

PEDOGENIC HORIZONS AND ASSOCIATED OPALIZED  
RHIZOLITHS IN THE OGALLALA GROUP OF  
WESTERN NEBRASKA

by

Janet Decker Wright

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Janet Decker Wright, M.S.  
University of Nebraska, 1987  
Advisor: Dr. David B. Loope

The Ogallala Group of western Nebraska contains prominent horizons known locally as "mortar beds". They consist of clastics from the Rocky Mountain Front Range as well as locally derived caliche clasts and nodules. These prominent ledges are carbonate and silica enriched paleosols.

A study of thin sections of specimens collected from these horizons verify that they are caliches of pedogenic origin. The presence of rhizoliths (fossil roots) and/or caliche glaebules from all twelve collection sites provide convincing evidence for pedogenesis.

Rhizoliths are plentiful in the thin sections. Measurements of their diameters were taken, both from caliche specimens and compound rhizoliths. A statistical analysis of these diameters show very similar distributions of microscopic rhizolith diameters in caliches and in the compound rhizoliths. This data may provide a tool for future caliche identification. The rhizoliths have been preserved by opal emplacement around original plant cortical cells and are best described as opalized root petrifications. Delicate root-hair sheaths, as well as the epidermal layer of plant cells, have also been preserved in some cases.

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PEDOGENIC HORIZONS AND ASSOCIATED OPALIZED RHIZOLITHS  
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INTRODUCTION

Carbonate and silica enriched horizons are prominent in the Ogallala Group (Miocene) of Western Nebraska. These horizons have been considered by Lueninghoener (1934) and Swineford and others (1958) to be pedogenic in origin. But no previous work has been done to verify these assertions by comparison of these horizons with recent studies of caliche and associated rhizoliths (rootcasts) studied by other authors. Identification of rhizoliths, for example, is a reliable way of recognizing paleosols (Klappa, 1980).

The purposes of this study are: (1) to report the diagnostic petrographic characteristics of Ogallala caliche, thereby verifying that these horizons are pedogenic; (2) to classify the Ogallala rhizoliths within the system proposed by Klappa (1980); and (3) to support the use of rhizolith-diameter measurements as a criterion for caliche identification.

THE OGALLALA GROUP

The Ogallala Group is the uppermost of the lithified Tertiary strata which underlie the surface of much of the High Plains Region. These rocks extend from South Dakota on the north to south of the southern boundary of New Mexico in Texas.

In western Nebraska the Ogallala Group is a complex set

of valley fills extending eastward from the Rocky Mountains. It includes the Runningwater, Box Butte, Sheep Creek, Olcott, Valentine, and the Ash Hollow formations (Figure 1) (Swinehart and others, 1985). These sediments were deposited during the Hemphillian, Clarendonian, Barstovian, and Hemingfordian Land Mammal Ages (Thompson and others, 1982).

Elias (1931) thought that carbonate layers of the Ogallala were lacustrine deposits and used the pisolites, which were described as algal limestone, as evidence to support this view. Swineford and others (1958) interpreted the same pisolitic limestone to be formed in much the same way as pisolitic bauxite which is known to have a subaerial diagenetic history.

Pedogenic carbonates of the Ogallala are described by Reeves (1970) from many locations. His caliche profiles (Figure 2) show the morphology and texture present from field observations and relate diagenetic quartz zones to various stages of caliche development. These profiles are described from outcrops in Texas and New Mexico. Diffendal (1982) reported numerous caliche horizons occurring throughout the Ogallala of western Nebraska.

Although vertebrates (Voorhies and Thomasson, 1979) and plant "seeds" (Elias, 1942; Frye and others, 1956; Thomasson, 1982) have been studied in great detail, only a few workers have reported rhizoliths from Ogallala sediments. "Silicified roots with fine root hairs" were reported by Elias (1942) in association with fossil grass

FIGURE 1

Cenozoic stratigraphic column for western Nebraska  
showing the formations in the Ogallala Group.  
(Swinehart and others, 1985)

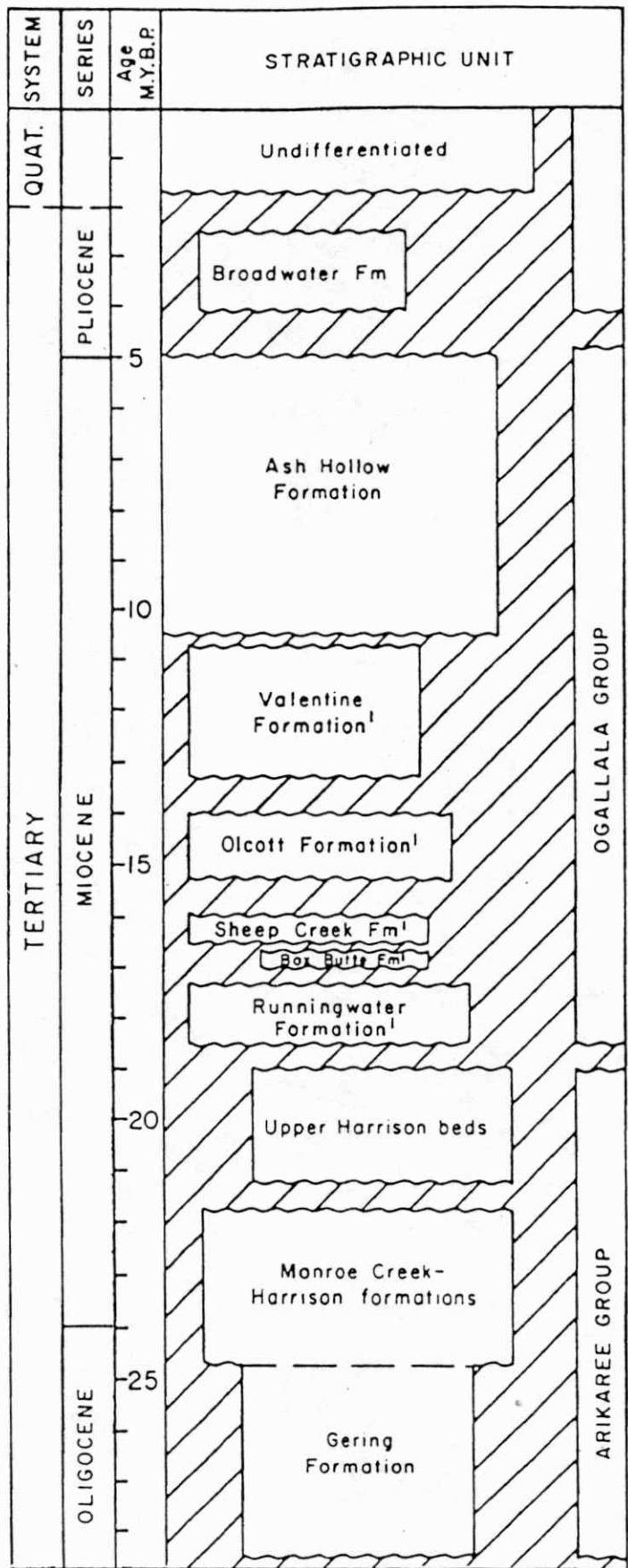


Figure 1  
after Swinehart, et.al.,1985

FIGURE 2

Diagrammatic cross-sections of the three  
most common massive caliche profiles  
From (Reeves, 1970, Fig. 1)

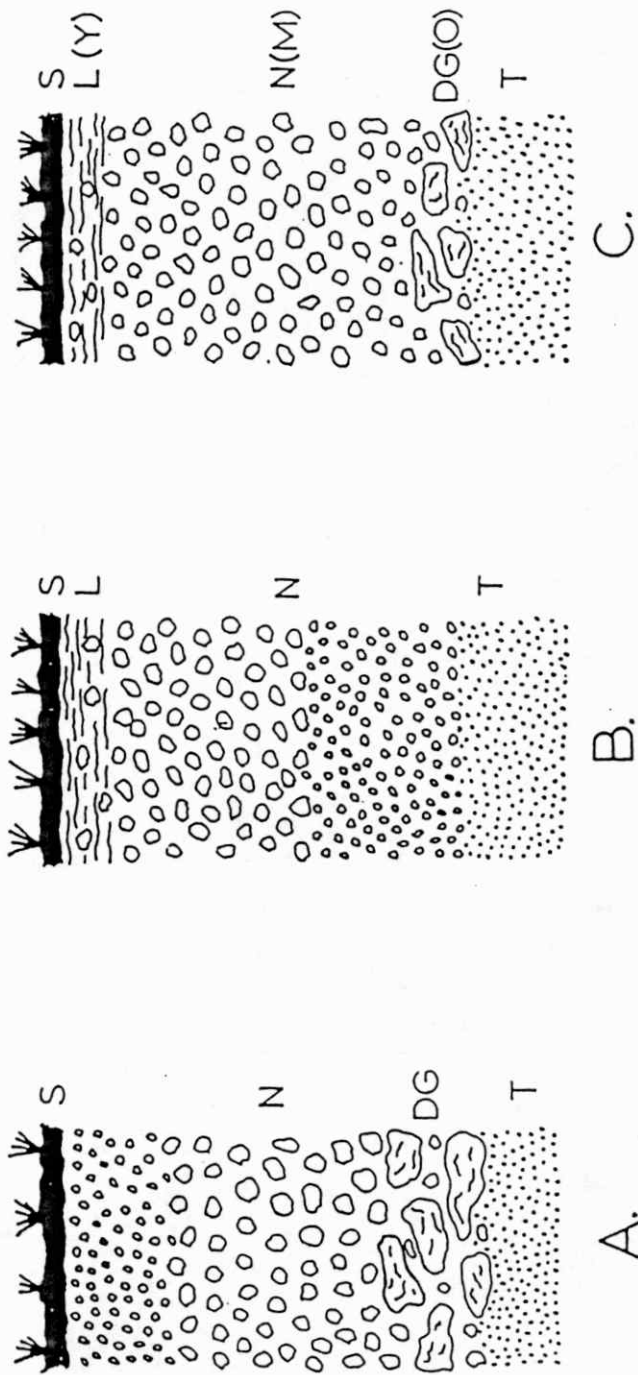


Fig. 2 —Diagrammatic cross sections of the three most common massive caliche profiles, southern High Plains, Texas. *A*, The profile developed by plugging of the caliche from the bottom up, but with infiltration still taking place. *B*, The profile developed by plugging in the top of the mature zone, no present infiltration taking place. *C*, The end result of caliche formation in an area where plugging has progressed from the bottom of the profile to the top, no present infiltration taking place. Laminated zone may be simple or complex. *S* = soil, *L* = laminated zone, *N* = nodular zone, *DG* = diagenetic quartz zone, *T* = transition zone, *Y* = young caliche, *M* = mature caliche, *O* = old caliche. From Reeves, 1970

seed hulls. Thomasson (1982) has an excellent SEM micrograph of a silicified (fossil) root with attached root-hair sheaths, which was collected from sediments of the Sheep Creek Formation.

Frye and others (1956) collected seeds from the sediments of the Ogallala Group of western Nebraska and ran laboratory analyses showing that they were all opalized. Most of these seeds were identified as various grasses; however, the fossil fruit of Celtis, the common hackberry tree, is abundant throughout the Ogallala.

#### METHODS AND MATERIALS

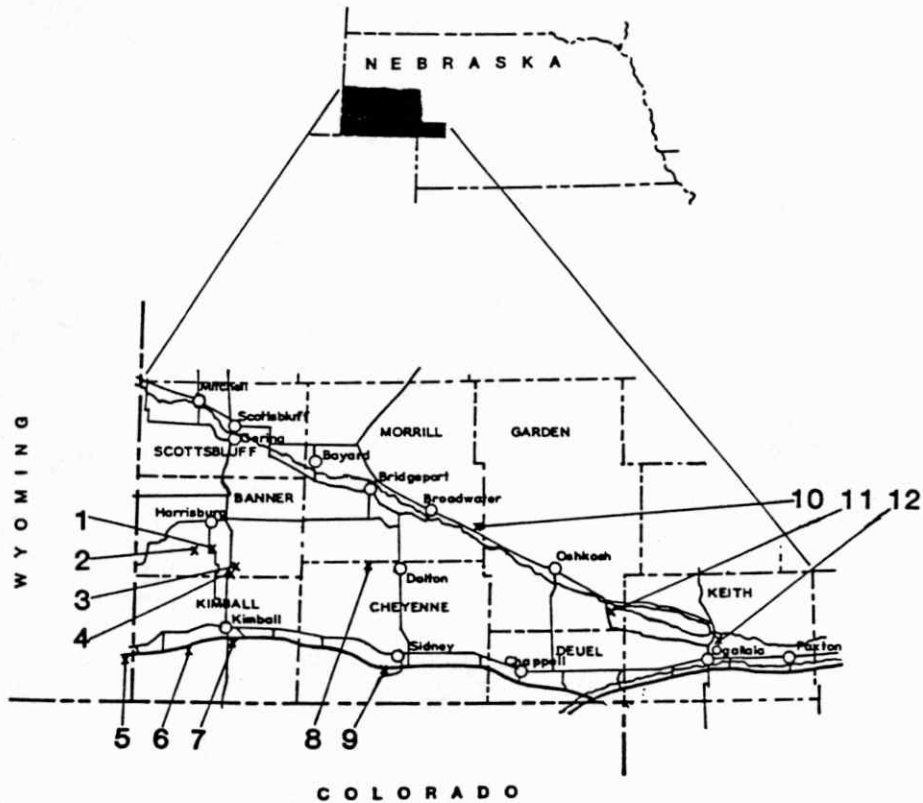
Rhizoliths, nodules, and calcite-cemented lithic samples were collected at eleven localities in western Nebraska and one site at Pine Bluff, Wyoming (Figure 3). Specimens of indurated caliche layers densely packed with small (0.5-1.0 mm) ramifying tubules were collected from sites 3, 4, 8, 9, 10, and 11. Weathered plates of caliche stacked in concertina fashion due to recent frost heaving were collected from site 4 (Figures 4 and 5). Conglomerates composed of ripped-up caliche clasts and nodules were collected from site 5 (Figure 6). A conglomerate of epiclastic sand and caliche clasts with opal spheres (1.5 mm diameter) on it's surface was also found at this site.

Eighty-three thin sections of these samples were made. Because many samples were friable and porous, thin sectioning was difficult. The best results were obtained by sample impregnation with "Scotchcast" Brand Resin 3, an

FIGURE 3

Locations of collection sites

# LOCATION OF COLLECTION SITES



## LOCATIONS

- |                                       |  |
|---------------------------------------|--|
| 1 SW1/4 SE1/4 SE1/4 Sec19, T18N, R56W | 7 NW1/4 NW1/4 NW1/4Sec8, T14N, R55W    |
| 2 NE1/4 SW1/4 SW1/4 Sec23,T18N, R56W  | 8 NE1/4 SW1/4 Sec21, T17N, R50W        |
| 3 NE1/4 SE1/4 Sec28, T17N, R55W       | 9 SE1/4 NE1/4 SE1/4 Sec30, T14N, R50W  |
| 4 E1/2 SW1/4 NE1/4 Sec33, T17N, R55W  | 10 NE1/4 NW1/4 SW1/4 Sec20, T18N,R46W  |
| 5 S1/2 SW1/4 Sec15, T14N, R60W        | 11 NW1/4 NE1/4 Sec3, T15N, R42W        |
| 6 NE1/4 NW1/4 NW1/4 Sec16, T14N, R57W | 12 SE1/4 NW1/4 NE1/4 Sec10, T14N, R38W |

Figure 3

FIGURE 4

Weathered caliche plates

[The divisions on walking stick represent 30  
centimeters of length (Site 4)]

FIGURE 5

Specimen showing the original shape of caliche plate  
prior to cracking (Site 4)



Figure 4



Figure 5

FIGURE 6

Specimen of ripped-up caliche conglomerate.

[Hackberries occur as circles and arcs on this cut slab. A stromatolitic structure is present in the lower portion. (Site 5)]

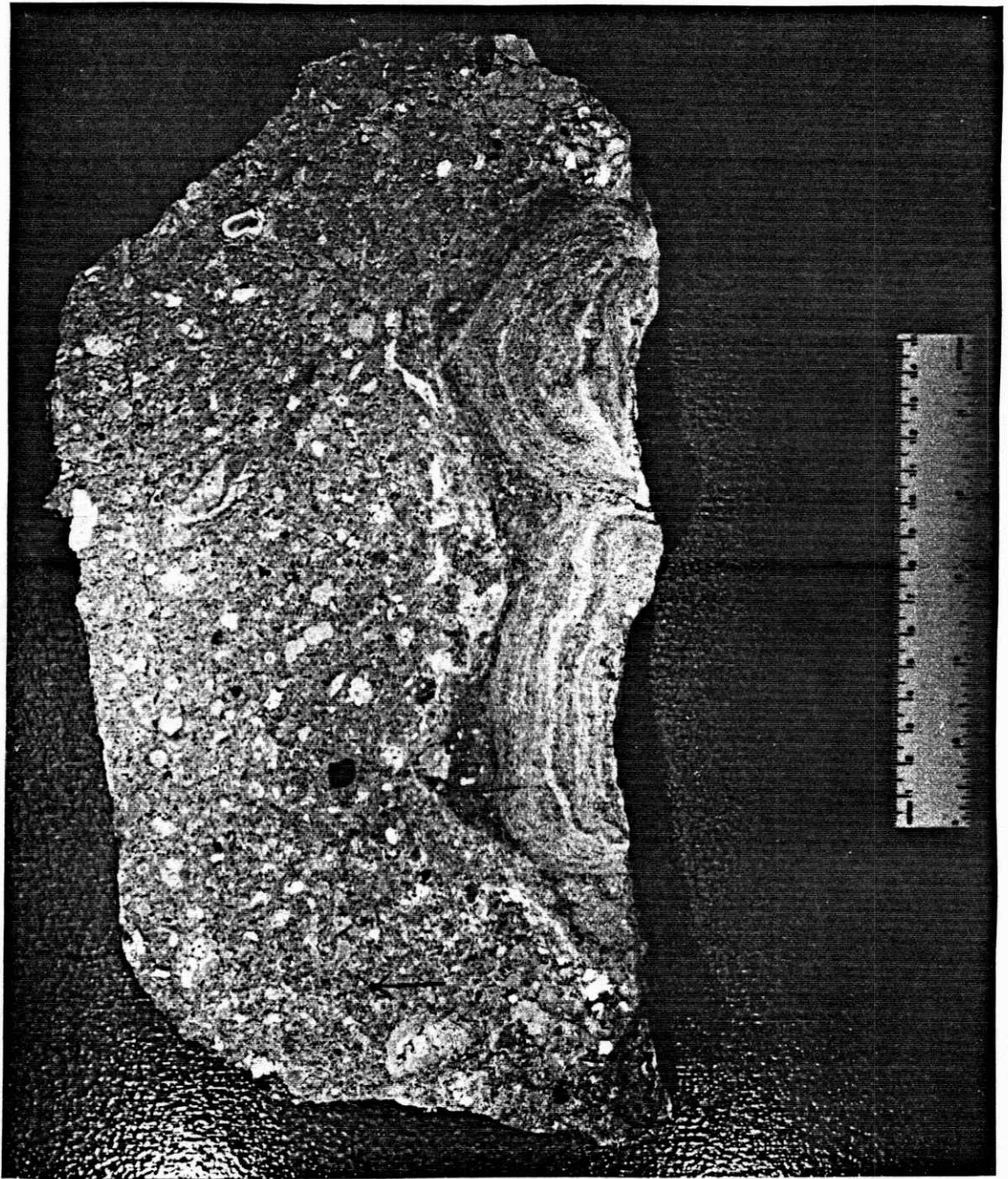


Figure 6

electrical resin, which has a low viscosity and a cure temperature of 77° C.

Rootlet-like tubules (0.2-0.5 mm in diameter and 1-4 mm in length) were removed from a coarse conglomerate from site 8. This was accomplished by first crushing the sample and then removing the tubules with a very fine paint brush. Other tubules in finer matrix from site 11 were removed by first treating them with a 10% hydrochloric acid solution to dissolve the surrounding caliche matrix and then picking them up with a very fine paint brush.

All tubule specimens were studied with a binocular dissecting microscope. Some of these specimens were mounted on Scanning Electron Microscope (SEM) stubs and sputter coated with gold palladium for SEM examination. Some tubules were treated with hydrochloric and hydrofluoric acid to determine mineralogy and organic content. A powdered X-ray diffraction (XRD) analysis of another portion of these collected tubules was run to determine mineralogy. The diffractometer used is a Philips APD 3720 with a graphite focusing monochromator, which has a width of 16 mm and CuK $\alpha$  radiation theta compensating slit. Instrument settings were 40 KV, 20mA, step size 0.020 degrees, and a count time of 0.50 seconds. The samples were scanned from 2.0 to 61.5 degrees.

I have used the microfabrics criteria described by Esteban and Klappa (1983) to assemble a table of identified caliche characteristics found in the thin sections from the collection sites (Figure 7). These criteria include: rhizoliths, alveolar textures, tangential (parallel alignment) low magnesium calcite needle fibers, calcified cocoons, caliche glaebules, clay cutans, and circumgranular cracking. Present in both karst and caliche facies are lichen (stromatolite) structures and random calcite needle fibers. I have not observed clay cutans, tangential calcite needle fibers, or calcified cocoons.

Glaebule is a general term used to describe three-dimensional structures such as caliche ooids, pseudo-ooids, peloids, pellets, pelletoids, coated particles, nodules, concentric structures, and concretions (Esteban and Klappa, 1983). This is a useful term in a paleosol description due to the difficulty in positively identifying the rounded micrite shapes. Peloidal-type fabrics occurred in many thin sections.

Circumgranular cracking is present and occurs around clasts. This type of cracking was described by Swineford and others (1958) as a possible mechanism for caliche pisolite layering. Some circumgranular cracking occurs around glaebules as well. These glaebules must be considered in three dimensions since they could easily be mistaken for cement or sediment filled rhizoliths in cross-

FIGURE 7

Petrographic microfabrics

\* Site 8 samples are friable coarse gravel conglomerates. No thin sections were made.

## Petrographic Microfabrics

X = Fabric Present	Collection Sites												
	1	2	3	4	5	6	7	8#	9	10	11	12	
Diagnostic for Caliche													
Rhizoliths		X	X	X	X			X	X	X	X	X	X
Caliche Glaebules	X	X	X	X	X	X	X		X	X	X	X	X
Circum-granular Cracking		X			X	X	X			X	X	X	X
Alveolar Texture		X	X	X	X	X			X	X	X	X	X
Diagnostic for Karsts & Caliche	1	2	3	4	5	6	7	8#	9	10	11	12	
Stromatolitic Structures		X	X	X	X	X	X		X	X	X		
Calcite random needle fibers				X					X	X			X

Figure 7

section. Many circular cement filled "spaces" show a similar cracking feature to that described and shown by Swineford and others (1958). Upon closer examination of these structures small remnants of opalized cell structure are present and no cracking has taken place.

The most common characteristics for identifying caliche were: caliche glaeboles, rhizoliths, and alveolar textures. Caliche glaeboles occurred in thin sections from eleven sites. These micrite structures range in size from silt to pebble.

Rhizoliths are present in thin sections from nine sites. Five kinds of rhizoliths have been described by Esteban and Klappa (1983). They are: (1) root molds and/or borings, (2) root casts (cement- or sediment-filled molds), (3) root tubules (cemented cylinders around molds), (4) rhizocretions (concretions formed around living or decayed roots), and (5) root petrifications (minerals encrust, impregnate, or replace the organic materials). Rhizoliths are millimeters to centimeters in diameter and centimeters to meters long according to Esteban and Klappa (1983, p. 35).

Alveolar structures are common in the thin sections from nine sites. These are spaces with circular, elliptical, or rounded shapes usually between 0.10-0.50 mm and a few up to 1.5 mm in maximum diameter (Esteban and Klappa, 1983). Upon close inspection of these alveolar structures, remnants of root cells are often present. This is to be expected since they are interpreted as being formed by rootlets penetrating the soil (Esteban and Klappa, 1983).

A study of 506 rhizolith diameters (alveoli) measured from thin sections shows that the mean size is 0.21 mm. The measurements were collected from two different types of thin sections. Two hundred and fifty six rhizolith diameters with a mean of 0.22 mm were measured from thin sections of larger rhizoliths. A study by Loope (in press) of alveoli in large rhizoliths collected from Paleozoic, Mesozoic, and Cenozoic rocks shows similar results. From the second type of thin section, two hundred and fifty diameters with a mean of 0.20 mm were measured. These thin sections are of caliches densely packed with small ramifying rhizoliths (Figures 8 and 9). I measured the caliche thin sections and the large rhizolith thin sections separately because I was not convinced the alveoli inside the large rhizoliths were really smaller rhizoliths. I had expected vascular tissue to be preserved.

The following statistics were derived from these measurements: mean, mode, standard deviation, coefficient of variation, and skewness (Figures 10 and 11). The similarity of the mean, standard deviation, and especially the coefficient of variation indicates that the alveolar diameters inside the rhizoliths are not statistically different from those measured caliches containing densely packed rhizoliths. These measurements indicate that the alveoli found inside larger rhizoliths are rhizoliths and not preserved vascular systems. Another line of evidence is present in thin section study, a picture showing smaller roots inside larger ones is shown in Figure 8. The skewness

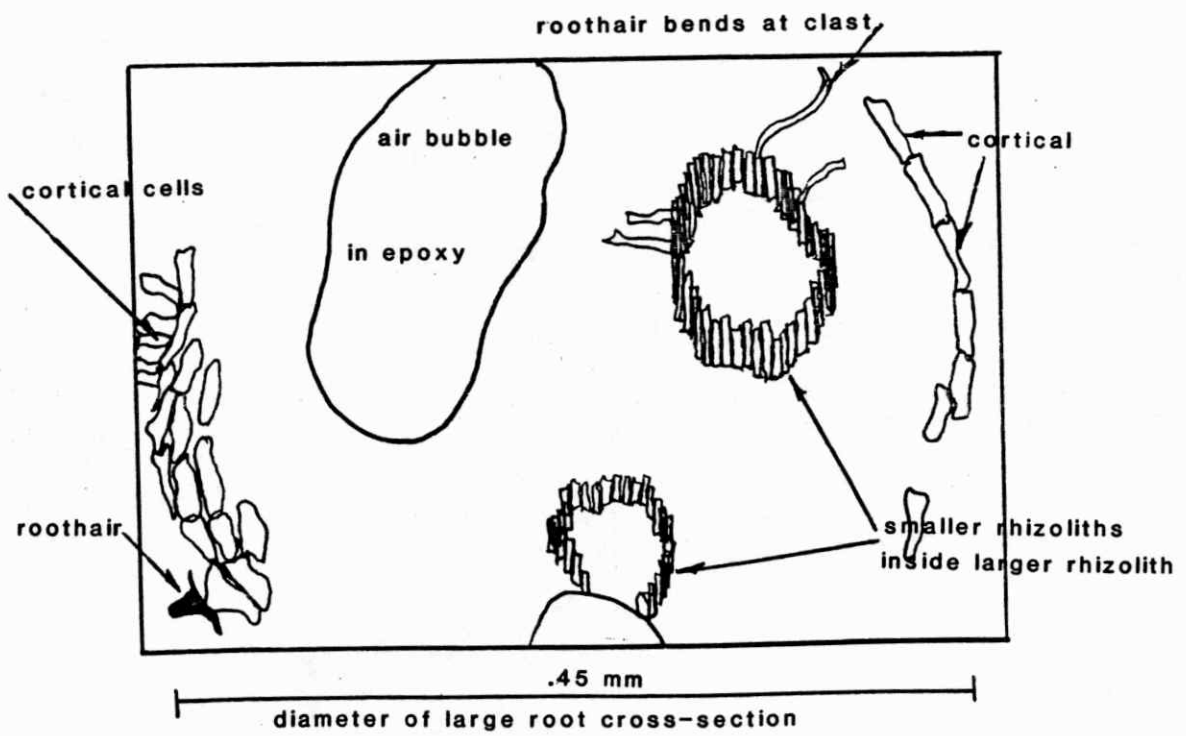
FIGURE 8

A. Photomicrograph of large rhizolith with cortical cells marking external (Site 9).

B. Sketch of the photomicrograph in part A.  
Small rhizolith inside of a larger rhizolith. Note bent root-hair sheaths. The larger rhizoliths with smaller ones inside are here termed compound rhizoliths (Personal communication, D. Loope, 1986).



A

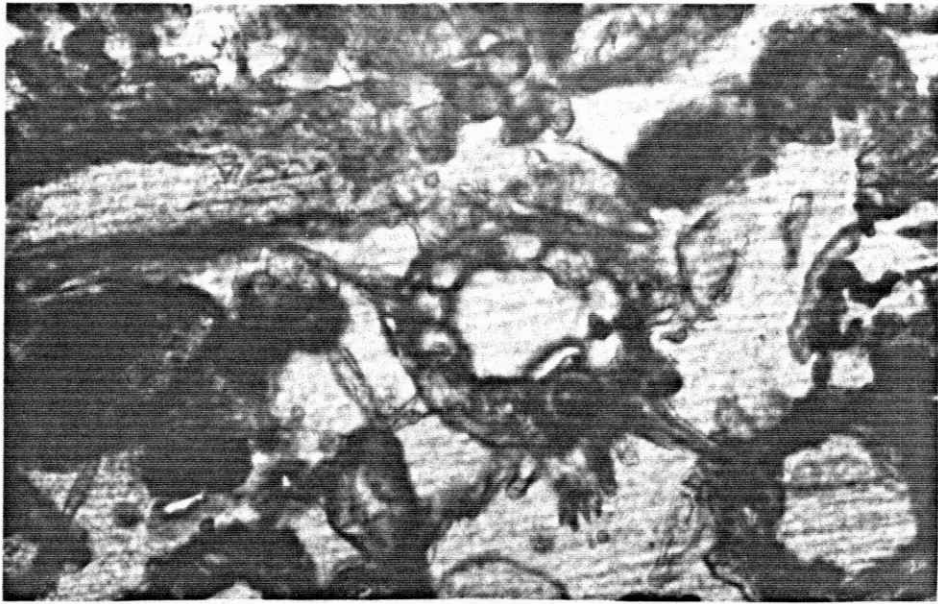


B

Figure 8

FIGURE 9

Small rhizolith with root-hair sheaths bending  
away from clast. (Site 5)



— .1 mm —

Figure 9

FIGURE 10

Histogram and statistics for all  
the rhizolith diameters measured.  
(The associated statistical findings  
are shown with each graph.)

Combination of all microscopic rhizolith diameters measured

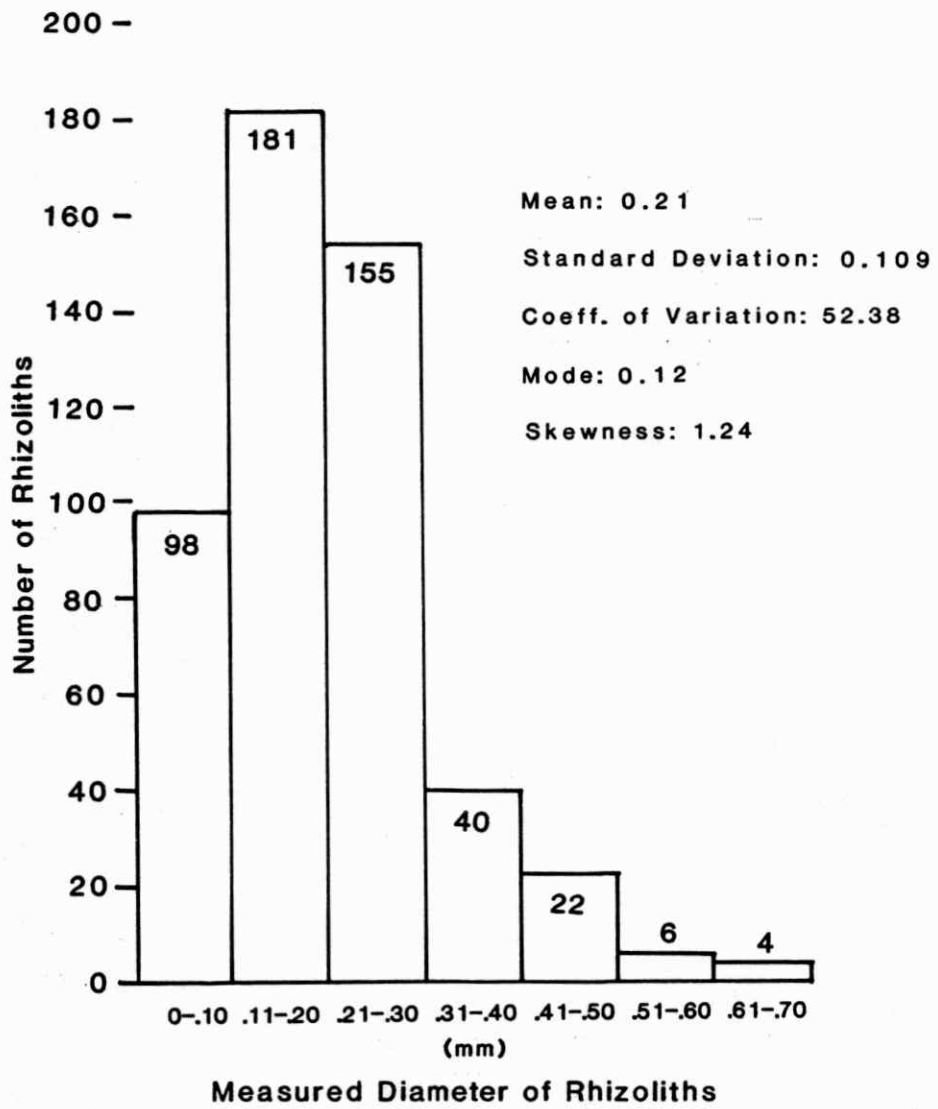


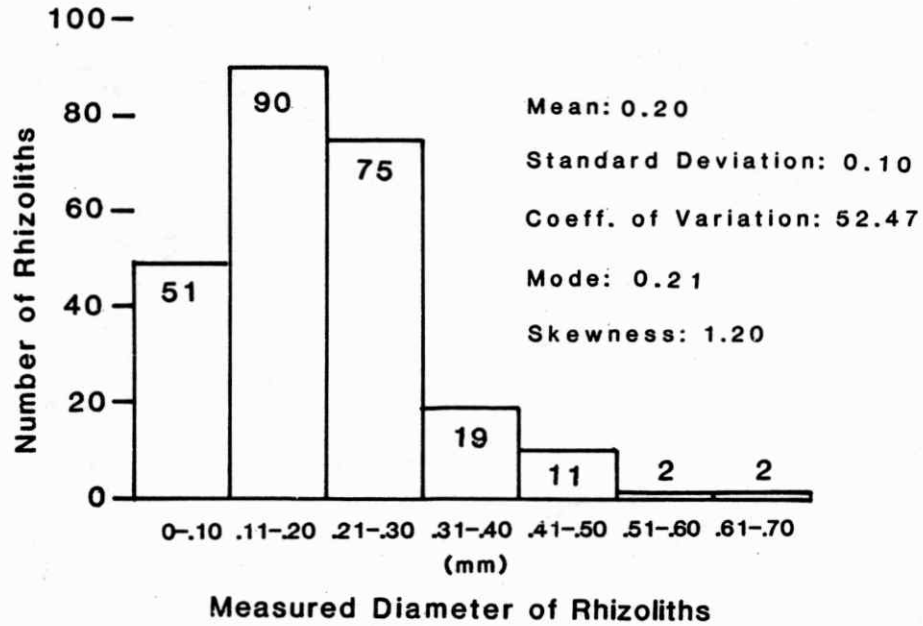
Figure 10

FIGURE 11

Histograms of the microscopic rhizolith diameters measured from caliche thin section and those measured from thin sections of macroscopic rhizoliths.

(The associated statistical findings are shown with each graph.)

Microscopic rhizolith diameters  
measured from caliche thin sections



Microscopic rhizolith diameters  
measured from thin sections of macroscopic rhizoliths

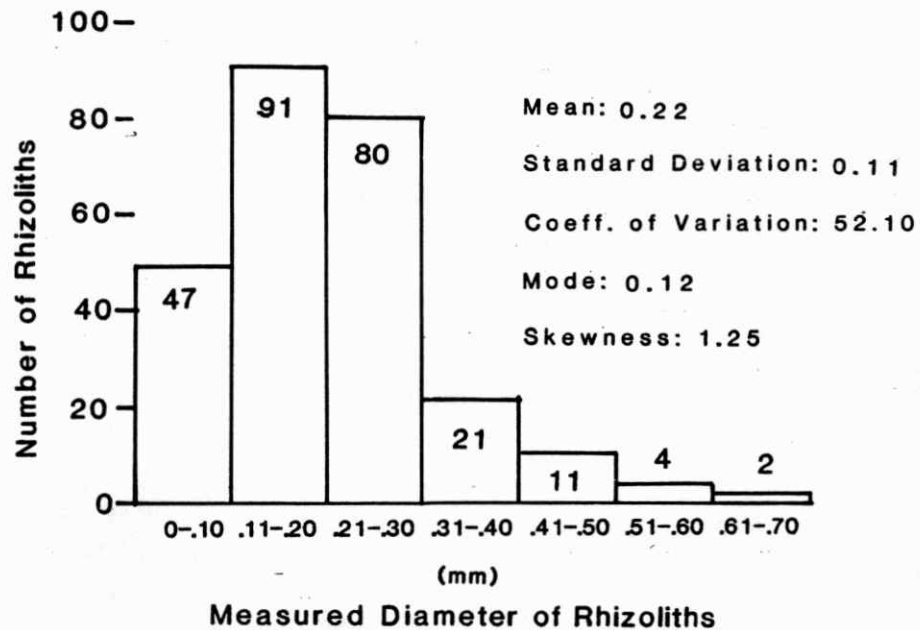


Figure 11

numbers of 1.25 and 1.20 indicate that most of the rootlets are small. The skewness results fit well the branching and tapering morphology found in plants.

The abundant rhizolith types observed in the thin sections were 1) root tubules which, at microscopic level, produce an aveolar fabric, and 2) root petrifications. The root petrifications are in the form of preserved endodermis, epidermis, cortical cells, and root hair structures (Figures 12 and 13). These cellular structures have been studied by Dr. David Dilcher, Department of Biology, Indiana University and Dr. Robert L. Lomason, Biological Sciences Department, University of Nebraska-Lincoln, with respect to plant classification. No conclusive determinations have been made. This question may provide a direction for further research in paleobotany.

The root hair opalizations found in Ogallala sediments are similar to root-hair sheaths which have been described by Ward (1975) in Pleistocene carbonate eolianites. Root-hair sheaths are also found in a Holocene and Pleistocene caliche from Florida (Coniglio and Harrison, 1983). In each case, the root-hair sheaths are preserved as calcium carbonate and are shown as occupying interparticle spaces. The root hair structures present in the Ogallala samples have similar diameters to those reported by Ward (1975), only the mineralogy is different. Rather than defining a new term for these structures I will extend Ward's definition to include them and use opal as an adjective modifier.

A small portion of the petrified cells are calcite.

FIGURE 12

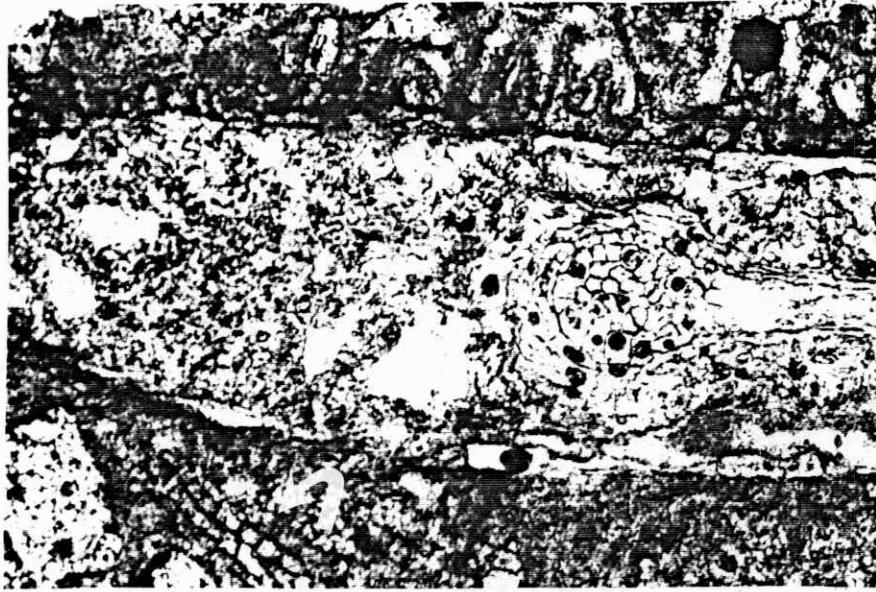
Preserved epidermis and root-hair sheaths

[Note epidermal cells broken away from main structure and enclosed in microcrystalline calcite matrix lower left. (Site 11)]

FIGURE 13

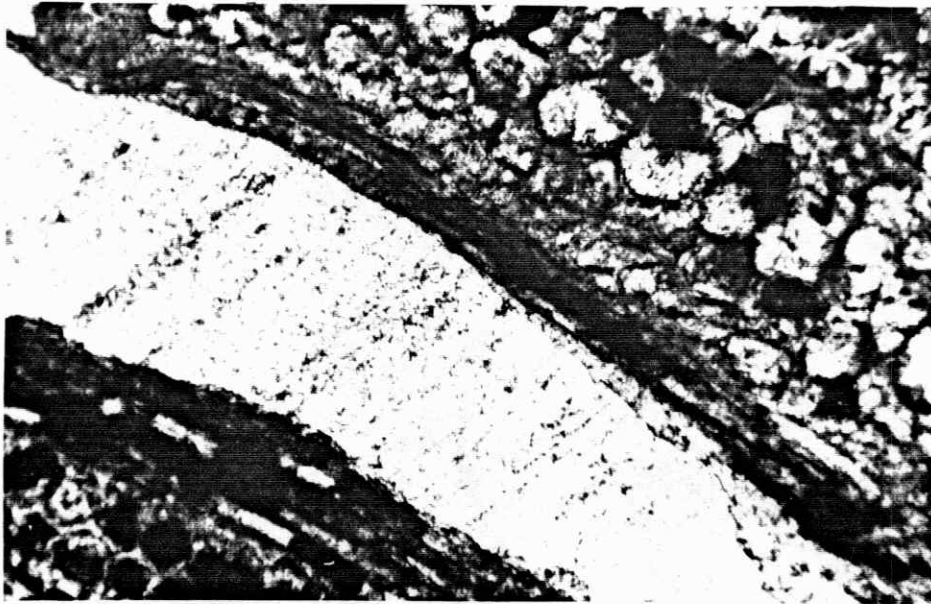
Cortical cell and endodermis cells with  
void space in the center

(This is part of a large root structure  
1.0 cm long and 0.5 mm wide.)



.2 mm

Figure 12



.02 mm

Figure 13

Most of these appear to be due to secondary alteration; preservation is poor. The mineralogy of the well-preserved cell structure in the samples I have studied is isotropic, amorphous opal. A concern over whether the preserved rootlets are part of a Miocene paleosol or a recent invasion of the rock material led to careful observations of the root hair relationships to the surrounding microscopic fabrics. Some of the opalized rootlets appear inside circular voids with micrite rims (alveoli) whereas others appear to be an integral part of the general caliche fabric. Root-hair sheaths are found to bend away from clasts and other solid surfaces (Figures 8 and 9). This bending indicates prior placement of the clast or micrite walls. If the calcite matrix is penetrated one would expect to see straight opalized root-hair sheaths and micrite in intimate contact and this would indicate root opalization at the time of micrite emplacement or prior to it (Figure 12). Caution is needed when using rhizoliths as indicators of ancient paleosols. If the root-hair sheaths are bent as they come in contact with cements or clasts or if the rhizoliths occur only on the upper erosional surface one may be looking at a later paleosol horizon superimposed upon much older strata.

The opalized root petrifications have sparry calcite filling the internal voids. Some alteration of opal to micrite has occurred. All of the well-preserved cell structure is due to opal emplacement. This conclusion is based on the following observations:

1. The material which preserves cellular shape is isotropic.

2. The caliches with preserved rootlets (from sites 8, 10, and 11) were treated with 10% dilute hydrochloric acid. Rhizoliths are not soluble in HCL, but are dissolved when treated by HF. Rootlets from site 8 dissolved within four hours and left no organic residue.

3. X-ray diffraction of the site 8 rootlets yielded a diffraction pattern between that of Opal A and Opal CT (Figure 14) (William and Parks, 1985).

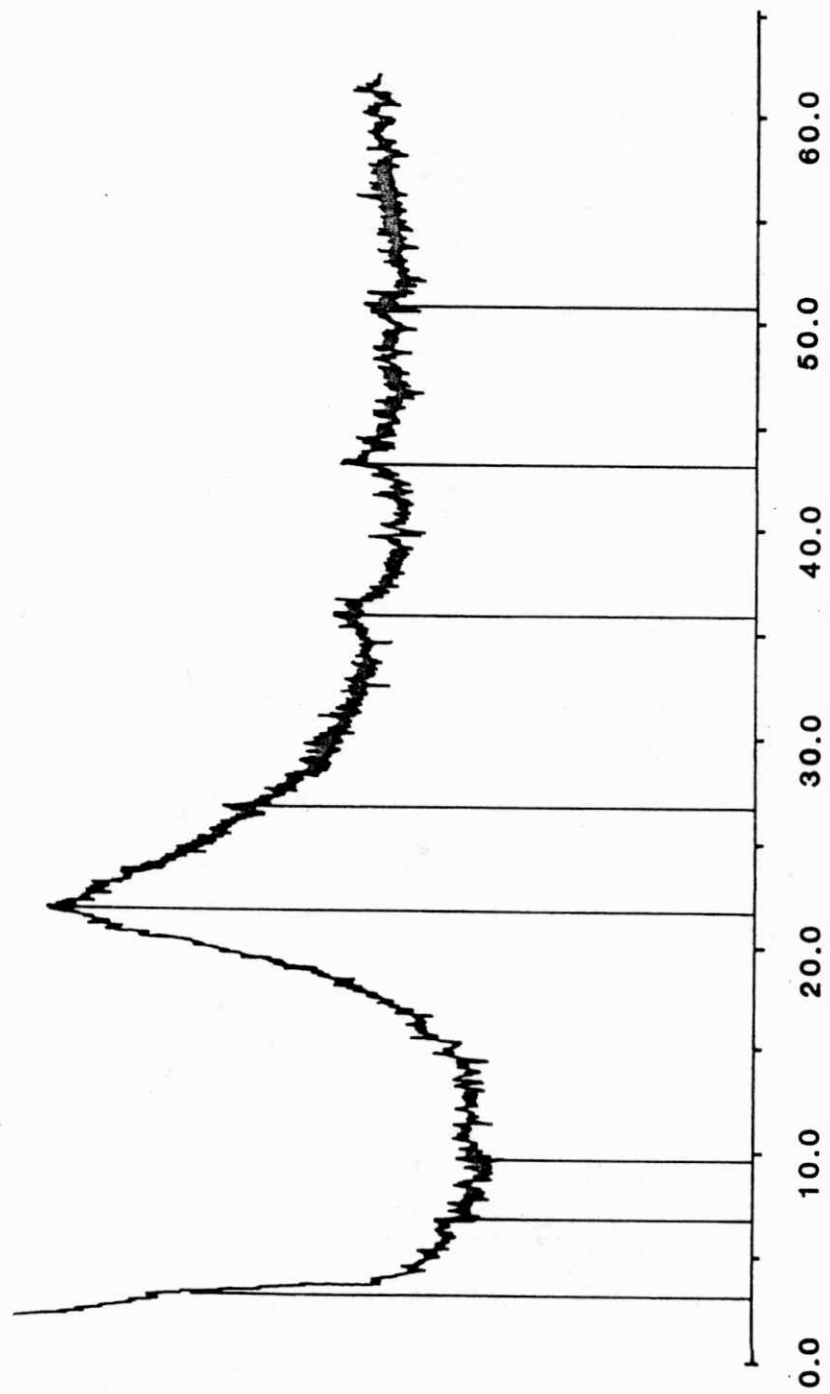
4. SEM pictures of the site 8 and 11 rootlets show a smooth sphere opal morphology and in some cases aggregate opal spheres composed of small smooth spheres (Figures 15, 16, 17, 18, 19, 20, 21, 22, 23).

#### OTHER DISTINCTIVE CALICHE MICROFABRICS

The platy caliche and stromatolitic structures described earlier (Figures 4, 5, and 6) show similar petrographic fabrics. Both have layers of dark material with few clasts alternating with lighter layers containing many clasts. The dark layers exhibit the same excellent cellular preservation that was described earlier and attributed to opal petrification. In the platy caliche the rhizolith layers parallel the cracks in the plates (Figures 4, 5, and 24). These observations are in accord with the production of platy caliche by crustose lichen as described by Esteban and Klappa (1983). Whether these light

FIGURE 14

X-ray diffraction pattern from powdered root  
petrifications (Site 8)



Degrees 2θ(CuKα)

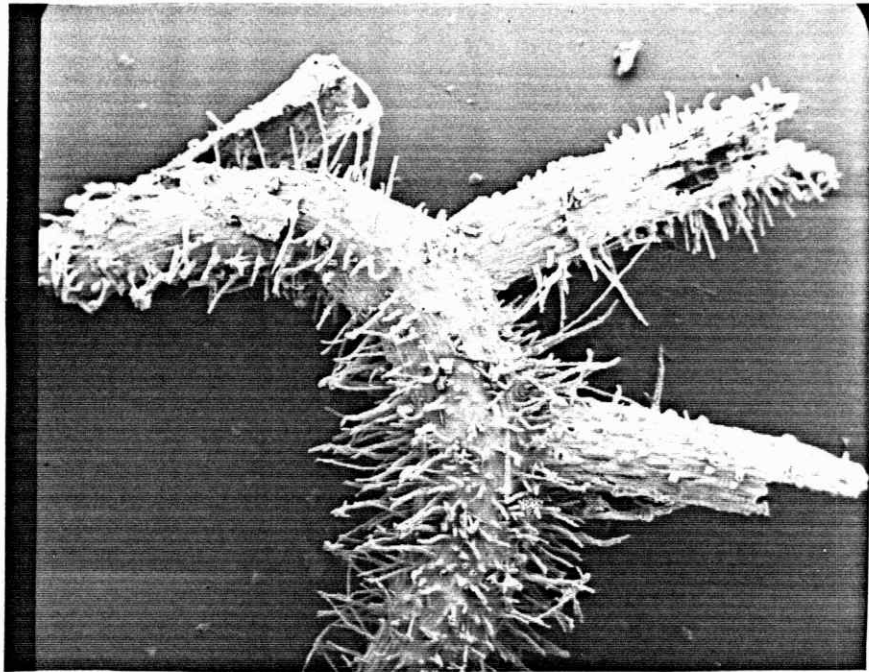
Figure 14

FIGURE 15

SEM picture of opalized root from Site 8 (57X)

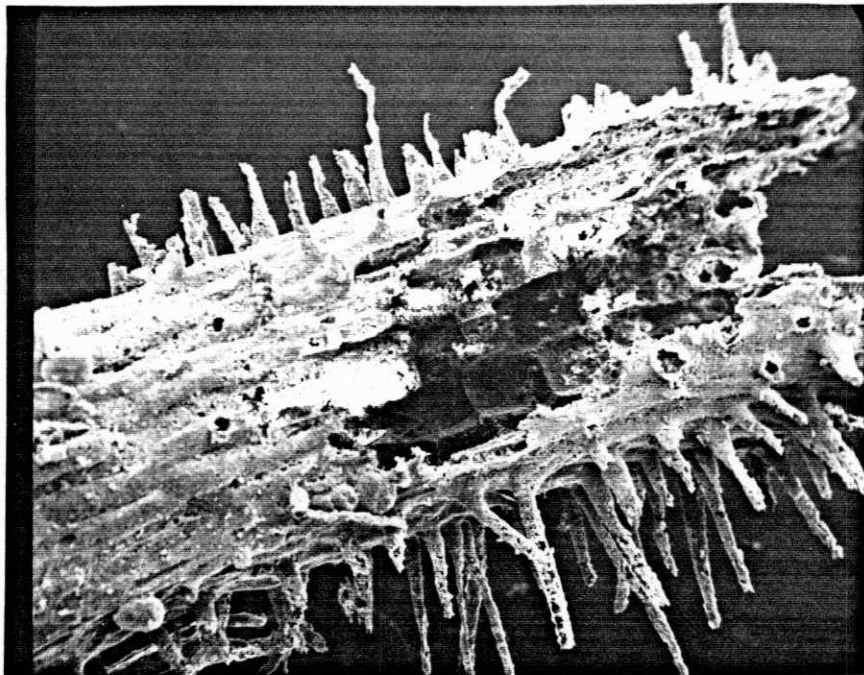
FIGURE 16

Enlargement of upper right hand corner of  
Figure 15; cortical cells, epidermis, and root-hair  
sheaths are pictured, Site 8 (230X)



500  $\mu\text{m}$

Figure 15

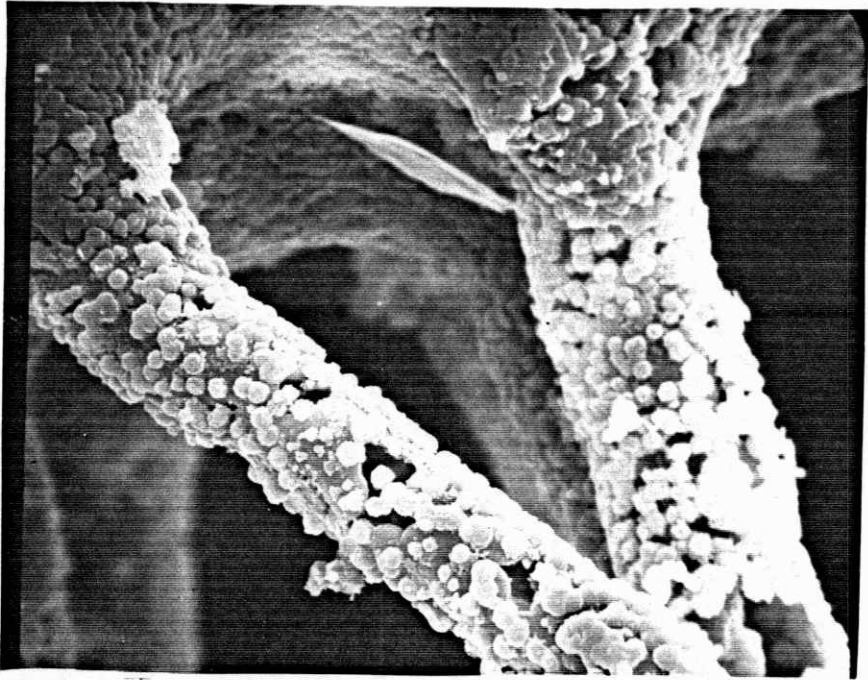


50  $\mu\text{m}$

Figure 16

FIGURE 17

Enlargement of lower center Figure 16;  
smooth opal spheres coat surface of root-hair  
sheaths, Site 8 (2300X)



10  $\mu\text{m}$

Figure 17

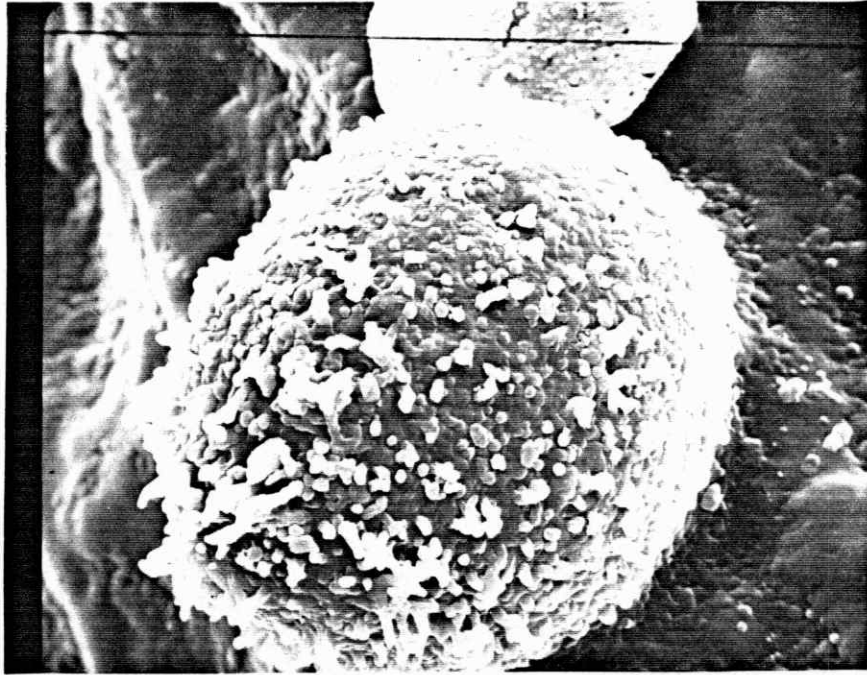
FIGURE 18

Aggregate sphere resting on ridged outer  
rhizolith surface, Site 8 (2600X)

[Similar to diagram of aggregate spheres  
shown by Darragh and others (1976).]

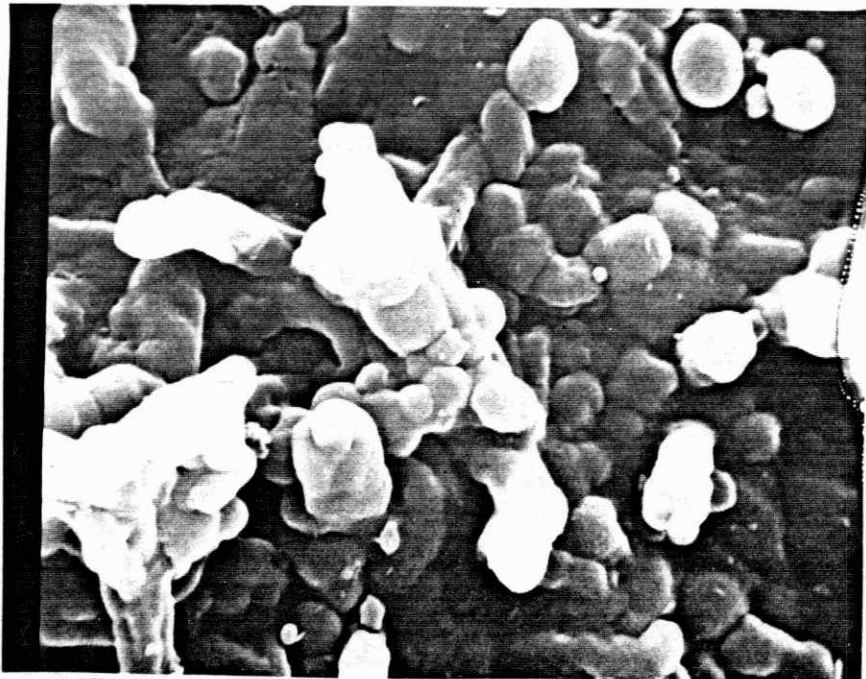
FIGURE 19

Enlargement of Figure 18; sphere sizes fit  
the sizes described by Darragh and others (1976),  
Site 8 (13,000X)



10  $\mu\text{m}$

Figure 18



1  $\mu\text{m}$

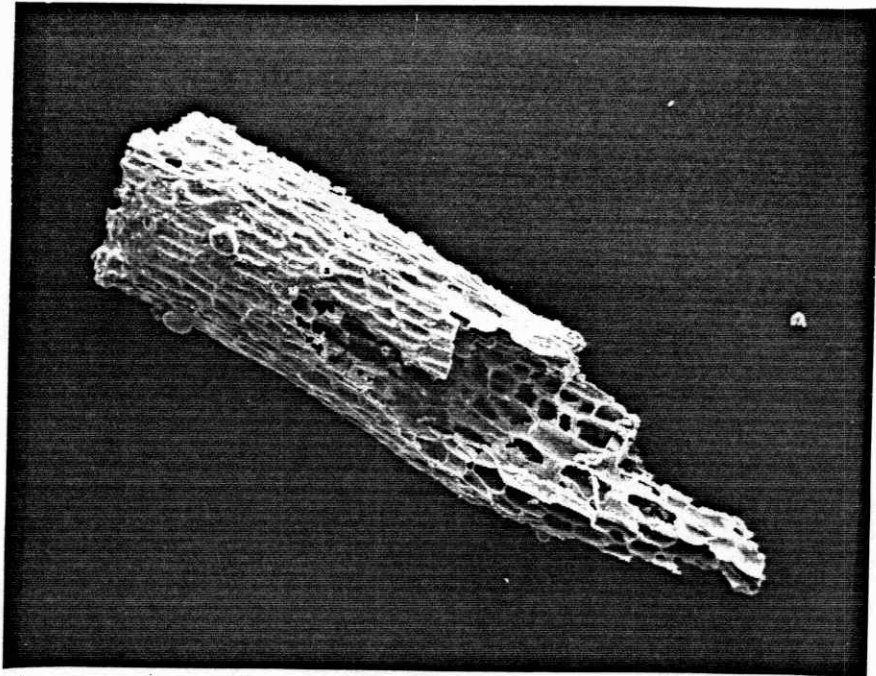
Figure 19

FIGURE 20

Preserved cortical cells, Site 8 (120X)

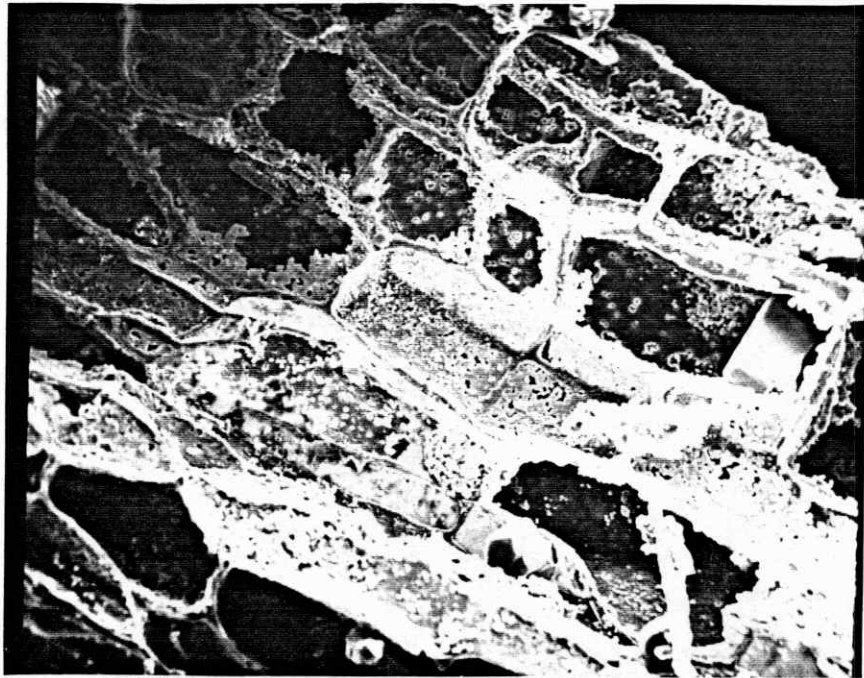
FIGURE 21

Enlargement upper right portion of cells,  
Figure 20, Site 8 (600X)



250  $\mu\text{m}$

Figure 20



50  $\mu\text{m}$

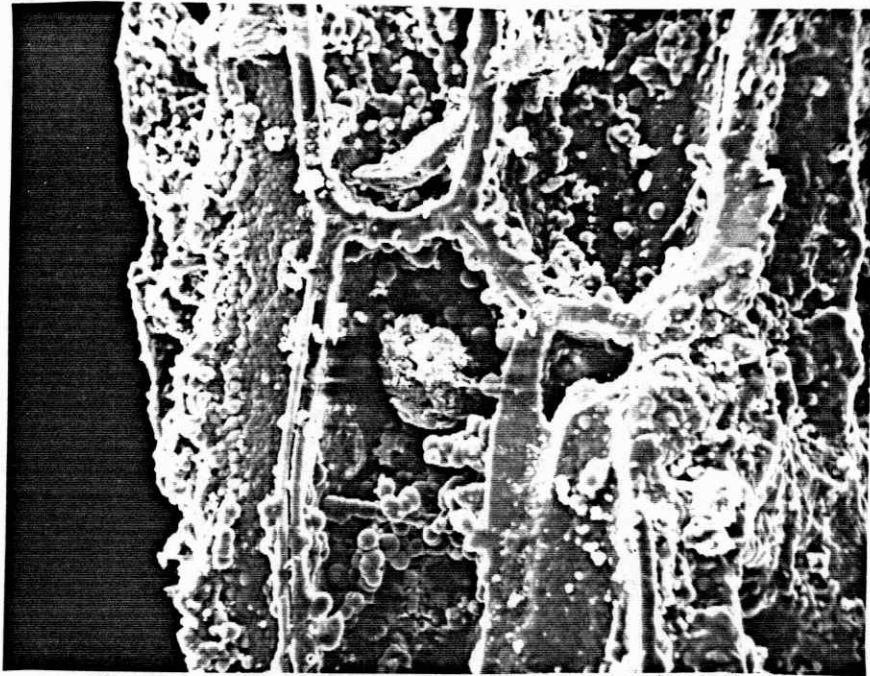
Figure 21

FIGURE 22

Sample in Figures 20 and 21 enlarged,  
Site 8 (1200X)

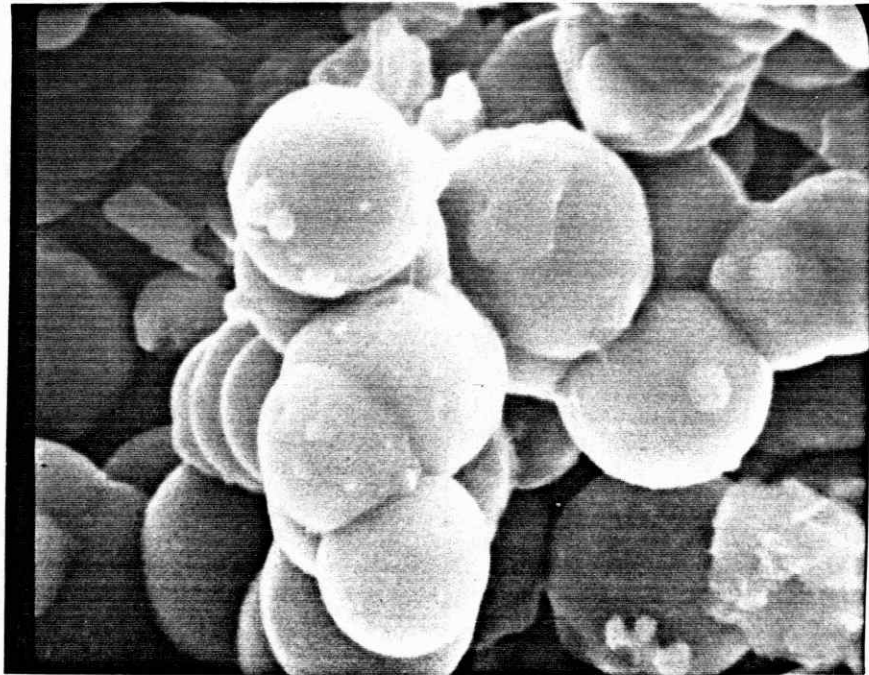
FIGURE 23

Enlargement from Figure 22, Smooth opal  
morphology present, Site 8. (12,000X)



10  $\mu\text{m}$

Figure 22



1  $\mu\text{m}$

Figure 23

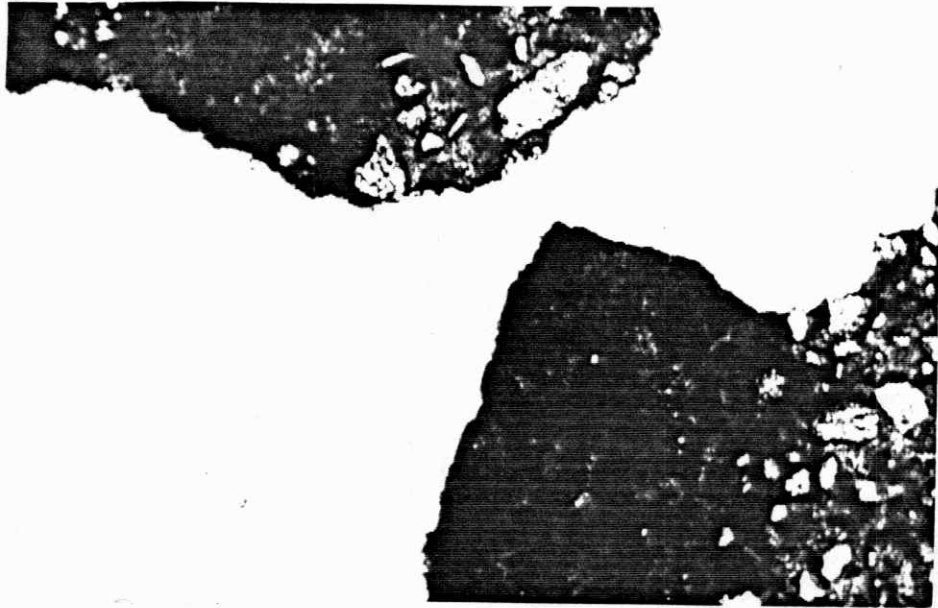
FIGURE 24

Platy caliche and stromatolitic structures

[White area on photograph is the space between plates. Darker area is one of the bands normally parallel to the cracks. Lighter areas contain more clasts shown here on the right sides of the two plates. These light and dark bands help to form the distinctive stromatolitic pattern from Site 4 (South Rocky Hollow).]

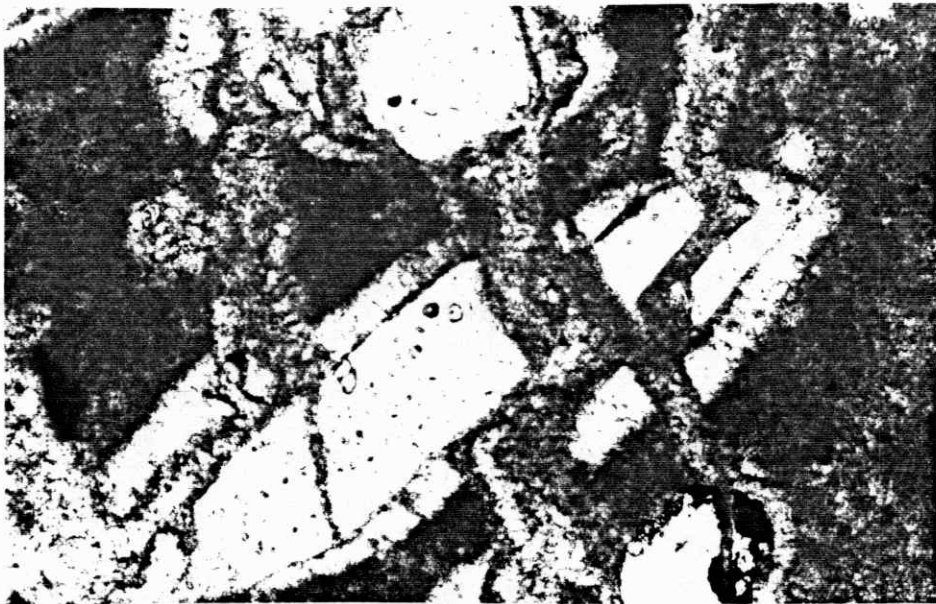
FIGURE 25

Feldspar clast with fibrous calcite spar and later displacive calcite veins cutting original coating (Site 7)



.45 mm

Figure 24



.10 mm

Figure 25

and dark layers were also produced by crustose lichens was not apparent. No lichen fruiting bodies (as described by Klappa, 1979) were observed.

In the very dense cap rock material found south of Kimball (site 7), the microfabric has isopachous crystals of sparry calcite surrounding both clasts and aveolar voids. Displacive calcite sparry veins, some with fibrous spar perpendicular to the fractures, occur in dense micrite and also split quartz and feldspar clasts (Figures 25 and 26; compare to Watts, 1978, Figure 2). The fibrous crystals often show two or three generations of growth. Clasts predominantly composed of quartz and feldspar appear to float in the micrite matrix. Multiple-coated glaebules (pisolites) similar to those described by Swineford and others (1958) are abundant.

Thin sections made from the conglomeratic sample with surface opal found at site 5 (Pine Bluffs, Wyoming) show coarse calcite spar surrounding caliche rip-up clasts and epiclasts. Opal pseudomorphs the outer rims of many calcite crystals (Figures 27 and 28). The paragenetic sequence for this sample of calcite emplacement and then opal replacement is like the sequence described by Stanley and Benson (1979) for early diagenesis of Tertiary sandstones of Wyoming and Nebraska.

#### FIELD OBSERVATIONS AND MACROSCOPIC FABRICS

All sites except site 1 show at least one mature caliche horizon (Figure 2). Stacked paleosol horizons were

FIGURE 26

Quartz with displacive calcite, showing at least  
two generations of crystal growth (Site 7)



.10 mm

Figure 26

FIGURE 27

Calcite spar in plane-polarized light (Site 5)

FIGURE 28

Same sample as in Figure 27 with crossed polarizers

[Note isotropic effects, outlines of crystals are now diffuse. Arrows show where opal has pseudomorphed the calcite. (Site 5)]

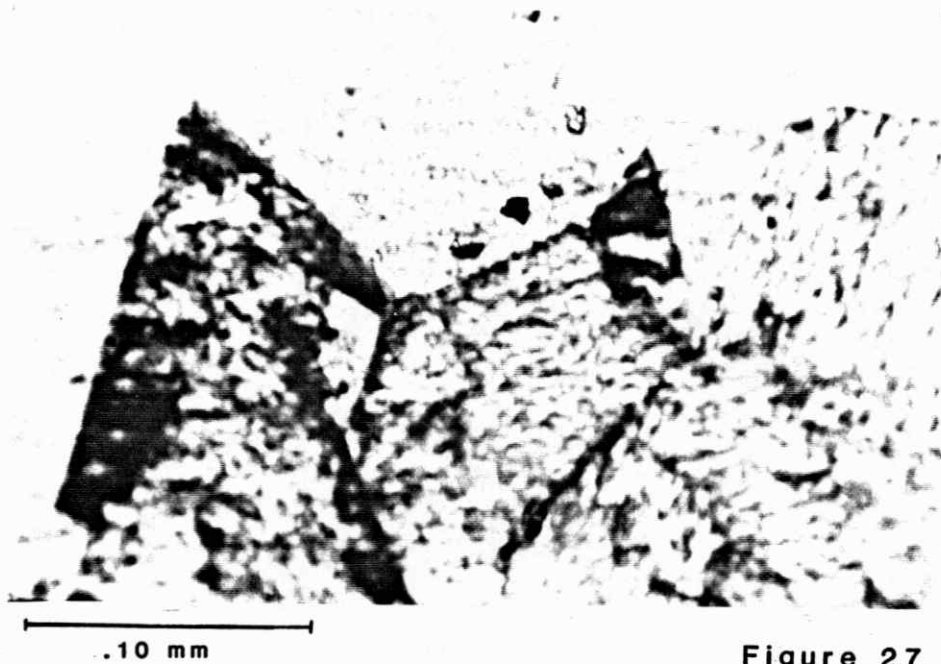


Figure 27

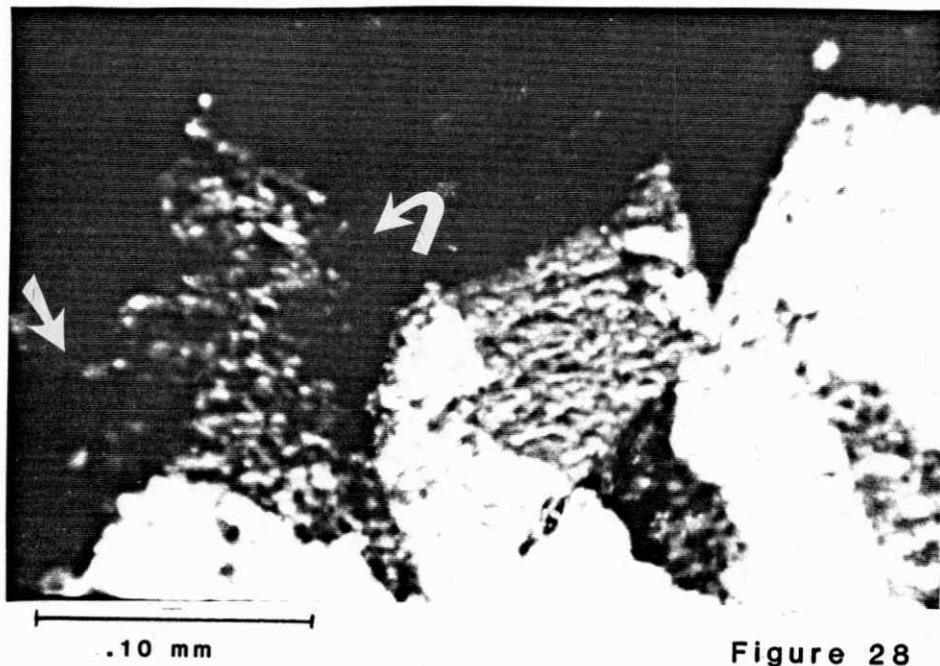


Figure 28

FIGURE 29

Stratigraphic section, Site 4 (South Rocky Hollow)

[Each numbered pedogenic unit is composed  
of a caliche layer (top), a transition zone,  
and parent material (base). (Site 4)]

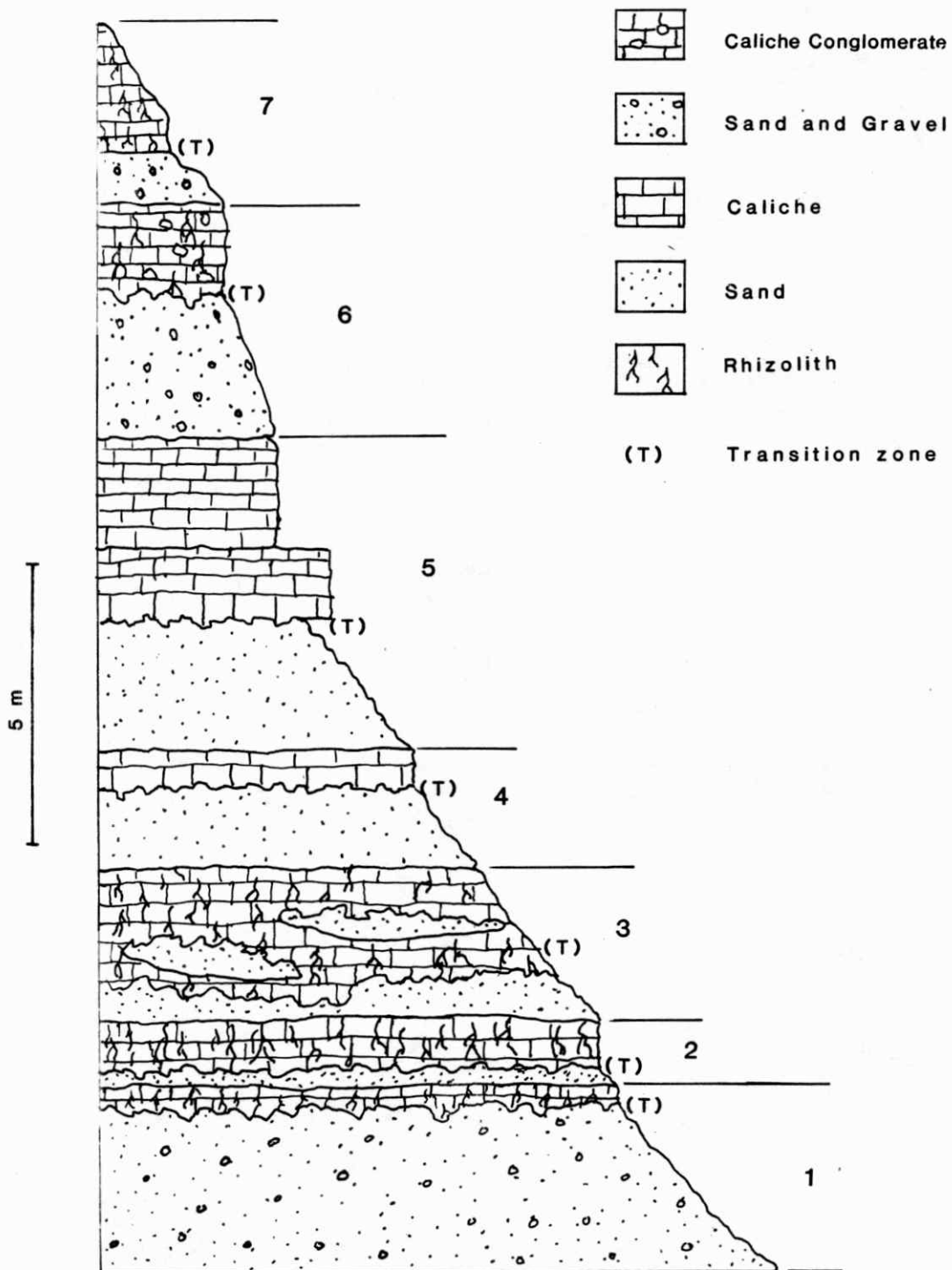


Figure 29

FIGURE 30

Transition zone at Site 9

[Pockets of original soil of parent material  
are preserved--possibly pedons.  
(Eastbound Sidney reststop)]

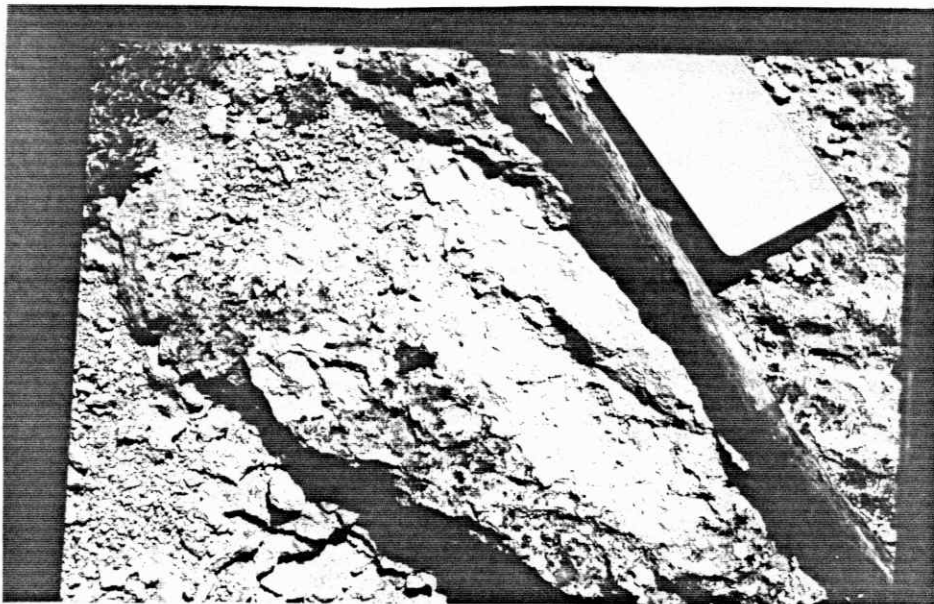


Figure 30

within the matrix of the paleosols.

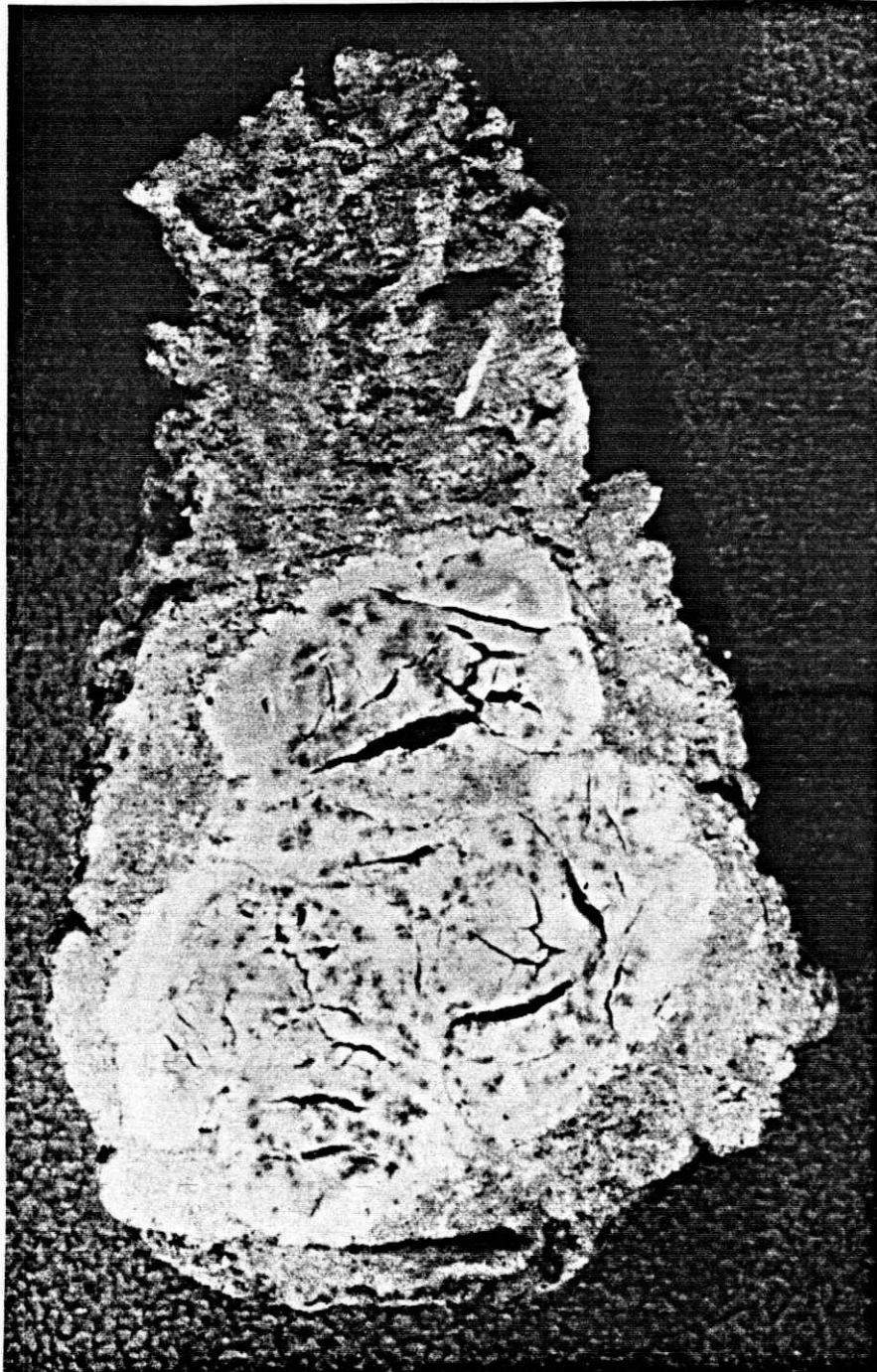
Vertically-elongated conical concretions up to 20 cm in diameter were collected at sites 10, 11, and 12. These have been called "yucca roots" by M. Elias (Lueninghoener, 1934). The "yucca root" structures are composed of dense calcite and silica with multiple cracks throughout the interior, a dense displacive calcite rind and a powdery calcite surface. Many small rhizoliths are associated with the exterior powdery surface and the adjacent caliche paleosol plasma. The outer fringes of these vertical concretions may have acted as conduits for downward movement of water and the smaller, now fossilized, rootlets followed the moisture. More study is needed to show conclusively whether these large concretions are indeed rhizoliths (Figure 31).

Nodules composed of dense calcite and silica, similar to that previously described, were collected from sites 3, 4, 5, 9, 10, 11, and 12. The nodules have rounded, botryoidal and often irregularly cracked surfaces with white powdery calcite exteriors. Minute quartz crystals occur in a few interior cracks and the centers of some nodules appear to be silicified. The largest nodule collected has a diameter of 7.5 cm. The smallest nodules fit the descriptions of glaeboles having diameters as small as 5 mm (Esteban and Klappa, 1983).

Fossil grass seeds in burrow structures were collected from site 10. The structures are probably insect burrows such as those dug by harvester ants (Thomasson, 1982).

FIGURE 31

Cross section of a large concretion (Site 12)



5 cm

Figure 31

Surface prospecting at this same site revealed vertebrate bone fragments and teeth. A typical Ash Hollow Formation fauna of Clarendonian age was identified by M. R. Leite (personal communication, 1986). It consisted of:

1. Large land turtle Geochelone?;
2. Small to medium size horse cf. Hipparion;
3. Larger horse cf. Pliophippus;
4. Small camelid;
5. Enamel fragments of proboscidian;
6. Carnivore tooth.

A stromatolitic fabric was found when cutting a large specimen from Pine Bluff, Wyoming (site 5). The sample is a conglomerate dominantly composed of locally derived glaebules and caliche rip-up clasts, with a matrix of medium to fine grained epiclastic sand probably derived from erosion of the Rocky Mountains. Stanley and Benson (1979) describe similar epiclastic sands with source areas in the Rocky Mountains. The lower portion of this specimen shows a large, well-developed stromatolitic pattern (Figure 6).

#### INTERPRETATION

The predominant cement in these pedogenic horizons is micritic calcite. The next most common is blocky mosaic calcite of equidimensional crystals, often filling voids and rimming clasts. Some needle fiber cement occurs but not in sufficient amounts to cause lithification of the prominent outcrops in the Ogallala. The thin sections of caliche containing rhizoliths have micritic calcite in close

association with the rhizoliths. This compares well with Ward's (1975) observations of rapid plant transpiration inducing formation of microcrystalline cement. Schlesinger (1985) indicates that evaporative pumping (by plants) will cause precipitation of calcite. Microcrystalline calcite formation in the soil root zone should therefore be expected. Blocky mosaic calcite is often present in thin sections as a void-filling, secondary cement with micritic envelopes and rims around clasts and rhizoliths already in place. The blocky calcite is present in the center voids of rhizoliths and filling cell lumina.

Opal emplacement to form rhizoliths occurs prior to calcite cementation in many cases. The source of silica for the opal is most likely devitrification of abundant rhyolitic glass although dissolution of feldspars and other epiclasts may contribute (Stanley and Benson, 1979). Devitrification of diatomeous earth present as pond deposits in Ogallala sediments and of phytoliths (the silica bodies present in grasses) may also contribute readily soluble silica to the system. There is petrographic evidence of calcite filling cracks in opalized rhizoliths and micro-crystalline calcite surrounding detached opalized epidermal cells (Figure 15). Root hairs are delicate and live only a few days before sloughing off (Reynolds, 1970). Their preservation indicates rapid opalization.

Root hairs sometimes remain intact after death and become lignified. This does not stop water from being pumped through them, however. A study by Kramer (1933)

showed that a plant can continue to pump water from a dead root system for several days to sustain the plant. The mineral concentrations within this water become similar to the concentrations in the soil and no longer reflect the osmotic responses across living cell walls. The actual amount of water pumped through the dead roots increases as the living cell barriers are broken down.

Two possible methods of opal emplacement merit consideration. The first is a simple physical pumping process, transpiration of plants. The root hairs carry on the primary water absorption and act as a physical boundary, eventually becoming coated with a layer of amorphous silica. Schlesinger (1985) provided an analogy with his description of calcite precipitation in the root zone. Given the differences in chemistries for precipitation of calcite and silica this mechanism may not work. However to preserve highly perishable root hairs a method of rapid emplacement is necessary. Evaporative pumping provides such a mechanism.

The second method involves a model developed for silicification of wood (Leo and Barghoorn, 1976). The silica, in the form of polysilicic acid, bonds to the hydroxyl groups found in the organic chemical structure of cellulose and lignens of the root, which act as a template. Once the process is started, more silica is added by polymer growth. Initially, the characteristics of the wood are replicated, but after deposition of several layers, the structure becomes less clear. A SEM photograph of root hairs

supports this second model by showing thin linear voids where organic material has been removed (Figure 32).

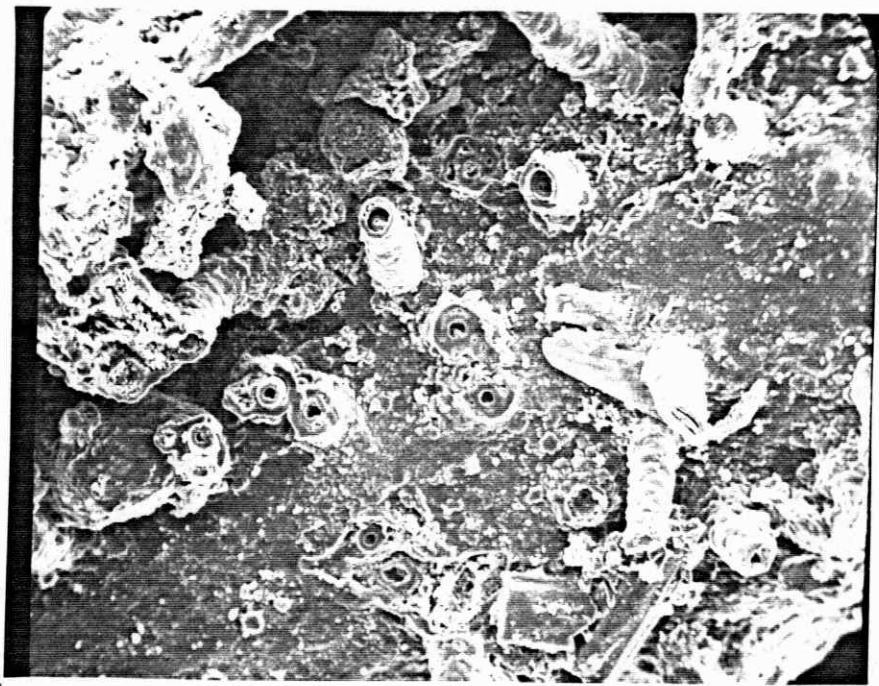
Leo and Barghoorn (1976) show evidence that organic components of wood have been preserved by encasement in silica in samples as old as Devonian. I think that organic material has also been preserved in the Ogallala due to opalization. Much of the material at the microscopic level is opaque, and I have not been able to identify it as organic material. The rhizolith samples I have used for many of the best SEM pictures are from site 8 and are part of a very coarse conglomerate. The coarse gravel would allow large amounts of water to percolate through the layer in which the opalized rhizoliths are found. This setting would enhance oxidation of decaying organic material, explaining why the samples had no organic material present when tested. The method of opal emplacement in the Ogallala may involve both processes described. The fact that the opal is associated with the plant fossils in the Ogallala sediments and has been shown to coat the inside and outside of structures as small as root hairs lends credence to combined actions of evaporative pumping and organic-hydroxyl templating.

#### SUMMARY

1. The petrographic features used as criteria for caliche identification of the Ogallala horizons are: rhizoliths, caliche stromatolites, glaeboles, random calcite needle fibers, circumgranular cracking, and alveolar

FIGURE 32

Root-hair sheaths with opal coating both the inside  
and outside of the tubular root hair structures,  
Site 11. (600X)



50  $\mu\text{m}$

Figure 32

structures.

2. Statistical evidence shows a mean of 0.2 mm for the measured diameters of over five hundred rhizoliths studied in thin section. The histogram and sample distribution provide a reference for rhizolith diameter (alveolar) measurements in caliches and within the compound rhizoliths.

3. Most rhizoliths found in the Ogallala are opalized. Remarkable detail has been preserved and they are classified as root petrifications. Opal emplacement in these rhizoliths may be due to evaporative pumping and/or organic-hydroxyl templating.

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