drying-surfaces, marked by zones without pollen, occur below 480 feet. However, unless there are higher disconformities not now recognized, one would infer that a lake persisted in the basin throughout at least the last interglacial. If desiccation to the present playa is a post-pluvial phenomenon not matched by earlier episodes in interglacial times, some convenient but simplifying assumptions about Pleistocene climate in New Mexico must be re-examined.

Of comparable importance is the demonstration, throughout the upper half of the core, that climatic fluctuations recorded by pollen are superimposed on a long-continued trend toward increasingly cool climate. The time represented almost certainly includes more than one glacial stage. Such a long-continued trend is implied nowhere by the record of continental glaciation. Rather, successive glacial stages appear to have been of roughly similar intensity. The pollen record of the core is consistent with an hypothesis of continued regional uplift during the Pleistocene and may be evidence for that hypothesis. Comparable inference has been drawn from geologic evidence in the Colorado Plateau, the San Juan Mountains, and the Rio Grande depression.

One must hope that continued study of this important core will eventually provide a firm basis for estimating the time span recorded. The sediments from 47 feet to 3.5 feet (zone I), marked by maximum abundance of arboreal pollen and by sustained abundance of spruce, certainly include the "last glaciation" ("classical Wisconsin" of recent terminology). Both arboreal pollen and spruce pollen appear to show two maxima in zone I, but it is by no means clear that the older maximum is or is not a pre-"classical Wisconsin" event. Tentative climatic inference, and the inference that sedimentation was slow during deposition of sediments of zone I, would suggest that it is. Available radiocarbon dates imply that it is not, and that zone II is also part of the Wisconsin record. Thus, one may infer that zone I (below 3.5 feet) represents as little as 20,000 years ("classical Wisconsin") or as much as 90,000 years (early "classical Wisconsin"). Foreman's conclusions that a relatively stable depositional environment prevailed in zones V through I, except for zone II, and that sedimentation was relatively slow, imply that this 950-foot interval of sediments may represent a time span 15 or 20 times that of zone I alone. This is the order of magnitude of current estimates of the duration of Pleistocene time, but may be as little as one-half or as much as twice as great. The possible error is large.

The marked lithologic contrast between beds above and below 950 feet, together with the "relict Tertiary" flora recorded below 950 feet, make this level an attractive choice for the Pliocene-Pleistocene boundary. Nevertheless, the conclusion that the total core does or does not go through the Pleistocene into older beds is probably premature.