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Title: POLLEN ANALYSIS OF CCCHITI PROJECT MATERIALS:
         PRELIMINARY REPORT

INTRODUCTION

The pollen analysis of sediments from archaeological sites allows
reconstruction of vegetation patterns from precisely dated time horizons.
Precision of dating allowed by association of the sample with dendro-
logical specimens, and cross-dated ceramic types, is often sufficient
to reduce standard errors on dates to less than one half of one century.
Such time control is not ordinarily afforded the palynologist, and in
itself raises certain procedural problems. Instead of attempting to
interrogate the pollen analyses in terms of major climatic conditions evi-
denced, as is the case where the standard errors are on the order of
one-half to two millennia, the palynologist seeks to reconstruct precise
vegetation histories and interpret their causes in terms of variations in
environmental conditions occurring within the broader framework of the
climatic type.

This must be accomplished by recourse to more than one kind
of palaeoecological data. The pollen analyses of one locality must be
compared with those from other areas from the same time horizon; also,
palaeoecological interpretations applied to the evidence from geology and
paleobiological disciplines of other types must be considered wherever
possible. Each of these other types of evidence, of course, must be
evaluated on its own terms.
Thus the best method of approach is to select a problem which the basic paleoecological technique, in this case pollen analysis, can hope to resolve in light of the kinds of evidence available from other paleoecological studies already undertaken and the field conditions. In this study the problem was twofold:

1. What were the patterns of vegetation change, if any, through the period of aboriginal occupation evidenced in the archaeology, and what were the causes for such vegetation patterns; and

2. What would be the effect of such causes on maize agriculture during this period.

METHODS OF ANALYSIS

There are two major analytic problems in a pollen investigation. First, there is the problem of determining the best laboratory techniques to free the pollen from its sedimentary matrix and concentrate enough of it from the sample to yield a statistically reliable pollen count. This problem was never entirely overcome in this investigation. The standard extraction technique used in this laboratory was applied to the first eighty samples processed and it was discovered that only twenty-one yielded enough pollen for analysis. The fact that some pollen was recovered from almost every sample indicated that it was not a matter of faulty lab processing, but simply that the number of pollen grains in the samples was so low that the extraction technique could not efficiently concentrate the pollen for analysis.

Another extraction technique, specifically designed to concentrate pollen from a larger amount of sediment, was therefore utilized on the next series of eighteen samples. This proved ineffective in all but two instances. Thus, though ninety-eight samples were processed to extract and concentrate the pollen they contained, only 23 yielded sufficient pollen
for any kind of analysis. Of these twenty-three, six gave pollen counts wherein statistical reliability is questionable.

The second problem is that of obtaining pollen statistics which have ecological meaning. Because the frequency of a pollen taxon is dependent upon many phenomena in nature (including its tendency to be preserved, the amount of pollen the plant tends to disseminate, and the proclivity of the type for long-distance transport) not all pollen taxa are equivalent. The frequency of maize pollen, for example, may be due to any number of cultural practices and have nothing to do with the natural vegetation patterns of the area. If all the pollen taxa were to be considered equivalent, a high absolute frequency of maize pollen would necessarily lower the absolute frequency of pine pollen. The resultant low pine pollen statistic might not accurately reflect the vegetation pattern and, because unknown cultural controls may well be involved, the high maize pollen statistic would probably be ecologically meaningless.

The method of analysis used in this investigation is the same one which has been used in pollen researches in the Navajo Reservoir District (Schoenwetter and Eddy, 1964), the Navajo Irrigation District (Schoenwetter MSa), and at Picuris Pueblo (Schoenwetter, MSb). This method has been shown to have empirical validity in allowing differentiation of existing vegetation patterns and has been applied with equal success to independently derived data from Arizona (Hevly, 1964).

The primary objective of this method is the definition of the amount of tree coverage in the area of the sample. The arboreal pollen (AP) frequency derived by this method allows recognition of whether the area was tree covered or not and, if it was, whether the coverage was
sparse (savannah) or moderate (woodland) when dealing with the pinyon-
juniper blochore. The technique also differentiates between pinyon-juniper
and ponderosa-spruce-fir blochores. By definition, prairie is any non-
tree covered ecological condition. Thus a sagebrush flat would be
considered prairie in this scheme.

THE PROBLEM OF SAMPLING

The low yield of analyzable samples is in part due to the types
of samples taken and the amount of material originally collected. The
matter is no longer possible to correct, of course, but it is gone into
here in an attempt to avoid its repetition.

The samples collected from sites excavated in 1963 were primarily
of room fill, and the deepest rooms were the ones selected for sampling.
The stratigraphic sample series of such rooms have a quite limited utility.
The floor samples can be dated by their association with artifacts, and
the surface samples can be considered representative of modern con-
ditions, but all of the others are members of a relative chronology which
floats somewhere between the maximal and minimal dates. Without
unusual stratigraphic control, the amount of time involved in the room
fill is unknown. Also, there is no assurance that some of the fill
samples represent the same amount of elapsed time as others. Sup-
posing that each sample is of 100 cubic centimeters of sediment, some
samples might have been deposited over a period of hours while others
were deposited over a period of centuries.

It was decided that the pollen sampling undertaken in the 1964
excavations would be of room floors and other definately datable hori-
zons. Since the ceramics were not analyzed in the field, it was
proposed that all features be sampled so that when the ceramic analysis of those features was well enough along those which could be best dated would be selected for pollen analysis. But this program was not carried out. At LA 70, for example, 156 features were excavated but only forty were sampled. And not all of these forty were critically dated by artifact content. The field situation, of course, necessitated that some features go unsampled because there was not delineate floor horizon, or because of time limitations.

The samples that were collected, especially those from room floors, tended to be too meager. The usual amount collected was less than 50 grams, when 150 to 200 grams was requested. Also, the procedural manual (Dittert, 1963, p. 35) pointed out that coarser sediments need to be sampled more generously than finer ones since the problem is one of pollen concentration per unit volume. The sediments in the Cochiti area are fairly sandy, as could have been determined by a number of simple field tests, and so should have been recognized by the field personnel as necessitating even more generous sampling.

The above are not offered as excuses for the lack of results. In all probability there would not have been too much difference in results if the sampling program had included more proveniences, or if it had involved larger samples. Enough proveniences were available as it was, though a larger selection would have been preferable, and out tests with large samples yielded no appreciably different results than those with small samples. Possibly an additional ten or twelve analyses would have been contributed to the total, and in all probability they would have offered no new information.
RESULTS

Six of the eight surface samples collected yielded pollen counts (Fig. 1). The critical pollen statistic in each of these analyses is the AP frequency, which is an indication of the present density of tree coverage. The modern savannah condition of the site localities is shown to be represented by between thirty and forty percent arboreal pollen. It will be noted that the majority of the tree pollen is of pine rather than juniper, which is the usual tree observed. This is consistent with pollen data from modern surface samples in other areas. Pine pollen is, apparently, better adapted to transport and preservation and it is ordinarily in greater frequency than juniper even in dense juniper woodlands. The total AP frequency, however, remains a good index to the tree coverage of the locality.

The double bar on this, as the other, pollen diagrams separates the taxa which are utilized in the pollen sum (N) for calculation of percentages—on the left—from those which are excluded from the sum—on the right. Those excluded are considered less responsive to the main controls on the vegetation pattern and more reactive to local edaphic conditions and to agricultural and economic practices. Their frequency of occurrence is expressed as a percentage of the pollen sum. Though such excluded taxa have no relevance for ecological interpretation, they can be utilized as horizon markers for chronological purposes.

The occurrence of Zea pollen in four of the six surface samples raises some suspicions. This pollen may have been transported from present cornfields in the area, but investigations along this line (Martin, pers. comm.) indicate the malze pollen is not disseminated very far from its source under natural conditions. It is not improbable that these
surface samples have picked up some ancient pollen from subsurface horizons at the sites, and therefore that the pollen frequencies are not altogether those of the modern horizon. What fraction of the percentages are due to contamination, of course, cannot be ascertained. We must perforce consider these statistics as representative of the present ecology, but should not be surprised if future research indicates that they are not altogether reliable.

By contrast with the more ancient samples relevant pollen statistics are recognized in the frequency of Ambrosceae pollen (averaging almost 20%) and the frequency of Artemesia pollen (averaging 1.5%). It will be noted that the frequencies of Cramineae and Chenopodiaceae pollen are quite variable under the present condition; thus they can be assumed to be variable in the past.

The Santa Fe Horizon (Fig. 2)

There are three samples of this time period. All are from positions above the floor contact in the rooms in which they were collected, but are associated with pottery which indicates no appreciable elapsed time after the deposition of the floor materials. The only statistically reliable count came from the sediment which had accumulated in a pottery vessel. This was from a room which had a dendrological construction date of A. D. 1280, so the pollen sample should not date later than 1300. The AP frequency of 18.0 percent is far less than the modern surface samples and indicates a reduced tree coverage.

The frequencies of the other two samples were based on 37-grain and 50 grain counts respectively. Thus the confidence interval surrounding any given frequency is much greater than that for the same frequency on
count of the pot fill sample. The 37-grain count gives a 21.6% AP frequency and that from the 50-grain count gives a 14.0% frequency. Because of the width of the confidence intervals involved both of these may be considered comparable to the AP statistic from the pot fill, and thus similarly representative of the prairie vegetation pattern.

The data is insufficient to allow relative ordering of the three samples in time. There are differences in the frequencies of Ambroseae pollen and these might form a sequence of either increasing or decreasing frequency through time, but on the other hand they may not

*The Early Glaze Horizon (Fig. 3)*

Six pollen samples, from three sites, have been relegated to this horizon by consideration of their associated ceramics, but only one can be given a more precise date within this horizon.

One of these samples yields an AP frequency of 36.5%, which is in the range of the modern surface samples, and thus indicates savannah conditions as occurring for some time on this horizon. The others all have AP frequencies less than 30%, indicating less arboreal coverage. If there was no supporting evidence, it might be considered that this particular sample from LA 70 was a statistical anomaly which did not accurately reflect vegetation patterns. But this sample also has 5.5% Artemesia pollen, which is more than the usual average, and another three Early Glaze horizon samples also have more Artemesia than usual. Also, the Artemisia pollen from sample 70-140-37 was almost all in the form of clusters—indicating a very near source of supply. If the individual grains were considered rather than the clusters, the Artemesia frequency would be very much like that of sample 9154-24-10, with a
consequent decline in AP frequency to much the same level as the other Early Glaze horizon samples. The four samples with higher *Artemesia* values are comparable, then, though one indicates savanna ecology and the others indicate prairie ecology.

Four of the Early Glaze horizon samples yield Ambroseae pollen frequencies in the range of 40-50%, which is appreciably higher than the frequency of this taxon in the surface samples. One of the four (70-136-21) can be dated by its ceramic associations to between A.D. 1400 and 1450. Two of the other three are very probably of the same age as no significant differences may be observed. Sample 6455-24-55 contains the high frequency of Ambroseae pollen, but also contains the high frequency of *Artemesia* pollen; it seems to be from a time position intermediate between the two groups. This particular sample is from the first component at this site and would not date later than 1400 or 1410.

Thus a relative chronology can be developed for the ecological conditions represented during the span of the Early Glaze horizon. The older condition is dated before 1410 and probably begins no earlier than 1350-1375. It is characterized by higher frequencies of *Artemesia* than occur at the present and, probably depending on local factors, arboreal coverage indicating a savannah. The younger condition is dated between 1400 and 1450 and is characterized by Ambroseae frequencies of 40-50%. It represents a prairie ecology.

The occurrence of *Typha* and *Polygonum* pollen, representative of marsh or cienega conditions, is supported by the pollen of another riparian plant, *Alnus*, in another sample from the early part of this horizon. Probably these all were tracked in from the nearby river, but they indicate high water tables.
The Middle Glaze Horizon (Fig. 4)

Five pollen spectra are associated with Middle Glaze ceramics. Four of these yield AP frequencies much like those of the late side of the Early Glaze horizon (between 10 and 30 per cent) and reflect the same kind of open vegetation pattern. The fourth contains only 2% arboreal pollen, which is significantly lower than any frequency previously observed. Taken at face value it would indicate that trees were very far removed from the site at the time this sample was deposited. Without additional data to support such an interpretation, however, it must be considered rather tenuous.

It was shown that Ambroseae frequencies in the range of 40-50% characterize the late part of the Early Glaze horizon. Two samples from the Middle Glaze horizon contain Ambroseae frequencies in the same range, and there is no ceramic evidence that they might not similarly date between 1410 and 1450.

There is one sample (6455-52-34) which must date later than 1450, as it is associated with a room whose construction timbers were cut in A. D. 1469. This sample contains a very high frequency of Ambroseae pollen (125%) and would indicate that about 1470 the Ambroseae frequency was higher than it was around 1410-1450. Sample 70-117-39, then was probably deposited between 1450 and 1470.

The Historic Horizon

Of the three samples from the Historic horizon, two yield a greater quantity of arboreal pollen than the modern surface samples, and one yields about the same quantity as the modern samples. This last, from LA 8178, was collected from the terrace of fill between the outer and
inner rings of cobbles of the Southwest corner "tower" structure. The
field records do not indicate the depth of this fill below the present sur-
face, nor is there any indication that this sample was collected below
the top 10 cm of fill—which does contain very recent artifacts. With
no evidence to the contrary, and considering that the pollen spectrum
of this sample is unlike the others from the Historic horizon which should
be of about the same age, I feel justified in maintaining that the sample
from LA 6178 is not necessarily much older than the surface samples,
and does not represent the Historic horizon, but the Modern horizon.

The samples from LA 34 and LA 70 are both dated to between
1650 and 1750. There is some small amount of ceramic evidence which
would date both before 1700, and that from LA 34 is probably somewhat
earlier than that from LA 70, but for the moment the 1650-1750 date
is the only secure one. Both samples yield higher AP frequencies
than the modern surface samples, indicating somewhat denser tree
coverage. By comparison with surface samples from other areas, it
is likely that both sites were located nearer the savannah-woodland border
than they are today. Ambrosia frequencies from this horizon match
those from the earlier part of the Early Glaze horizon; higher than
those of the present, but not as high as the Middle Glaze horizon.
Artemisia frequencies are somewhat higher than those of the present,
but not significantly so.

The sample from LA 34 has an unusually large number of pollen
grains of Ephedra, and also yields Nyctaginaceae pollen. The latter
are found in no other sample analyzed and, which probably of no climatic
or ecological significance, may be some indication of different activities
between the Puebloans and the Spanish-Mexicans. The occurrence of *Polygonum* pollen indicates nearby marsh or clénega conditions, but this is expectable in a site so close to a major river.

**The Economic Flora**

The cactus represented in the pollen spectra is of the genus *Opuntia*, but whether of the cholla or prickly pear is uncertain. Both cholla and prickly pear are fairly common in the area today, and the pollen is recovered in half of the surface samples. But cactus is an insect-pollinated family, and the pollen is not well disseminated far from the source in such groups. When recovered from samples deposited within and around dwellings, cactus pollen most probably represents the collection of the plant for food and other purposes.

As is the case at other archaeological sites, pollen of maize, cactus and beeweed was not uncommon and squash pollen occurred occasionally. The record of beeweed pollen from LA 34 would indicate that this plant was still being utilized on the historic horizon. The same phenomenon is evident in the pollen records from Picuris Pueblo, but at LA 34 we are dealing with persons who are not Indians culturally. One pollen grain was recovered at LA 34 which might be that of the cultivated bean (*Phaseolus*). This genus is quite difficult to identify positively on the basis of its pollen, and bean pollen has never before been recognized from a sediment sample. This might very well be a misidentification.

**CONCLUSIONS**

The pollen chronology begins shortly after A. D. 1280 with indi-
cations of a prairie ecology, as opposed to the present savannah ecology. The varying Ambroseeae frequencies of the few samples available indicate the probability of some minor ecological variations occurring on the Santa Fe horizon. Future research might find these valuable guides to horizon markers on the Santa Fe-Early Glaze horizon, but the present data are insufficient for refined analysis.

There is a gap in the palynological record between 1300 and 1350-1375. Sometime between 1350 and 1400, and definitely not as late as 1410, an ecological change had occurred and a savannah ecology like the present one became instituted at some localities and a sagebrush zone had developed at others. During this period Ambroseeae frequencies are on the order of ten to twenty per cent higher than those occurring at present, and the occurrence in two out of three samples of riparian plants (Alnus, Typha, Polygonum) is an indication of water surplus.

By 1410 the basic ecology had reverted to the prairie condition, but the Ambroseeae frequencies of the pollen spectra continued to increase and were maintained between 40 and 50%. The trend towards higher Ambroseeae counts culminates with the youngest sample from the Pueblo Period—dating about 1470—to reach a frequency of over 100%. That is, there is more Ambroseeae pollen than all the other pollen put together.

There is extremely little evidence to go on, but the very youngest sample from the Pueblo Period contains significantly less arboreal pollen than any of the other samples. If this is acknowledged as sufficient evidence of an ecological change, the indications are of a significantly great retreat of the savannah border up the elevational gradient between 1450 and 1470.
After another gap in the record, the pollen chronology picks up again sometime between 1650 and 1750. At this time the basic vegetation pattern was one of savannah, but unlike the present or the 1350-1400 period the savannah-woodland ecotone, not the savannah-prairie ecotone—seems represented. Ambrosia pollen frequencies during this period are somewhat higher than the present but not so high as those of the 1350-1450 period, and there is some evidence of the riparian plants as occurred during the 1350-1400 period.

The present ecology is that of the savannah-prairie ecotone at all sites. Some modifications in ground water patterns have no doubt been recently fostered by the local dam on the Rio Grande and by the reservoir at Santa Fe.

CORROBORATORY EVIDENCE

There are four pollen studies with which this one may be compared. On the Santa Fe and Early Clave horizons Havly (1964) has accumulated data on vegetation fluctuations in the area of Hay Hollow Wash, a trib to the upper Little Colorado in Arizona. A pollen study at Picuris Pueblo (Schoenwetter, MSb) yields data on all of the time horizons covered in this investigation, and data on the Santa Fe and Historic horizons are also available from a study undertaken on the Irrigation District of the Navajo Reservation (Schoenwetter, MSa). Some pollen information on the Navajo horizon (Schoenwetter and Eddy, 1964) is applicable to the Historic horizon in the Cochiti area. In addition, much of the work done on alluvial geology in the Southwest encompasses these horizons and adds paleoecological information.
Hevly's analysis indicates that in east-central Arizona areas presently sustaining a juniper savanna ecology were less densely tree-covered between A. D. 1100 and 1300. Sometime between 1300 and 1400 a change occurred and these areas were tree-covered at least to the extent that they are at present, and possibly somewhat more. About 1400 Hevly's dating controls are not very precise. Thus there are a series of pollen spectra which might date any time between 1375 and 1450 which all show savannah or woodland conditions. The similarity between these conclusions and those of this study is too great to be dismissed. This study also shows a more dense tree cover between 1300 and 1400 than before 1300, but allows more precise dating than Hevly's data afforded. The results of this study would indicate that none of Hevly's samples is as old as 1410, since by then the prairie condition has occurred in the Cochiti area.

The Irrigation District study dealt with the Pueblo Period only up to the date of A. D. 1275. Between 1200 and 1250 in that area vegetation underwent a change from a savannah to a prairie condition, and between 1250 and 1275 the prairie was maintained. The prairie ecology evidenced in the Cochiti area shortly after 1260 thus seems in accord with the Irrigation District conclusions.

In the stratigraphic profile which was analyzed for pollen at Peculis Pueblo a number of ceramic types were recovered, including Santa Fe W, which allow dating of the pollen spectra. Until the ceramic analysis of the more extensive excavation is completed the dates applied to the pollen sequence must be considered preliminary, but there is every reason to believe that the A. D. 1250 and the A. D. 1375 spectra can be well defined even if the precise dating of the intervening spectra is as yet
tenuous. At 1250 the pollen record shows far less AP than at 1375. The ecology of the vegetation patterns are not as yet well understood because of the lack of surface samples in the Picurlis area, but it seems very likely that a change from prairie to savannah or woodland is involved. About 1375 there is a maximal frequency of arboreal pollen at Picurlis, with subsequent declining values to the 450 horizon. At this juncture there may be some truncation of the record to A. D. 1600—a matter which will have to be resolved by the analysis of the archaeology of the site as a whole. In any case, the Picurlis pollen record accords well with that of the Cochiti area through the Santa Fe, Early Glaze and Middle Glaze horizons.

On the Historic horizon, the present dating of the Picurlis profile is not as precise as could be wished for. The first appearance of domestic animal bone is taken to be a marker for a date of 1600, but at the moment we cannot say where in the superimposed sediments the 1700 horizon might fall. AP frequencies are generally lower after A. D. 1600 than before at Picurlis, but there are two intervals of time wherein more forested conditions might be evidenced. One of these may be between 1650 and 1750.

In the Navajo Reservoir District and in the Irrigation District there are pollen spectra from Navajo sites which yield indications of more densely forested conditions than the present. These are undated in the Irrigation District, but most probably are before 1850, and in the Reservoir District they are dated to the Dinetah Phase—sometime between 1550 and 1700. There is every reason to suppose that these Navajo pollen spectra are correlative with those from the Cochiti area.
CAUSES

There is no reason to doubt that the same species of plants observable
in the area today are those which compose the fossil record, with the
exception of such plants as tumbleweed and cocklebur which have been
introduced in recent times. Whatever the causes for the ecological
variations observable on the prehistoric and historic horizons, then,
they have not been of sufficient magnitude to disrupt plant community
organization to the point that major climatic change is evidenced. The
country is now part of the semi-arid climatic region of North America,
and it was in all probability semi-arid throughout the period of aboriginal
occupation. The basic vegetation resources have not changed. But
this does not mean that it has been continuously semi-arid in the same
way that it is semi-arid now.

The range of ecological limits on these plant communities is not
extreme, but it is fairly wide. While a pinyon-juniper savannah will
not compete successfully under a much more temperate climate, it can
compete successfully in the semi-arid climate of Utah or the semi-arid
climate of central Mexico. In other words, there are a number of
quite different environmental conditions to which this plant community can
potentially adapt. Thus knowledge of the vegetation pattern variations
through time does not in itself reveal all of the information on climatic
conditions that we would like to know. Other types of paleoecological
evidence must be sought which, combined with that of the pollen research,
will yield more precise interpretations.

On the basis of concurrent agreements between palynological,
faunal and geological evidence it has been proposed (Schoenwetter and
Eddy, 1964) that the semi-arid lands of New Mexico and Arizona have undergone a series of environmental fluctuations since the first century A.D. The primary variation has been in the periodicity of rainfall; varying from a pattern involving the major percentage of rainfall occurring during the summer months (as it does now) to one involving the major percentage of rainfall occurring during the winter months. Another sequence of variations involves total annual rainfall; varying from less than now falls to more than now falls.

Variations in periodicity of rainfall and in total annual rainfall produce similar results in terms of vegetation zone movement up and down the elevational gradient. This occurs because the vegetation is reacting not to the climate, but to the effective moisture for plant growth. A pinyon tree does not respond to the way water becomes available to its roots so much as it responds to the amount of water available.

In its present state of formulation, the hypothesis is that a winter-dominant rainfall pattern was present between A.D. 1 and 750-800, at which time a summer-dominant pattern was instituted. This was retained at least until 1100, but at that date the record was truncated. Some time before 1700 it is hypothesized that the winter-dominant pattern was again reinstated. Sometime between 1550 and 1860, when weather records begin to be available, the present summer-dominant pattern came into effect.

Increased effective moisture values are responses either to the availability of the winter-dominant pattern, which yields more rainfall of greater effectiveness, or to an increase in total annual rainfall, relative to the present, during a summer-dominant pattern horizon.
Decreases in effective moisture values are responses to reductions in total annual rainfall or to lowering of water tables during periods of the summer-dominant rainfall pattern.

The critical time period, from the point of view of this study, is A.D. 1250 to 1750. We can note an increase in effective moisture values during the 1350-1400 period and during the 1650-1750 period, and recognize decreased effective moisture values between 1410 and 1470. The 1470-1650 period remains as yet unstudied. The formulation of interpretations of the variations between winter-dominant and summer-dominant rainfall pattern during the 250-1650 period remains incomplete because of lack of data through truncation of records. Thus we know the pattern of vegetation zone movement during some of the 1250-1650 period, and we believe that some time between 1100 and 1700 a winter-dominant rainfall pattern came into effect, while sometime between 1550 and 1860 the present summer-dominant pattern came into being.

As the effective moisture values associated with the winter-dominant rainfall pattern tend to be higher than those associated with the summer-dominant pattern, the period of shift from a summer-dominant to a winter-dominant condition is expectably correlative with a movement of vegetation zones down the elevational gradient; i.e., an increase in AP. Just such a movement occurs, judging by the palynological evidence of this and other studies, after 1350 but before 1400.

But another such movement occurs between 1650 and 1750. The Reservoir District study concluded that the shift had taken place by 1700, but this does not rule out the possibility that it took place on the Historic horizon. Also, the period between 1470 and 1650 remains poorly studied, and it is possible that a similar vegetation movement could have occurred then.
The only recourse is to independent data, of which two types are available: dendroclimatic records and geological records. Tree-rings of ponderosa pine in Arizona and New Mexico (Schulman, 1956, pp. 42-43) seem to show a good correlation (0.67) with October-July rainfall records, so it would at first appear that period of wide tree-rings of ponderosa pine would be periods of winter-dominant rainfall pattern. Unfortunately, these trees also show positive correlations with May-August rainfall receipts (0.30) and with total annual rainfall receipts (0.64). It must be concluded that while winter rainfall is that primarily recorded by the tree rings, the total annual and the summer rainfall plays some role. As yet we are unaware of how to evaluate that role. In effect, we cannot quite trust the tree-ring record to support or negate hypotheses derived from other sorts of evidence.

Interpretation of geological evidence is also difficult. Under the interpretive model developed by Bryan and Antevs (Antevs, 1952, 1955; Bryan and Albrighton, 1943) and followed by others such as Hack (1942) erosion of floodplain alluvium is a consequence of drought and aggradation the usual condition in semi-arid lands. Under the interpretive model developed in Martin, Schoenwetter and Arms (1961) erosion is the consequence of an increase in the number of summer rainstorms. Under the refinement of this model offered by Schoenwetter and Eddy (1964) aggradation is the consequence of an increase in the number of winter storms. The arguments proposed in the last reference are to me, quite understandably, the more convincing and allow a more comprehensive explanation of the totality of the paleoecological data. The model which interprets erosion as due to a summer-dominant rainfall pattern and aggradation as due to a winter-dominant rainfall pattern is the one accepted in this analysis.
Hack (1942) found that the aggradation of the Naha formation must have begun after 1300 and before the end of the Pueblo III period, since post-1300 pueblo sites are buried in this formation. The Naha formation can be correlated with formations in Texas, Arizona and New Mexico (Hack, 1942, p. 68; Schoenwetter and Eddy, 1964, p.) and therefore the indications are that a period of aggradation—i.e. a period of winter-dominant rainfall pattern—was general over a large area beginning after 1300 and before 1450.

Thus the palynological evidence indicates an increase in effective moisture values between A.D. 1350 and 1400 which could well be the result of a shift from a summer-dominant to a winter-dominant precipitation pattern. The geological evidence indicates a period of aggradation beginning between 1300 and 1450 following a period of erosion, and this may also be interpreted as due to a shift from a summer-dominant to a winter-dominant precipitation pattern. The result of such a shift would be an increase in the occurrence of cold semi-arid conditions, and there is some palynological evidence that this is the condition at the 1350-1400 horizon. This is the horizon on which Artemisia pollen accounts for significantly more of the pollen spectrum than it does at present and sagebrush is well adapted to cold semi-arid conditions. At Pecuris, Picea and Abies pollen occurs much more frequently in spectra dated after 1250 but before 1400, and spruce and fir might be expected to descend the elevational gradient under conditions colder than those of the present. In Arizona this horizon evidences more ponderosa pine pollen, while earlier horizons have more pinyon pollen—another indication of colder conditions.
The most reasonable explanation of the paleoecological data from the anfa and early Glaze horizons in the Cochiti area is that about 28 summer-dominant precipitation pattern was in effect with total annual rainfall 10% less than those now obtained. Between 35 and 40 the ecology patterns were changed by a shift to winter dominance precipitation pattern with consequent drier and longer winter, but an increase in effective storage values. There is no explanation offered for the subsequent change in the Middle Air horizons. There is no reason to believe the basis of the Naco Reservoir District geology data that the winter-dominant infall pattern was still prevalent in 197 and it may be climatologically considering the atmosphere that must have been involved that such a pattern could have existed for periods of 25-50 years. The most reasonable explanation that by 40 total annual precipitation values were substantially less than they had been years previously and that these values were in effect until at least 47.

For the little paleoecological information available, the historical horizon presently imposed to make a well-educated guess the causal factors involved in the occurrence of upper savannah ecology in the Cochiti. Though this is be correlated with similar occurrences at Navajo Site and perhaps with Picuril Pueblo, the present dating is too imprecise in these cases to be sure that they are due to the same environmental conditions.
It is likely, however, that one of two alternative causes is involved.

Either a winter-dominant rainfall pattern was still in effect and the total annual rainfall values were greater than they had been between 1350 and 1470, or the summer-dominant rainfall pattern had already come into being and the total annual rainfall receipt was greater than it is at present. The geological indications are that the Naha formation ceased aggradation about 1700. If the historic horizon dates earlier than 1700 in the Cochiti area, then, the first alternative becomes most probable. If it dates later than 1700, the latter alternative becomes most probable.

MAIZE AGRICULTURE

On the Santa Fe horizon there would be two major natural limitations on maize cultivation. First, the spring drought would be more severe than at present and second, the summer rains needed for crop maturation would be less reliable than they are at present. The growing season would be longer, however, so the date of the first summer rains might not have been as critical as it is now to the farmer. If the first rains came before the last week in July the crop would probably be ripe before the first frost.

Dry farming could have been practiced, but by so doing the community would accept a fairly respectable risk of crop failure. Floodwater irrigation from the permanent streams is likely to have been restricted since it is probable that the streams were incised at that time. Ditch, as opposed to floodwater, irrigation would have been the only fully adequate water control, but the Akchin field pattern, wherein the entirety of a small drainage net is diverted to a particular field, would have been effective in reducing crop failures under these environmental conditions. To support any kind of population concentration with a degree of security either the
Akchin field or the ditch irrigation systems could have been used. There is no archaeological evidence for either.

On the early Early Glaze horizon, dry farming would have been a very reliable agricultural practice. The problems would have been those of a shorter growing season, and there may have been some years when a dearth of summer rains would have failed to mature a crop under this system. The amount of arable land would have been decreased by the invasion of trees to lower altitudes, assuming that land clearance measures were not used. The best agricultural land would have been the floodplains which, under these environmental conditions, would have been aggrading and would have had high water tables. It is evident, from the occurrence of corn pollen, that corn was being grown so the reduced growing season was not an insuperable problem.

During the later Early Glaze and the Middle Glaze horizons dry farming would have been almost impossible, except where peculiar soil conditions retained water very efficiently. Floodplain irrigation may have been sufficient during most years, but except along streams with good flow there may have been a real water stress on the maize crop during the summer months. Ditch irrigation would have been the only effective system during this period to insure excellent harvests. Since erosion was not greatly going on, ditch irrigation systems would have been relatively easy to implement during this period. If any one period during the lifespan of Pueblo Culture should be selected when the practice of ditch irrigation is most likely to first appear, this period would probably be it.
On the Historic horizon, regardless of the causes thereof, it is
obvious that greater effective moisture values than those of the present
were available. Dry farming could have produced quite good crops almost
anywhere, and more sophisticated techniques would assure excellent
harvests. It is interesting to note that the habitation areas of the peoples
of Spanish-Mexican culture was well within the savannah zone—almost
in the woodland. In all the pollen records from Pueblo Culture sites
very few are situated in such an ecology, and those only for very short
periods. Early Navajo sites, however, are sometimes located in such
vegetation patterns.

The explanation for the early Navajo sites being so located would
probably revolve about the hunting patterns of the groups involved. The
Puebloans, however, appear to have avoided such situations even though
this ecological zone is excellent for dry farming, once the trees are
cleared, and may be dry farmed between the trees in many instances.

It seems probable that land clearance technology was not too
well understood or not too well developed by Puebloans. Stone axes
are not rare in Pueblo sites, but they are not particularly frequent either.
Also, the savannah and woodland niches formed a resource for wood
and game and might have been considered to valuable to use as farmland
especially since it involved much labor to clear. The Spanish-Mexican
culture, on the other hand, had a well developed land clearance technology
and had little compunctions about using it. Their settlement in the savannah
and woodland areas might reflect the exploitation of these zones by virtue
of superior tools, on the one hand, and their inability to confiscate farm
lands in the lower vegetation zones from the Puebloans, on the other
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