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AUTECOLOGY, DEVELOPMENT AND DIAGENESIS
OF A
PHYLLOID AND STROMATOLITIC BLUE GREEN ALGAL BIOHERM, LABORCITA FORMATION, SACRAMENTO MOUNTAINS, NEW MEXICO

by

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ABSTRACT

A Lower Permian phylloid algal bioherm, developed in the middle of the Laborcita Formation near Tularosa, New Mexico, is comprised of blue green algal bound phylloid algal wackestones and packstones. It contains a restricted fauna of erect, interlocking phylloid algae encrusted by wavy, digitate, and botryoidal masses of blue green algae and other minor epibionts. Primary void space developed in the bioherm as shelter cavities beneath phylloid algal thalli. Fan arrays of slightly radial fibrous cement, which appear as dark patches in the core rocks, developed in the submarine environment on masses of blue green algae and on phylloid plates and grew into the shelter cavities. They exhibit three stages of inversion and recrystallization which progressively obscure the original fibrous fabric. The intimate association between robust phylloid algae and encrusting blue green algae, penecontemporaneous marine cementation and infiltration of micrite and layered pelletal micrite between algal thalli controlled mound development.

After deposition of the mound, subaerial diagenesis created an extensive network of interconnected solution voids which transect primary structures. Subsequently, the bioherm was saturated by fresh water below the water table where the solution voids were lined by a clear, equant to slightly bladed, isopachous cement. A second solution initiated neomorphism of micrite and allochems to microspar and precipitated a clear, coarsely crystalline, calcite mosaic in remaining void space.

INTRODUCTION

Previous descriptions of Late Paleozoic phylloid algal bioherms have attributed the build-up of the mounds to parautochthonous accumulations of fragmented algal blades and carbonate mud (Wray, 1962; Toomey and others, 1977). New evidence from an Early Permian algal bioherm in south-central New Mexico reveals an unusual biotic relationship between unbroken and erect interlocking plates of phylloid algae and encrusting and digitate blue green algae that appears to have controlled mound development.

The mounds were initially cemented in the submarine environment. Subsequent exposure to freshwater in the vadose zone created a network of interconnected solution vugs which indiscriminately transect primary fabrics. The solution vugs were then lined by an isopachous, slightly bladed cement and completely occluded by coarse sparry calcite.

The purpose of this study is to: 1) describe the intimate relationship between phylloid algae and blue green algae and demonstrate its role in the build-up of the mound, and 2) untangle the complex diagenetic history of the mound based on cement morphologies and relationships.

GEOGRAPHICAL AND GEOLOGIC SETTING

The Laborcita Formation was originally defined by Otte (1959) as the transitional strata overlying the marine Holder Formation (Virgilian) and underlying the non-marine redbeds and sandstones of the Abo Formation (Wolfcampian). It crops out along a narrow, northwest trending strip north of Alamogordo, New Mexico, along the western flank of the northern Sacramento Mountains and ranges in thickness from about500 feet in the southeast to about 1000 feet towards the northwest. The Laborcita Formation is comprised primarily of interbedded shallow marine carbonates, fluvial sandstones and conglomerates, and calcareous mudstones and shales which reflect the relative fluctuations of the slowly regressing sea that occupied the area during latest Pennsylvanian and earliest Permian times.

Northeast of Tularosa, New Mexico, a biohermal lithofacies occurs in the middle part of the Laborcita Formation extending to the north about three miles and ranging in width from one-fourth to one-third mile (Fig. 1). This study is concerned with the two southernmost mounds in sec. 16, T. 14 S., R.10 E., Otero County, New Mexico. The eastern flank of the northern mound dips slightly to the east and exhibits a gently undulating character (Fig. 2) which grades into a knoll of massive limestone approximately 50 feet thick at its eastern end (Fig.3). The southern bioherm is exposed as a single knoll about 60 feet thick with a prominent northwest-facing limestone ridge (Fig. 4). Fluvial sandstones and conglomerates fill in the topographic depressions between the mounds. The mounds are developed on a thin, continuous bed of shallow marine pelletal wackestone.

METHODS

Rock samples were collected from the biohermal core and from laterally equivalent units in the back bioherm by Dr. T. A. Cross during the summer of 1977. Fabric studies were conducted on acetate peels and polished faces of large slabs. Staining techniques similar to those described by Friedman (1959) were employed for differentiating calcite and dolomite and for any possible ferroan calcites. Thin sections were also examined petrographically and with cathodoluminescence, SEM, and microprobe.

ROCK DESCRIPTIONS

Back bioherm

Strata in the back biohermal position are comprised mainly of bedded and bioclastic mudstones, wackestones and packstones which contain a diverse biotic assemblage: whole gastropods with geopetal structures; broken, horizontally bedded phylloid algae; bryozoan fragments; fusilinids and other benthic foraminifers; disarticulated bivalves; echinoderm plates and columnals; ostracodes; brachiopod fragments and spines; and rarely, trilobites (Fig. 5). Intraclasts of unfossiliferous micrite are commonly found embedded in the wackestones.

The back bioherm contains a patchy distribution of microenvironments as evidenced by the wide range of rock types and the local accumulation of specific faunal assemblages. One such microenvironment contains pelletal phylloid algal packstones which resemble biohermal core facies of other Late Paleozoic mounds, but which are dissimilar to the Laborcita core facies. Long, sinuous phylloid algal plates up to 4 cm in length wind through the rock with alternating dark and light colored bedded pelletal micrite, unbedded, unfossiliferous, buff-colored micrite, and unbedded greyish micrite with whole gastropods occurring between the algal plates. Unlike the Laborcita core facies, these rocks contain no encrusting stromatolitic algae and no solution vugs (Fig. 6).

Biohermal Core

In contrast to the bioclastic wackestones and packstones of the back-bioherm is the biohermal core with a more restricted biotic assemblage comprised of blue green algal bound phylloid algal wackestones and packstones (Fig. 7). Erect phylloid algae are in an interlocking network (Fig. 8) which is encrusted by pelletal blue green algae in three distinct shapes: wavy lamination, digitate knobs (Figs. 9, 10, 11), and botryoidal masses (Fig. 12). Pelletal micrite and unfossiliferous micrite in laminae about 1 mm thick are supported by the erect phylloid algal thalli. Primary void space is developed beneath individual phylloid algal plates (Fig. 13) by a sheltering effect that excluded micrite (Wray, 1968). Fibrous calcite, arranged in radial fibrous fan arrays is developed on the blue green algae, oriented perpendicular to the underlying rounded surface, and growing up, down, and sideways into the shelter cavities. These fan arrays, which appear as dark crystalline masses in the rock, were described as stromatactis by Otte and Parks (1963) and ascribed a biologic origin. A fine mosaic of equidimensional calcite grains or crystals rests geopetally in topographic lows on the fan arrays (Fig. 19) and on phylloid algal thalli and partially fills the bottom of shelter cavities (Fig. 15).

An elaborate network of solution vugs, now lined by a slightly bladed isopachous cement and filled by a very coarse, white sparry calcite, cuts indiscriminately through the core rocks (Fig. 14). The network is visible on weathered surfaces and individual solution cavities can be traced in three dimensions in hand sample and on the outcrop.

Bioclastic wackestones with a high faunal diversity dominate the back bioherm. Phylloid algae are broken and fragmented and often horizontally bedded, which gives them the appearance of having been mechanically transported from the mound. Intraclasts of buff-colored non-fossiliferous micrite, very similar to the micrite in the bioherm core, also appear to have been transported and deposited in the quiet water of the back bioherm.

By contrast with the back bioherm, the bioherm core has a low faunal diversity and preponderance of erect, interlocking plates of phylloid algae encrusted by successive layers of blue green algae. Although mounds comprised predominantly of phylloid algae appear commonly in Late Paleozoic shallow-shelf, marine banks (Wray, 1968; Toomey and others, 1977), the Laborcita bioherm differs from these mounds in that the phylloid algae are erect and unbroken and capable of supporting encrusting blue green algae. The intimate association between phylloid and blue green algae, as well as penecontemporaneous marine cementation and infiltration of micrite and layered pelletal micrite, created a biologically originated mound.

PALEOENVIRONMENT

Toomey (1976) described a phylloid algal community from the Lower Permian of southern New Mexico. His synecological reconstructions portray the alga as an upright, fragile plant a few inches high with broad, somewhat rigid leaves or fronds that thrived in waters below or beyond the zone of appreciable wave action. So rapid was it growth that in a relatively short time it dominated the available substrate. Organisms such as foraminifers, brachiopods and Tubiphytes, an encrusting blue green alga, which lived as epiphytes on the algae survived most successfully in this environment while the abundance of epifaunal organisms was restricted by the limited amount of available seabottom.

The Laborcita bioherm reflects an environment similar to the one described by Toomey in the sense that it was dominated by erect phylloid algae and contained a limited fauna composed mainly of epiphytes. However, in this case, encrusting stromatolitic blue green algae with an occasional encrusting foraminifer is the most common epiphyte, while brachiopods are a very rare component.

The phylloid algae probably thrived in shallow marine water in a zone of little wave action as evidenced by the large amount of micrite and the in situ development of interlocking algal fronds. Occasionally, slight fluctuations in sea level caused expansion of the algal meadow into the back biohermal environment where an interlocking network of algal thalli but no encrusting blue green algae developed.

Figure 16 gives a reconstruction of the phylloid algal meadow during Early Permian times. The geometry of the thalli provided the plant with an efficient means of trapping and holding sediment. This baffling action caught suspended or current-washed sediment which was then deposited, often bedded, between individual thalli.

That the erect phylloid algae, while in growth position, was capable of supporting encrusting blue green algae, forming large shelter cavities, and trapping large amounts of micrite suggests that the phylloid alga is sturdy and not fragile or delicate, as it has been suggested (Toomey, 1976). In this sense, it can be considered as the framework support of the mound.

CEMENTS

Four different types of cement are recognized in the Laborcita bioherm core on the basis of their morphologies and their occurrence in primary or secondary voids. Primary cavities were developed during deposition and in situ construction of the mound. The most abundant primary cavities are the shelter cavities formed beneath erect phylloid algal thalli which were described previously. Fan arrays of radially oriented fibrous calcite in botyroidal masses, developed in the submarine environment on blue green algal masses or on phylloid algal plates, growing up, down, or sideways into available space in the cavity. Inter-particle voids, such as those within whole gastropod shells, are less common and are filled by a finely crystalline sparry mosaic. Secondary voids formed by a solution which appears to have occurred after partial submarine lithification while the bioherm was exposed to vadose weathering conditions. The solution formed an elaborate network of interconnected voids which runs through the core rocks either cutting indiscriminately across primary depositional structures (Figs. 17 and 18) or following the general shape of some of the larger shelter cavities, slightly enlarging them through dissolution of older cements and allochems. Subsequent depression of the bioherm or a relative rise in groundwat er level placed the bioherm in a fresh phreatic environment where available void space was lined by a slightly bladed, isopachous cement and later occluded by a solution which caused neomorphic alteration to microspar of some marine allochems and subsequent precipitation of a clear subequant crystalline calcite mosaic.

Fan arrays

Radial fibrous calcite is common on blue green algae and within primary void space in cavities beneath phylloid algal thalli and is arranged in single fans (Fig. 19) or as composite arrays of two or more interpenetrating fans (Fig. 20). Individual fans are 3 - 5 mm wide and 2 - 5 mm high while the composite arrays are as much as 20 mm wide and 10 mm high. Under plane light, the original fibrous structure (aragonite or high-Mg calcite) can be discerned when not obscured by subsequent inversion, recrystallization, or dolomitization. Individual fibrous crystals, 6 - 8:1 length-width ratio, are sometimes arranged from a point source radiating upward, but more often, are found oriented perpendicular to the rounded perifery of the underlying blue green algae which gives the crystals a slightly radial appearance.

Both single and composite fan arrays are developed on hummocky masses of blue green algae and extend up into the shelter cavities created by phylloid algal plates. They also are attached to phylloid algae and extend down and sideways into primary voids and interpenetrate with upward-growing fan arrays (Fig. 21). A fine equidimensional calcite mosaic with an average dimension of 10-15 microns, rests geopetally on the fans. It is usually clear and faintly bedded, occasionally grading into very dense micrite, which gives it the appearance of having been mechanically deposited. The fan arrays are similar to those described from the Laborcita Formation by Cys and Mazzulo (1977) and to submarine cements from other ancient and modern shallow marine environments (for example, Davies, 1977; Mazzulo and Cys, 1977; Ginsburg and James, 1976).

The association between blue green algae and encrusting fan arrays is previously unreported. Locally, a series of concentric bands or laminae about 0.1 mm wide, are superimposed on blue green algal masses

(Fig. 21). The bands have irregular layers of pellets with an internal fibrous habit oriented perpendicular to the boundary of each laminae. The fibrous hands are separated by a thin layer of dark, amorphous, possibly clay-rich or micritic material. A progressive decrease in fibrous habit occurs in each band towards the blue green algae. This gradation from encrusting fan array to blue green algae with no change in overall shape may suggest influence by the blue green algae on the growth of accretionary bands of fibrous cement or possibly, may be a neomorphic alteration of the blue green algae to slightly radial fibrous aragonite.

The fan arrays exhibit three stages of inversion and recrystallization that progressively obscure the original fibrous fabric. Fan arrays exhibiting the first stage of recrystallization are developed directly on phylloid algal thalli without intervening blue green algae (Fig. 22). They are composed of yellowish, equant to slightly elongate, calcite crystals with a hint of preferred orientation of crystallites to that of the original fibrous habit. A thin yellowish margin, possibly a product of the recrystallization process, surrounds the outer edge of the fan.

Asseretto and Folk (1976) described Triassic pisolites from Lombardy, Italy. The pisolites, originally fibrous aragonite, now consist of microsparite laminae with a brick-like fabric, or fine mosaic crystals with an external form of square-ended rays. The inferred diagenesis suggests that the original fibrous aragonite 1) formed large square-ended rays during local aggrading recrystallization, and 2) inverted to mosaic or brick-like calcite on a piece-by-piece basis that preserved original textural details when the pH or Mg/Ca ratio dropped.

The resulting calcite mosaic in the pisolites is very similar to the first stage of recrystallization found in the Laborcita fan arrays.

The slightly radial orientation of crystallites in the fan arrays suggests that similar diagenetic processes may have affected the original fibrous cement. The yellowish margin along the edge of the fan may have been caused by the migration of Mg from the fan arrays and concentration along the fan periphery during recrystallization. Occasionally, dolomite has formed along the edges of the fan near the yellow margin, which may indicate that the yellowish margin is the initial stage of dolomitization.

In the second stage, continued recrystallization and crystal growth has oriented areas of individual crystallites in the calcite mosic in optical continuity, creating irregularly bounded calcite crystals with a maximum dimension of 2 mm (Fig. 23, 24a,b). These neomorphic crystals, visible only in cross-polarized light, have a patchy extinction that cross-cuts the original fibrous fabric. The relict fibrous fabric is visible under plane light through the overprint of these irregularly bounded crystals.

The fourth stage shows the limit of recrystallization within the fans. Fan arrays devoid of any relict fabric are now composed entirely of very coarse calcite crystal. The yellowish margin observed in the second and third stages is also well-developed around the fans in this stage and clearly outlines the outer extent of the fan arrays. In reflected light, these fans are indistinguishable from fan arrays with a well-preserved relict fabric and have the shape of the composite arrays. The fan arrays of this stage are found on phylloid algae, growing downward and interpenetrating an upward-growing fan or occur as gradations from fans typical of the third stage. Recrystallization of the fans has caused continued growth of the coarse calcite mosaic until very coarse spar forms destroying the relict fibrous fabric. The complete sequence of recrystallization and inversion is found ocassionally in one fan array (Fig. 25).

Cathodoluminescence reveals the fans as mottled deep blue, non-luminescent patches (the same color as a blank epoxied thin section slide) with thin dull orange streamers. The yellowish margin and the pelletal micrite layers between fibrous bands luminesce more intensely to a brighter orange. The fine equidimensional calcite mosaic resting geopetally on the fans is mostly non-luminescent with finely verigated dull orange surrounding individual crystals.

That the fan arrays developed in a submarine environment is attested to by several lines of evidence. The fans form directly on top of blue green algae or on phylloid algae and grow into primary cavities. The acicular character is a common cement type in submarine environments (Folk, 1974; Badiozamani, 1977). There is no evidence for subaerial weathering such as caliche crusts or for precipitation in the vadose zone, that is, there are no meniscus cements. Finally, the least altered fibrous calcite in the first stage contains irregular rows of pellets which most likely are of submarine origin and which were incorporated during the growth of the fan arrays.

Isopachous cement

An equant to slightly bladed isopachous cement lines solution voids. It is developed on a thin layer (0.1 mm) of fine calcite crystals and is itself approximately 1 mm high (Fig. 26). The cement, oriented perpendicular to surfaces, completely rims large solution voids. In the larger shelter cavities the isopachous rim is developed on previously existing fabrics such as first generation cements, internal gravitational sediment, and the fan arrays. Where solution voids cut across primary depositional structures, the cement is oriented perpendicular to the cross-cutting surface.

The rim cement also serves as a boundary between primary and secondary voids in areas where first generation cements in shelter cavities come in contact with cements in secondary solution voids. Under cathodoluminescence the distinction between cement generations is clearly seen because the isopachous cement is non-luminescent with the first generation cement below the isopachous rim a mottled blue with orange streamers and the coarse spar above the rim a brightly luminescing orange. Electron microprobe determinations indicate the concentration of FeO in the isopachous cement as approximately 0 - 0.8 weight percent and the concentration of MnO below detectable readings (less than 0.1 weight percent).

The formation of isopachous cement requires water-filled voids which are usually found in either a submarine or a fresh phreatic environment. However, Harrison (1977) has described bladed isopachous cement from the vadose that has formed by the ponding of meteoric water in voids. The difference in luminescence between the rim cement and the coarse spar may suggest formation in the vadose zone during periods in which voids were filled by water. Alternatively, the different luminescence qualities may indicate precipitation from different groundwaters.

Equant calcite mosaic

Coarse, clear, subequant spar with plane crystalline boundaries fills remaining void space, increasing from 0.02 mm along the periphery to a maximum crystal dimension of 8 mm in void centers. The spar appears to be the same as that found in primary shelter cavities, except the larger solution voids have allowed increased growth of the spar while the smaller cavities restricted crystal growth. In both primary and secondary voids the cement luminesces very bright orange which indicates relatively high concentrations of Mn^{++} and low concentrations of Fe^{++} in the spar since the manganese ion is usually considered the cause of luminescence in calcites while ferrous iron is the quencher (Sippel and Glover, 1965). Estimates of the concentrations of Mn^{++} in calcite needed to produce distinct luminescence average around 1000 ppm (Martin and Zeeger, 1969; Freeman, 1971). However, no manganese in either oxidation state was found using the electron microprobe and, more important, no detectable difference in composition could be found between the non-luminescing isopachous cement and the brightly luminescing coarse spar. Further investigation is imperative to pinpoint causes for the variation in luminescence of the two cements.

Meteoric water-filled voids in a fresh phreatic environment or in a deeply buried environment are most likely to precipitate a clear, sparry calcite. Badiozamani and others(1977), simulating natural environments, described a clear, equant spar that formed in a low temperature, fresh phreatic zone and suggested that lack of Mg^{++} in the groundwater allowed the growth of the coarse equant spar. The fact that the tectonic history of the bioherm includes no evidence for deep subsurface burial and that the morphology of the cement is very similar to to that described by Badiozamani suggests that occlusion of the voids probably occurred in a fresh phreatic environment.

Neomorphic microspar

Equidimensional calcite crystals with a crystal size ranging from 0.03 - 0.05 mm is found in three occurrences: 1) in thin bands about 1 mm away from the void edge, 2) linearly along one edge of a fragment of a phylloid algal plate, and 3) around blebs of micrite in a somewhat stellate habit. In all three cases the microspar increases in size away from the nearest allochem or surface.

In the first case, the microspar, which is coarser than the internal gravitational sediment on the fans, occurs in thin linear band, 0.3 - 0.5 mm thick between the isopachous cement in the large solution voids and about 1 mm away from the void boundary. The crystalline bands appear to have resulted from complete recrystallization of a phylloid algal plate because where the band of microspar stops, an extensively recrystallized phylloid alga continues. In the second occurrence, the utricle layer on one side of a fragmented phylloid alga has been recrystallized to microspar which coarsens outward. Both phylloid alga and neomorphic microspar appear to float in the very coarse void-filling spar (Fig. 27). In the third case, blebs of micrite, floating in the coarse spar mosaic, have recrystallized to slightly bladed stellate microspar (Fig. 28).

Under cathodoluminescence, the microspar is deep-brownish red to bright red and grades into either the non-luminescent isopachous cement in the first case or into very bright orange in the second and third case. The separation between neomorphic spar and void-filling calcite mosaic and between neomorphic spar and allochem is indistinct. Movement of groundwater through the solution voids appears to have caused the recrystallization of the allochems simultaneously with precipitation of the coarse, void-filling spar mosaic.

LATE STAGE CEMENTATION

Vein calcite

Thin veins of calcite, 0.5 - 1 mm in width, run through the rocks.

Individual crystals are equant and range in size from 0.3 to 1 mm in diameter. Crystallization of veins occurred in optical continuity with surrounding crystals and go to extinction with adjoining host crystals in large, irregular patches (Fig. 29). Under cathodoluminescence, the veins are a very bright orange, similar to that found in the coarse spar (see above). No analysis was made by electron microprobe to determine trace element content. Precipitation of the veins occurred after lithification of the bioherm rocks as witnessed by the indiscriminate cross-cutting character and are probably a late stage meteoric alteration.

DIAGENESIS

A sequence of diagenetic events can be determined through close examination of cement morphologies and by the geometric relationships between different generations of cements. Figure 30 gives the diagenetic path taken by the bioherm, showing its initial deposition and subsequent cementation and lithification. Also included in the diagram are the proposed diagenetic environments for each step.

During step 1, the initial growth and development of interlocking phylloid algal thalli generated shelter cavities beneath thalli by an "umbrella" effect which prevented significant accumulation of fine sediments or mud. Pelletal and non-pelletal micrite, mechanically transported by currents, was trapped by the thalli and deposited in laminae at the base of sheltered cavities. Stromatolitic blue green algae grew upon the phylloid algae in distinctive shapes and grew into available space, protected by the overlying phylloid algae. The stromatolitic algae formed the substrate for precipitation of fibrous cement, either aragonite or high - Mg calcite, in fan arrays. Internal gravitational sediment, similar to Dunham's (1969) "vadose silt", was deposited geopetally in topographic lows on the fan arrays, along the bottom of small shelter cavities, and on margins of blue green algal stromatolites.

Inversion of the unstable aragonitic or high - Mg calcite fans to the more stable, less dense mineral, calcite, left an excess of $CaCO_3$ which precipitated as syntaxial overgrowths on the fibrous cement, widening the primary fibrous needles into equidimensional crystals aligned along the primary fan array. Recrystallization and crystal growth in optical and crystallographic continuity of small calcite crystal gradually created coarse, irregularly bounded, interlocking crystals which, under cross-polarized light, cut across the primary fibrous fabric. Continued recrystallization of the fans caused continued growth of the coarse interlocking crystals into very coarse, subequant spar and destruction of the relict fibrous fabric.

Lowering of the sea level or uplift of the bioherm brought the bioherm into a vadose environment where meteoric water, undersaturated with respect to $CaCO_3$, indiscriminately dissolved portions of the rock, forming a network of interconnected cavities which cut non-preferentially across primary depositional structures and enlarged remaining void space, predominantly the shelter cavities.

Subsequently, the biohermal facies were saturated by fresh water below the water table where a slightly bladed isopachous cement precipitated from the solution in the fluid-saturated voids. The isopachous cement outlined the solution voids and marked the boundary between cements precipitated in a submarine environment and those precipitated in a fresh phreatic environment.

A second generation of cement was precipitated as coarse, clear, subequant calcite in the fresh phreatic zone. This cement completely occluded remaining void space and triggered neomorphic alteration of allochems along the edge of the voids.

Late stage diagenetic events not included in the diagram include the precipitation of thin, crosscutting streamers of calcite, dolomitization of fan arrays, and stylolitization.

SUMMARY

The back-biohermal facies of the Laborcita Formation contains a diverse faunal assemblage of fragmented, horizontally-bedded phylloid algae and whole and unbroken allochems, many with geopetal structures. In contrast to the back-bioherm, the biohermal core facies contains a limited fauna consisting primarily of a previously unreported association of phylloid algae and stromatolitic blue green algae. The phylloid algae were erect, flexible plants which proliferated the substrate forming an interlocking system of thalli which created shelter cavities by an "umbrella" effect which excluded fine sediment. Blue green algae bound or encrusted the phylloid algae in wavy, digitate and botryoidal or mamillary masses. Carbonate mud and bedded pelletal carbonate mud was trapped and deposited in primary cavities, thus providing substrate for successive generations of phylloid algal growth.

Fibrous cement in fan-like arrays developed in the submarine environment on masses of blue green algae in single and composite arrays and filled in much of the primary void space. The fan arrays exhibit three gradational stages of inversion and recrystallization: 1) inversionof the original fibrous cement, either aragonite or high-Mg calcite, to equant or slightly elongate calcite crystallites oriented in the direction of the primary fibrous habit, 2) recrystallization of individual crystallites to optical continuity creating coarse, patchy calcite crystals which cut across primary fabric, and 3) continued recrystallization and crystal growth to a very coarse calcite mosaic with no preservation of primary fabric.

Mound development was controlled by growth of erect, sturdy phylloid algae in an interlocking pattern, binding by stromatolitic blue green algae, trapping of carbonate mud and penecontemporaneous marine cementation.

Subaerial weathering after deposition of the mound created an extensive network of interconnected solution voids which either cut across primary depositional structures or enlarged primary void space through dissolution of older cements and allochems. Flooding of the secondary void space in the fresh phreatic environment caused precipitation of an equant to slightly bladed isopachous cement which grew perpendicular to the margin of the voids. Continued precipitation in the phreatic environment filled remaining void space with a very coarse, subequant calcite mosaic.

Examination of the cements under cathodoluminescence showed the isopachous cement as non-luminescent and the coarse calcite mosaic as a very bright orange,although no detectable difference in trace element content between the two cements could be found using the microprobe. Further research is imperative to determine what effect, if any, cement morphology, environment of formation, or diagenetic environment has on the luminescence of different minerals.

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CAPTIONS FOR FIGURES

Figure 1. Map showing locations of Wolfcamp bioherms of northern Sacramento Mountains, New Mexico. (From Otte and Parks, 1963, Jour. Geol. p. 381).

2. South face of the northern Laborcita bioherm exhibiting undulating core facies. Sacramento Mountains in the distance.

3. Photograph to the east of Figure 2, showing knoll at the southern limit of the northern bioherm.

4. Prominent ridge on the northwest face of the southern bioherm.

5. A fusilinid in upper center; small trilobite floats in pelletal micrite.

6. A broken phylloid algal thallus abuts against an unbroken thallus, trapping fragmented skeletal material and craating small cavities. Back bioherm, 12X

7. Typical blue green algal bound phylloid algal packstones found in the biohermal core. White areas are either micrite or calcite spar. Darker areas are phylloid algae encrusted by blue green algae and fibrous calcite fan arrays.

8. Close-up of blue green algal bound phylloid algal packstone clearly showing the interlocking network of phylloid algae and encrusting stromatolitic algae.

9. Distinctive digitate knob of stromatolitic blue green algae encrusting a phylloid algal plate.

10. Thin section of digitate stromatolitic blue green algae. 20X

11. Cross section of three digitate knobs encrusting phylloid algae. Note truncations of laminae. 12X

12. Mammillary mass of blue green algae encrusting a phylloid algal plate.

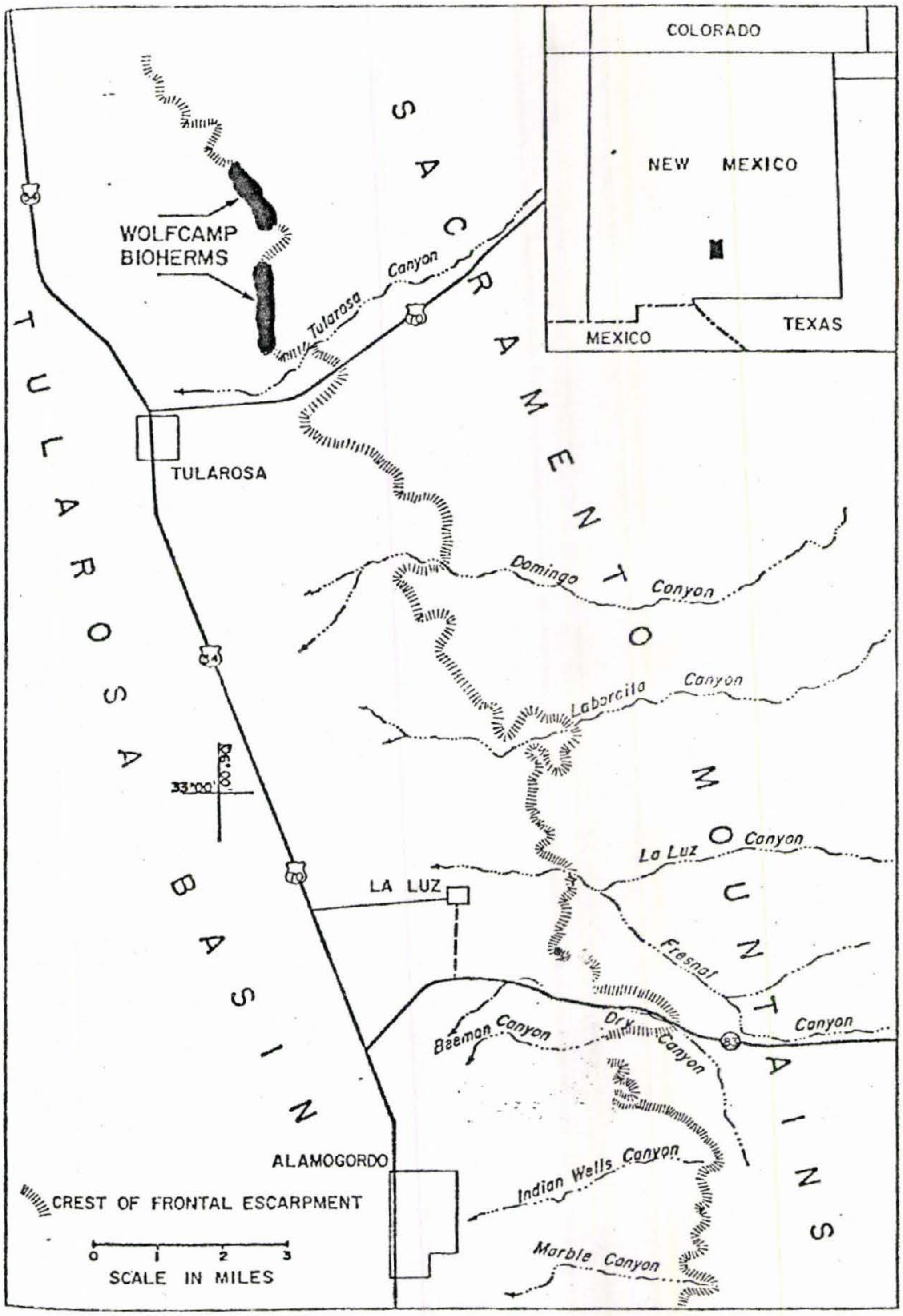
13. Primary void space developed beneath a phylloid alga thallus by the exclusion of fine-grained micrite. Shelter cavity has been partially filled by pelletal micrite and completely filled by a clear, equant crystalline calcite mosaic. 20X

14. An elaborate network of interconnected solution voids (white areas) runs through the biohermal core that have since been lined by an equant to slightly bladed isopachous cement and occluded by very coarse spar.

Figure 30. Diagenetic history of the Laborcita bioherm. Fine dots represent the fine equidimensional calcite mosaic (internal gravitational sediemtn); closely spaced wavy lines: blue green algae; nearly parallel, slightly parallel lines: fibrous fan array; long, finger-like elements: phylloid algae.

See text for discussion.

FIGURES


COLORADO
NEW MEXICO
TEXAS
MEXICO
SACRAMENTO MOUNTAINS
TULAROSA BASIN
WOLFCAMP BIOHERMS
Tularosa Canyon
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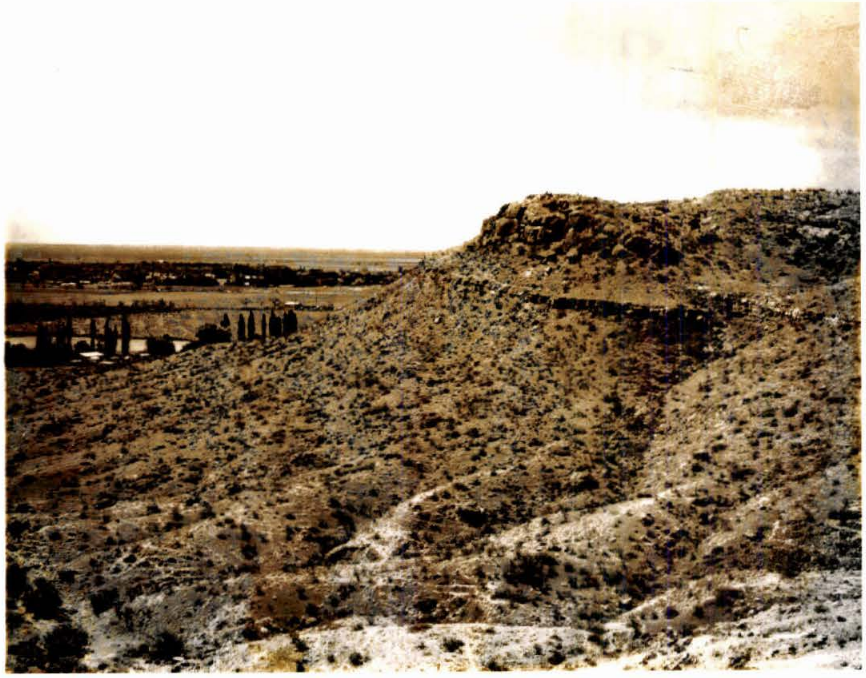
54
70
82
Domingo Canyon
Laborcita Canyon
106°00'
33°00'
La Luz Canyon
LA LUZ
Fresnal Canyon
Beeman Canyon
Dry Canyon
ALAMOGORDO
Indian Wells Canyon
Marble Canyon
CREST OF FRONTAL ESCARPMENT
0 1 2 3
SCALE IN MILES

Figure 1

Figure 2

Figure 3



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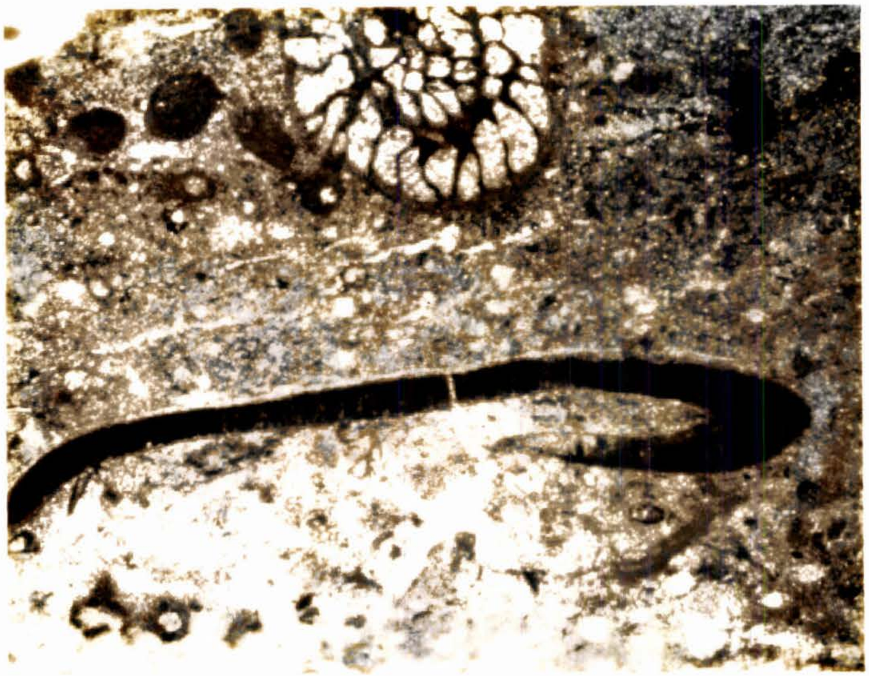


Figure 5

Figure 6

Figure 7

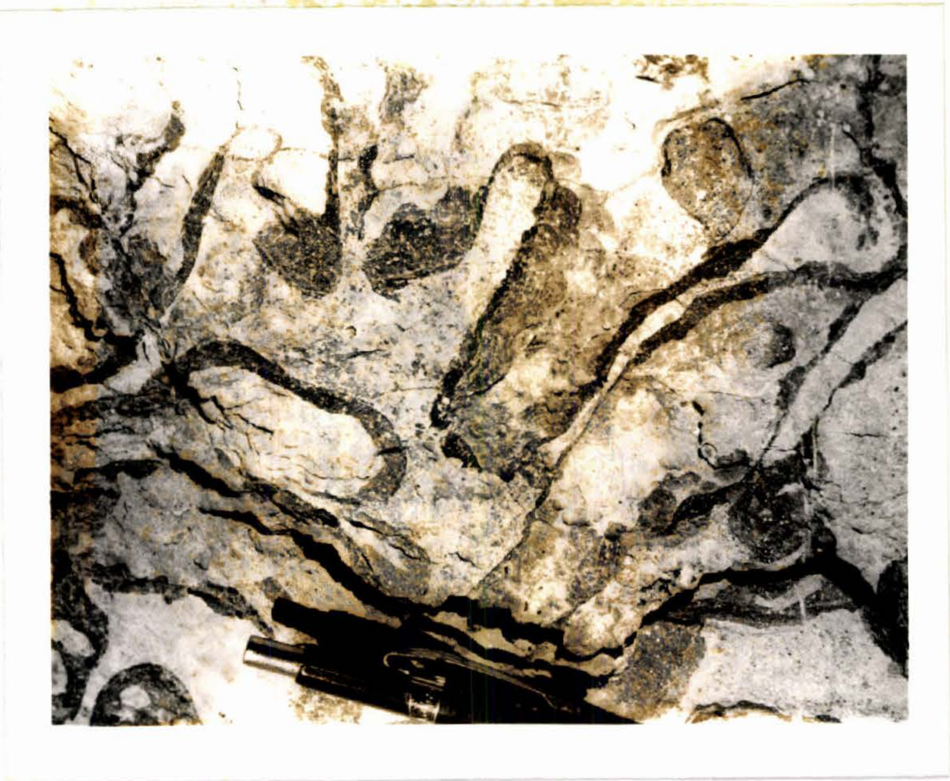
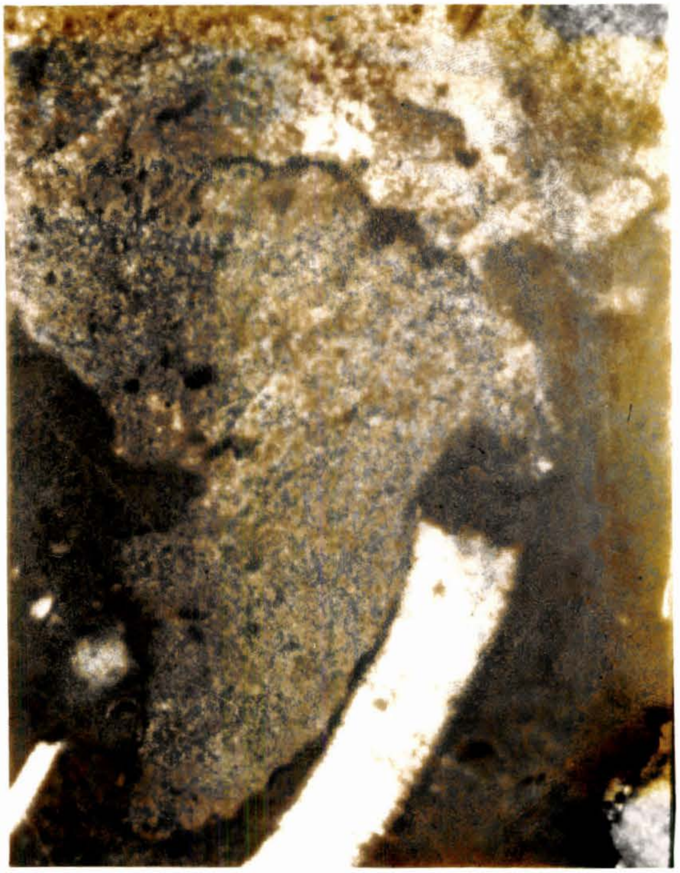


Figure 8

Figure 9

Figure 10



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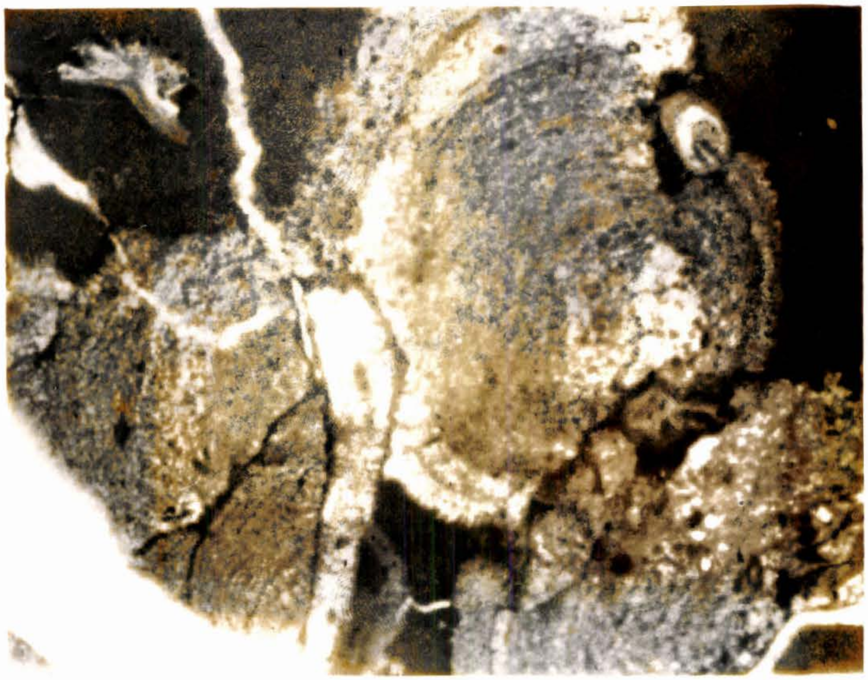
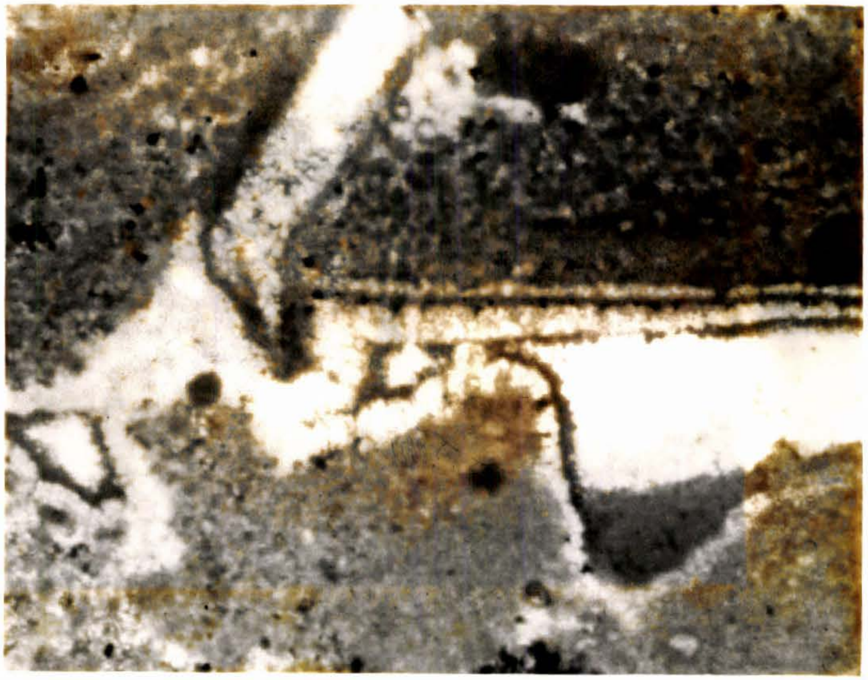


Figure 12

Figure 13

Figure 14

Figure 15



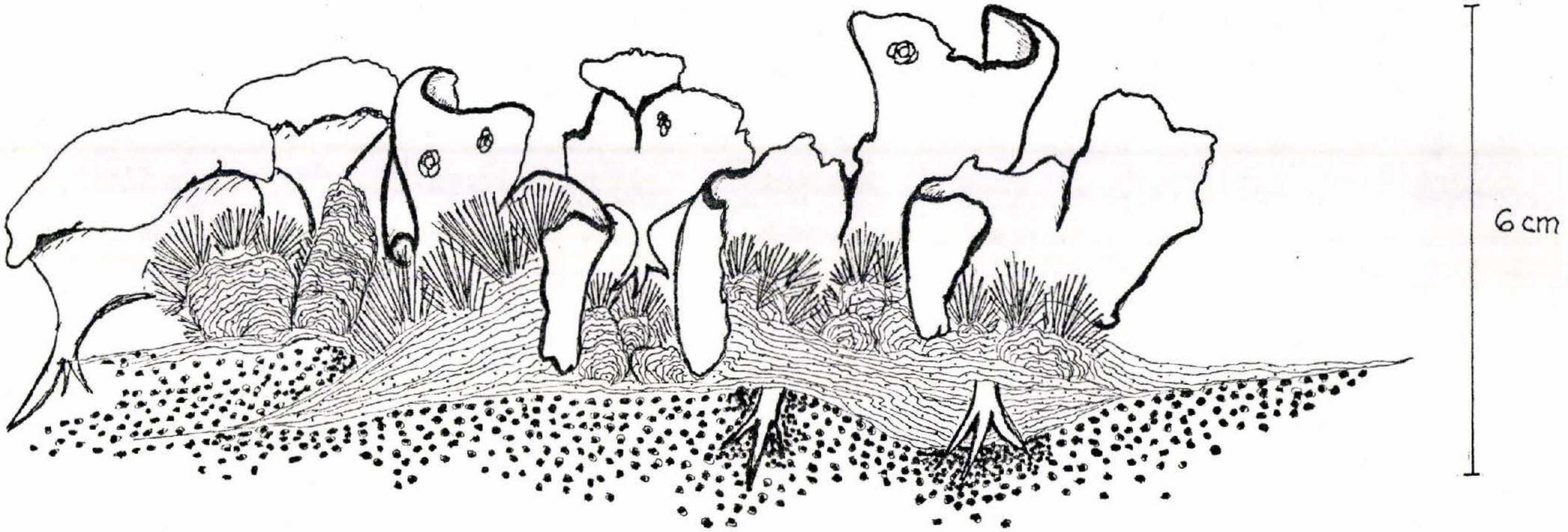
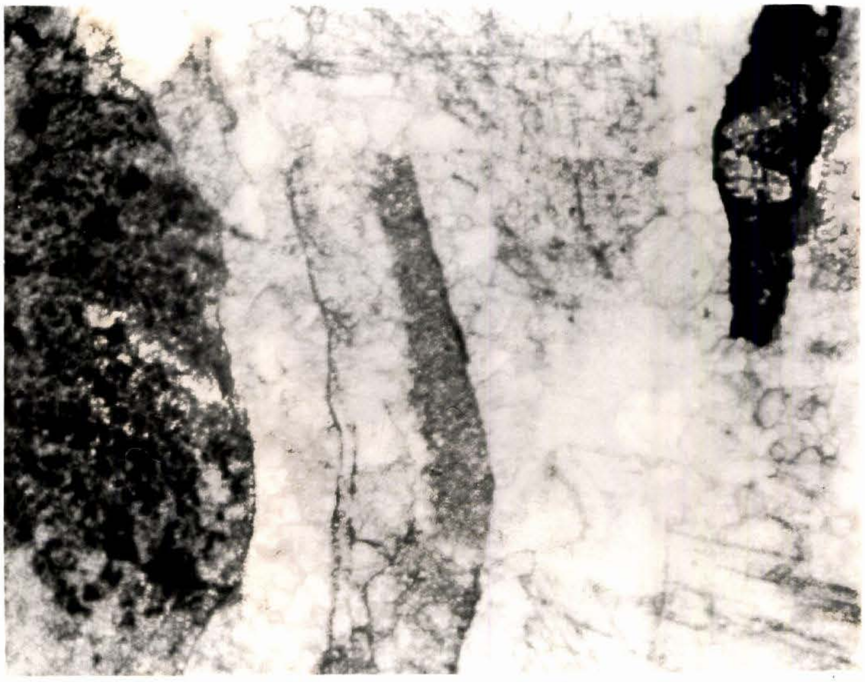
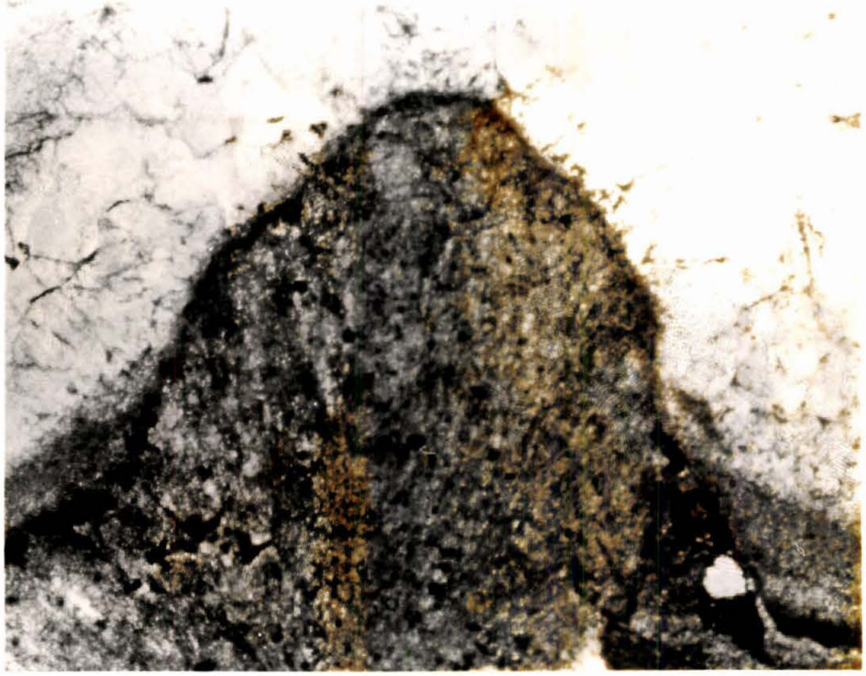


Figure 16

Figure 17

Figure 18





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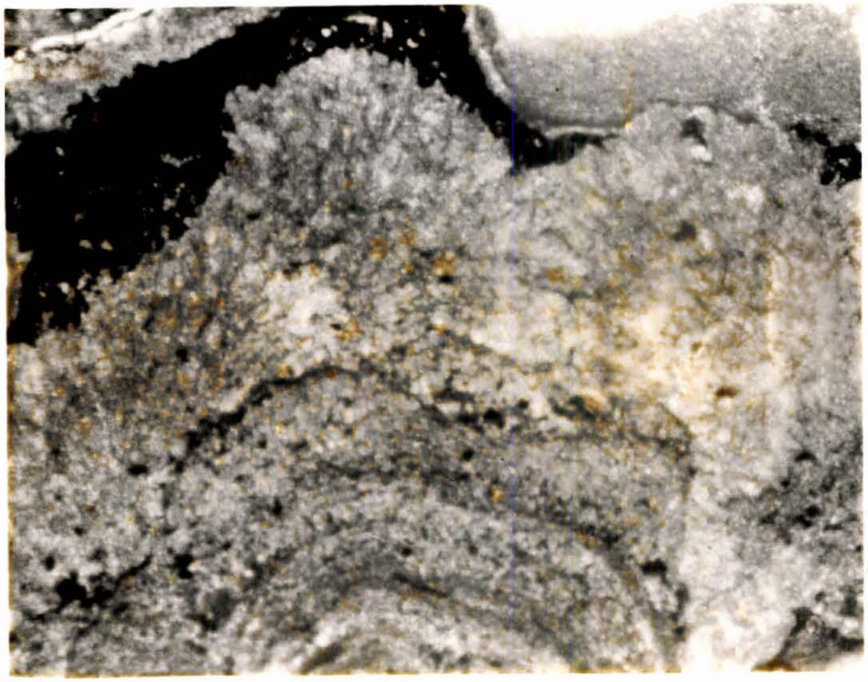

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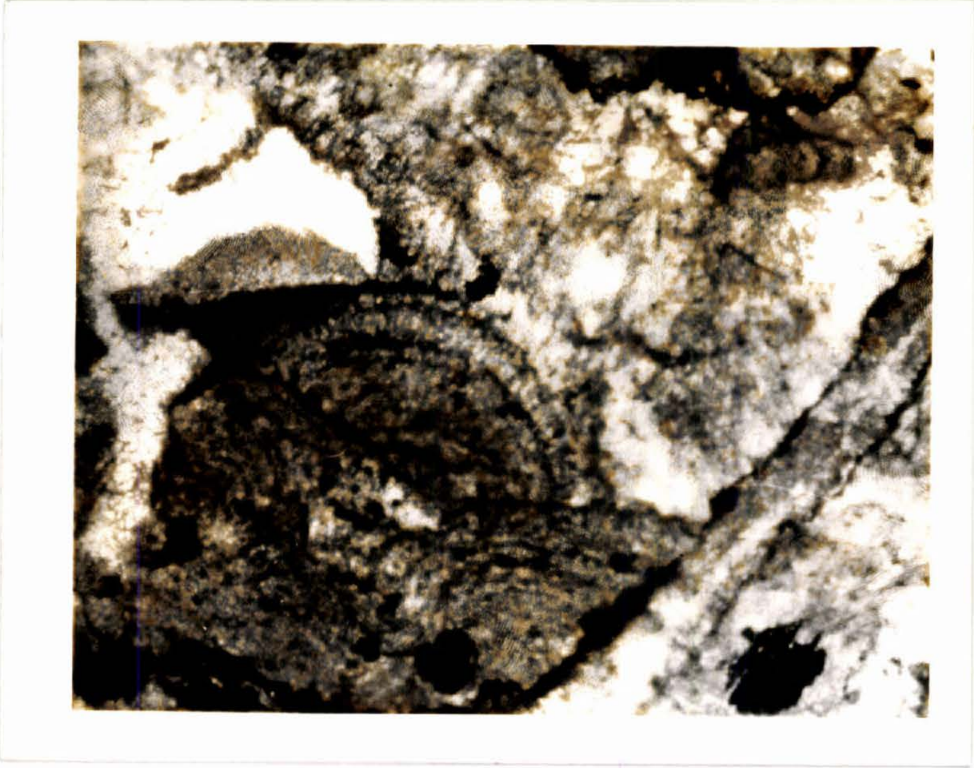

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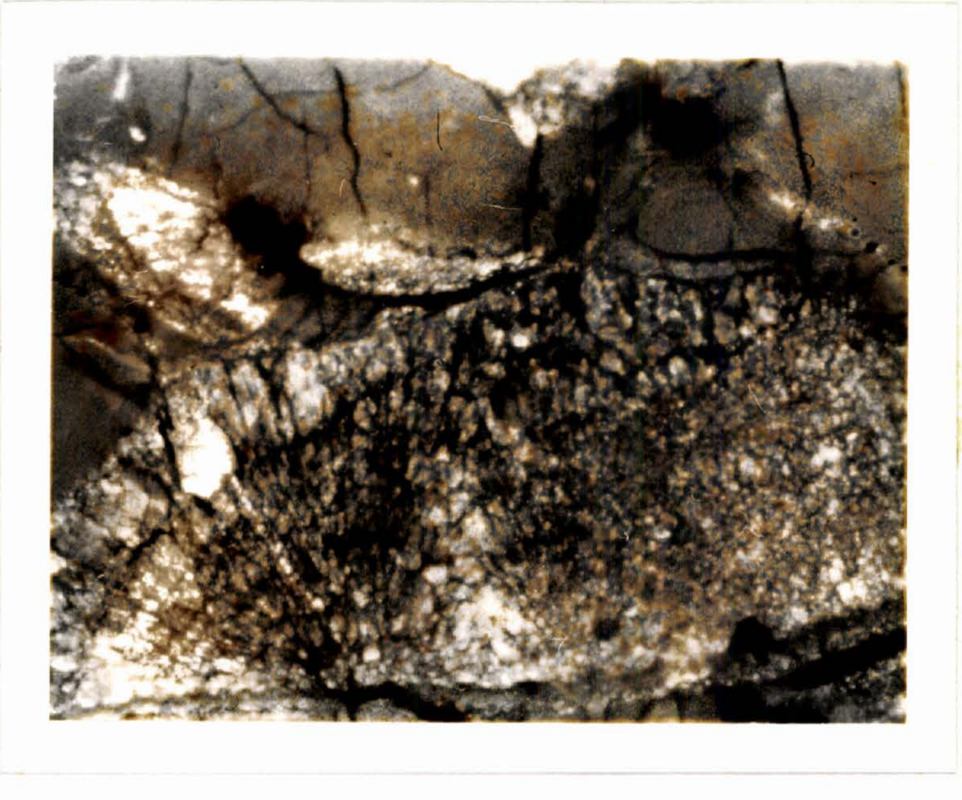

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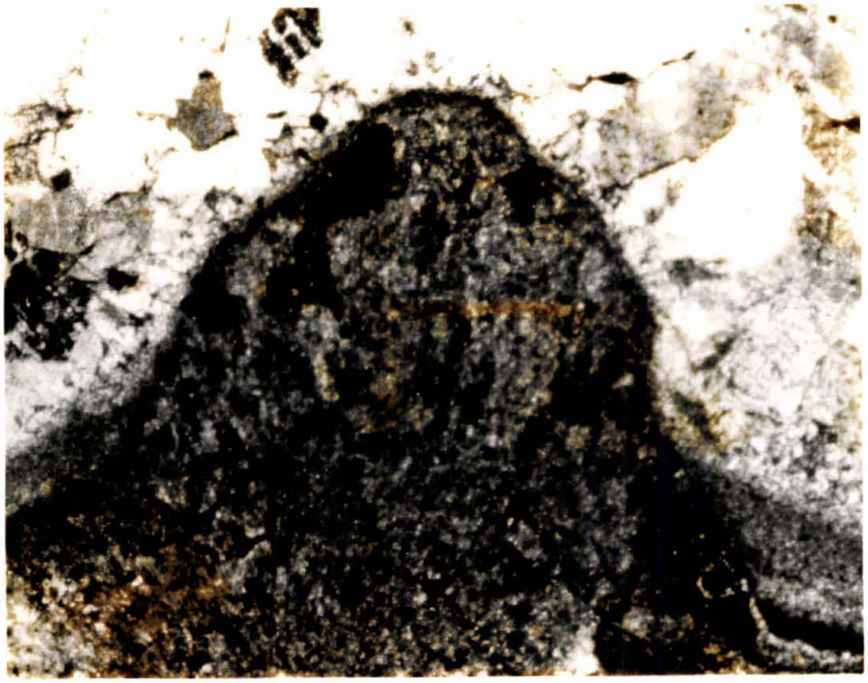

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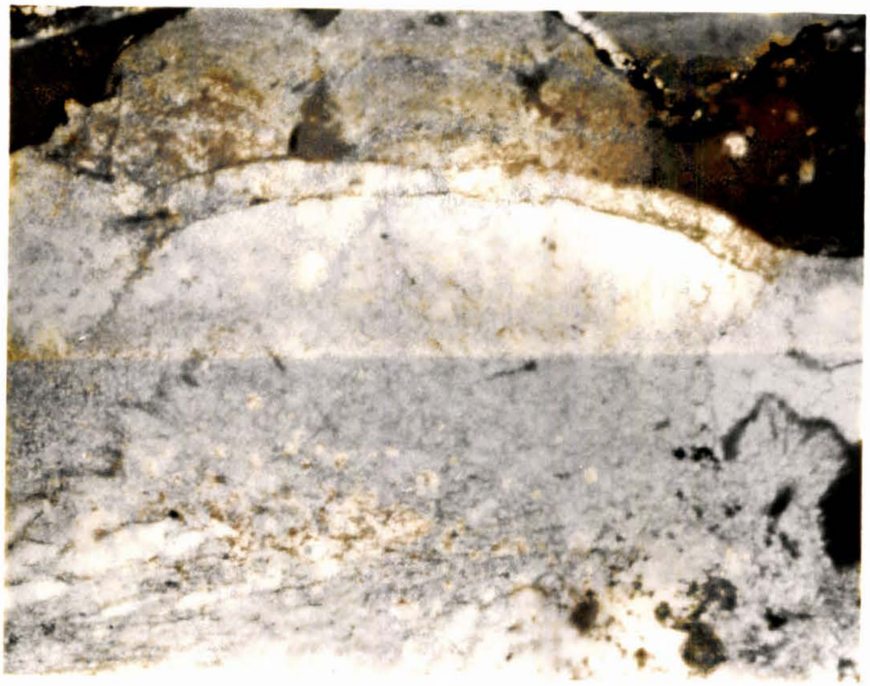

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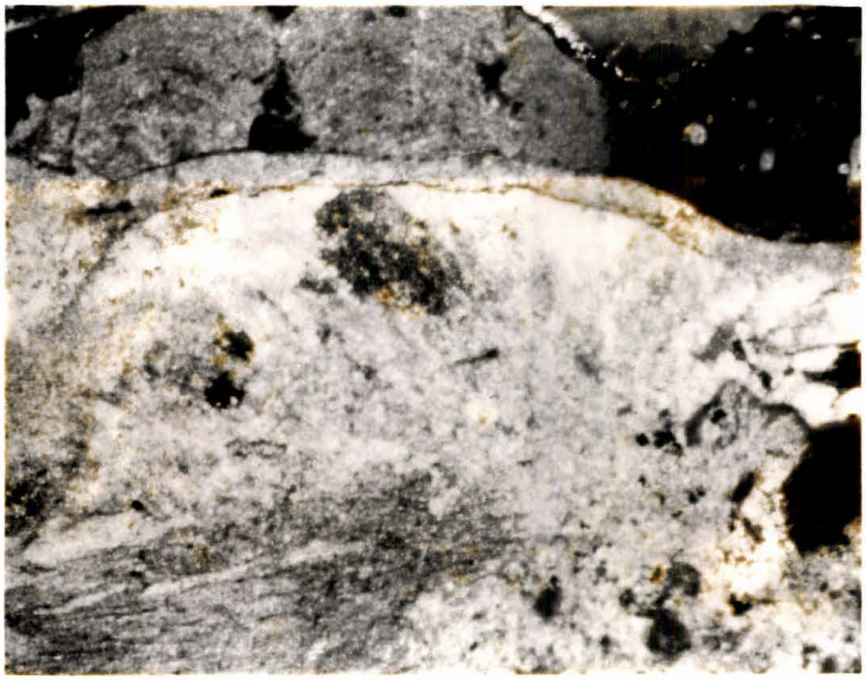
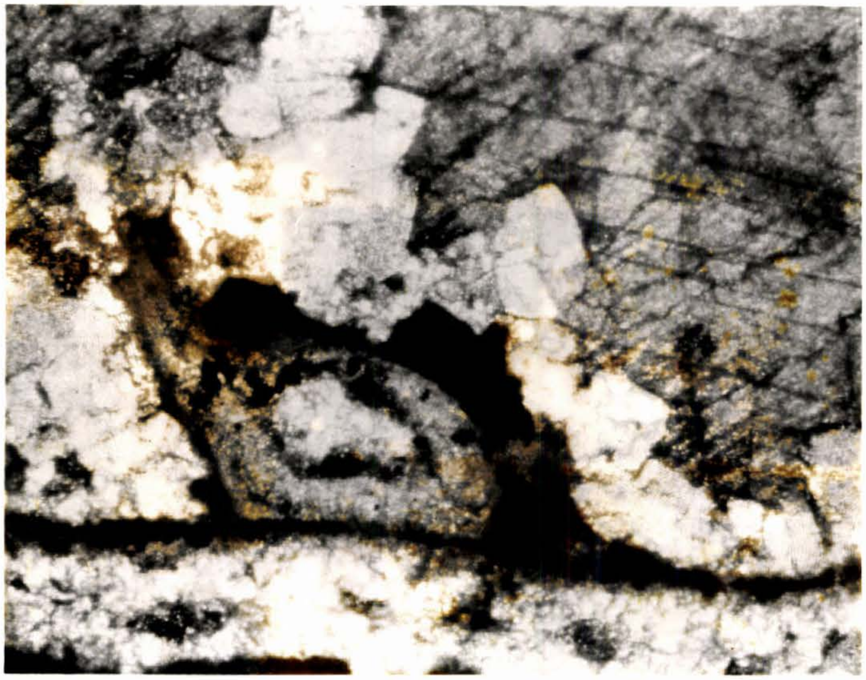


Figure 24b

Figure 25



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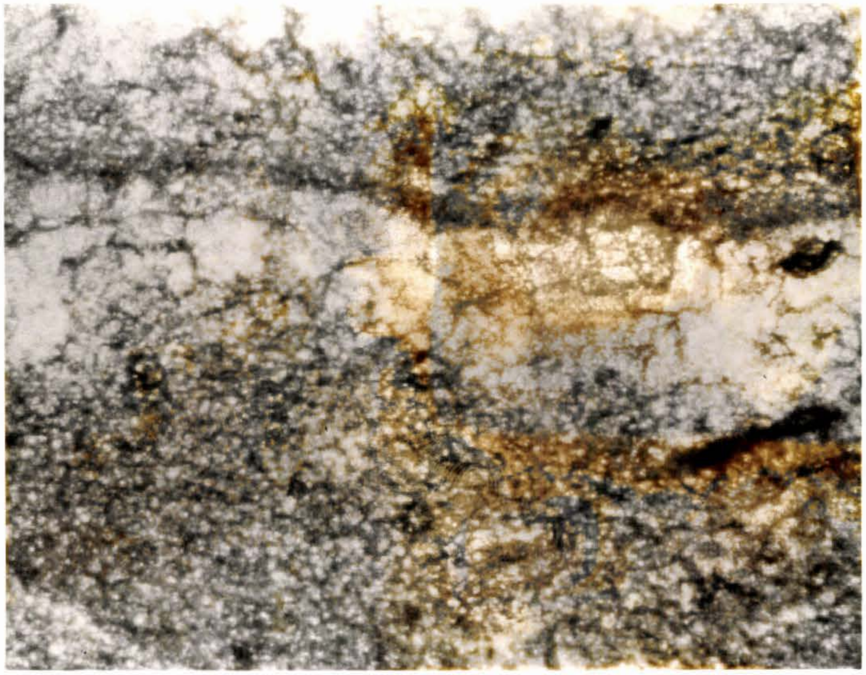
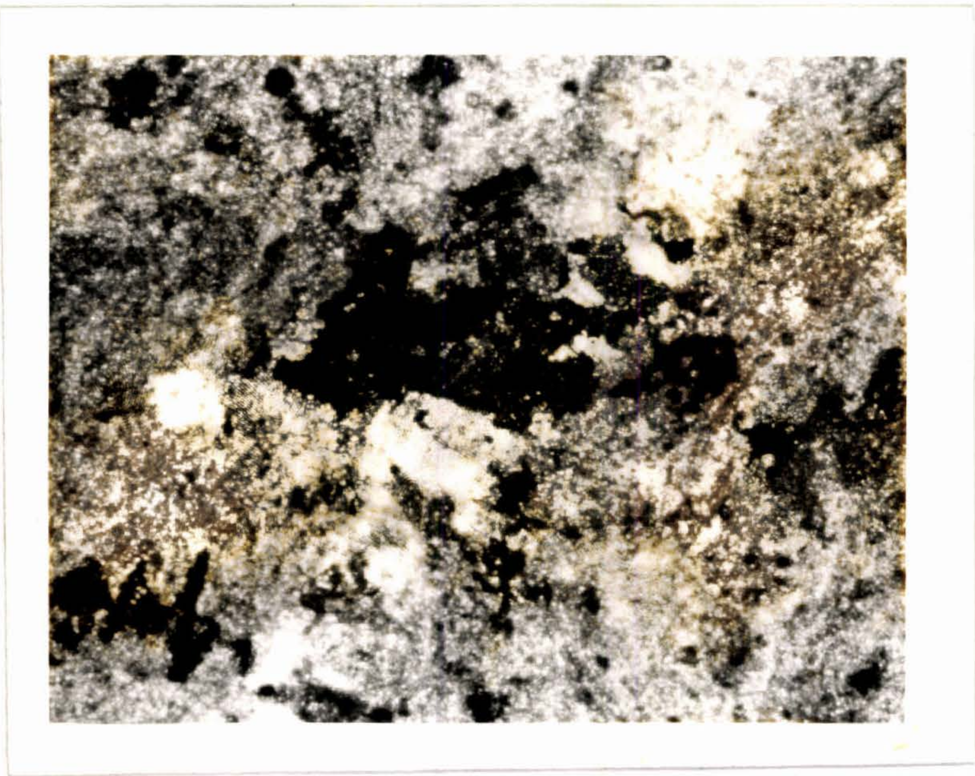


Figure 27

Figure 28



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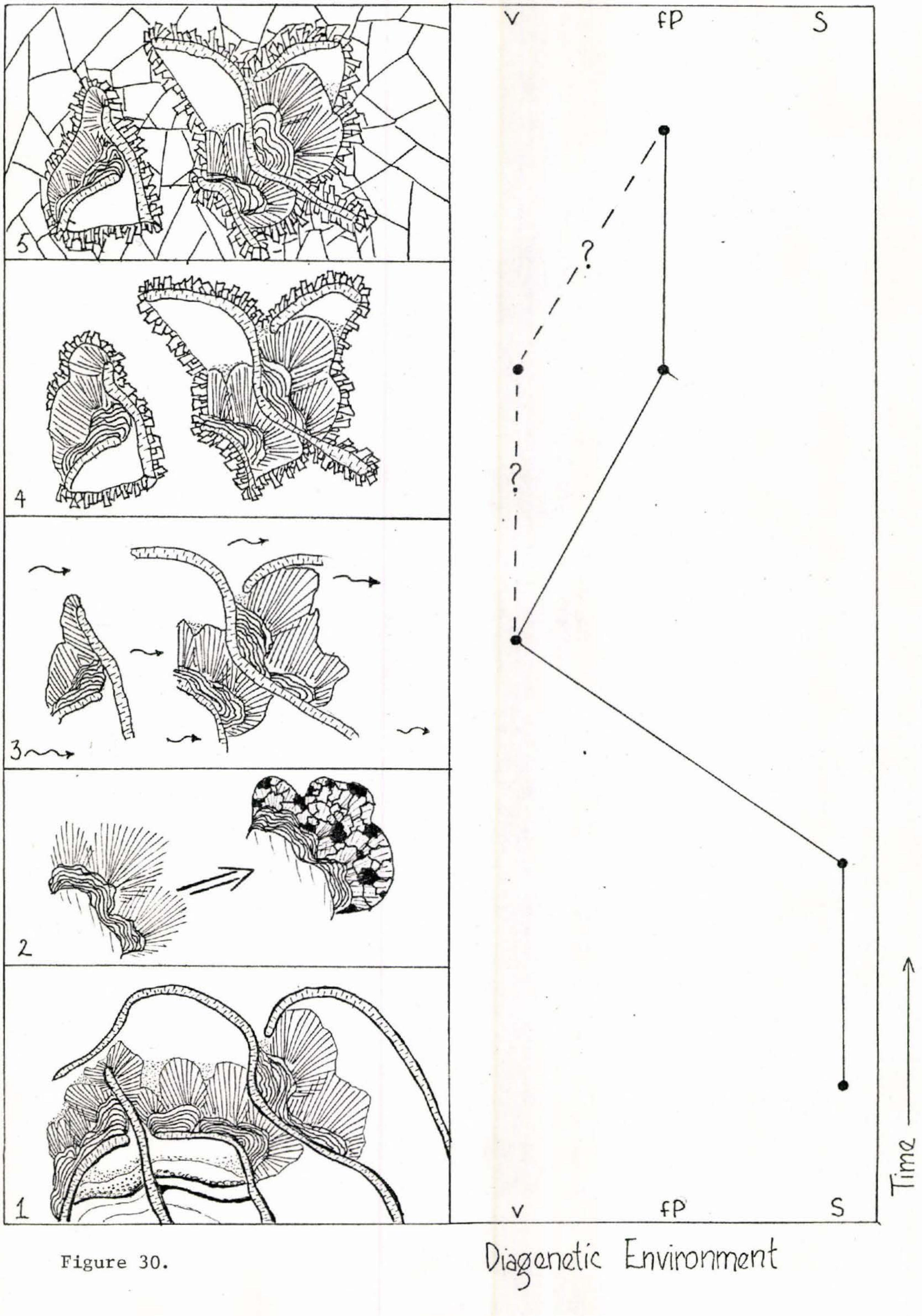

Figure 30.