PETROLOGY OF PALAEOSOLS AND OTHER TERRESTRIAL SEDIMENTS ON ALDABRA, WESTERN INDIAN OCEAN

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[Plates 1–5]

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Rocks exposed on Aldabra include at least six groups of marine deposits separated by terrestrial horizons. Sediments considered are divided into three major groups following important marine formations, the Picard Calcarenites, the Takamaka Limestone and the Aldabra Limestone.

Seven textural groups have been identified (1) homogeneous textures in unmodified sediments, (2) crumb-like aggregates of micrite believed to have developed in a dry system, (3) fractured sediments, resulting from drying of wet coherent micrites, (4) vesicular structures, (5) glaebular textures, including concentric glaebules, faecal pellets and bodies formed by inorganic processes of surface accretion, (6) pedotubules, resulting from penetration by rootlets or burrowing organisms and (7) laminate structures formed by incremental deposition of sediment controlled by organisms or, possibly, climatic factors.

Identification of the environments of deposition is confirmed by the presence of terrestrial faunas, but textures might be used alone to identify similar horizons within sequences where fossils are absent.

Deposits overlying the Picard Calcarenites include unmodified sediments consisting of marine bioclasts but containing terrestrial snails (*Trophidophora*), tortoise bones and rootlet horizons. With these are associated yellow-brown sometimes laminate soils with distinctive textures and a fauna which includes *Succinea*.

The Takamaka Limestone is overlain by deposits which include dense micrites containing well preserved rootlets, and texturally disorganized materials with cavities which have opened by shrinkage and differential compaction. Some are again strongly laminated. Multiphase cementation sequences are present in limited areas. At least two discrete terrestrial events followed the formation of widespread marine erosion surfaces.

The emergence which halted deposition of the Aldabra Limestone brought about the formation of laminated crusts, solution cavity fillings (some containing large numbers of tortoise and other bones), cave deposits, stromatolites and soils, probably in a series of discrete events rather than during a single extended time interval.

Within the terrestrial sediments diagenetic evidence proves unreliable in indicating the complexity or frequency of environmental changes of individual samples. Once a stable mineralogy is established the potential for alteration is confined to the periphery of the rock unit.

Mineralogically most of the sediments are calcite but small quantities of chlorites and phosphates have been detected. Insoluble residues appear not to contain clays and the bulk are believed to be derived ultimately from organic sources.

INTRODUCTION

This account is concerned with the petrography and sedimentology of a series of terrestrial sediments from Aldabra, a raised atoll in the Western Indian Ocean, figure 1 (lat. 9° 24′ S, long. 46° 20′ E). Samples were collected from June to September of 1969 during phase 8 of the Royal Society's Aldabra Expedition.

There is an extensive literature on continental soils, and residual deposits, of which caliche (Blank & Tynes 1965; Aristarain 1971), bauxites (Valeton 1972; Gordon, Tracey & Ellis 1958), laterites (Mohr & van Baren 1954) and similar duricrust deposits (Goudie 1973) are perhaps the best known. Little attention has been paid to such sediments in marine-influence situations, although examples have been described recently from Bermuda (Ruhe, Cady & Gomez 1961), Florida (Multer & Hoffmeister 1968) and Barbados (James 1972*a*, *b*).

Terrestrial sediments provide important evidence of intervals of emergence within dominantly marine sequences. They have an obvious significance in marking sea-level fluctuations,

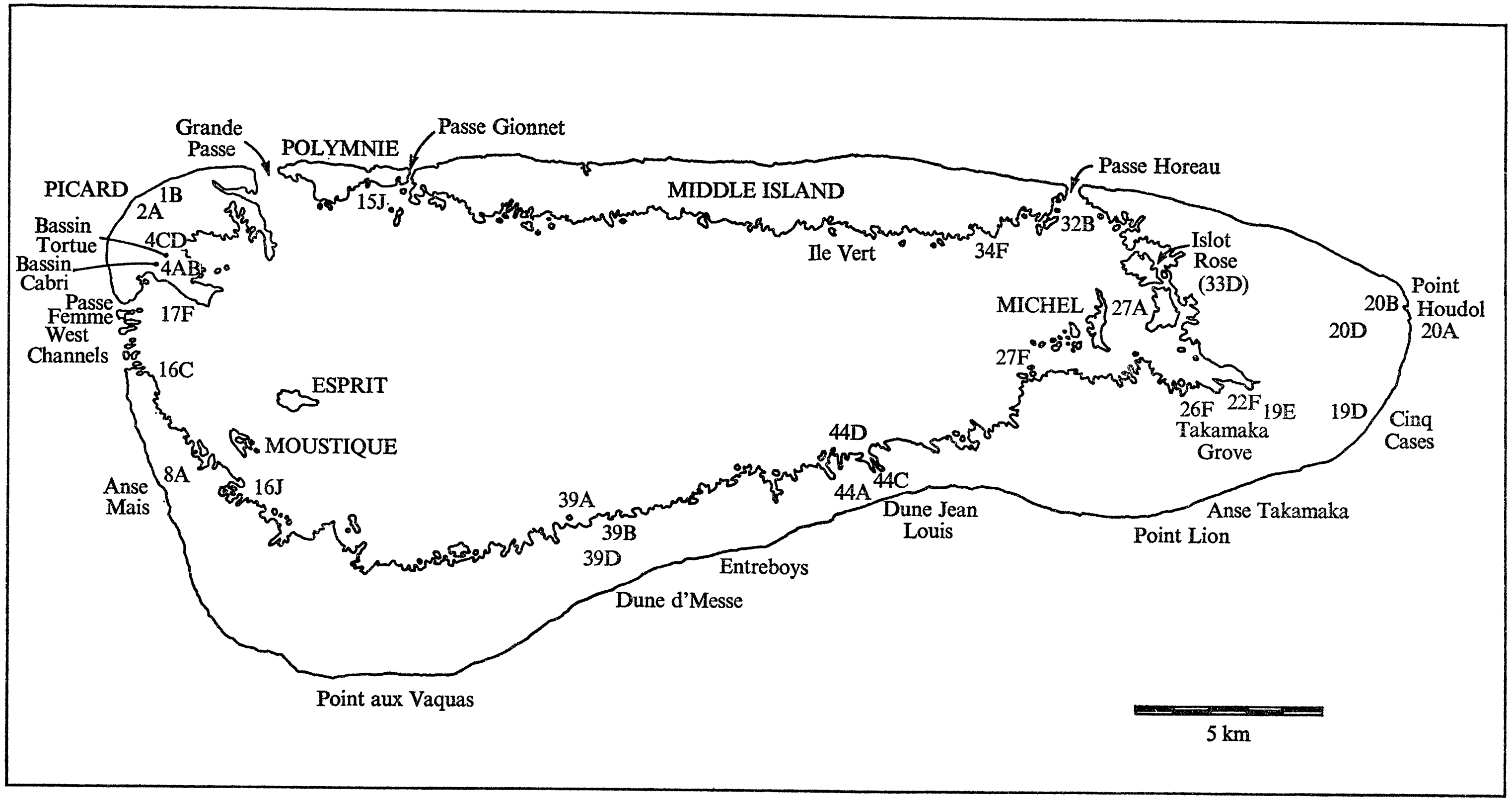

FIGURE 1. Locality map of Aldabra, numbers refer to sample groups described in the text.

and dramatic variations in depositional environment, but also record periods of abrupt change in the diagenetic regime of sediments beneath. Their faunas reveal patterns of colonization and extinction of particular species in the area and are thus of special importance to regional biogeography.

The mechanisms of deposition differ radically from those of other sediments and syn- and post-depositional processes are important in producing a number of distinctive textures. In the examples described the faunal content and stratigraphic situation leave little doubt as to the nature of the depositional environment. Elsewhere textural characters alone might be used as criteria for the recognition of terrestrial deposits. These, and the diagenetic fabrics associated with them, form the main subjects for discussion.

Summary history of Aldabra

The stratigraphy of Aldabra is described by Braithwaite, Taylor & Kennedy (1973). Limestones which range from late Pleistocene to Recent form discontinuous layers which reach about 8 m above sea level (figure 2). These record a pattern of emergence and submergence in which sedimentary units result from separate periods of deposition. The general stratigraphy is illustrated in figure 2 and table 1, but it seems necessary to summarize depositional history.

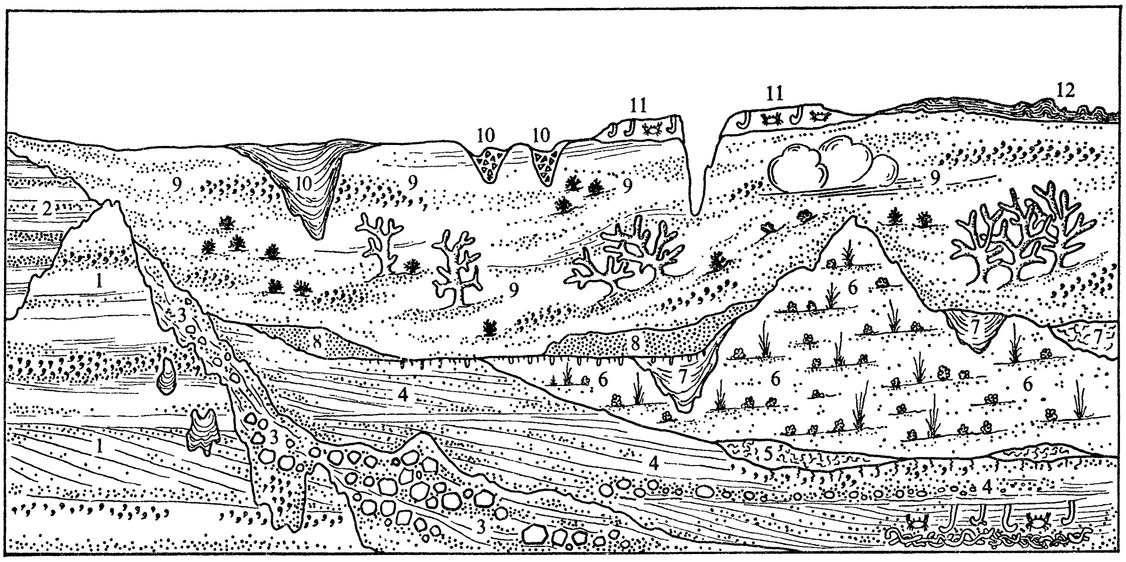

Figure 2. Stratigraphic model for Aldabra. Stratigraphic model for Aldabra indicating general relationships of terrestrial and marine units. Lateral scale approx. 10 km, vertical scale 9 m. Bed thicknesses not to scale. 1, Esprit Limestones; 2, Esprit Phosphorites: oolites; 3, Esprit Phosphorites: conglomerates; 4, Picard Calcarenites; 5, post-Picard Calcarenite 'soils'; 6, Takamaka Limestone; 7, post-Takamaka Limestone 'soils'; 8, hard calcarenites with *Strombus-Polynices* fauna; 9, Aldabra Limestone; 10, post-Aldabra Limestone solution pits and fillings; 11, crab-burrowed calcarenites; 12, Stromatolites.

The oldest sediments exposed on Aldabra are the *Esprit Limestones*, shelly calcarenites, probably deposited on a shallow subtidal platform. The succession, about 8 m thick, records a period of progressive shallowing. These rocks were subject to sub-aerial solution before deposition of the *Esprit Phosphorites*, oolitic, laminated and conglomeratic phosphatic sediments which may represent two separate phases of sub-aerial deposition.

The next well defined event resulted in deposition of the *Picard Calcarenites*. Proto-Aldabra was probably again a broad subtidal platform on which coarse calcarenites, extensively burrowed by crustaceans, accumulated. Beach deposits prograded across these to form a low vegetated sand cay of about 20 km^2 area at the western end of the platform. This was populated by tortoises, crocodiles, lizards, birds and land snails. A second cay, covered in aeolian sand dunes but of unknown area, was present to the east.

Sea level at this time probably stood a little below present datum, but it rose by at least 4 m to deposit the *Takamaka Limestone*. This varies from coarse calcarenite to calcilutite, and contains numerous fragments of *Lithothamnion* but few corals. No dates are available for the duration of this period. It was terminated by a fall in sea level which produced a superficial lithification of exposed sediments and extensive sub-aerial solution. The resulting surface was delicately fretted, with red-brown residual soils accumulating in hollows.

TABLE 1

unit	inferred sea level relative to present	unit number in figure 2
Terrestrial Sediments	up to −100 m	10, 12
Aldabra Limestone	+10 m	8, 9
Terrestrial Sediments	+0.5 to +1 m	7
Takamaka Limestone	+4 m	6
Terrestrial Sediments	+1 m	4, 5
Picard Calcarenites	+1 to +2 m	4
Esprit Phosphorites	+4 to +8 m	2, 3
Esprit Limestone	+8 m	1

These sediments are all limited by a marine planation surface bored by *Lithophaga* and *Cliona*. A brief re-emergence was marked by the local development of beaches, soils characterized by terrestrial snails, and low sand banks. These are, however, again limited by a marine planation surface.

The widespread deposition of the *Aldabra Limestone* has been positively dated at 125000 years B.P. Sediments are principally calcarenites with a rich coral and molluscan fauna. Growth-frame areas, occurring around the outer margins of present outcrops, probably formed behind any reef-edge zone which may have been present. Sea-level ultimately rose to at least 10 m above present datum, but it did so gradually. Brief emergence is suggested by the local presence within the sequence of irregular surfaces coated with brown laminated crusts. These are believed to be of sub-aerial origin.

The subsequent fall in sea-level was punctuated by still-stands at 8 m and 4 m above present datum. Proto-Aldabra consisted of a circle of low rocky islets with a shallow central lagoon. This land area was open to colonization by a new terrestrial fauna and flora, but associated terrestrial sediments can only be dated as post-Aldabra Limestone. Further marine withdrawal may have been by as much as 100 m during the last glacial interval. This would have formed a high rocky island surrounded by steep solution-eroded cliffs (cf. Purdy 1974). Terrestrial sediments were probably accumulating but, with the exception of one deposit containing species of *Trophidophora* now found in high forests on Madagascar, there is no positive evidence. The occupation of the island by a diverse fauna of tortoises, crocodiles, lizards and birds may have taken place before or after this low stand, but it is unlikely that such a fauna could have survived perched on 100 m high cliffs!

Since this period of maximum depression there has been a gradual rise in sea-level. There have undoubtedly been more terrestrial sediments deposited during this time. However, there is no means of identifying the relative ages of deposits which are spatially isolated.

The Aldabra sediments, therefore, include at least six groups of marine deposits, separated by terrestrial sediments. The exact content of any particular group is sometimes open to doubt, but the reality of the terrestrial intervals seems beyond question.

The present account is concerned with the calcareous and residual deposits, the phosphorites noted above are to form the basis of a separate publication. The terminology is that of Brewer (1964) and Brewer & Sleeman (1963, 1964) with variations in line with conventional petrographic descriptions following Folk (1962) and Dunham (1962).

TEXTURAL GROUPS

Seven major textural groups are recognized.

(1) *Homogeneous textures* occur in general in unmodified sediments which may be either calcarenites or calcilutites, ranging from mudstones to grainstones (Dunham 1962). They are recognized as having functioned as soils on the bases of fossil content (terrestrial gastropods) and the presence of rootlets. In Brewer's (1964) terminology they would be crystic or asepic fabrics. Vadose structures are generally absent even where micritic elements are a late addition (plate 1, figure 3). This may be an effect of grain-size. Small grains, because of boundary curvature and the surface tension of water films, are unable to support pendulous drops capable of generating microstalactites or similar structures (cf. Purser 1969).

The presence on present-day tropical beaches and dunes of uncemented calcarenites supporting growths of grasses, shrubs, or substantial trees (*Casuarina*, etc.) shows that such sediments can exist for long periods without cement. When cementation does occur, it may be in an entirely different regime.

Modified sediments have an irregular texture with mixed micritic and calcarenitic elements (plate 1, figure 4). This is markedly heterogeneous when compared to poorly sorted sediments generated by density current or similar means.

(2) *Crumb aggregates* are limited to the finer grained (micritic) sediments. They appear as irregular fine-grained aggregates of varying size, separated either by open voids or by calcite filling such voids (plate 1, figure 5). They have not been transported: the minute details of surface irregularities seem unlikely to have survived even moderate attrition. Bounding surfaces are not fractures and it is supposed that aggregates formed *in situ* in a moderately dry system. Micrite deposited in water might be expected either to form a uniform layer or, in the presence of larger grains, geopetal or vadose meniscus structures. Apart from the aggregates themselves

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DESCRIPTION OF PLATE 1

FIGURE 3. Calcarenite with introduced micrite components and rootlets (4A1); negative print.

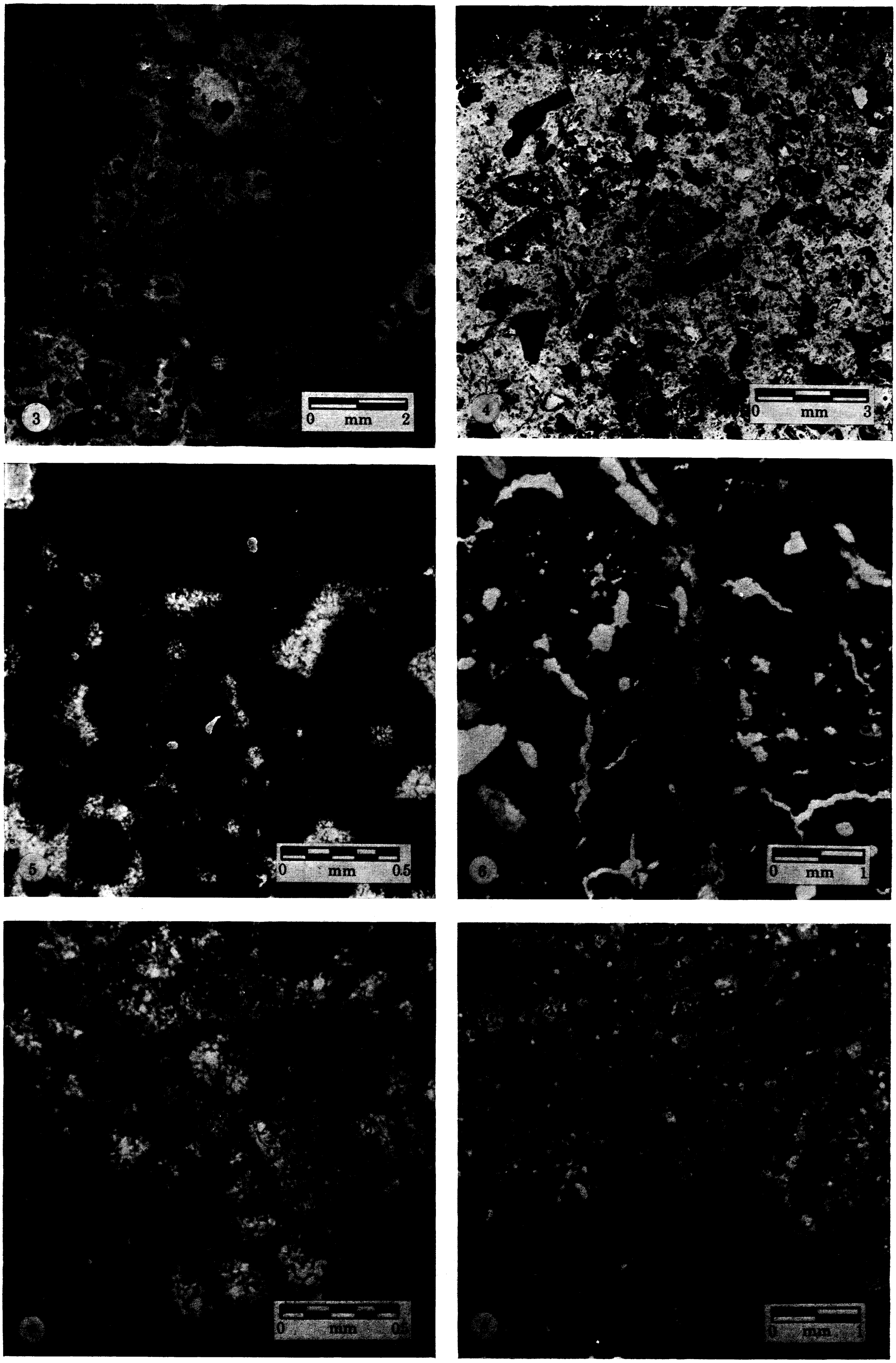
FIGURE 4. Irregular texture and poor sorting in soil (2B9); negative print.

FIGURE 5. Crumb aggregates of micritic particles with granular calcite cement (19D8A); photomicrograph.

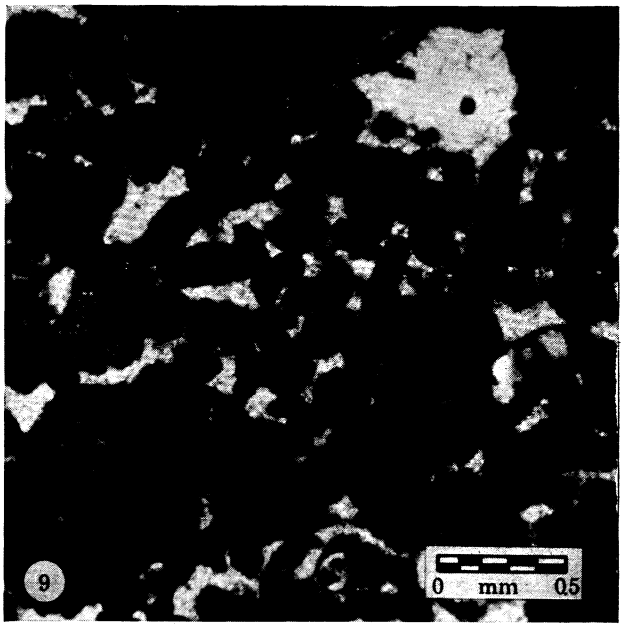
FIGURE 6. Dense micritic sediment with fractures caused by shrinkage. Note rootlet (5A2); photomicrograph.

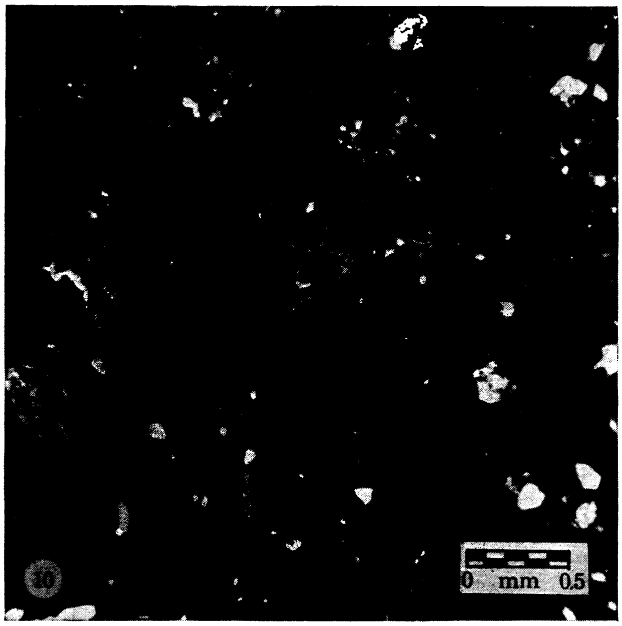
FIGURE 7. Vesicular structure (44C3C); photomicrograph.

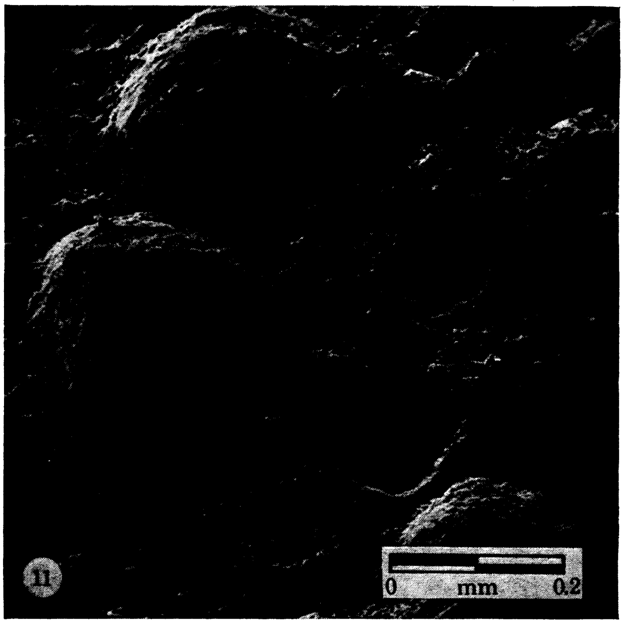
FIGURE 8. Amorphous glaebules (4C10); negative print.

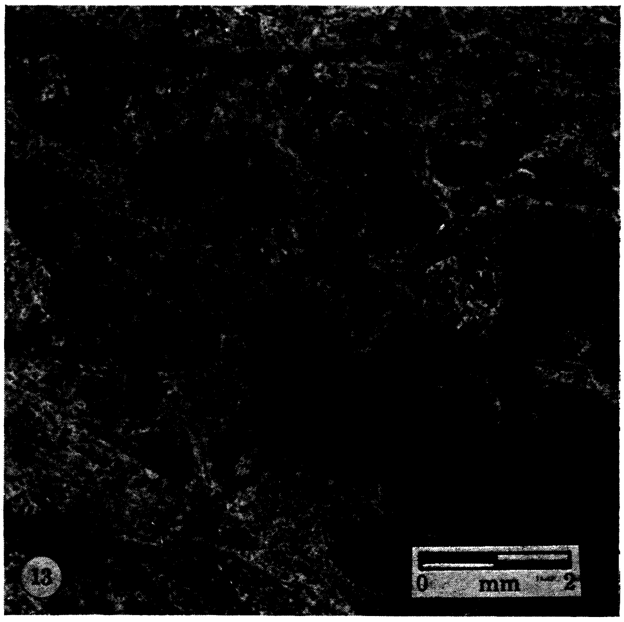


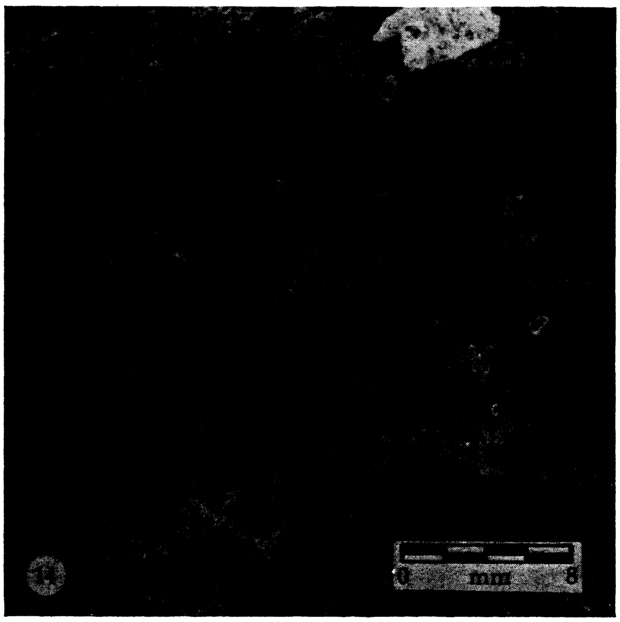
FIGURES 3–8. For description see opposite.











FIGURES 9–14. For description see opposite.

no large grains are present. Brewer (1964) referred to crystalline fillings of vughs, packing voids, fractures and other open spaces under the general term of 'crystallaria'. For the present purposes the conventional petrographic term 'cement' is preferred since in most cases the precipitate was not a feature of a functional soil.

(3) *Fractured sediments* have generally been produced by discontinuous wetting. The micritic sediment is coherent and subsequent drying has produced a series of tapering shrinkage fractures (plate 1, figure 6) which would be classified by Brewer (1964) as skew planes or craze planes. Two situations are recognized, one in which fractures separate lenticular sheets parallel to the depositional surface, and the other in which a polyhedral system defines more equant blocks (peds). In either case cavities are commonly filled with coarse granular calcite cement (crystallaria) and no sediment fillings or cutans have been seen. Polygonal syneresis cracks may be produced subaqueously but are thought of as being less extensive. Ostracods and rootlet moulds in some of these sediments support a model of drying fresh or brackish-water pools, but the terrestrial molluscs associated with others suggest that they were wet or damp rather than deposited in water.

(4) *Vesicular structures and 'birds-eyes'* occur in dominantly micritic sediments. 'Vesicular' structures are formed by thin micritic sheaths surrounding polygonal 'bubbles' (spar-filled spaces, (plate 1, figure 7). Bubbles, sometimes achieving quite high densities are known to form in intertidal sediments (Reineck & Singh 1973), where they may be preserved. High-gas-content 'vesicular' structures have, however, also been described in cultivated soils (Miller 1971) where they appear to result from a comparable process of alternate wetting and drying. The other structures which fall into this group are the so-called 'birds-eyes' (Shinn 1968). These are irregular cavities which form either as a result of gas bubble formation during emersion or by small-scale grain-support ('umbrella' or grain-arch effects). There is some evidence that 'birds-eyes' as described by Shinn (1968) are formed in the intertidal or immediate supratidal, but similar irregularly supported cavities also form in desert soils (Evenari, Yaalon & Gutterman 1974).

(5) *Glaebular textures.* As defined by Brewer (1964), glaebules are minute soil units which differ in constituents or fabric from the enclosing soil matrix. They thus include nodules, concretions, septaria and related forms recognized by sedimentologists (cf. Pettijohn 1957), as well as bodies which would be described as 'pellets' (plate 1, figure 8). (This grouping of two genetically unrelated assemblages has led to some confusion.) Within the last group are well defined, uniformly sized, oval pellets which consist of amorphous micrite and are faecal in origin (plate 2, figure 9). Some are ascribed to *Cardisoma* and *Sesarma*, but without body-fossils they are non-specific and cannot be used as environmental indicators. A number of sediments contain con-

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DESCRIPTION OF PLATE 2

FIGURE 9. Faecal pellets with sparry cement (28A2); photomicrograph.

FIGURE 10. Concentric glaebules (2B13A); photomicrograph.

FIGURE 11. Scanning electron microscope photograph of surfaces of concentric glaebules (4C11).

FIGURE 12. Burrows with faecal pellets in micrite sediment with rootlets (3B7); negative print.

FIGURE 13. Well preserved rootlets. Note cellular structure preserved in areas outlined (17M6); negative print.

FIGURE 14. Peat-like structure of sediment packed with rootlets. Contact with marine calcarenites along upper and lower margins (23A3); negative print.

centric glaebules, spheres or spheroids of millimetre or sub-millimetre dimension with a well defined concentric structure (plate 2, figure 10). The grains forming these show no preferred orientation such as is seen in ooliths, and there is no trace of the tangential needle fibres described by James 1972*b*). S.e.m. photographs reveal minute angular flake-like particles which appear to have been plastered onto exposed surfaces (plate 2, figure 11). Glaebules commonly occur without any matrix, bound together by a granular calcite cement so that the sediment is texturally an 'oosparite' or pelsparite. Oolitic and pisolitic structures in aqueous environments are generally crystalline, zonal forms indicating successive levels of accretion as in marine (Bathurst 1971) and fresh-water oolites (Donahue 1969; Baker & Frostick 1947). They are also quite common among soils and have been recorded in laterites (Gordon *et al.* 1958), bauxites (Gordon & Tracy 1952; Valeton 1972) and caliche (Swineford, Leonard & Frye 1958; Rutte 1958). These last sub-aerial examples are particularly relevant since relationships suggest that free-rolling accretion of ooliths would not be possible in the present deposits.

In general, sediments containing concentric glaebules (pisolites) are believed to result from a climatically controlled (seasonal) alternation of wet and dry periods. Opinion differs, however, as to the relative importance of particular seasons and often omits reference to the precise position and manner of formation of these bodies. Siesser (1973) believed ooids in South African calcretes to have formed by a diagenetic solution/precipitation process. Swineford *et al.* (1958) and Reeves (1970) ascribed caliche pisolite formation to alternating seasons, the former emphasizing a generally arid climate with wet periods, the latter feeling that a balance between humidity and aridity was ideal, with local temperature, precipitation, and run-off acting as controls. Gordon & Tracey (1952) favoured a generally moist climate for the formation of pisolitic bauxites, with rainfall exceeding precipitation for most of the year. This, and a temperature of more than 25 °C provided an environment in which the soil microflora was able to destroy humus faster than the macroflora could manufacture it. Swineford *et al.* (1958) also held that a warm climate with abundant rainfall and short dry periods was necessary for the formation of pisolitic bauxites. Brewer (1964) believed that concentric fabrics in general were commonly a result of alternate wetting and drying.

It is difficult to see, in the present case, why finely divided particles, carried in intermittent water films, should be deposited on the surfaces of spheres rather than in the lower levels of intergranular voids. There is a strong argument against any process which would not promote a progressive dispersion of the centres of accretion. Separation of grains would be necessary to accommodate successive laminae and any failure would inevitably mean a progressive occlusion of intergranular porosity and the assumption of a polyhedral faceted surface by individual 'ooids'. Such fabrics, which have a strong directional quality, and are commonly graded, have been figured by Dunham (1969) from caliche and cave-pearl deposits. However, even in these cases it is evident that there has been a separation of nuclei. The implications of this are far reaching since the material added to nuclei would require a large increase in sediment volume.

Given that the control over concentric structures is likely to be climatic, zoning might result from a number of processes. Laminae may be produced by some purely chemical process and be analogous to Liesegang rings. These are ruled out by s.e.m. evidence and by the absence of sediment between 'grains' in which diffusion centres might have formed.

Three possibilities remain: growth (crystallization) of material precipitated from solution, or the mechanical accretion of colloidal or clastic particles. It is tempting, since these soils are calcareous, to relate their origin to that of calcretes, caliche and the like, particularly where pisolitic and laminated structures are concerned. Such ideas are rejected: there is no evidence in the petrography which suggests that any of the structures were formed during emplacement of the cement. On the contrary, almost all of them appear to have formed a coherent framework which was structurally unaltered by cement deposition. Goudie (1973) points out that it is common for calcretes to contain more carbonate than could be accommodated by the original pore-space in the parent sediment. It is evident in these that crystals do physically push grains apart and displace point-to-point contacts. In the present sediments this would require a phase of growth, for which there is no evidence, to precede cementation.

The general appearance of concentric bodies under both the optical microscope and s.e.m., and the inclusion of 'foreign' bioclasts and other grains are sufficient to suggest a purely mechanical accretion of clastic particles. Some of these may be organic and may have been colloidal. Whatever the process of accretion the weight of overburden would be the main factor in limiting any natural tendency (such as force of crystallization) to move grains apart. It therefore seems an inescapable conclusion that these concentrically zoned bodies were formed at or very close to an air/sediment interface. In this situation dispersal may be aided by swelling or shrinkage of organic components, but primarily by actual physical movements promoted by normal surface processes such as rain-wash and infiltration. In spite of many statements to the contrary there seems to be no convincing evidence that such accretionary growth is mechanically possible beneath a sediment load.

(6) *Pedotubules* (Brewer 1964) are of two kinds. First are animal burrows, generally of a few millimetres diameter and most obvious where they contain faecal pellets (plate 2, figure 12). The relative size of structures suggests that several species are involved. A few sediments consist largely of pellets believed to have been formed by *Cardisoma*, but no large-scale tubular structures have been recognized, presumably because of the normal high density of burrows and reworking of fillings.

Tubules have also been formed by sediment being thrust aside by rootlets (plate 2, figure 13). Some are hollow or lined with fine-grained laminated coatings (cutans), generally of similar mineralogy to the host sediment, and have sometimes been filled by growths of sparry calcite. Other tubes contain well preserved plant tissue and a few sections resemble peats figured by Cohen (1973) although they have added fine grained carbonate material between roots (plate 2, figure 14). Good preservation may indicate deposition in a somewhat acid environment since Brewer & Sleeman (1969) noted that such conditions tend to preserve plants while alkalinity destroys them. A possible analogy is seen in the association of some peats with freshwater marls in the Florida Everglades.

(7) *Laminated structures* occur in a variety of forms. They include laminae produced by deposition of successive sediment increments draped from the walls of cavities, stromatolite-like forms, and laminae which resemble those developed in caliche deposits. Laminae produced by discrete depositional events, even where these are biologically controlled, are defined by variations in grain size (plate 4, figures 24, 27 and 28). These are accompanied by variations in porosity and, sometimes, differences in cementation. The most distinctive are formed where concentric or amorphous glaebules are present in graded layers, but laminae visible in the field may be less obvious in section. Where such textural changes are involved, it seems unlikely that lamination could have formed *in situ* and some degree of transport, perhaps in rainwash, must be involved in their generation.

Many laminated crusts closely resemble those figured by Multer & Hoffmeister (1968) and some of these described by James (1972*a*, *b*), Kaye (1959), Newell & Rigby (1957) and Purser & Loreau (1973). At least some of them (17F1A) derive their laminate character from the presence of plant tissues, and may be analogous to laminate peats (cf. Cohen 1973). If this is so the sediment may not originally have been calcareous, but have become so by replacement. However, this cannot apply to sediments lacking plant debris. Fossils indicate that some of these materials are of sub-aerial origin. Multer & Hoffmeister (1968) ascribed porous crusts to formation beneath a relatively thick aggrading tropical forest cover, while dense crusts were believed to form beneath thin azonal soils. These authors suggested a mechanism of solution of carbonates by acid waters within the soil and re-precipitation at the soil base overlying bedrock. A similar process forming laminae above an impervious horizon was outlined by Flach, Nettleton, Gile & Cady (1969).

These solutions to the problem seem to have been intuitive rather than observational. In the area investigated limestone surfaces are available from which soil has been stripped by erosion. In none of these is there evidence of coating by incipient crust formation.

Crusts similar to those described by Multer & Hoffmeister (1968) can be observed in the Florida Keys, in the Nicollstown area on northern Andros and on Eleuthera in the Bahamas. Some of these deposits were briefly described by Newell & Rigby (1957), who were unable to suggest any origin. However, they found high magnesium contents which may imply the influence of marine-derived waters.

There is a strong morphological resemblance between some laminated crusts and aragonitic coatings described by Purser & Loreau (1973). Although these authors drew a distinction between non-marine, soil related, crusts and supratidal aragonitic laminates (coniatolites), there seems to be no sharp boundary which allows these two groups to be differentiated where the aragonite has altered. Kay (1959) described some laminae formed by algal accretion and others by an *in situ* alteration.

The laminated horizons described by James (1972*a*, *b* and personal communication) from Barbados can be seen to have arisen *within* a limestone sequence. They are the result of an *in situ* process of alteration and solution. Very few of the present examples (see descriptions of post-Aldabra Limestone deposits) show any sign of soft-sediment interfaces.

The present work has suggested no improvement to these theories but no clear support either: observations suggest deposition of a *detrital* sediment or at least mobile grains. Precipitation might be expected to produce crystals with a directional fabric related to existing grains, which has not been identified (compare work by Thorstenson, Mackenzie & Ristret 1972), or a displacive fabric in which allochems 'float' in a neomorphic matrix.

It seems likely that red-brown laminated crusts are of a number of different origins. Those on Aldabra, Andros and Eleuthera appear similar and their formation must be seen in terms of some widespread and common process.

Field relationships of terrestrial sediments

A quasi-stratigraphic description has been adopted to give some order to this heterogeneous group. Rapid lateral changes in character are normal in the environments represented, and diagenetic features often do not provide evidence of the relative age of deposits. Field relations commonly only indicate a maximum relative age.

The sediments may be divided into three groups, overlying and post-dating respectively, the

Picard Calcarenites, the Takamaka Limestone and the Aldabra Limestone (see table 1 and figure 2). Within each group individual occurrences can only be related to each other in their apparent stratigraphic position. Because of the inherent difficulties of reproducibility descriptions will be based on reference to specific samples in the author's collection. Localities are given on figure 1 and general relationships shown on the diagrams indicated.

The Picard deposits

Description

The Picard deposits occur principally within the Bassin Cabri area and on adjacent lagoon shores of Picard. Two kinds of sediment are involved: those formed by modification of the calcarenites themselves, and later additions.

The calcarenites in this area are cross-bedded in sets of about a metre with cross-laminae spaced at intervals of a few centimetres, dipping in a westerly or south-westerly direction. Smaller sets of 10–20 cm can be found locally, together with a few shallow channel-like forms. These sediments have a total exposed thickness of about 3 m, but the base is not seen.

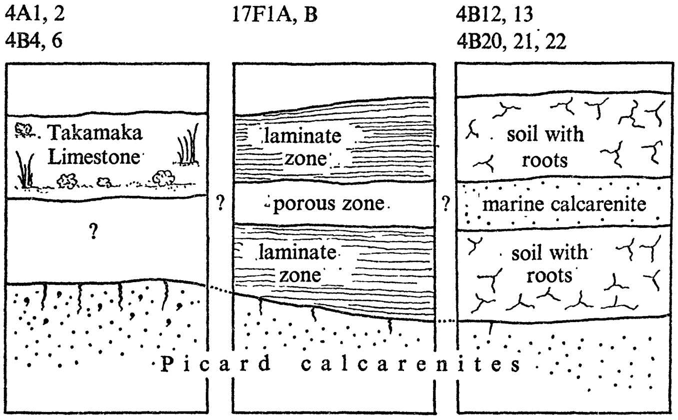

FIGURE 15. Schematic diagram illustrating general relationships of terrestrial sediments overlying the Picard Calcarenites. Numbers are of specimens referred to in the text. No intended scale.

Towards the top of the sequence more massive units contain scattered bones of tortoises, including some partially articulated skeletons, and numerous moulds of the terrestrial gastropod *Trophidophora*. Rootlet moulds are common, generally occuring as open tubules lined with friable brown oxidized plant tissue. Two rootlet horizons are present in the West Channels area.

Rootlet-bearing calcarenites (4A1, 2; 4B4, 6) are biomicrites (dominant) and biosparites. Mean grain-size of allochems is 0.3–0.7 mm maximum diameter, although some larger particles are also present. Recognizable bioclasts include fragments of calcareous algae (*Lithothamnion*, *Lithophyllum* and *Amphiroa*), echinoderm plates, calcite mollusc shells, forams (*Amphistegina*, *Marginopora*, and *Homotrema*), ostracods, a few bone fragments and lithoclasts. Some grains have been replaced *in situ* by brownish coarse crystalline calcite which retains traces of their original structure. These are accompanied, however, by numerous spar-filled cavities produced by early solution of aragonite bioclasts. Since fillings were deposited at the same time as the granular cement in biosparites, the grain margins in these are only defined by dusty micrite envelopes.

In the biomicrites irregular pedotubules are present (plate 3, figure 16) filled with a brownish micrite. They are differentiated by alinements of bioclasts and were probably formed by burrowing organisms. Other tubules, formed by rootlets, have remained open and are lined with granular calcite. These occasionally contain traces of cellular plant tissue.

These calcarenites were cemented and subject to solution before deposition of the group of soils which lie above them (see figure 15). Close to the contact the intergranular cement can be differentiated into three zones. The inner zone, developed on bioclast surfaces, is granular and essentially one crystal thick. It is separated from the outer by a dark zone which was apparently fibrous, fibres occurring as inclusions within blocky crystals. The outer zone is a clear blocky calcite. Locally the cement lacks these zones and is formed entirely by large crystals in optical continuity with those replacing grains. Larger solution cavities contain similar sequences but in some the fibrous zone rests on a solution-eroded calcite surface while others contain only clear granular calcite.

On a larger scale these cements are overlain by terrestrial sediments (plate 3, figure 17). These brownish fine-grained porcellanous limestones occur south of the Bassin Cabri pools (4B12, 13; 4B20, 21, 22). A typical occurrence (4B20) 10–15 cm thick includes three well defined layers.

(1) The lowest layer is white, grading into a pale yellowish brown (10 YR 6/2, U.S. Geol. Soc. Munsell rock colour chart) finely laminated sediment penetrated by darker rootlet tubules. Microscopically, lamination is less obvious, the sediment is a relatively homogeneous brown biomicrite packed with ostracods and, towards the upper margin, (?) miliolid forams. Burrows are indicated by local alinements of bioclasts. Irregular cavities contain a consistent sequence of deposits. The earliest is a dense greyish micrite which is sometimes crudely laminated parallel to cavity walls. This was probably eroded before deposition of a micropelleted micrite which forms geopetal layers on floors. Pellets are probably biogenic. These sediments are cemented by coarse granular calcite which fills residual voids.

(2) This unit is overlain abruptly by 5–15 mm of white calcarenite, a biomicrite (packstone), resting on a well defined erosion surface (plate 3, figure 18). Bioclasts include calcareous algae (*Lithothamnion* and *Amphiroa*), mollusc shells, forams (*Marginopora* and *Amphistegina*) echinoderm fragments and occasional chips of bone. Allochems presumed to have been aragonite have been removed by solution and the moulds filled by granular sparry cement. Although thin, this calcarenite is important, since it represents a discrete incursion of fresh, marine-derived, sediment onto a lithified surface. It was certainly lithified itself before deposition of the sediment above since bioclasts are truncated against the limiting surface.

(3) The upper sediment is dark yellow brown (10 YR 4/2) at the base, grading up into white. Tapering fractures form an anastomosing network isolating angular blocky peds (plate 3,

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Description of plate 3

Figure 16. Biomicrite (4A1) Bassin Cabri; note particularly penetration by rootlet (outlined); photomicrograph.

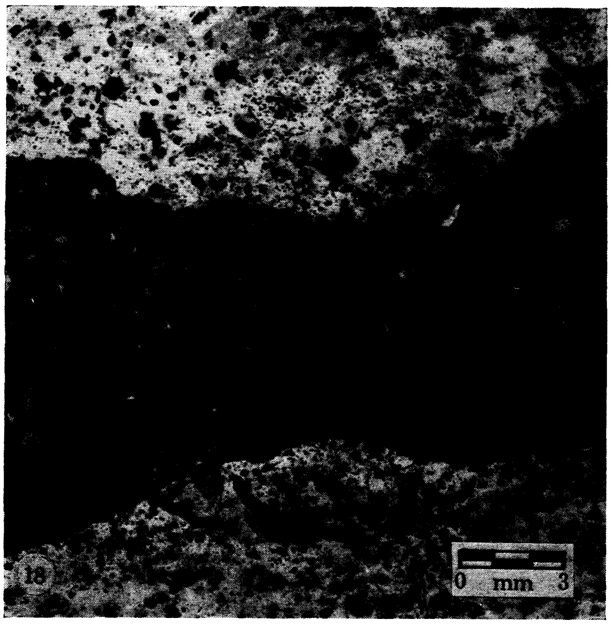
Figure 17. Contact of glaebule-bearing sediment overlying cemented soil (note truncated cement filling fracture), (4B4); negative print.

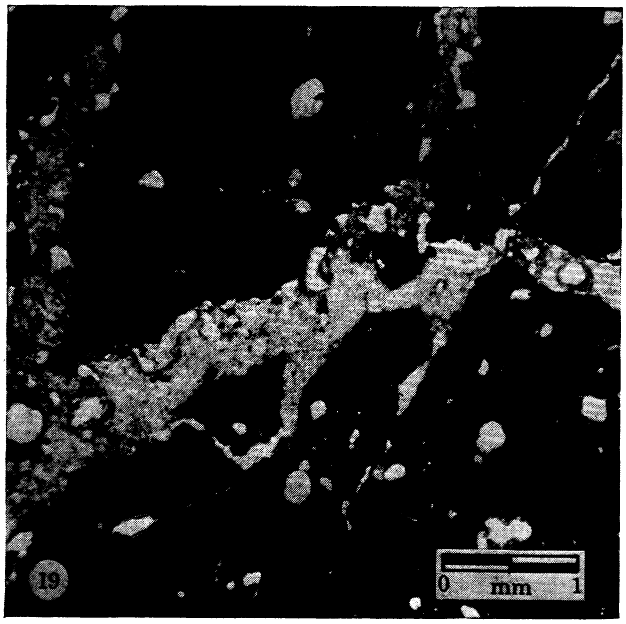
Figure 18. Marine intercalation between two terrestrial sediments (4B20); negative print.

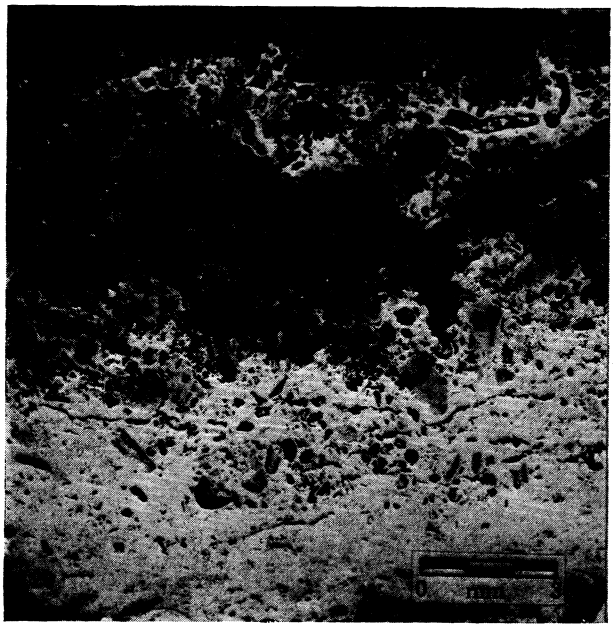
Figure 19. Fractures in ostracod bearing micrite (4B22B); photomicrograph.

Figure 20. Transitional contact between soil and *Halimeda* bearing biosparite (27A2); negative print.

Figure 21. Soil with loosely packed amorphous glaebules (4C10); negative print.







Figures 16–21. For description see opposite.

figure 19). Specimens of *Succinea* leave no doubt as to the sub-aerial origin of this deposit which is a dense micrite, crudely laminated parallel to the lower surface and containing many ?miliolid forams and ostracods. A few coral fragments retain a fibrous structure but are not thought to be aragonite. Numerous minute (70 μm maximum diameter) oval bodies (faecal pellets?) appear close to the lower surface. Occasional burrows are indicated by open cavities or alined bioclasts. Areas of greyish calcite are common; the majority fill secondary voids formed by solution of unstable bioclasts, but there is also an extensive cavity system. As in the calcarenites below, this contains a complex depositional sequence. The earliest sediment was a dense grey micrite. This was probably solution eroded before deposition of a micropelleted micrite which was cemented and overlain in turn by a thin coat of well-terminated granular crystals. These are themselves overlain by a zone of dusty micrite separating them from the final granular calcite cement. This sequence is not ubiquitous and the history of individual cavities may have begun and ended at different times.

Strongly laminated sediments (17F1A, B) of similar age to these deposits occur on islands in the West Channels area. Cross-laminated Picard Calcarenites with *Trophidophora* are overlain by a laminated porcellanous layer (1.5 cm thick), a porous amorphous layer (3 cm), a second laminate layer (1.5 cm) and, at the top a porous amorphous sediment (2 cm) (figure 15). The calcarenites, as elsewhere, are biosparites with micritic patches. Most bioclasts have been removed by solution and are represented by micrite envelopes in the granular cement. Some molluscan and coral fragments have been replaced *in situ* by coarse brownish calcite charged with inclusions. Calcareous algae are among the few allochems retaining their original structure.

These calcarenites may have been case-hardened, but were probably not cemented before deposition of the lower laminate zone. At their upper margin the cement in intergranular spaces is differentiated into two layers, the brownish basal layer retaining traces of a fibrous structure. The laminate horizon is of brownish micrite, but cellular plant tissue is common and includes frequent sections through roots and sheet-like structures which may be leaf-bases. Some cavities are residual spaces between micritic clasts or plant debris, but elongate lenticular fractures have formed by sediment shrinkage, and more irregular cavities by internal erosion. These last two reflect different degrees of coherence in the sediment at the time of formation. All are lined with coarse granular calcite.

The central amorphous zone is not distinctive in section. Bioclasts increase in frequency (towards a packstone) but rootlets are still present and cavities have sometimes formed around their shrunken remnants. The upper contact is abrupt and overlain by dense micrite with many cellular sheets partly defining a laminate structure. At the top of this layer the micrite is organized into pellets (amorphous glaebules), forming a loose pelsparite. Some of these are well shaped and may be faecal, but less regular forms are of indeterminate origin. The cement is generally clear granular calcite, but in a few cavities a thin micrite separates a basal single-crystal layer of brownish calcite.

Interpretation

The three sequences described relate to sediments overlying the Picard Calcarenites but are, presumably, older than the Takamaka Limestone. They are non-marine in origin but differ in details of formation.

The first occurrences (4A1, 2; 4B4, 6) form at the top of the Picard Calcarenites. Neither the grains, which are obviously 'marine', nor the structures, are specifically of soil origin, but the gastropods, tortoises, and other terrestrial fossils show that these were indeed sub-aerial sediments. The high concentration of bones and the rootlet horizons point to generally low rates of deposition, but the partially articulated skeletons are also important. Observations on the dispersal of modern tortoise remains suggests that these could only have been preserved by rapid burial, perhaps by storm overwash.

The post-depositional history of the sediment is also significant. Granular calcite cement may be deposited in a sub-aerial environment, although it could be marine, but the local fibrous cement probably represents an early marine or splash-zone cementation by aragonite.

There is no doubt that these sediments originated on the surface of an emergent sand cay and functioned as azonal soils. Although penetrated by burrowing organisms and by rootlets, they have been little modified and have developed few soil-specific structures comparable to those seen in some younger deposits.

Recent beach berm and dune sediments on the south coast of Aldabra are commonly colonized by small plants, (*Sporobolus*, *Fimbristilis*, etc.) and shrubs (*Pisonia*, *Scaevola* and others), without apparently developing more than a darkened organic-rich upper margin. They remain uncemented, and it is not known what kind of event would finally bring about their lithification.

The second soil group (4B4, 12, 13; 20, 21, 22) produced a number of problems. The Picard Calcarenites are limited by an erosion surface and there is no evidence of the time lag before deposition of the lowest soil unit nor of the total time involved in deposition. The thin calcarenite within the sequence is of marine origin, but does it represent a real marine event or is it the result of ephemeral storm overwash of a low island (cf. McKee 1959)? The fact that both upper and lower boundaries are erosional favours a marine explanation. The sequence of cavity fillings implies changes in environment over a relatively long history, while the similarity of cements in upper and lower sediments suggests that most of these post-date the deposition of the upper unit.

Perhaps the sediments originated in marine pools. In time these became brackish and, finally, fresh water. The original fauna (forams) was succeeded by ostracods, snails and burrowing organisms as pools dried out and sediments were colonized by plants. Shrinkage of damp coherent sediment in the upper unit produced tapering fractures. The sequence of events can be followed in both upper and lower units.

The third succession (17F1A, B) might also result from two event sequences. The Picard Calcarenites may have been case-hardened, forming a surface on which an organic soil could be deposited. The increasing bioclast content of this might result from storm overwash. The second organic layer represents a renewal either of plant growth, or of the supply of plant detritus but, as the soil became thicker, animal and microbial activity promoted breakdown of plant debris and the formation of a more open structure. The local brownish cements may originate from calcitizing fluids which preserved plant tissues, both result from events which probably occurred some time before deposition of the clear granular calcite cement.

In these three groups of sediments, cement characters and cement sequences offer no clear guide to depositional history: there is no general correlation between cement complexity and age. The fibrous cement, where present, was probably originally aragonite, formed in a marine environment. No such cement survives, the granular calcite replacing it is ascribed to freshwater deposition, although the only evidence of non-marine origin is the negative factor of presumed stability of aragonite in a consistent marine environment. The complexity of cements in some samples reflects a varied diagenetic history and, that being so, the most important point about such cements is their general absence from many areas. This follows from the fact that once a granular high magnesian (marine) or low magnesian (fresh-water) calcite is established it will remain unchanged in form. If it completely fills intergranular spaces, short of solution, there is no opportunity for any other cement to be added to it, however complex the history.

The Takamaka deposits

Description

The lower margin of the Takamaka Limestone may be interbedded with the uppermost sediments of the Picard Calcarenites. It is thus possible that some of the soils described above, resting on eroded surfaces, are younger than the Takamaka Limestone. The sediments described below, however, are demonstrably younger.

The typical area for these deposits is along the southwestern lagoon shore. The Takamaka Limestone was exposed to sub-aerial solution which produced a delicately fretted and pitted surface. Purdy's (1974) work is important since it suggests that this kind of solution does not occur beneath a soil cover. However, soils did accumulate and these are typically brownish or buff (10 YR 8/2) often containing minute branching tubules.

The Takamaka Limestone is commonly greyish biomicrite with metastable bioclasts represented by granular sparry cavity-fillings. Of the remainder, fragments of *Lithothamnion* and *Lithophyllum* are by far the most common, and occur as nodose masses of several centimetres diameter which have probably undergone little transport. Residual voids are widespread and this limestone has extensive moldic porosity.

Soil occurrences can be sub-divided into two groups. The first comprises sediments of a single type or environment, the second multiple sequences (see figure 22).

(1) Many terrestrial sediments (e.g. 16J4, 16C2, 1B6) are either dense micrite or ovoid amorphous glaebules of 0.1–0.2 mm maximum diameter. Some burrows are present and tubules formed by rootlets. As these shrink the margins become laminated by wall alteration and cutan deposition. There are few large bioclasts but angular lithoclasts are locally common, identified by their crystalline cement and greyish micrite enclosing unaltered bioclasts.

Close to the Takamaka Limestone surface intergranular spaces are lined with a prismatic calcite cement. This is absent throughout most of the sediment, and coherence presumably results from grain adhesion following precipitation at contact points.

Cavities in the Takamaka Limestone in the Passe Horeau area contain similar earthy brown sediments, but with a more complex cement sequence (32B4). Dominantly micritic, with crumb-like aggregations, they are poorly sorted. Large bioclasts include bones, terrestrial gastropods, and fragments of lithified laminated crusts. The cement is generally granular sparry calcite, but in some cavities there is a granular basal layer 50 μm thick of clear calcite, with a rounded colloform-like outer surface unrelated to crystal terminations. This is overlain by fibrous inclusions, 25 μm in length, which form a zone in the bases of coarse clear calcite crystals. These terminate in well defined trigonal faces coated with opaque micrite which fills much of the residual space.

Sediments deposited in a slightly different environment occur about 100 m north of Takamaka Grove. *Succinea* and other terrestrial gastropods collected point to a damp 'fresh-water' environment (26F8). The sediment is poorly sorted and texturally disorganized with cavities formed by differential compaction. Some areas consist of amorphous or concentrically zoned glaebules (0.1–0.5 mm maximum diameter) set in a sparry cement. In others an irregular lamination is formed by changes in size and packing density, close packing producing an apparently amorphous micrite. Burrows (about 1 mm diameter) are present, some containing ovoid faecal pellets. Sediment at the base is generally denser and is crudely laminated parallel to the contact surface as a result either of some depositional process or of post-depositional movement of materials. Towards the exposed surface the effects of case hardening are seen in a progressively increasing opacity in glaebules and the development of granular crystalline cement. No analyses are available but this may result from concentration of iron and manganese oxides.

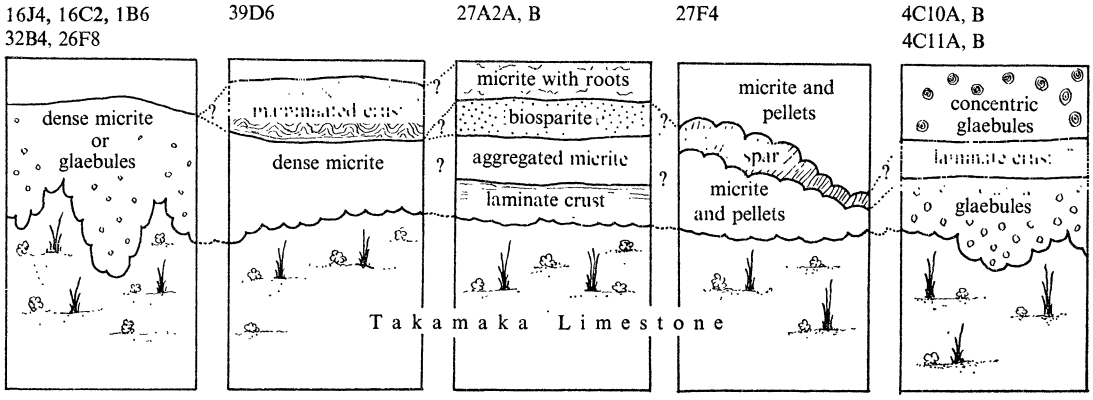


FIGURE 22. Schematic diagram illustrating general relationships of terrestrial sediments overlying the Takamaka Limestone. Numbers are of specimens referred to in the text. No intended scale.

(2) Multiple sequences are seen in a number of areas and emphasize the commonly intimate association of marine and terrestrial deposits (figure 22). Red-brown terrestrial sediments occur on the north and west coasts of Michel. On the west coast they are accompanied by brown porcellanous laminated crusts (centimetres thick) intercalated with coarse calcarenite. These all post-date the Takamaka Limestone and are overlain by a chalky friable sediment believed to be part of the Aldabra Limestone. The laminated crusts (27A2A, B) rest on a biosparite surface. They are predominantly brown micrite containing well sorted micro-pellets (0.5 mm max. diam.) which are probably faecal. Fractures and irregular 'birds-eyes' are common, resulting partly from sediment shrinkage but also from differential settling and 'roofing' effects during deposition. Rootlet traces are also common, some with well preserved cellular structures. All cavities are filled with a clear granular calcite cement.

The upper margin of the unit (27A2B) is cut by a number of narrow (millimetre) passageways lined with granular cement. It is overlain by a light coloured loosely aggregated micrite. Cellular fragments of rootlets and concentrically laminated structures which appear to be lined burrows are present within this.

The upper boundary of the younger micrite includes bioclasts, but it is followed abruptly by a clean-washed biosparite (plate 3, figure 20). *Halimeda*, forams and echinoderm plates indicate that this is of marine origin, but it is only 1 cm thick and is overlain, apparently *after* cementation, by a brownish micrite containing many rootlet traces. Irregular cavities associated with these contain a granular cement, but this is differentiated from others by fibrous inclusions which parallel c-axes of crystals and are *not* normal to walls.

On high islands along the southern lagoon shore two soils are separated by a layer of spherular translucent calcite (27F4). This has a mammilated surface with crystal terminations which suggest unrestricted growth into an open cavity. The lower sediment is dark brown (10 YR 6/2) and the younger orange brown (10 YR 6/6), both are micritic with tapering fractures and areas of pellet-like aggregates. Cavities contain a granular calcite cement.

Two separate depositional increments are also seen about 100 m southeast of the pools at Bassin Cabri (4C10A, B; 4C11A, B, see figure 22). A mound some 20 m long rises 1.5 m above the general erosion surface and probably stood as a low islet above the +4 m lagoon floor. The base is Takamaka Limestone, a muddy calcarenite containing numerous crustose calcareous algae and coral fragments. This has a fretted surface similar to existing 'champignon' with irregularities filled by a fine-grained greyish orange (10 YR 7/4) friable sediment. This consists of large numbers of amorphous glaebules (plate 3, figure 21) 0.03–0.3 mm diameter (few larger), which are oval or sub-spherical (larger ones tend to be irregular). Packing varies, and areas of glaebules grade laterally into dense micrite. Burrows and probable rootlets are common. Three species of terrestrial gastropods are present, including *Truncatella.* Lithoclasts, principally a biosparite with many bioclasts represented by void-filling cement, are frequent. The general cement is granular calcite but in some cavities two phases of deposition are separated by a zone of dusty micrite.

This sediment is covered with a yellowish-brown (10 YR 6/2–4/2) laminated crust indistinguishable in section from a paler (10 YR 8/2) unlaminated material above. Within this glaebules are so large (15–1000 μm) that they are visible in hand specimen, bound together by granular calcite and giving the rock the appearance of an oosparite. Most of the larger glaebules have a conspicuous concentric, 'oolitic', structure. Constituent grains are about 3 μm diameter but there is no orientation such as is normal for ooliths. Minute opaque grains present in the cores of some of them are believed to be late diagenetic iron oxides. Other allochems include micritic lumps of about 1 cm diameter, large micritic (mudstone-wackestone) or glaebular lithoclasts, and partially calcitized bone fragments. Shell fragments are also present, in which coarse replacive calcite retains palimpsest structures from the original fabric. Pedotubules include burrows, filled with pellets, and rootlets, with pale micritic coatings on the walls of cavities.

The size range of components is large and apparently random; there is no obvious sorting. There are areas in which some movement has taken place, smaller bodies have settled into what may have been internal cavities (other than intergranular porosity). 'Birds-eye'-type spar-filled spaces resulting from differential compaction are common. They are associated particularly with near-horizontal fractures probably formed by shrinkage during consolidation. All of these contain a granular sparry cement.

One other occurrence within this post-Takamaka Limestone group seems worth comment. In localities north of Dune d'Messe the fretted surface of the limestone is overlain by a buff friable soil (39D6). The upper surface of this is limited by 5 cm of dense laminated crust containing terrestrial molluscs. Laminae are usually parallel, but a few discrete horizons (bounded by normal laminae) are mammilated. In adjacent cavities this crust may be overlain by a fine-grained calcarenite with well preserved marine molluscs, or by a buff sediment with terrestrial molluscs.

The crust (39D6) is a laminated micrite forming 'pisolites' and stromatolite-like domes (plate 4, figure 24). Large numbers of minute (2–3 μm diameter) filaments are present. These are simply branched, with long straight sections, but are not related to laminae or granular masses; they appear to be post-depositional borings. It is possible that less extensive filaments in the soil above were contemporary but these are also unrelated to laminae. Residual cavities in porous horizons are lined with two generations of granular calcite. The basal layer is yellowish and is separated from the outer by a thin dusty micrite. In some areas within the sediment dark (?)organic laminae are separated by zones of clear crystalline calcite. These have either grown in the solid, replacing or pushing aside particles, or represent deposition of a cement in cavities formed between laminae by gas expansion or similar mechanism.

Interpretation

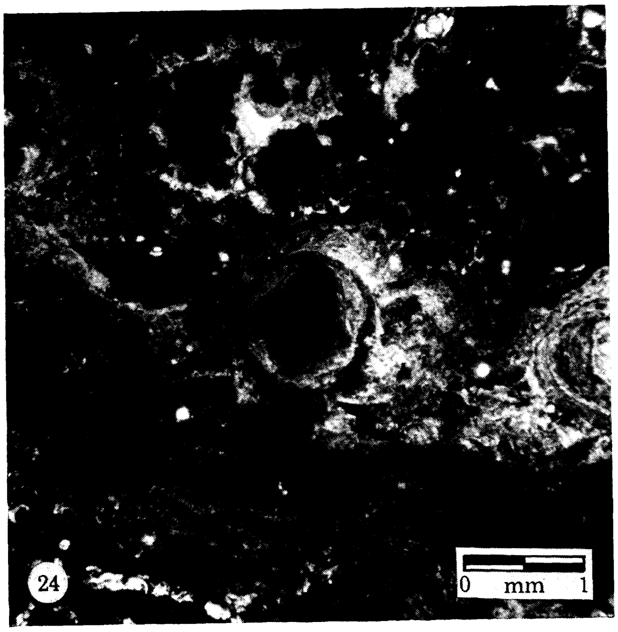
There seem to be two main series of post-Takamaka Limestone sediments separated by an interval during which some event brought about cementation. This is probably related to the formation of an extensive marine planation surface (Braithwaite *et al.* 1973). If this is the case, however, it follows that there were either *two* discrete terrestrial events between the deposition of the Takamaka Limestone and the Aldabra Limestone, or, and more probably, that the second terrestrial interval corresponds to a hiatus during Aldabra Limestone time. Although the Aldabra Limestone 'unit' is the most extensive and is the only one to contain prolific coral growth-frame assemblages, its formation was not the result of a steady-state deposition but of a discontinuous series of discrete events.

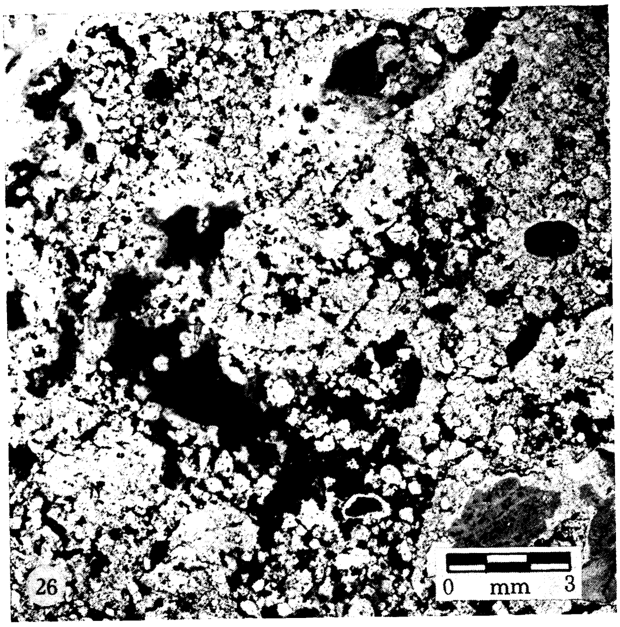
Both damp and relatively dry environments are represented but it seems clear that the allochemical element in these soils was deposited in increments as a sediment. It was not simply an *in situ* weathering product and the deposits rest on erosion surfaces. There is insufficient evidence to suggest clear analogues with contemporary accumulations.

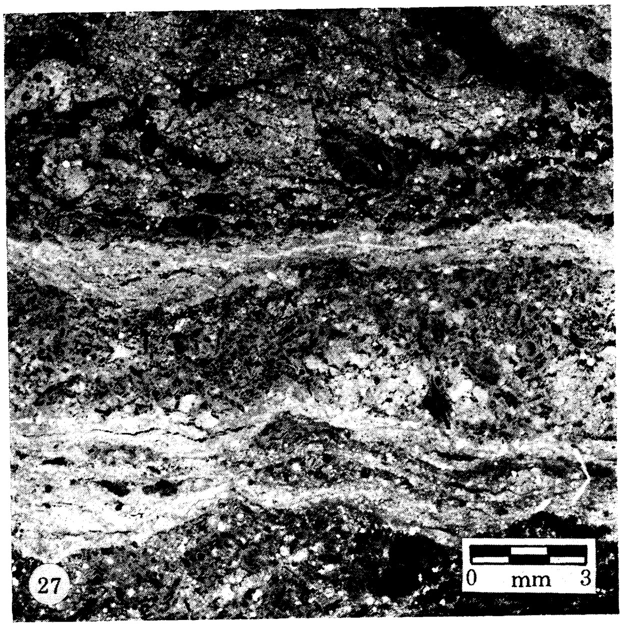
As in the previous group the evidence offered by cement sequences is often ambiguous. There is little diagenetic difference between the two sediment series. Growth of individual crystal fragments is probably greater in the older material, resulting in a general hardening, but it seems again that a low magnesian calcite cement, once deposited, remains stable over a wide range of environmental changes.

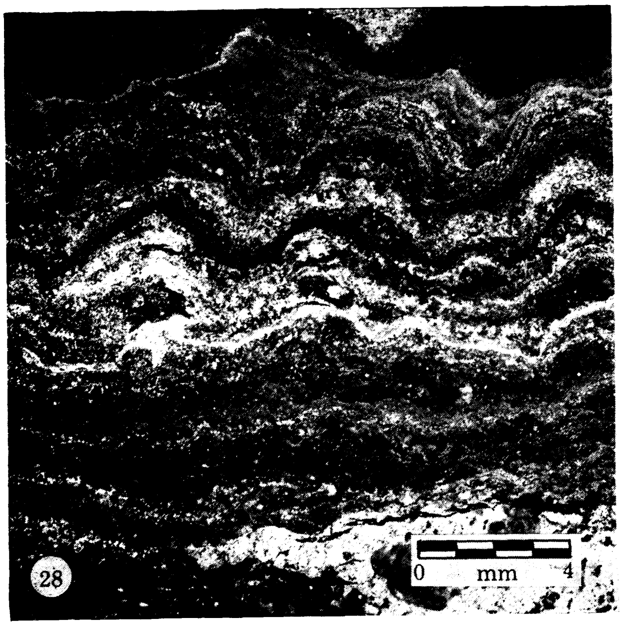
The Aldabra deposits

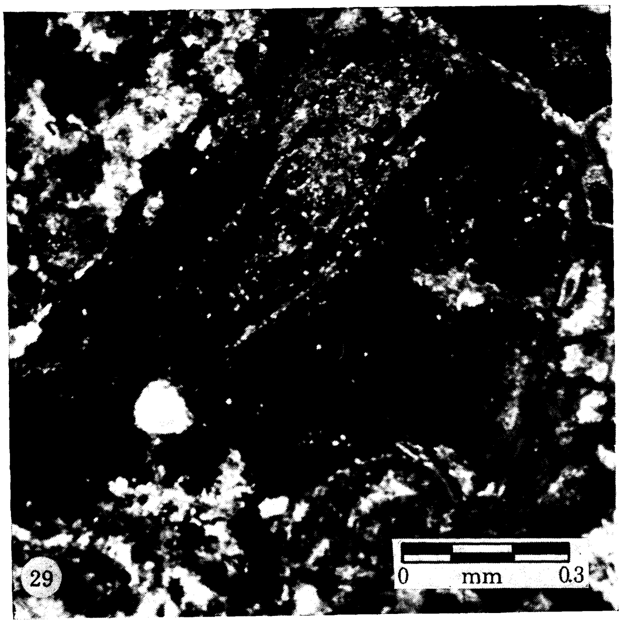
As noted above, the Aldabra Limestone is not a single unit. In some areas the Takamaka soils are overlain by a dense, tightly-cemented, fine-grained calcarenite with well preserved *Strombus*, *Polynices* and *Fragrum*. This is probably a basal phase of the coral limestones, but it is separated from them by terrestrial sediments. The difficulties of this situation, in the absence of any absolute dating method, are demonstrated in localities near Dune Jean Louis. Here the planated surface of the Takamaka Limestone has been bored by *Cliona* and *Lithophaga*. Whether this erosion follows the solution and terrestrial deposition described previously is not clear, but borings are filled with a hard, fine-grained, calcarenite (44C1, 6; 44D7, figure 23). This biomicrite (wackestone) contains *Halimeda*, Lithothamnid algae and lithoclasts, but many other bioclasts are altered. They may either show *in situ* growth of a new coarser fabric, preserving traces of their original structure, or have been dissolved and the resulting cavity filled with sparry cement. A few molluscan shells with patchy *in situ* replacement contain irregular cavities with a thin (30 μm) lining of clear calcite. This has commonly been overlain by calcite so full of dark brown inclusions that crystal boundaries cannot usually be recognized. Irregular cavities at the top of the unit contain the same cement sequence and patches of the original structure within some bioclasts are also deeply stained. Both cement precipitation and staining (or alteration) might be related in time to the deposition of the sediments above.











FIGURES 24–29. For description see opposite.

(*Facing p.* 19)

The soft chalky sediment overlying this hard marine calcarenite contains the terrestrial snails, *Trophidophora*, *Truncatella* and *Melampus*. It is light brown (10 YR 6/2) and micritic, with some areas indistinctly pelleted. In addition to molluscan bioclasts there are a few coral-bearing lithoclasts. Some areas are penetrated by laminated pedotubules, probably rootlets, and residual spaces are lined with clear granular calcite. The unit is a few centimetres thick, and the irregular upper margin is overlain by a second hard, well cemented, calcarenite containing many intraclasts. However, both sediments are cut by a second marine erosion surface, once again bored by *Cliona* and polychaets and encrusted with *Lithoporella* and foraminifera. Borings penetrate both the micritic sediment and its cement, and are thus important since although cements above and below the erosion surface are similar they must be separated in time. Material overlying this surface is undoubtedly marine, containing *Halimeda*, *Lithophyllum*, *Amphiroa*, *Millepora*, molluscan and coral fragments. At the base of the unit many of these have a prominent brownish stain.

To summarize, this sequence, a terrestrial deposit, post-dating marine erosion of the subaerially lithified Takamaka Limestone, is bounded by a second marine surface. It may be contemporary with younger soils overlying the Takamaka Limestone, or with supposed erosion surfaces *within* the Aldabra Limestone.

Terrestrial sediments overlying Aldabra Limestone are divisible into three sub-groups.

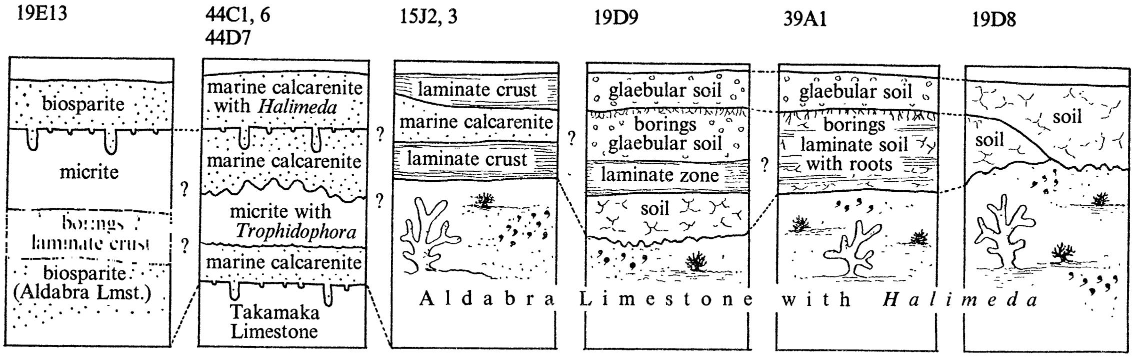


FIGURE 23. Schematic diagram illustrating general relationships of terrestrial sediments overlying the Aldabra Limestone (see also figure 30). Numbers are of specimens referred to in the text. No intended scale.

(1) *Laminated crusts*

There are two stratigraphic groups of laminated crusts; those within and those post-dating the Aldabra Limestone. There are no clear textural distinctions. Dark brown (10 YR 5/4) laminated deposits within the Aldabra Limestone are seen on Polymnie (15J2, 3; figure 23). These are 1–2 cm thick, dense and micritic overlying, with an abruptly gradational contact,

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DESCRIPTION OF PLATE 4

FIGURE 24. Stromatolitic banding in micrite (39D6); photomicrograph.

FIGURE 25. Erosive contact between two soils (39A1). Note loosely packed glaebules above; negative print.

FIGURE 26. Crumb-aggregate with granular calcite cement (19D8); negative print.

FIGURE 27. Laminated soil (44A1). Note lenticular fractures in more porous unit above; negative print.

FIGURE 28. Blackened (manganese?) stromatolitic micrite (44D10); negative print.

FIGURE 29. Partially calcitized bone fragment (8A1); photomicrograph, crossed polars.

coral-bearing sediment penetrated by laminated rootlet channels. This may be an example of an *in situ* derivation but there are unfortunately no diagnostic fossils. A more recent crust overlies the Aldabra Limestone in this locality.

Not all laminated crusts have the same origin. Evidence of the depositional environment of one example was seen at Cinq Cases creeks. This sediment (22F3) rests on an irregular (subaerial erosion?) surface of Aldabra Limestone. It ranges from millimetres to centimetres in thickness and contains well-preserved *Melampus*, *Succinea* and *Terebralia*. The smaller genera may have been transported but could reflect colonization of a sediment originally wet enough to support *Terebralia*.

Other crusts post-dating the Aldabra Limestone, but probably older than these, also occur in the Cinq Cases area. Blocks of *Halimeda*-bearing sediment have been separated from the main outcrop by narrow flat-lying fissures filled by brownish-orange (10 YR 6/6) soil (19D7) with a prominent vermicular structure. This results from numerous interdigitating rootlet tubules which have laminated margins but little preserved cellular tissue. Areas occupied by roots are dominantly micritic, although *Halimeda* and other bioclasts are present, but grade into the biosparite of the host rock. In this *Halimeda*, *Lithothamnion*, coral and molluscan fragments rest in a brownish granular calcite cement. An earlier acicular cement in some *Halimeda* tubes may also have been present in intergranular spaces, but evidence is ambiguous. The surface of the Aldabra Limestone was probably uncemented during deposition of this sediment, although presumably coherent, and this may be another example of *in situ* formation.

One other example of sediment within this group is a (?) manganiferous stromatolitic crust in a cavity-fill sequence at Dune Jean Louis (44D10). The friable sediment is a dark yellowish orange (10 YR 6/6 with patches of 10 YR 7/4) separated into polygonal blocks by dendritic fractures. One large (centimetre) burrow was noted and numerous small pale orange (10 YR 8/2) tubules. The upper irregular surface bears a porcellanous crust about 1 cm thick with millimetre laminae (plate 4, figure 28). This is dusty brown to greyish orange (5 YR 2/2–7/2), and is overlain itself by a greyish orange (10 YR 7/4) soil containing scattered rootlets.

The laminations are formed by alternations of dense micrite and porous horizons containing pellets and crumb-like aggregates. Most residual cavities contain a granular calcite cement but in a few this has a brown outer margin within which crystals contain fibrous inclusions. These do not represent a relict radaxial growth but parallel *c*-axes of existing crystals. Later cavities, including lenticular fractures opening parallel to laminae, contain only clear calcite.

Deposition of these laminated crusts and soils is incremental and was interrupted by periods of erosion demonstrated in samples from Dune d'Messe. The crust in these (39A1) is greyish red (10 YR 4/2) and porcellanous. It is a crudely laminated micrite with areas of glaebules and poorly preserved roots which have not been compressed. The surface of the unit is infested to about 1 cm depth with minute straight filaments (less than 2 μm diameter) which resemble those figured by Perkins & Halsey (1971) and are probably fungal. The overlying soil is dominantly amorphous glaebules up to 0.25 mm maximum diameter (plate 4, figure 25). The cement in both sediments is granular calcite and there is no diagenetic difference. Similar boundaries in other sediments are frequently stained, but with two alternative distributions. The surface itself may be stained, or the sediment above have a diffuse stain limited at the surface.

Intercalations of marine and laminated terrestrial sediments are seen northwest of Cinq Cases. Friable Aldabra Limestone rich in *Halimeda* is overlain by 4.5 cm of brown (5 YR 5/2–6/4) laminated crust (19E12, 13, 14; figure 23), followed by dense fine-grained calcarenite with coral and molluscan fragments. The Aldabra Limestone is a coarse biosparite, but towards the top aggregates of greyish micrite appear on the walls of intergranular spaces, increasing to form a biomicrite in which the micritic element is probably introduced. In other cases (19E13) micrite is limited to specific areas between which grains are bound by two generations of granular calcite, an early brownish phase and a later colourless one, which in some cavities are separated by a thin dust. Well preserved plant roots occur within the micrite, generally with each cell filled by a single brownish calcite crystal with undulose extinction. Thus, a marine sediment has been colonized and modified by supposed terrestrial plants before cementation. The upper surface may have been eroded since it is marked by a concentration of algal filaments interpreted as borings.

The sediment above is crudely laminated, with some laminae separated by thin sheets of fibrous calcite. These might have been organic, but may represent desiccation partings between algal laminae. In a few areas the micrite has a vesicular structure believed to result from alternate wetting and drying (cf. Miller 1971). The general texture of the sediment (which is macroscopically laminated) is irregular, with unworked micritic peds surrounded by areas of root penetration and burrowing which include possible fungal filaments. Some areas are micropelleted, while others contain rounded amorphous glaebules (0.25–0.5 mm dimater) which locally increase in frequency upwards. Residual voids are filled with radiating prismatic calcite cement, but in one cavity this overlay a fibrous cement which had presumably been removed from other spaces. The upper limit of this unit is an abruptly truncated surface, extensively bored by *Cliona*, algae, and (probably) fungae. In some samples the crust has actually been fractured and fracture surfaces are also bored.

Larger borings are filled, and the sediment overlain by a biosparite with *Halimeda*, echinoderm, coral and molluscan fragments, and forams (particularly *Marginopora*). Close to the erosion surface intergranular spaces are completely filled with a granular sparry cement, but vague fibrous inclusions suggest that this was preceded by a fibrous phase. The cement decreases upwards and is rapidly reduced to scattered prismatic crystals with scalenohedral terminations, associated with a granular microspar which coats surfaces but which is not clearly identifiable as a cement. There are similarities between this sequence and one group (19D9) from Cinq Cases, and yet these supposedly post-dated the Aldabra Limestone.

(2) *Interpretation*

Brown laminated crusts are common on Aldabra and general origins have been discussed under textural groups. Laminae are the result of surface processes of deposition which are incremental, sediment being transported to a site rather than forming by *in situ* decay. Filamentous algae or fungae may have influenced deposition, but are not ubiquitous and many laminated sediments formed without them. Some are probably a result of the separation of depositional increments, aided by shrinkage during drying.

Most of these sediments have mottled soil-like textures, and some, with dense plant debris, are interpreted as calcified organic-rich soils. In sediments which are largely detrital structures present are those formed by re-working by organisms or as a result of *in-situ* mechanical processes.

(3) *Unlaminated soils and cavity fillings*

The most ubiquitous 'terrestrial' sediments post-dating the Aldabra Limestone are a series of rusty brown (10 YR 8/2–10 YR 6/2) solution-cavity fillings. These may be crudely laminated, but laminae lack the definition seen in the crusts described above. Where present, bedding is draped from walls and thickens across the floors of hollows. In typical occurrences west of Anse Var on Picard, solution pits in a *champignon* surface (see Braithwaite *et al.* 1973) are 1–2 m deep. Deposits are restricted, probably by erosion, to some of the larger cavities, reaching a maximum thickness of about 1.5 m. Surfaces are case-hardened but within a few millimetres sediments are normally soft and friable. Thin blackened (? manganese) coatings are present locally.

These sediments (2A1; figure 30) range from pelsparites, with amorphous brown pellets and a granular calcite cement, to micrites. Tapering lenticular fractures, formed by differential settlement, also contain a calcite cement. Allochems, including probable aragonitic grains, calcite bioclasts, and small lithoclasts, are small and volumetrically unimportant. Minute orange-brown granules which may be iron oxides (see mineralogy) form the centres of diffuse-stained areas or more discrete dendritic growths. Small-diameter (1.5 μm) borings are common at the presumed surface of the sample.

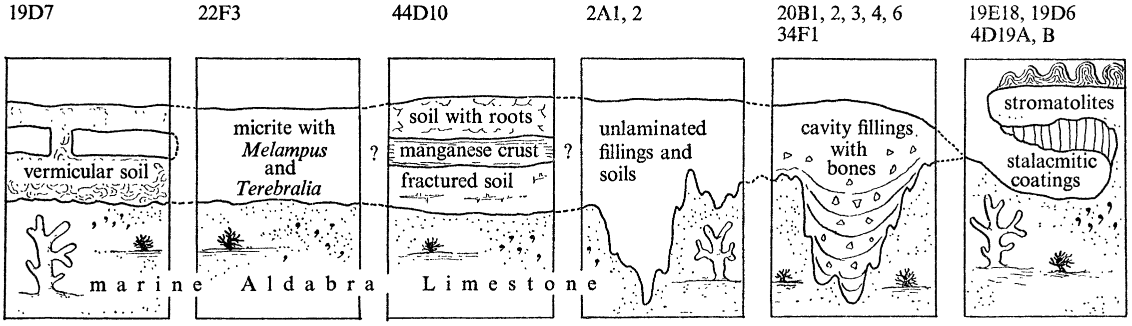


FIGURE 30. Schematic diagram illustrating general relationships of terrestrial sediments overlying the Aldabra Limestone (see also figure 23). Numbers are of specimens referred to in the text. No intended scale.

There is as much variation in sediment structure within this field grouping as in the laminated crusts. Close to the above outcrops (west of Anse Var) a pale brown (10 YR 8/2–10 YR 6/2) crudely laminated friable material (2A2) was collected. This has a marked vermicular texture formed by closely packed, poorly-preserved, roots interspersed with brownish micrite. Rounded amorphous glaebules of about 50 μm diameter appear locally, and a few residual spaces contain a clear granular cement.

Fine-grained sediments filling cavities are also seen on the coast at Dune Jean Louis. Exposed outer surfaces bear mammilated crusts with glossy, varnish-like coatings. The sediments (44A1, 2) consist of thin alternations (plate 4, figure 27) of dense micrite and porous horizons formed by amorphous glaebules and rootlets. The latter sometimes retain traces of cellular structure and usually have laminated margins. Dense (?) iron-stained nodules appear in some samples and are commonly surrounded by a narrow cavity, giving the impression that they have shrunk. In general this staining is concentrated along horizons believed to have been surfaces of exposure during deposition. Residual cavities are filled with a clear granular calcite.

Many samples show complex sequences of depositional events, post-dating cementation of the Aldabra Limestone. At Cinq Cases (19D9; figure 30), this is a *Halimeda*-rich calcarenite containing heterostegenids, echinoderm, coral and molluscan fragments. Patches of greyish soil-like aggregated micrite are present which are locally micro-pelleted giving an open and porous texture. The cement is irregularly distributed, ranging from well-defined fringes of elongate crystals to isolated crystals or no cement at all. This modified marine sediment is overlain by a more obvious soil, the lower portions of which contain small bioclasts. This is generally micritic with an open cavernous texture partly defined by interlacing rootlets. The margins of tubules are laminated but cellular structures are not well preserved.

There is no sharp boundary between this sediment and a micrite, partly micro-pelleted, in which flat-lying or upward-arched lenticular cavities are filled with either a yellow-brown spherular calcite or a clear granular cement. This micrite is about a millimetre thick and for 5 mm above the sediment consists of ovoid amorphous glaebules (0.05–1.75 mm max. diameter) with intraclasts of soil and a few small fragments of fresh *Halimeda*. There may be an erosion surface separating these two units, and the laminated micrite might be organic, but there is no clear evidence. The cement is a uniform granular calcite.

This glaebule and intraclast-bearing sediment was eroded before deposition of the overlying soil. The break in this case is sharp and well defined, and the sediment types are strongly contrasted. It is not clear whether the lower unit was lithified, but it was strong and cohesive. Its margin is marked by a dense orange-brown stain which covers a zone of boring (including fungal filaments, algal tubes and *Cliona* borings). Above the contact the soil is also orange-brown, consisting of irregularly sized amorphous glaebules. These have a porous texture with scattered *Halimeda*, mollusc and bone fragments but locally pack to form a dense micrite. Intergranular spaces and tapering fractures, probably resulting from shrinkage, are filled with prismatic calcite, but the constituent crystals have ragged rather than planar boundaries.

This sequence is interpreted as the result of three terrestrial events post-dating part of the Aldabra Limestone. The time intervals and the events separating them are not known, but some marine influence is inferred from the character and frequency of bioclasts. It is tempting to correlate events in this sample group with those at Dune Jean Louis (44C1, 6; 44D7) but without some absolute marker this seems impractical. The difficulties are emphasized by samples from the same locality which show different sequences (19D8; figure 23). Two separate soils are present, the earlier resting on uncemented limestone, the later on cemented contacts. The transitional soil contains *Halimeda* and altered molluscan fragments with areas of dense greyish micrite penetrated by poorly preserved rootlets. Areas at the upper margin are partly pelleted and cut by numerous shrinkage cracks which give a blocky polygonal appearance. They are also differentiated by a bright orange stain. Both sediment types have been eroded. The soil overlying is a dark yellowish-orange (10 YR 6/6) with an open texture, micritic areas forming crumb-like aggregates (plate 4, figure 26), pellets, and larger blocky masses cut by tapering fractures. Although this soil has every appearance of being relatively young, *two* discrete cements are present. Both are clear granular calcite. The earlier has a pale brownish stain and, where it terminates in open cavities, well defined scalenohedral crystals. These have locally been eroded to form a more uniform surface overlain by a micritic coating. The micrite fills gaps between the original crystals, and free surfaces bear a single layer of calcite crystals which also show scalenohedral terminations against residual voids. There seem to be no simple parallels between this sequence and that described above (19D9).

Like the laminated crusts, many of these large-scale cavity-fillings have formed as a series of increments, separated in some cases by important diagenetic events. Rootlets are common and, even where sediments are laminated, are believed to be essentially *in situ*. Diagnostic fossils (other than plants) are generally rare.

(4) *Bone-bearing deposits*

There is a curious divergence between the unlaminated cavity-fill deposits described, which are generally bone-free, and bone-bearing sediments. These are relatively resistant and commonly form residual pinnacles. They are typified by outcrops at Islot Rose which rises about 2.5 m from the lagoon floor with an area of 40 m^2. The rock (33D1) is a breccia with a light brown (5 YR 5/6) earthy matrix. Local patches may be lighter coloured or have a reddish tinge. Bone fragments, principally of tortoises, are numerous and vary widely in size. They are usually phosphatic, but some show calcitization (8A1; plate 4, figure 29), an *in situ* replacement preserving structures. *Halimeda*, *Lithophyllum*, echinoderm, coral and molluscan fragments, *Marginopora* and *Amphistegina* have been identified but lithoclasts are common and some bioclasts may be derived. Blocks of neomorphosed limestone and travertine up to 30 cm diameter are visible in outcrop and were probably derived from pit walls.

The sediment is micritic, but aggregated into pellets which are of two kinds. Well formed uniformly sized ovoid structures are probably faecal, while smaller more variable bodies are believed to have been formed by soil generating processes. Locally, crude laminated structures are associated with possible algal filaments. These may be fragments of more extensive deposits and may point to the presence of damp surfaces within the cavity.

Many sections contain large numbers of (?) iron oxide granules and have an extensive but diffuse red-brown staining.

'Birds-eyes' and cavities opening through compaction or shrinkage are common and both these and the intergranular porosity are lined with a clear granular cement.

Sediments comparable to those at Islot Rose are seen in spectacular outcrops at Point Houdol. These have a rich vertebrate fauna including crocodiles, birds, and varanid lizards. They are broadly of two kinds; in one the sediments have crude bedding draped against cavity margins, in the other no bedding is recognized. Both (20B1, 2) are dark yellowish brown (10 YR 4/2) with a compact but earthy texture. Bones (pale orange, 10 YR 8/2) range from minute fragments to unworn bones, 8–10 cm in length.

The sediments include pellets (0.1 mm max. diameter), sometimes grouped into crumb-like aggregates, and structureless micritic areas cut by tapering shrinkage fractures. The cement is a clear granular calcite. Crude layering in some samples suggests packing on successive surfaces. Intraclasts of soil-like sediments similar to the host are common and also indicate more than one cycle of deposition. Both rootlet tubules, lacking preserved organic structures, and burrows are present. Bone fragments are usually pale yellowish dahllite but some are made virtually opaque by grey-black granules which appear initially in the haversian canals and canaliculi. In others canaliculi are the sites of patchy calcification.

In a few samples (20B4) coral bioclasts retain their original structure and, although extensively blackened, seem unaltered mineralogically. Elsewhere, varying degrees of alteration are seen.

In one section (20B7) a general 'micritic' groundmass is ordered into what might be called 'birefringence domains'. Individual grains are 5 μm diameter or less and have no identifiable cement, but under crossed polars, within the area of the domain, they extinguish simultaneously, appearing as unified, ragged, interlocking crystals 70–80 μm diameter (plate 5, figure 31).

Locally, micritic pellets are poikilotopically included in crystals continuous with a coarse intergranular cement. The cement may be optically and crystallographically continuous over wide areas and enclose micrite particles, but such growth should preserve the optical characteristics of the original grains so it seems that some form of replacive growth is involved.

Not all sediments at Point Houdol are like this. In one pit thin lenticular sheets of hard well-cemented material are separated by soft earthy layers. Much of this soil (20B6) consists of crumb-like aggregates with irregular (millimetres diameter) cavities containing a sequence of botryoidal dahllite deposits, some of which enclose dense ovoid phosphatic pellets (0.15 mm maximum diameter). There are a number of concentrically zoned structures associated with these areas which may have been *Lithoporella* oncolites. These were originally replaced by coarse carbonate but are now partly replaced by phosphate (20B3). Some are apparently within lithoclasts and relationships are not clear. In other specimens (20B4) cavities are larger and contain recognizable marine bioclasts (*Halimeda* leaves, echinoderm plates), and amorphous micritic pellets cemented by a multilayer colloform phosphate similar to that described by the author (1968) from Remire. Some bioclasts (*Halimeda*) have been replaced by phosphate, much of which is poorly crystalline and essentially isotropic (plate 5, figure 32). Several phases of phosphate deposition and replacement have occurred, followed by the precipitation of a clear coarse granular calcite which fills residual voids.

These samples are particularly interesting since, although bone-bearing deposits are common and contain high densities of bone fragments, precipitated phosphates are rare on Aldabra. Even in this case the phosphate may not be derived from bone but from some relatively recent deposit of avian guano not represented in present outcrops.

(5) *Interpretation*

Most large-scale cavity-fillings on Aldabra have formed by the deposition of discrete sediment increments. They are not the result of any *in situ* process of limestone decomposition. Sediments such as the Islot Rose deposits can be compared with those forming in present-day solution pits occupied by *Cardisoma*. Many of the structureless pellets resemble faecal pellets and pseudo-faecal sediment extrusions. Limestone fragments, broken travertine, and fragments of probable algal crusts are also all in keeping with such an origin. The bone fragments, however, are anomalous. They do not appear to form a significant proportion of modern solution-pit fillings. Bones are usually broken and are never articulated and, although they are unworn, this seems to indicate some surface transport. It is inconceivable that they would have become so broken and intermixed by animals having simply fallen down a hole. Skeletons could have been destroyed and fragments reworked by scavengers such as *Cardisoma* and *Sesarma*, but this only seems plausible for unbedded deposits.

(6) *Other terrestrial sediments*

The last clearly defined sediment in the post-Aldabra Limestone group is a cavity-filling found on the Lagoon shore west of Passe Horeau. The sediment (34F1) is well cemented, pale to dark brown (5 YR 5/2, 5 YR 3/2) with soft friable areas which are bright orange (5 YR 7/2). It is dominated by large (25 mm diameter), closely packed, coarse-ribbed *Trophidophora*. These contain smaller (1–3 mm) shells of at least four other species. The shells show patchy solution, but no sign of the growth of new minerals. The sediment is dense and micritic, and is crudely laminated parallel to some shell surfaces. Micro-pellets and scattered coarser allochems are locally present. Rootlets preserved in calcite are common, although cell walls are poorly defined. They occur both between and within shells and this is probably a thanatocoenose association.

Of particular interest in this sediment is a colourless crystalline mineral which lines some residual voids. This occurs either as acute pyramidal crystals, or as a disordered mass of irregular interlocking grains (about 0.05 mm maximum diameter) with fibrous inclusions resembling a cleavage trace. It is believed to be a chlorite (see mineralogy) but may be a pseudomorph.

In addition to the sediments described above, all of which are terrestrial, in the sense of having been deposited on a land surface free from marine influences, there are two groups of deposits which are not marine and yet are genetically different from other terrestrial sediments (figure 30).

The first are deposits formed within caves. The most impressive of these are seen at Bassin Tortue but similar caves and sediments occur on the lagoon shore east of Passe Gionnet and southeast of Passe Horeau. The caves seem to have been a horizontal system, and may have formed through solution by the reactive surface waters of a sea 1–2 m above the present datum. However, fresh-water solution is probably more effective and there is no doubt that stalacmitic crusts formed in the vadose zone above any marine water-table. The Bassin Tortue deposits include thick (20 cm) fibrous calcite coatings and buff-coloured calcilutites, some of which show shrinkage cracks. Associated with these are coarse calcarenites (4D19A, B) whose allochems include '*Lithothamnion*', *Amphiroa*, and echinoderm fragments, forams, and sand-size carbonate and phosphorite lithoclasts. Phosphatic pebbles are common and were probably derived by solution of Picard Calcarenites, having originated from Esprit. A specimen sequence (from within a cave) has a base about 2 mm thick with alternating zones of bladed sparry calcite (x.r.d. analysis) and greyish micrite. Some crystals have enlarged downwards at the expense of the micrite which they overlie (plate 5, figure 33). The top of the sequence is formed by crystals (greater than 1 cm) which enlarge upwards. These contain numerous inclusions and are partially replacive at the base. The cements in contiguous biosparites are of similar calcite, with well defined scalenohedral terminations. These may also be replacive but there is no evidence of any widespread early cement. Echinoderm fragments normally have large epitaxial overgrowths.

These structures are of particular interest since accessible Recent caves do not contain substantial crystalline deposits, perhaps because of lower rainfall.

Description of plate 5

Figure 31. Birefringence domains (20B7); photomicrograph, crossed polars.

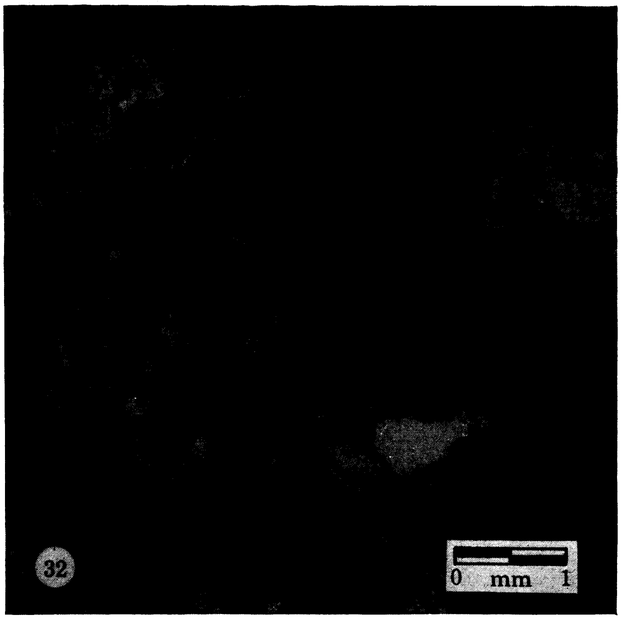
Figure 32. Multilayer colloform phosphate cement of partially phosphatized carbonate bioclasts (20B4); photomicrograph.

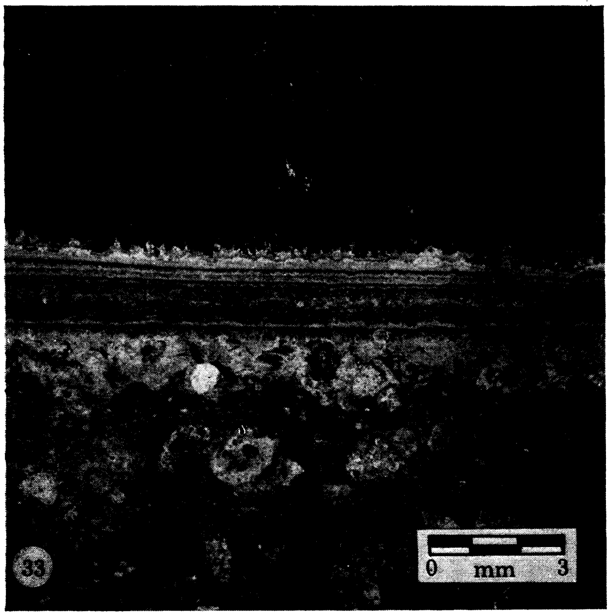
Figure 33. Coarse calcite (dark) overlying calcarenite in cave (4D19A); note extension (arrowed) of crystals at the expense of micrite; negative print.

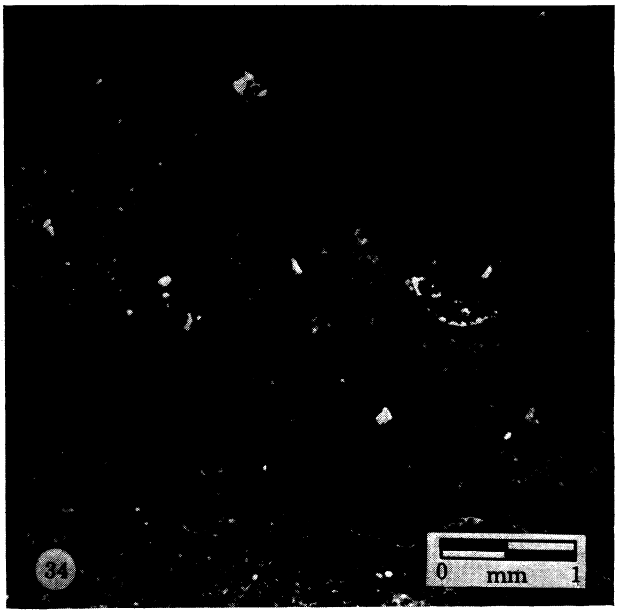
Figure 34. Pelleted 'soil' within stalacmite (20A10) photomicrograph.

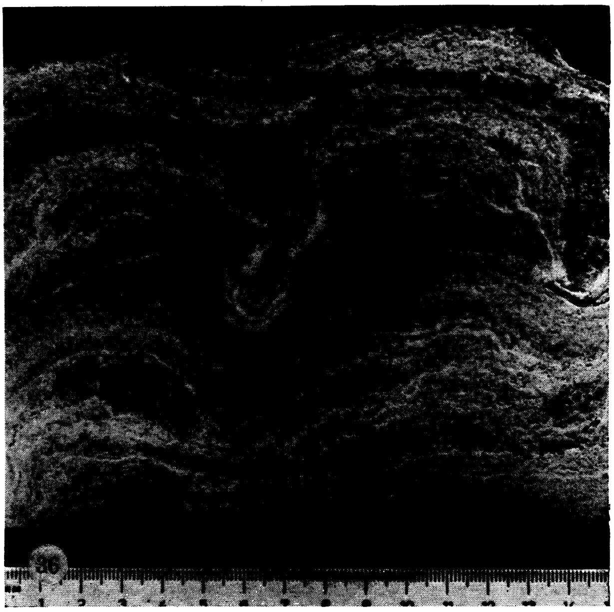
Figure 35. Recent stromatolite (19E18); negative print.

Figure 36. Macro-laminae in rootlet-bearing stromatolitic dome. Scale in centimetres (19D6).









FIGURES 31–36. For description see opposite.

(*Facing p.* 26)

One additional deposit, post-dating the Aldabra Limestone but of unknown relative age, was seen at Point Houdol. This has a stalacmite-like appearance (20A10) but internally is fine-grained and laminated. Some areas are tufa-like while others are concentrically laminated and resemble oncolites. The tufa consists of coarse blade-like crystals, an *in situ* replacement of an earlier fibrous fabric. Inclusions define the edges of fibres and successive levels of accreting botryoidal surfaces. These crystals form a superficial coating on a finely laminated (20 μm) micrite. No cellular structures are present within this but poorly preserved algal (or fungal) filaments are common. The unlaminated sediment below this material has a heterogeneous soil-like texture (plate 5, figure 34) and contains areas of pellets and aggregates. Large cavities are lined with a well defined prismatic cement (40–50 μm diameter crystals) overlain by a loose pellet-rich sediment. Although this has a granular calcite cement it also has a high residual porosity.

The second group of sediments which may indicate emergence are best described as 'stromatolites'. They are of two kinds. In the Cinq Cases area laminated structures up to 3 cm high and 2.5 cm diameter are of cylindrical or inverted slightly conical form with an apical depression. Internally (19E18) millimetre laminae are formed by alternations of granular calcite and micrite containing numerous denser micro-pellets (plate 5, figure 35). There are many cavities and in some larger ones an early bladed calcite cement is overlain by micrite. Algal filaments occur between laminae and are locally present in large numbers, but may not have dominated the process of accretion.

Larger dome-like stromatolites are found in two areas, one at Cinq Cases (Braithwaite *et al.* 1973, Pl. 37, Fig. 38), the other near Takamaka Grove. In the latter locality they range from a few centimetres diameter to smooth cushion-like forms 50 cm high and a metre across. Internal laminae tend to be thickest at the sides, tapering across upper surfaces and towards bases. Some domes are composite and unconformities (breaks in deposition accompanied by erosion) are common (plate 5, figure 36). Larger bodies frequently have their surfaces covered with papillose second generation forms. In general the mounds within a particular group are of similar size.

The sediments (19D6) consist of dense micrite aggregates with a loose porous texture and numerous cavities. Some areas are micro-pelleted, but the dominant feature is the presence of large numbers of roots. These are not well preserved, but have not been deformed by compaction. Plant tissue is replaced by coarse, brownish, granular calcite, similar to that lining cavities. In these it overlies, and sometimes replaces, an earlier fibrous cement. In one area it is itself overlain by micrite. These cements are probably superficial, associated with exposed surfaces, leaving the sediment beneath unaffected. Algal or fungal filaments which locally appear to penetrate cement are probably borings rather than filaments concerned in sediment accretion.

The change in cement in these structures might be related to a change in environment, for example, from saline to fresh-water. The large 'stromatolites' are not comparable with those described by Logan (1961). In spite of appearances they have either formed sub-aerially, in an environment dominated by the growth of higher plants, or have incorporated a sediment consisting largely of fragments of such plants. This seems in little doubt, but it is difficult to conceive of a pedogenic process which would be both incremental and result in the production of dome-like forms.

Recent stromatolites which resemble the smaller (19E18) structures have been seen close to low-water mark in tidal channels at Takamaka Creeks (22F4, 6). These are either permanently immersed or emersed only for short periods. Form varies from small scale (centimetre) domes to almost continuous crusts of 1 or 2 cm thickness on rock surfaces, shells or cobbles. The sediment is partly micritic and partly calcarenitic and contains large numbers of 'birds-eye' cavities. Algal filaments are common, but are accompanied by blackened and shrivelled residues, and if destruction is a continuing process there would be few identifiable filaments in fossil examples.

MINERALOGY

Virtually all of the cements in these sediments are calcitic and the greater interest therefore lies in the allochemical components. From general appearances it might be thought that clays were the most likely constituents, but X-ray analyses suggest that this is not the case. Insoluble residues are commonly less than 20 % and this is taken as evidence that the allochems are themselves carbonate. Some residues still show strong calcite reflexions, perhaps indicating incomplete digestion, while a few are dominated by carbonatian hydroxy-fluorapatites, minor variations in composition producing small shifts in *d*-spacings. One sample (20B1) gave a clear trace which compares with published figures for Florencite, a rare-earth mineral which is normally associated with soils overlying carbonatites.

Most samples contain no non-carbonate material which can be identified optically. A few exceptions have been noted. In one sample (34F1) a colourless crystalline mineral is seen lining residual cavities. This occasionally appears as well formed acute pyramidal crystals, but more often as a disordered mass of irregularly shaped interlocking grains (about 50 μm max. diameter). These contain fibrous inclusions which resemble a cleavage trace. Extinction is either straight or low angle but tends to be undulose. The interference figure is biaxial, positive with a moderate 2V. Birefringence is low, first order whites and greys, but with an anomalous bluish tinge in some areas. It seems from these properties that this might be a chlorite, possibly close to clinochlore, but since it could not be identified in hand specimen it has not been possible to analyse it further.

A similar mineral has been noted in light coloured porous sediments seen overlying surface crusts close to Point Houdol (20D11). The sediment is a brownish micrite, locally pelleted, but containing large numbers of well-preserved roots (0.35–0.4 mm diameter). These are filled with and preserved in a brownish granular calcite and show a progressive loss of structure. It is not clear whether this pre-dates the mineralization. Some have been replaced by masses of minute irregular granules of a low birefringence mineral. As in the previous sample, this might be a chlorite, but optical evidence is insufficient to rule out either silica or dahllite. However, in addition, irregular 'birds-eyes' are lined with a spherular carbonate cement (30 μm thick) which locally has a well-defined colloform layering. In a few cavities this is followed by a discontinuous fibrous fringe resembling acicular crystals of aragonite.

In one section (4C11A) a similar colourless mineral, suspected as being a chlorite, was noted replacing biogenic carbonate within a shell fragment.

Uncertainty also surrounds a mineral noted in samples from Dune d'Messe (39A3B). This usually occurs as water-clear colourless crystals coating void walls but may also be fibrous or spherular, showing undulose extinction 'parallel' to long axes. A few large crystals show multiple twinning. Interference figures are uniaxial and optically negative, an unusual combination, while birefringence is moderate, producing first order greys or bright second order colours where sections are a little thicker. These properties accord with members of the plumbogummite group of minerals to which florencite belongs, specifically to the crandallite-deltaite series. It is suspected (but not confirmed chemically) that iron has substituted in many of the lattice positions normally occupied by alumina.

However, none of these minerals accounts adequately for the character and volume of the residues (compare Patterson, 1971) and it is suggested that amorphous substances, probably consisting of mixtures of hydrous oxides of iron and organic matter, are also present. Walker (1967) showed that much of the iron staining present in red-beds was amorphous. There is some confirmation of this in the results of differential thermal analyses. Silverman, Fuyat & Weiser (1952) showed that in d.t.a. of carbonation fluorapatites there is a gentle endothermic trend over the active temperature range, the main peak lying between 780 and 880 °C, increasing with increasing carbonate content. Results from the present samples do indicate a major endotherm within this temperature range, but also include evidence of other relatively abrupt reactions or dissociations taking place at generally lower temperature. It is believed that these reflect the presence of a series of amorphous (non-crystalline) substances which may be organic.

Discussion

Of the seven textural groups described four seem soil-specific: crumb-aggregates, sediments with shrinkage fractures, vesicular structures and birds-eyes, and some glaebules. These are related to deposition above any water table and concentric glaebules and vesicular structures probably only develop under a low sediment load. More than one depositional environment is represented. Associations include sub-aerial solution pits inhabited by *Cardisoma*, derivatives of 'forest-litter' soils, azonal soils colonized by grasses, swampy areas, perhaps with peats, and shallow fresh-water pools with little vegetation. The laminate sediments are not environmentally unique although most of the examples described here and by other authors are sub-aerial.

The recognition of alternating marine and terrestrial sediments between or within major units adds to problems of correlation. There are at least two bored marine surfaces within supposed Aldabra Limestone, but if only one is present is it the upper or the lower? (see figure 23). The sediments below a surface offer only ambiguous evidence since they are dependent upon levels of erosion.

Diagenetic features of the sediments have been referred to in comments on stratigraphic groups. If the outline history of Aldabra given is correct, then almost all of the sediments within the sequence have been subject to a number of changes in environment. The most drastic, so far as mineral stability is concerned, are changes from marine to sub-aerial conditions, affecting aragonite and high-magnesium calcite. Changes from sub-aerial to marine situations are less important since low-magnesium calcite is stable in both. However, where changes are so rapid, minerals are not necessarily affected in the ways which one might expect. Above the phreatic zone, case-hardening produces a protective curaisse which excludes water from the sediment and confines diagenetic changes to the outer few centimetres. Fresh water is the critical medium and sub-aerial conditions are less destructive than those which are saturated with, or allow free access of, reactive water. However, having been in a situation where a stable cement can be precipitated, a sediment loses porosity and with it the potential for change. At low porosities, and on the time-scale of the present sediments, the most extreme changes will only affect the outermost margins of the sediment unit. Thus, the rock may be subject to a number of environmental changes which leave no trace. The value of diagenetic sequences in solving stratigraphic problems is therefore greatly reduced.

The origin of the material within these deposits also needs some discussion. Insoluble residues form 50 % by mass of some samples (e.g. 20B4), but are generally less (25 %) (X-ray analyses suggest that high figures are incompletely digested samples). In general the sediments are calcium carbonate recognizable in biogenic carbonate particles and well-defined carbonate cements. It is difficult to account for the remaining material. Blackburn & Taylor (1969) showed that even in areas where some clays might have been formed by weathering of included volcanic rocks approximately 150 m of marine limestones were required to form 1 m of soil by normal solution-weathering processes. Similar figures were suggested by Mohr & van Baren (1954) in Barbados and Java, and Sayles (1931, quoted by Ruhe *et al.* 1961) concluded that on Bermuda 100 m^3 of limestone was destroyed to produce 1 m^3 of soil. However, as Ruhe *et al.* (1961) pointed out, there are additions to a soil during pedogenesis, from organic carbon from vegetation and from sesquioxides, guano-derived phosphates, and wind-borne detritus. In the present examples there is no clear evidence of the amounts of limestone which have been removed, although field relationships suggest no necessity for more than about 10 m at any one period. The thicknesses present therefore emphasize the importance of transport and accumulation rather than *in situ* decay.

A likely origin for this material (excluding residues from biogenic carbonates) is in meteoric dust from volcanic or other sources. Gaseous eruptions from the Rift Valley or from volcanoes in the Comoros, Reunion or Mauritius might all have supplied dust, and lateritic or similar particles could also have blown from the African mainland or Madagascar. Unfortunately the X-ray data available suggest that there are no clay minerals and no iron or aluminium oxides present attributable to such sources, unless the possible chlorites described are chemical derivatives. This is surprising since fragments of pumice several centimetres in diameter are reasonably common among modern beach detritus on Aldabra and similar particles in older sediments would have been concentrated by solution. The amounts of phosphate detected are also generally small and it is concluded that the bulk of these residues is primarily from organic sources.

Conclusions

Examination of sediments from Aldabra reveals a number of horizons with distinctive textures reflecting deposition in terrestrial environments. Identification of such environments is confirmed in these examples by a terrestrial fauna, but similar textures might identify terrestrial horizons within a marine sequence in the absence of such fossils.

In the situations described diagenetic evidence proves unreliable in indicating the complexity or frequency of environmental changes to which individual samples have been subjected. Once a stable mineralogy has been established and cementation completed, the potential for alteration is confined to the periphery of the rock unit, where solution may be possible.

The non-carbonate fraction of the sediments formed largely from organic sources; there is no evidence for clay mineral development or material similar to 'terra rosa' which might have been derived from wind-borne sources.

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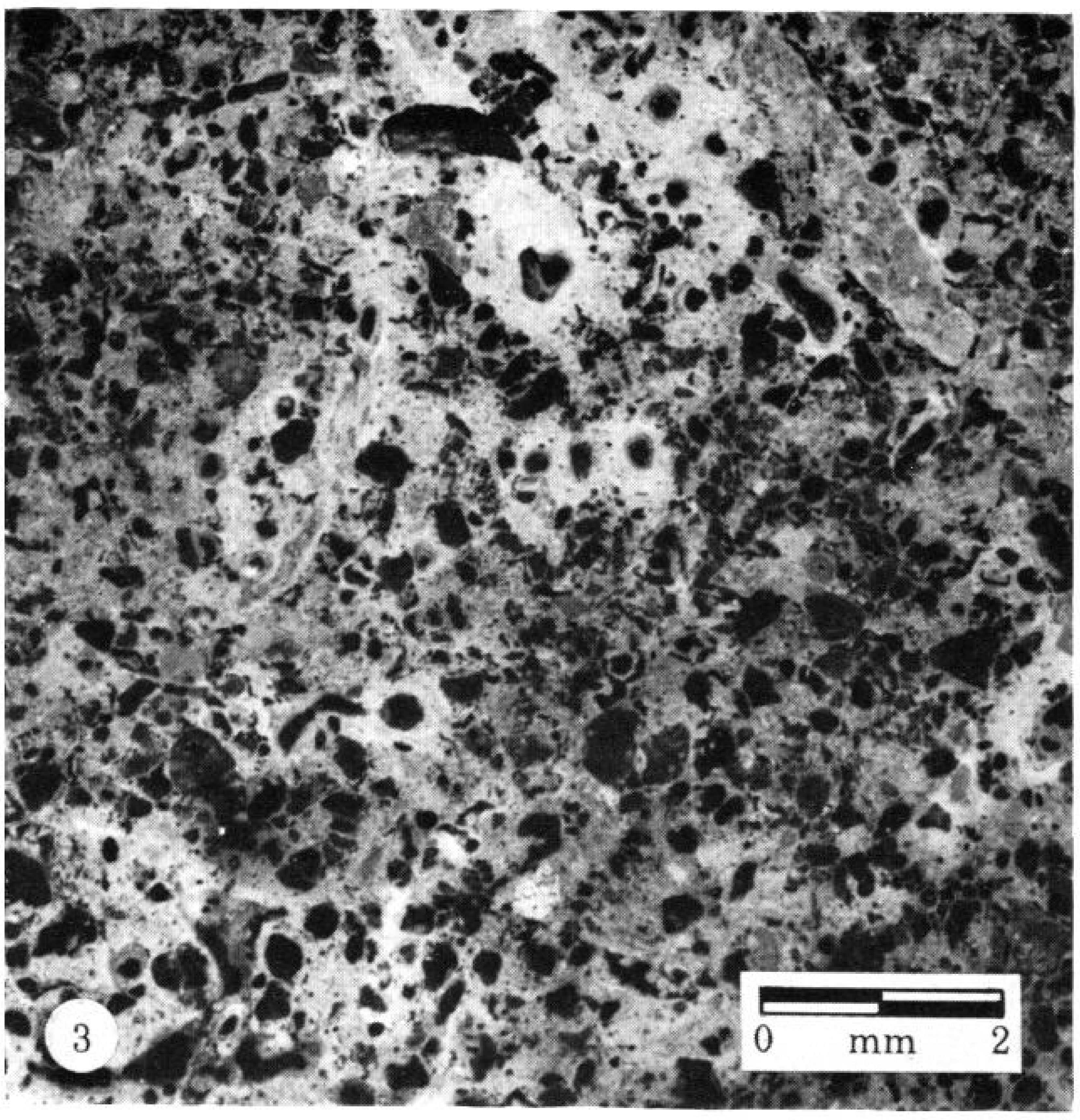

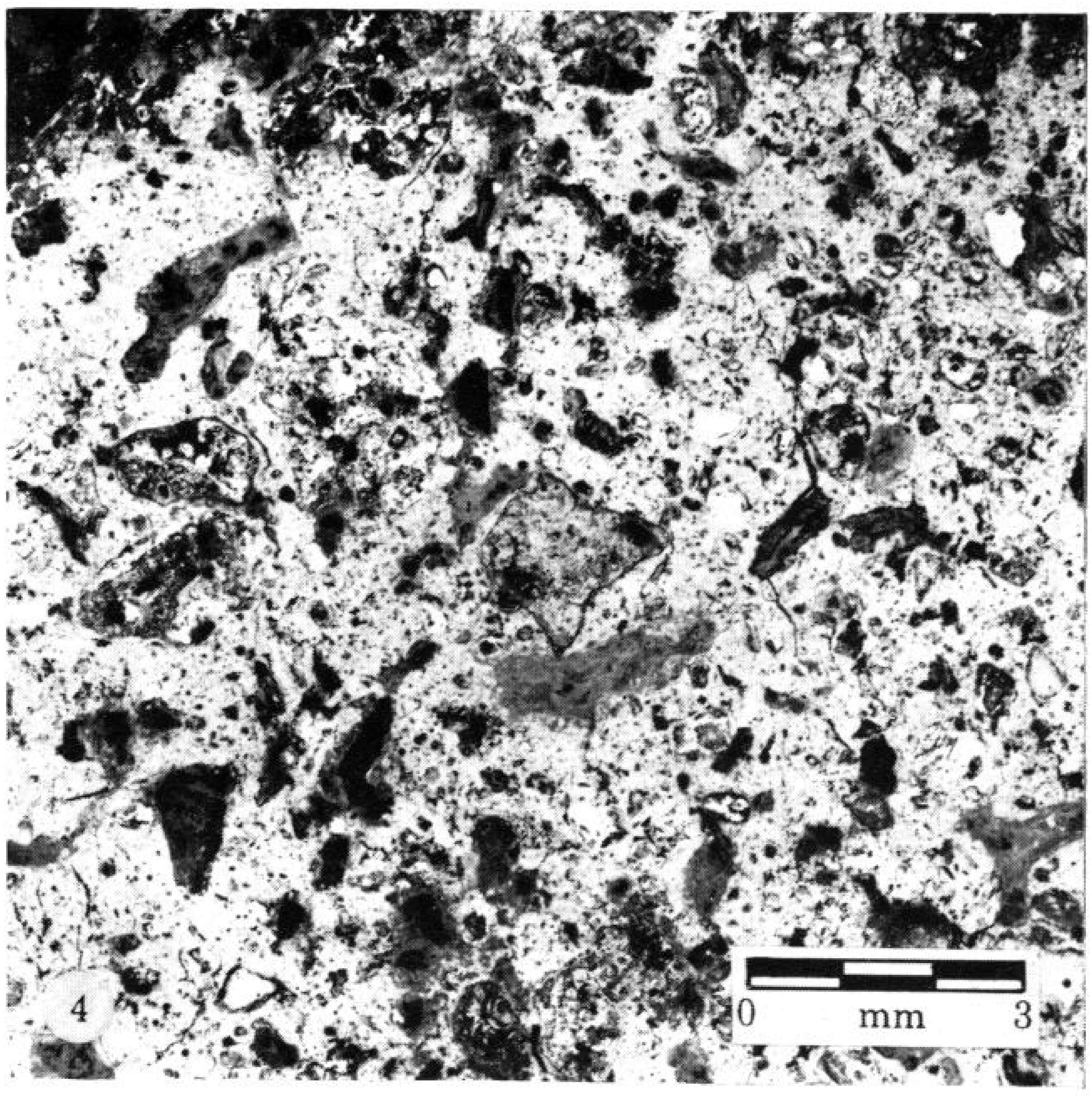

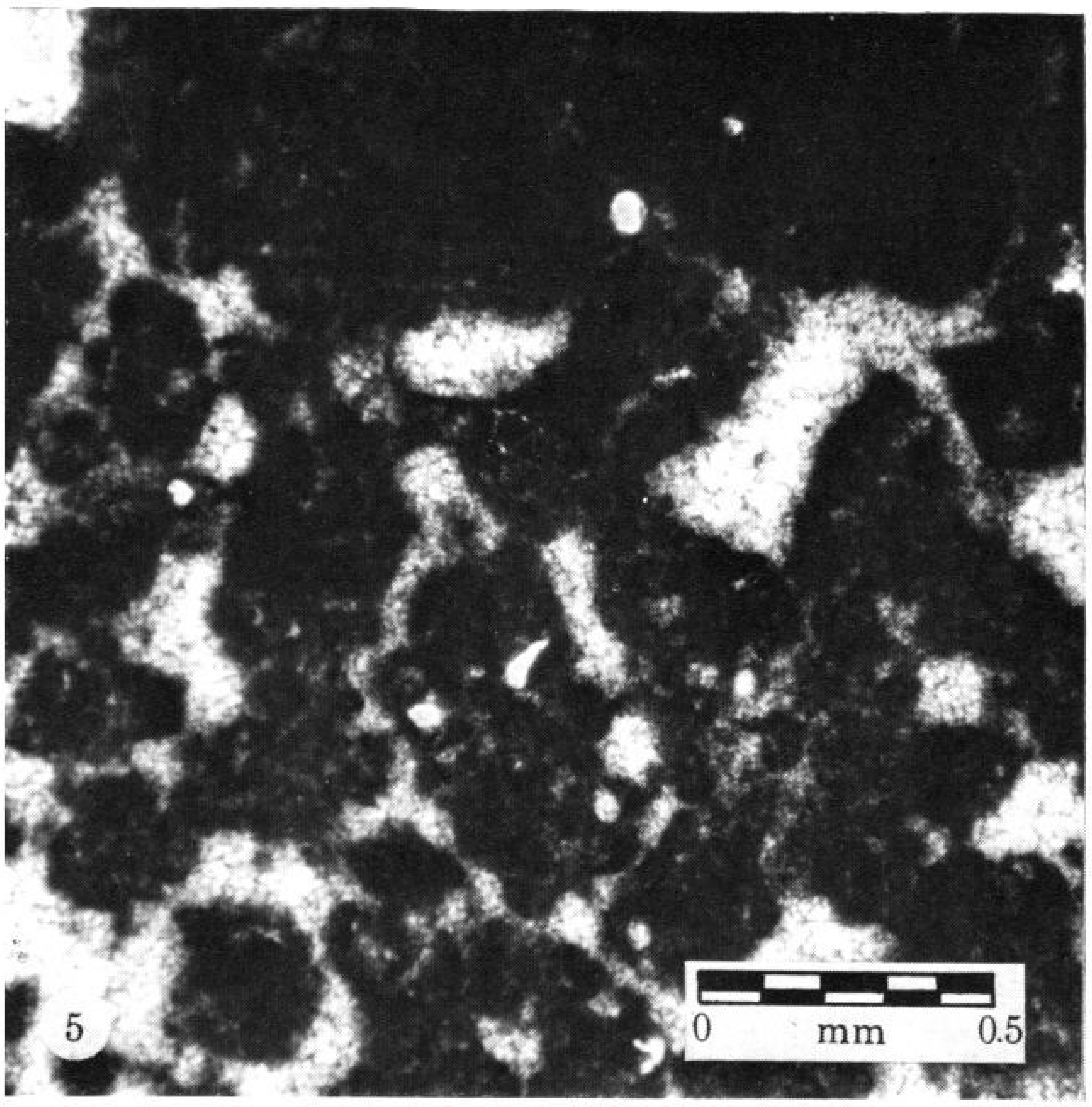

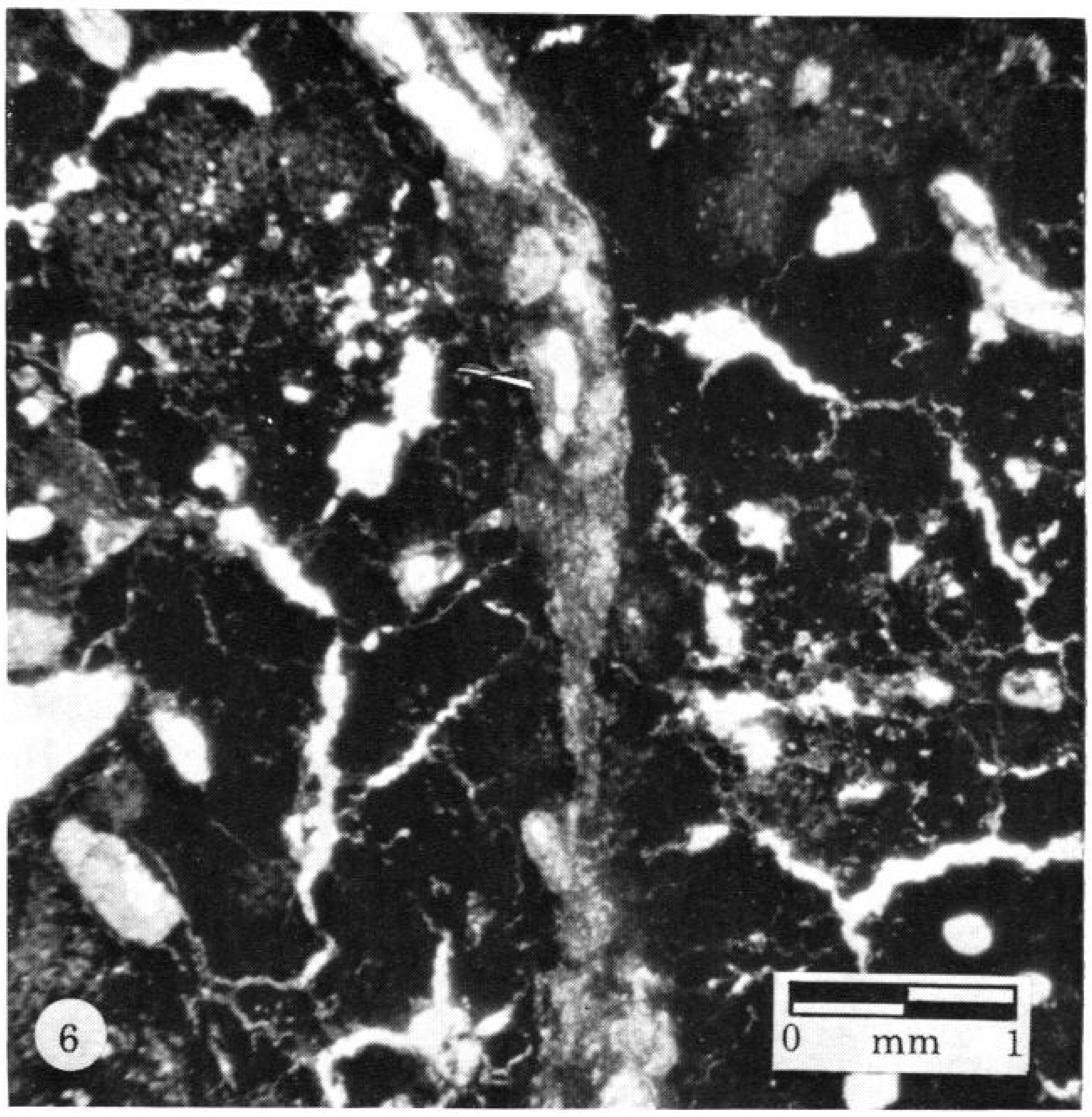

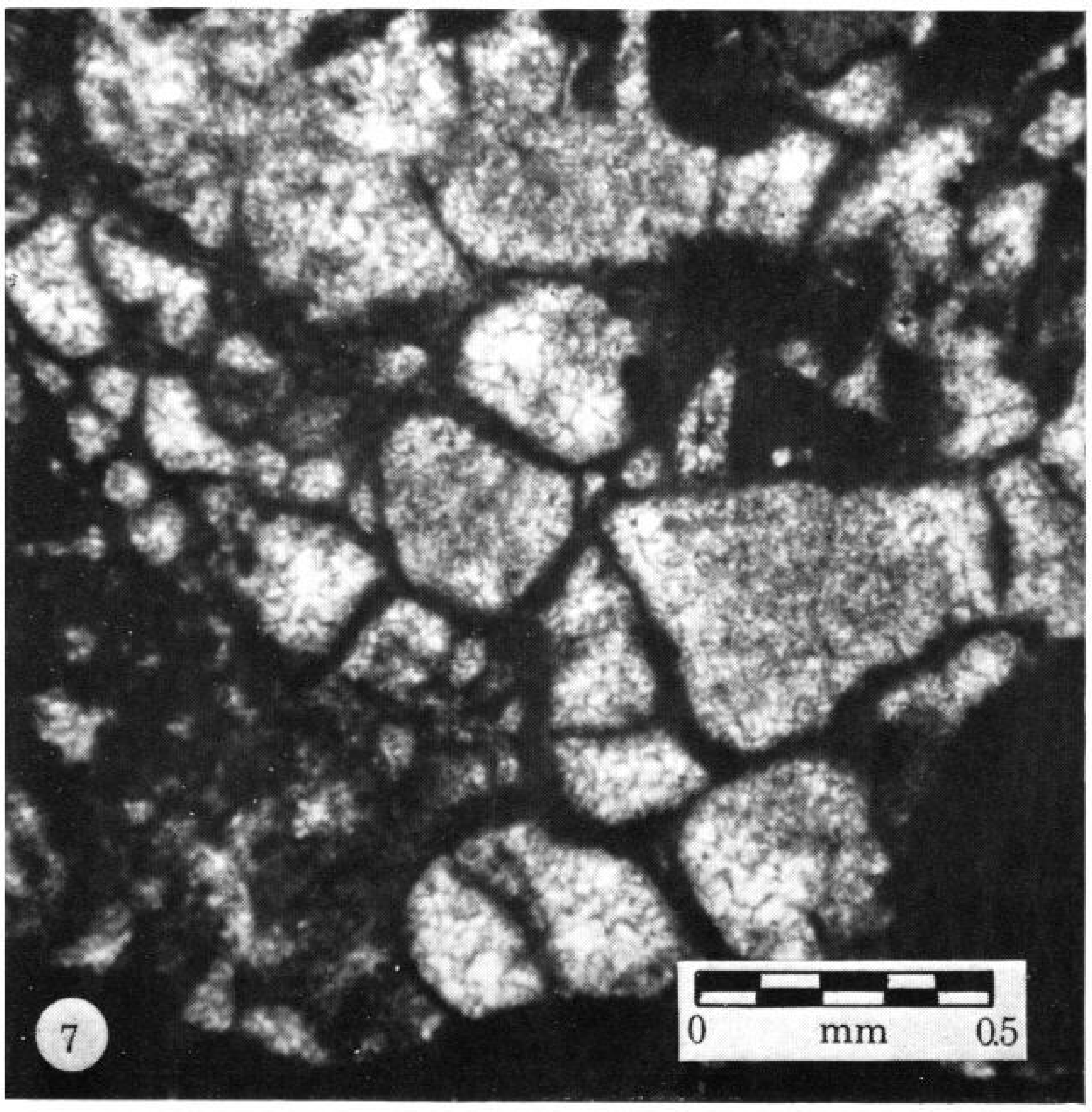

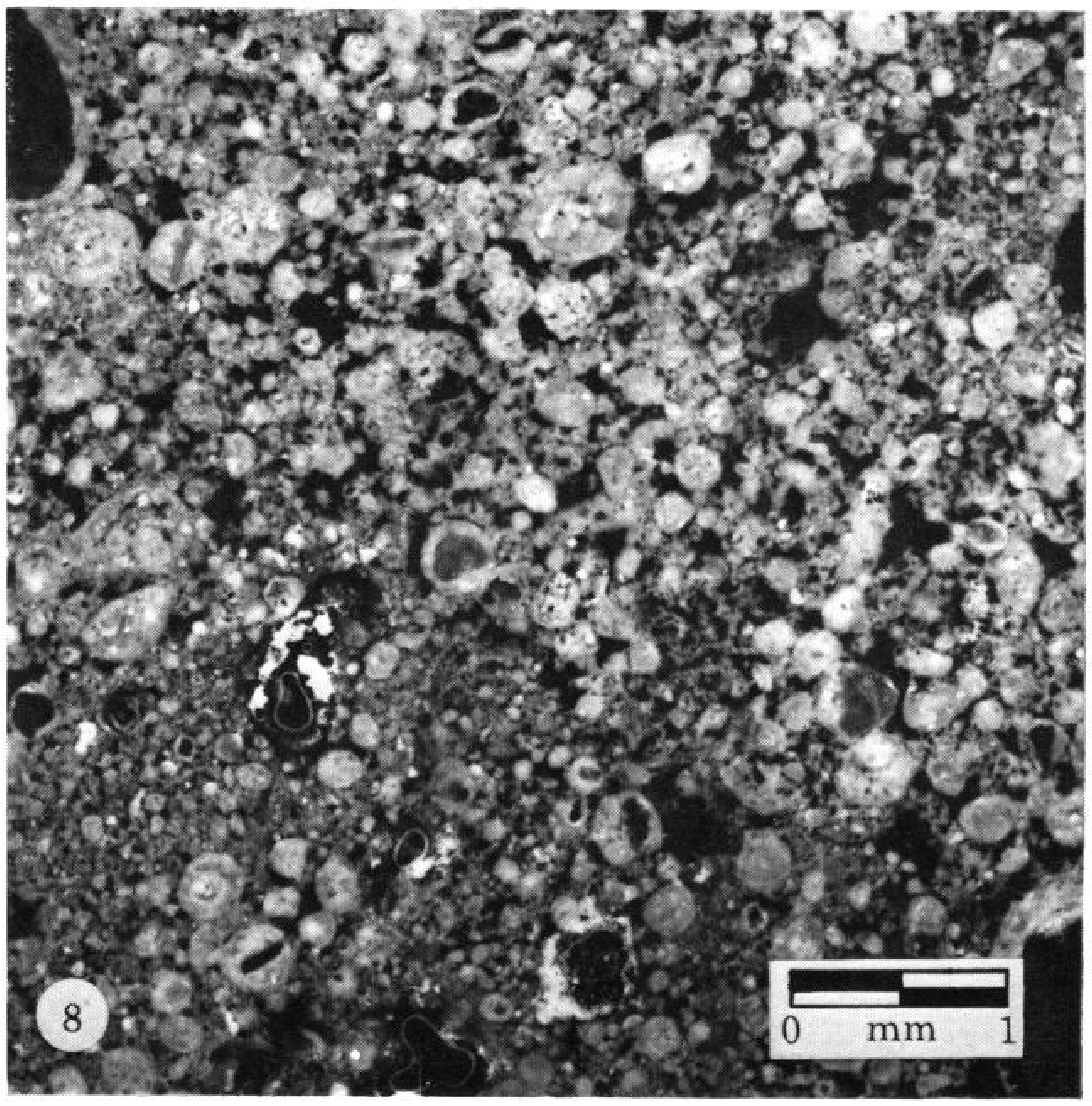

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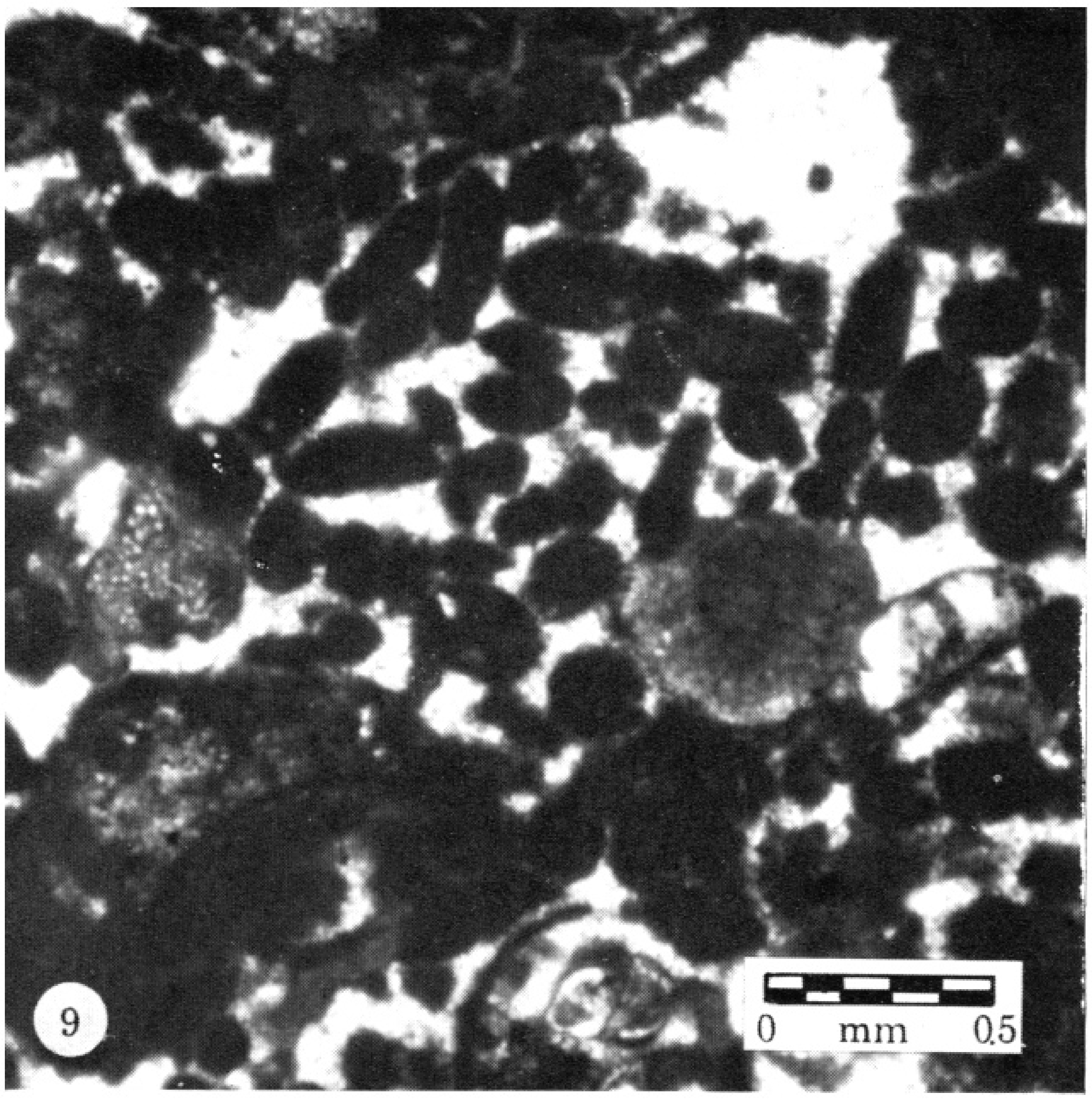

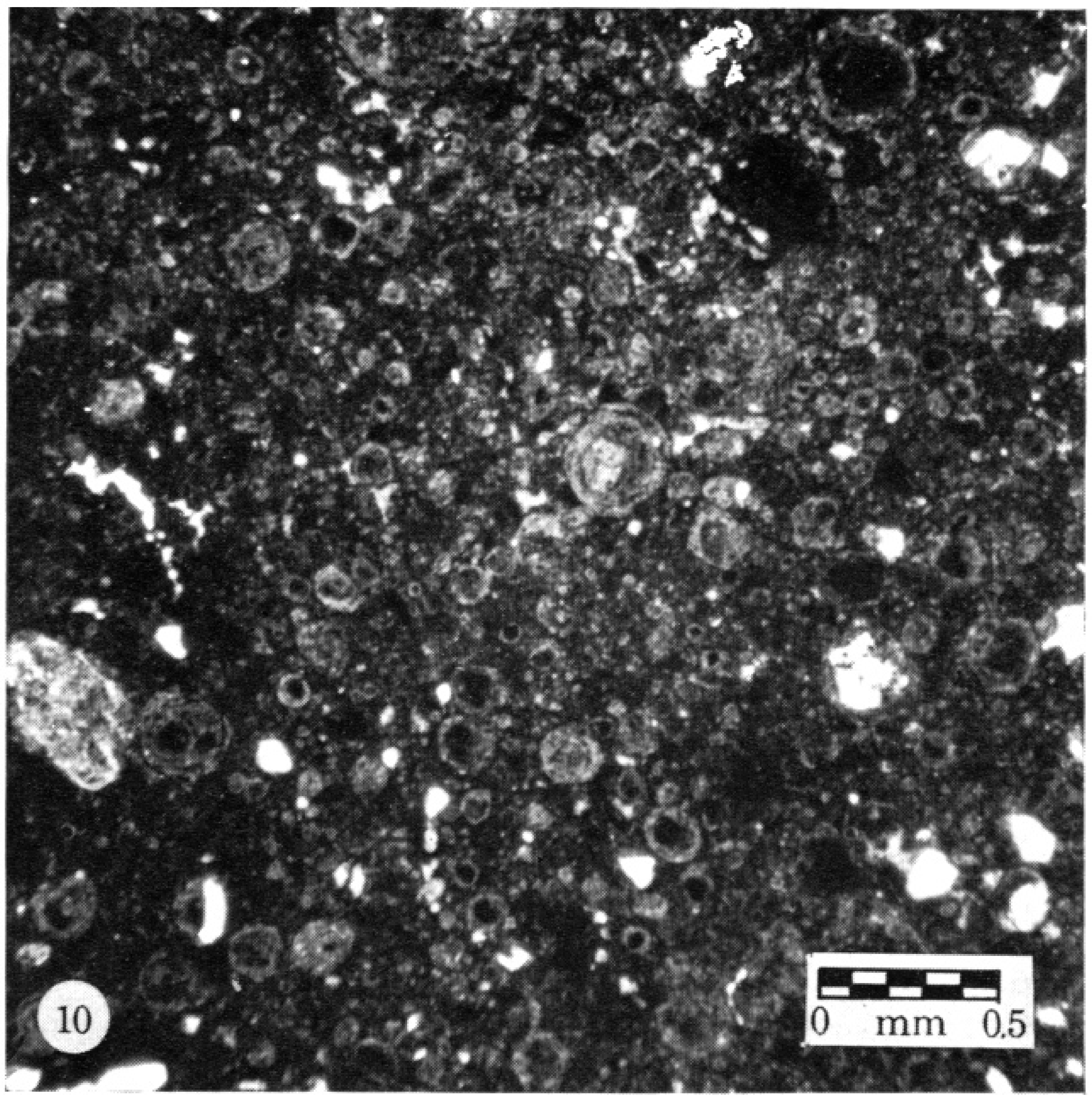

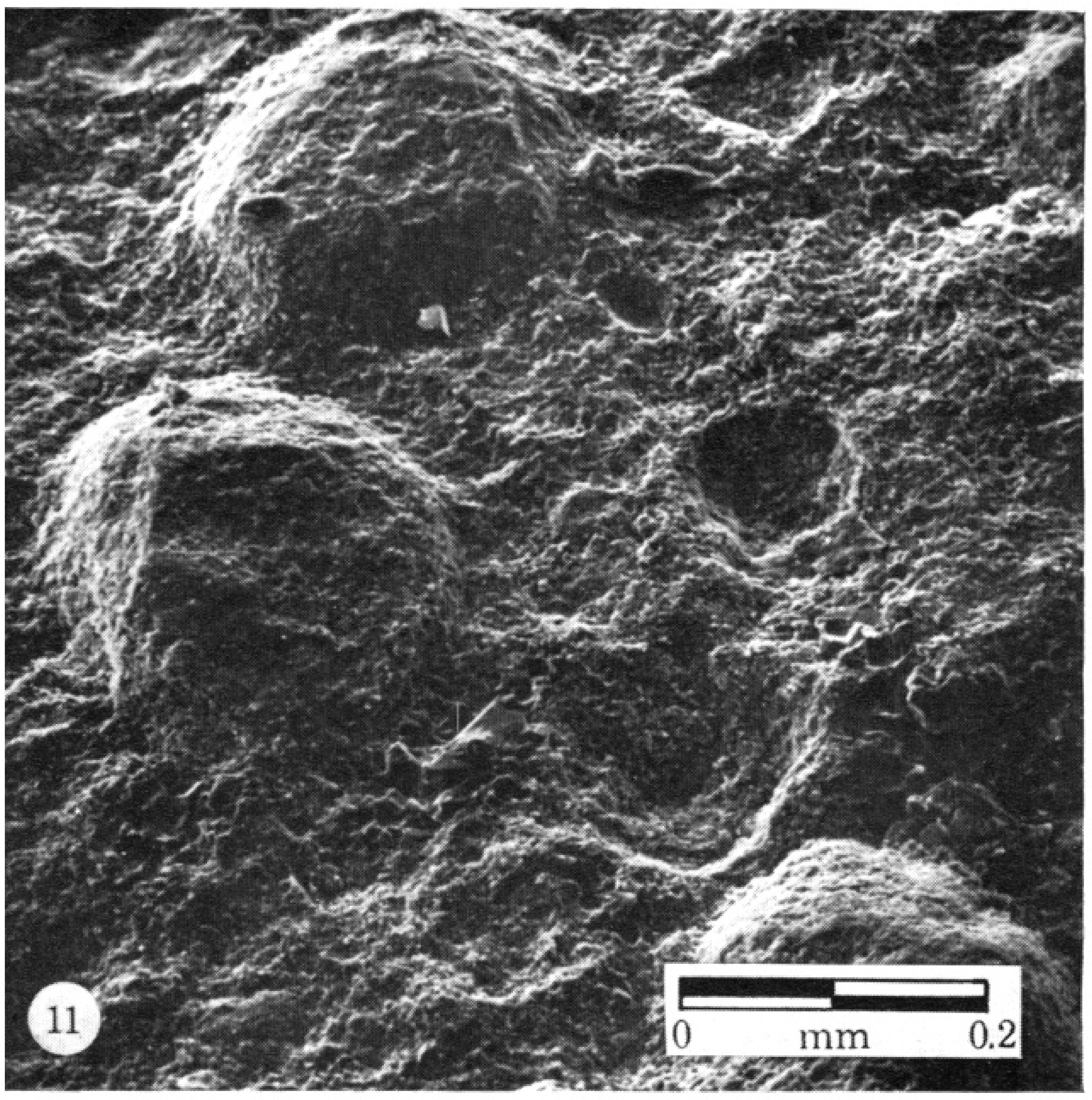

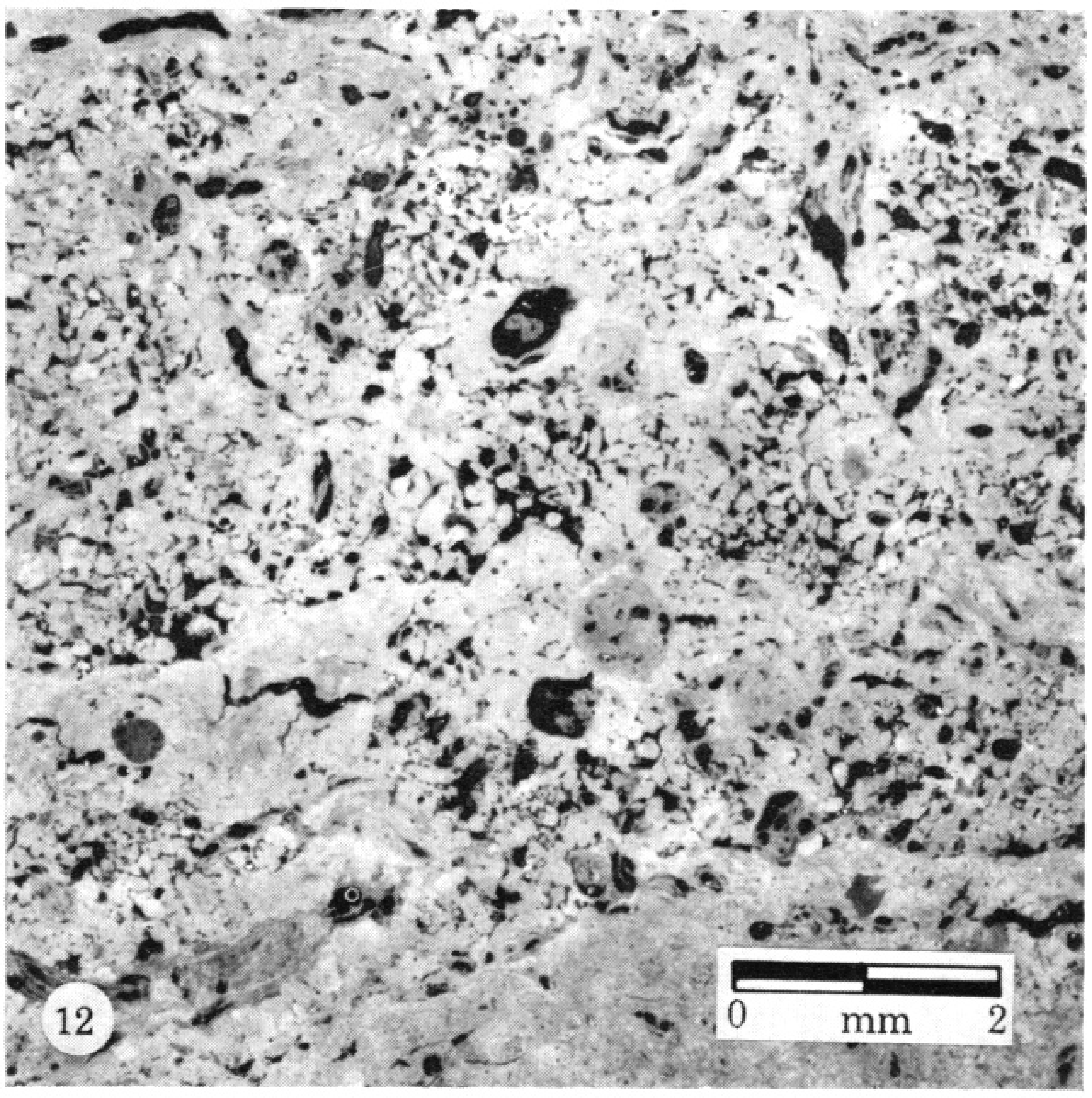

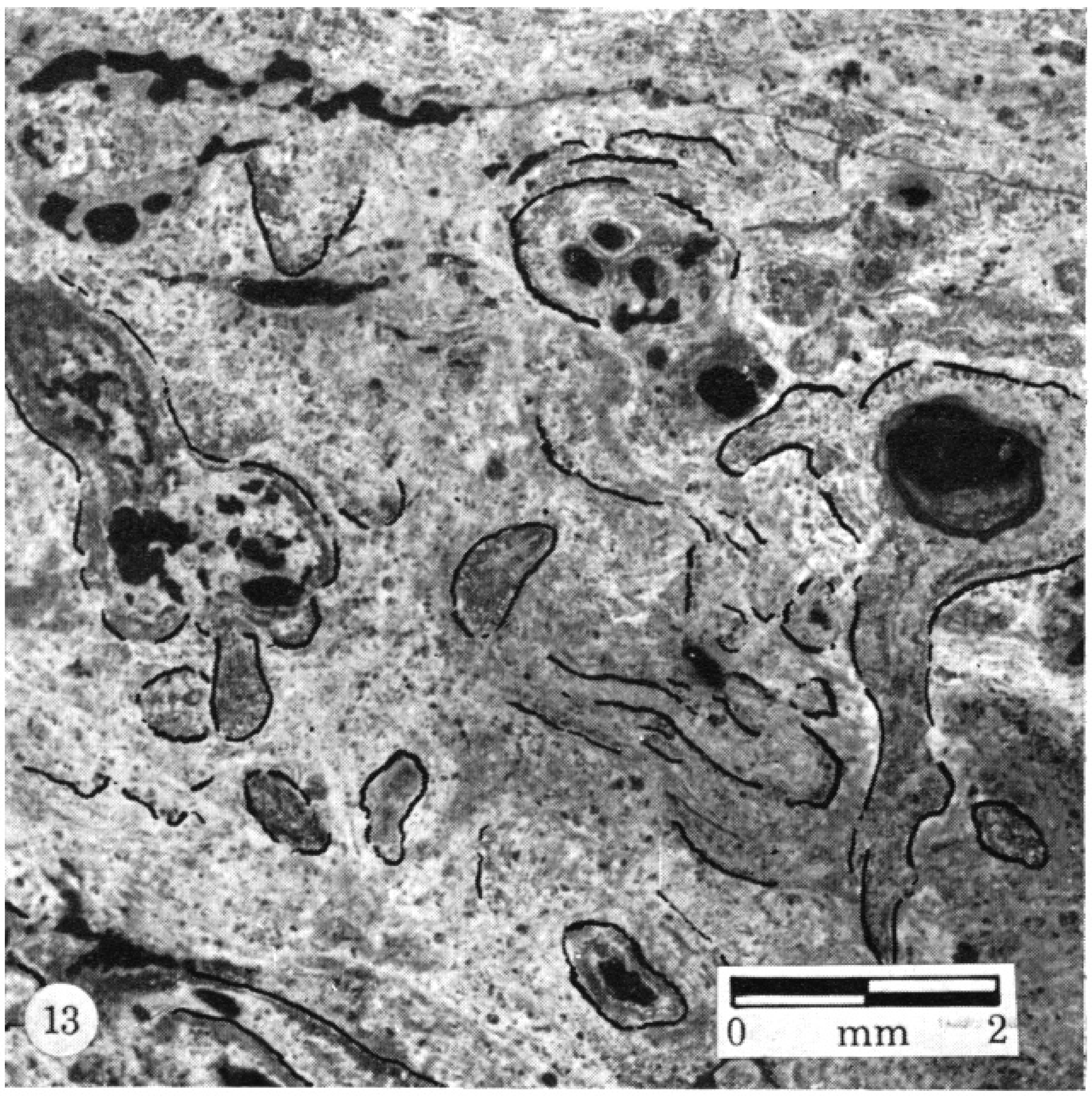

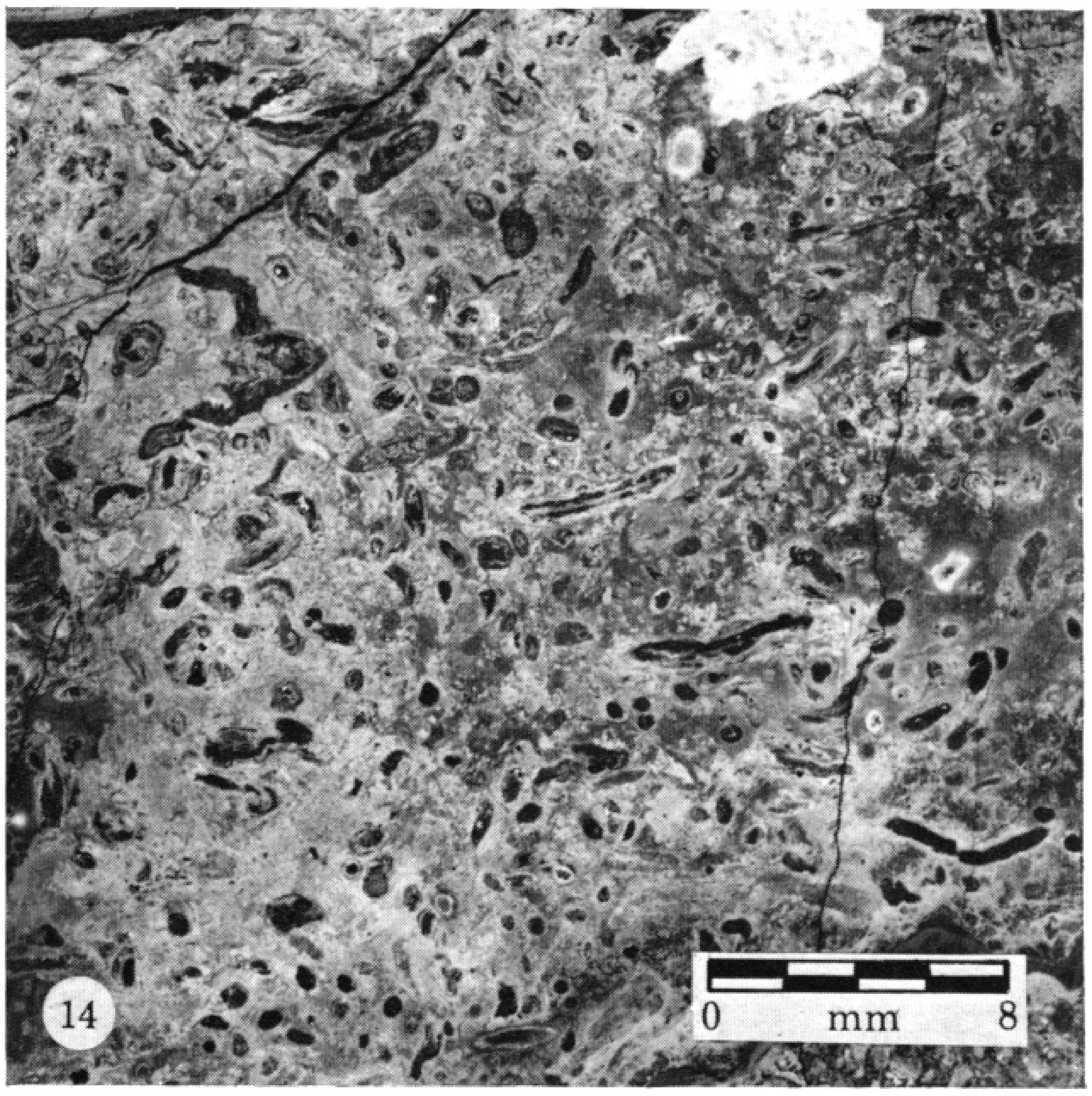

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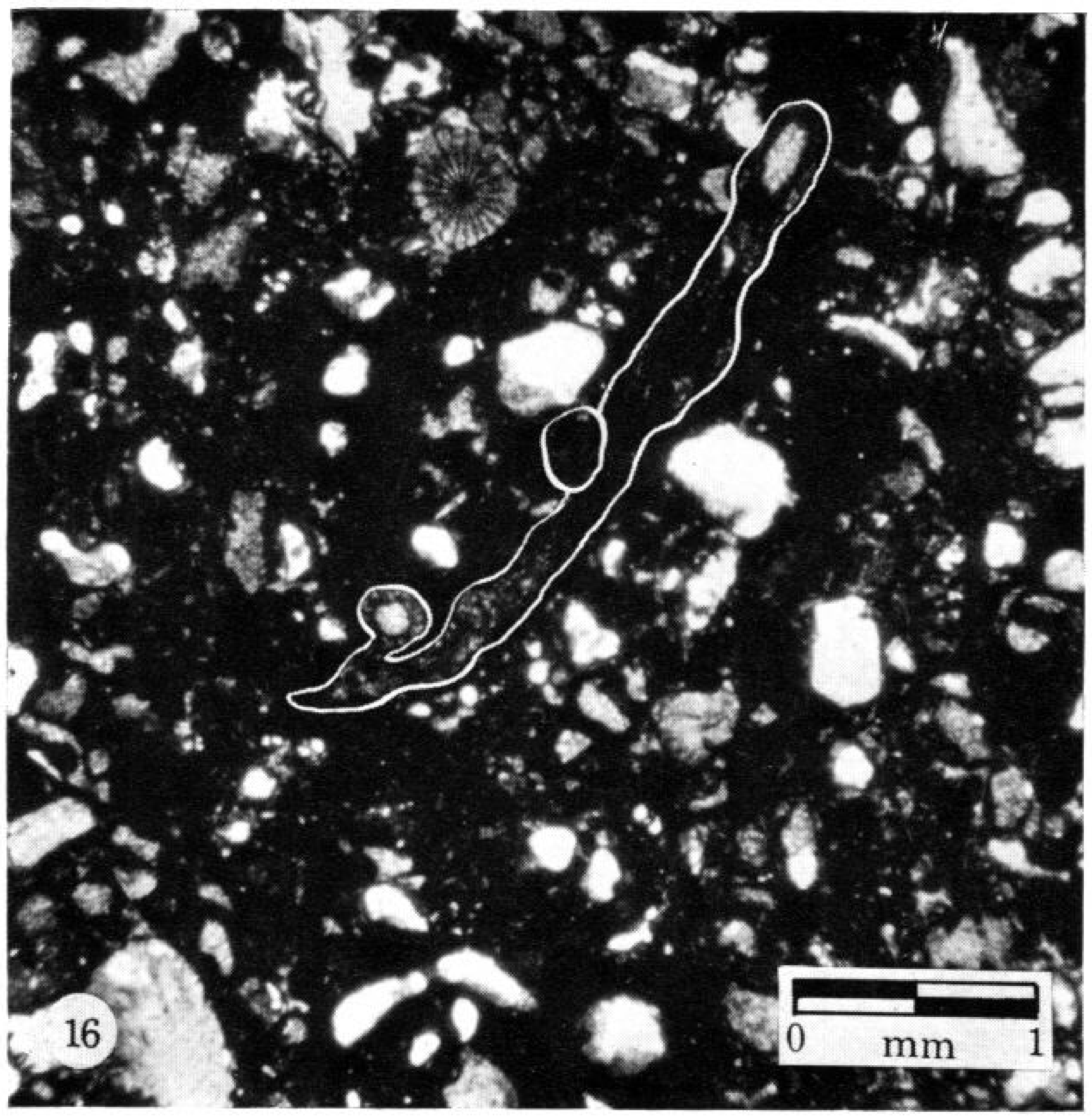

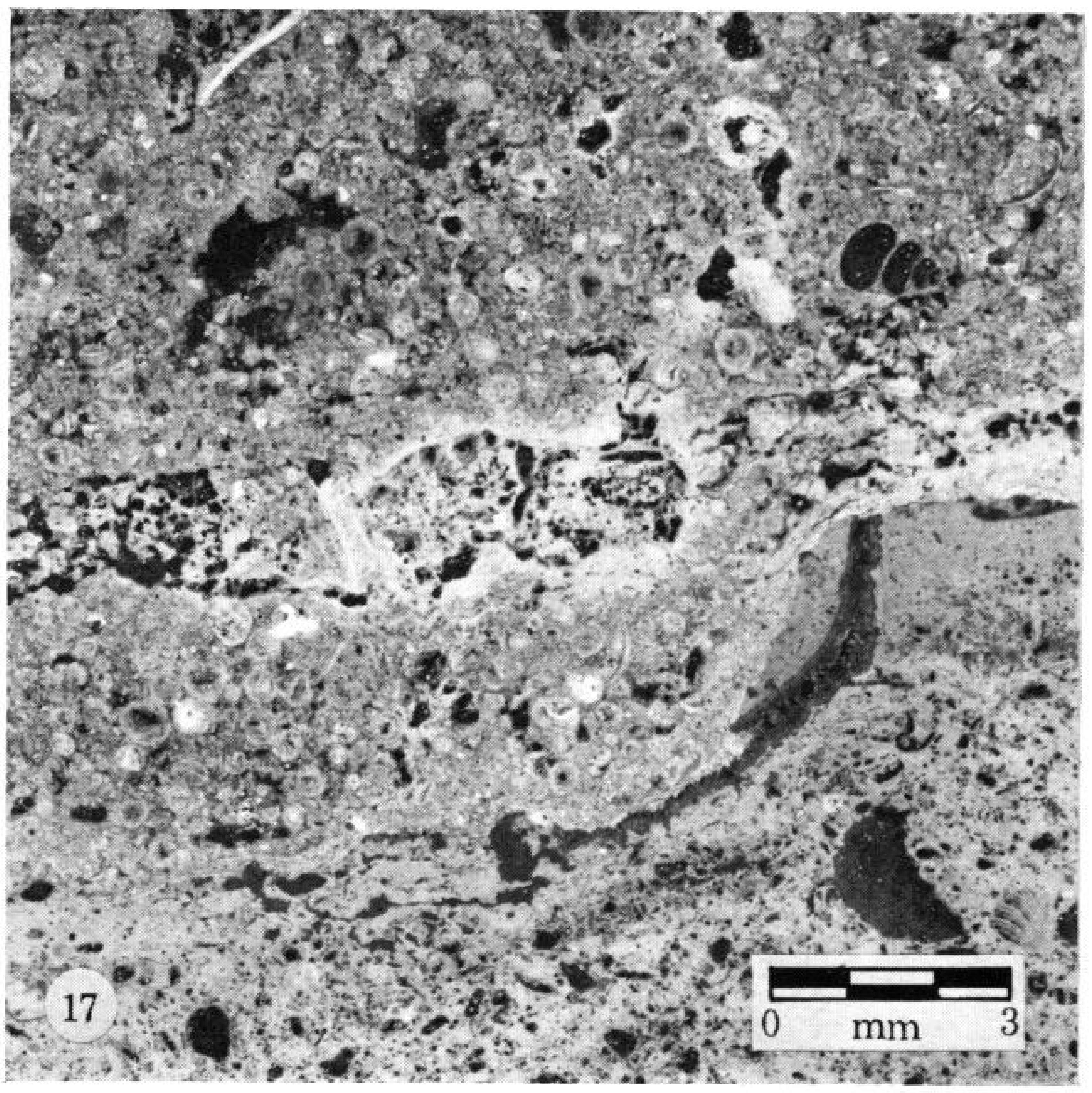

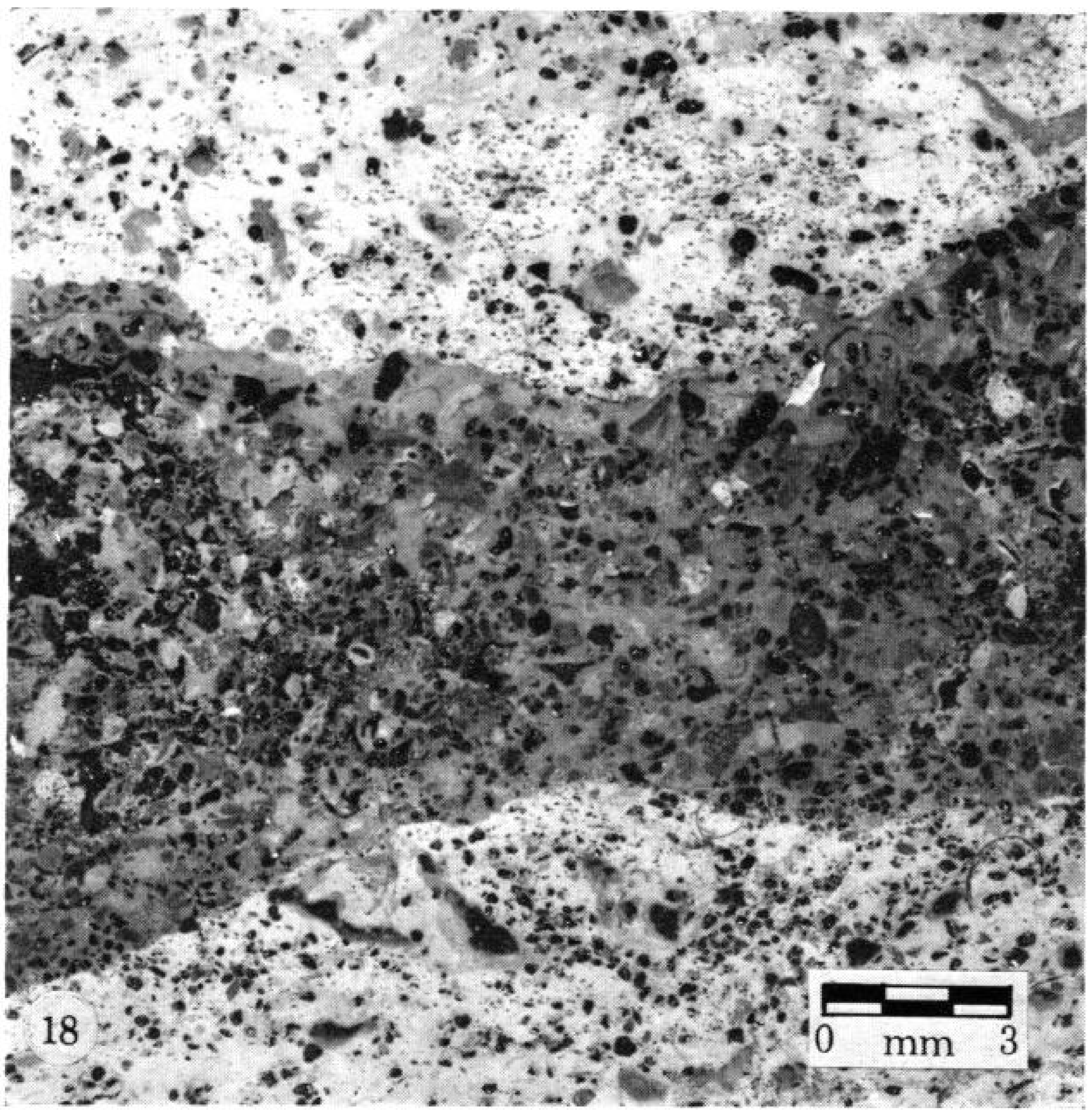

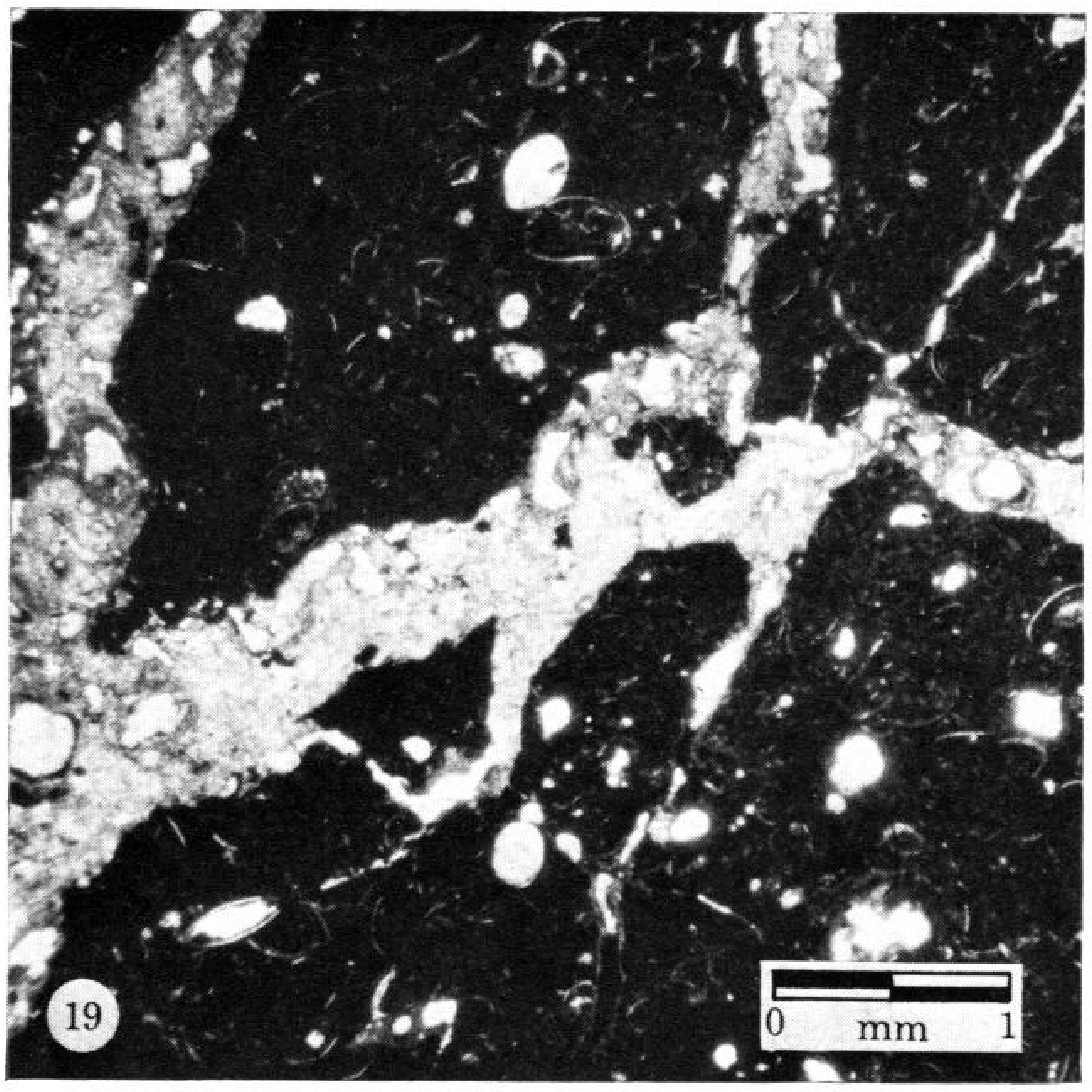

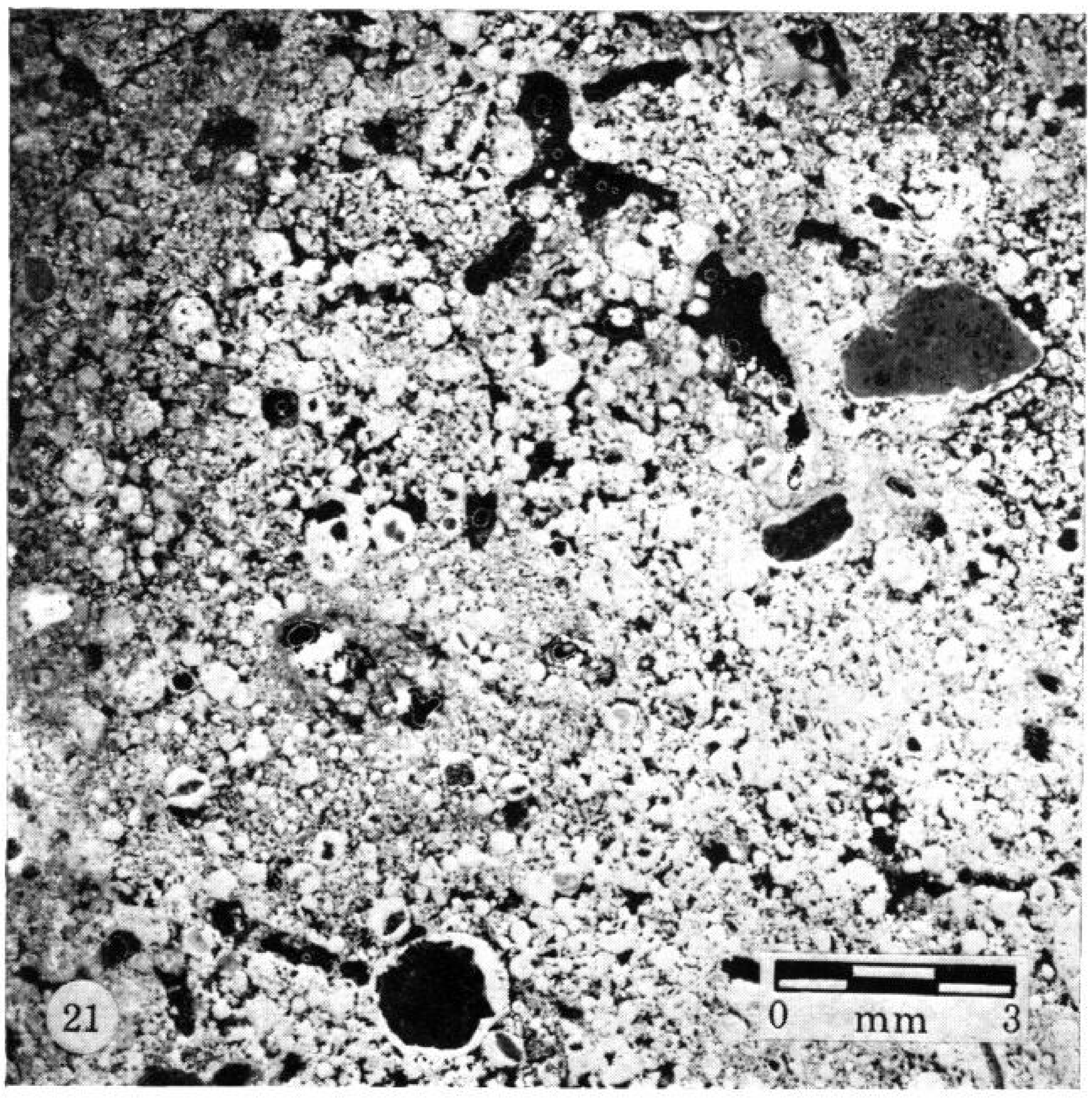

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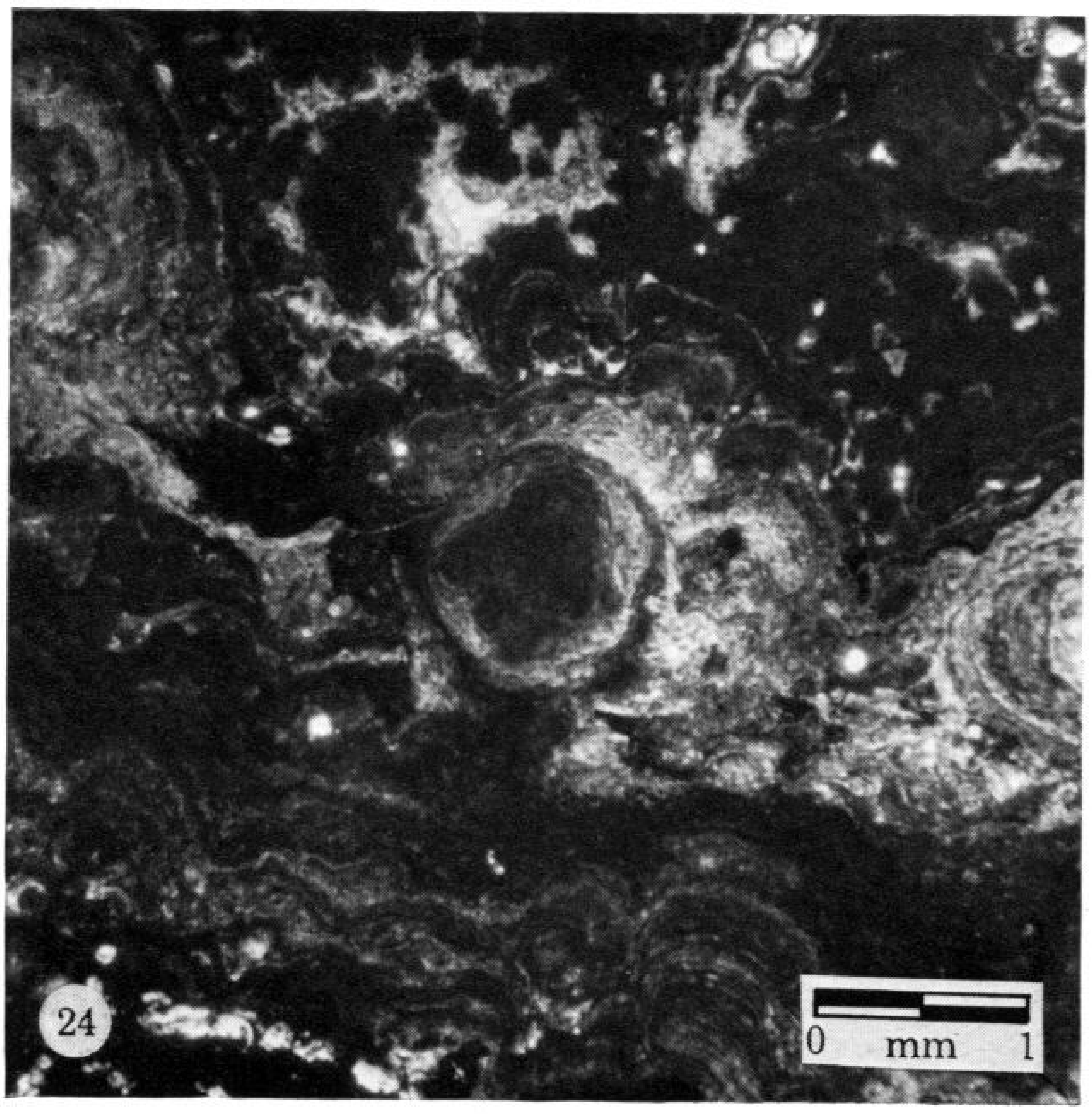

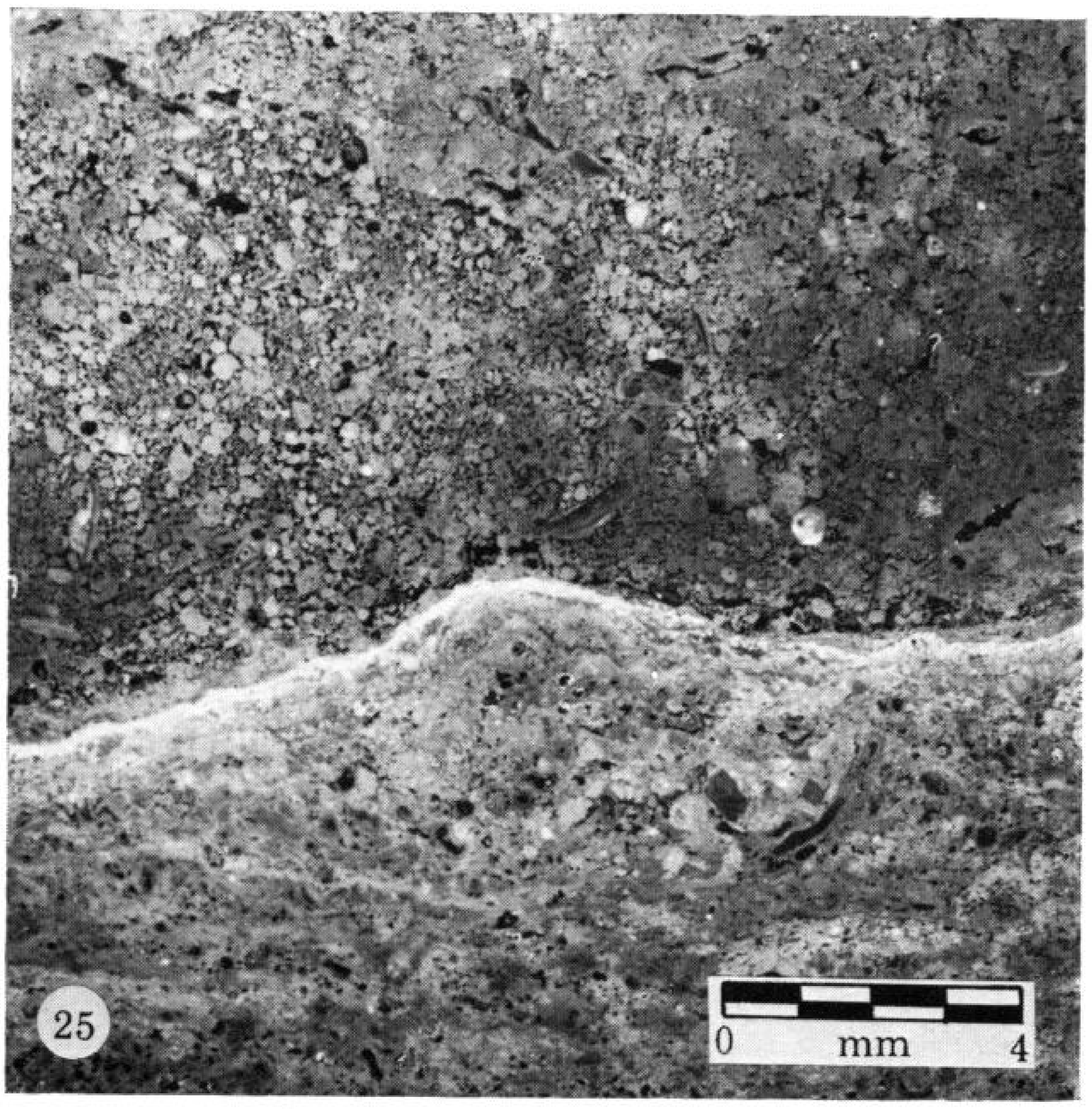

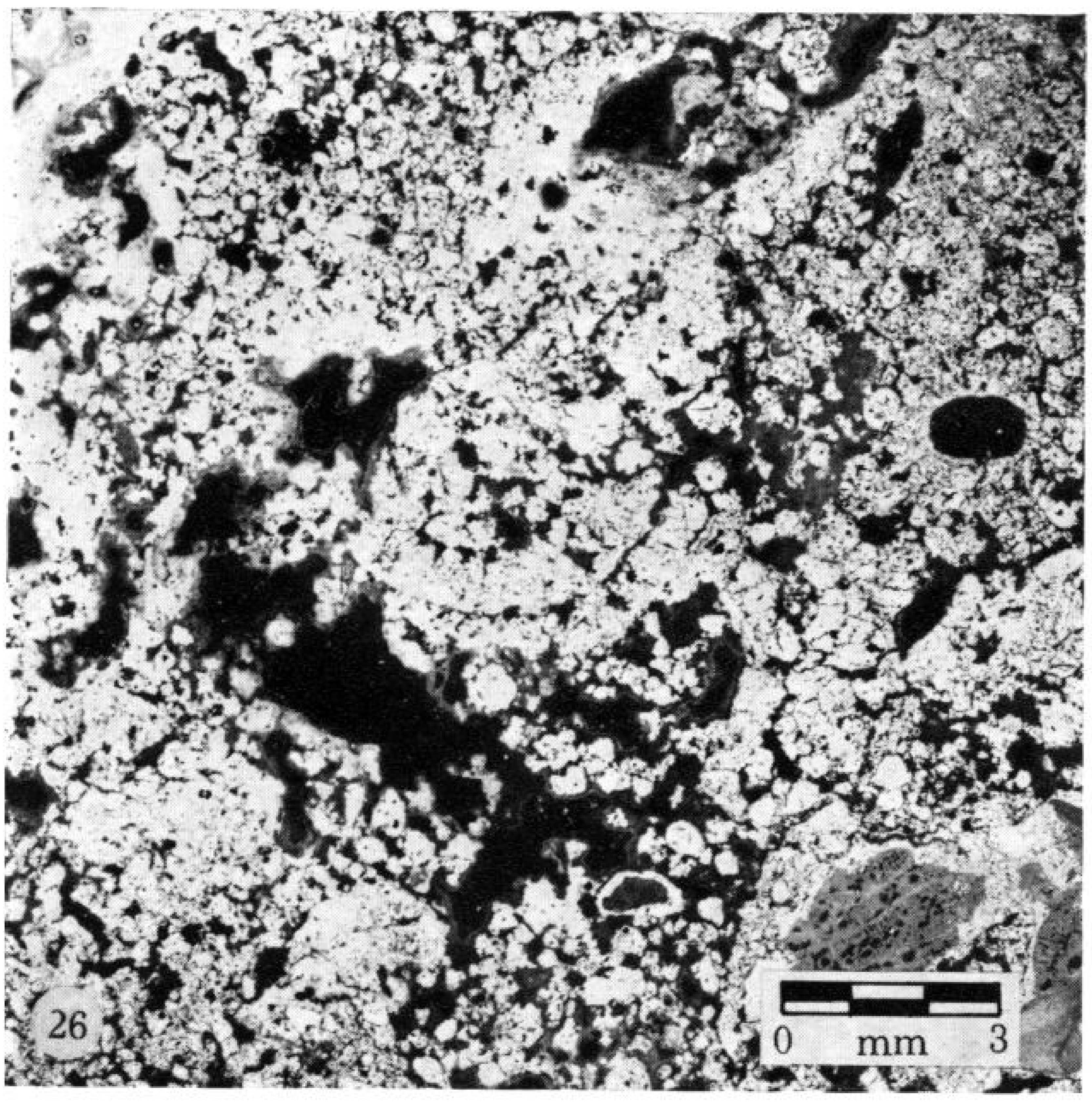

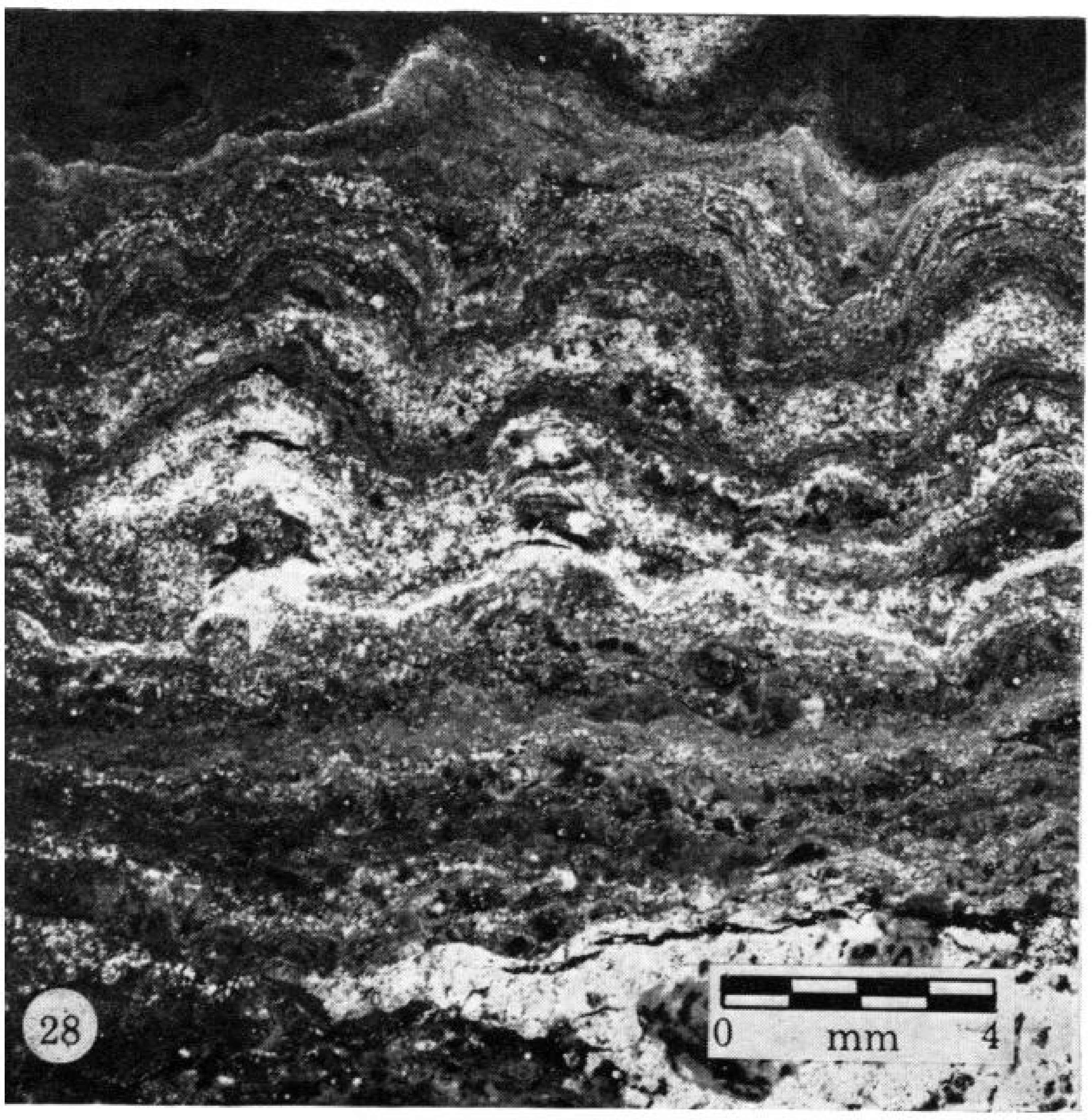

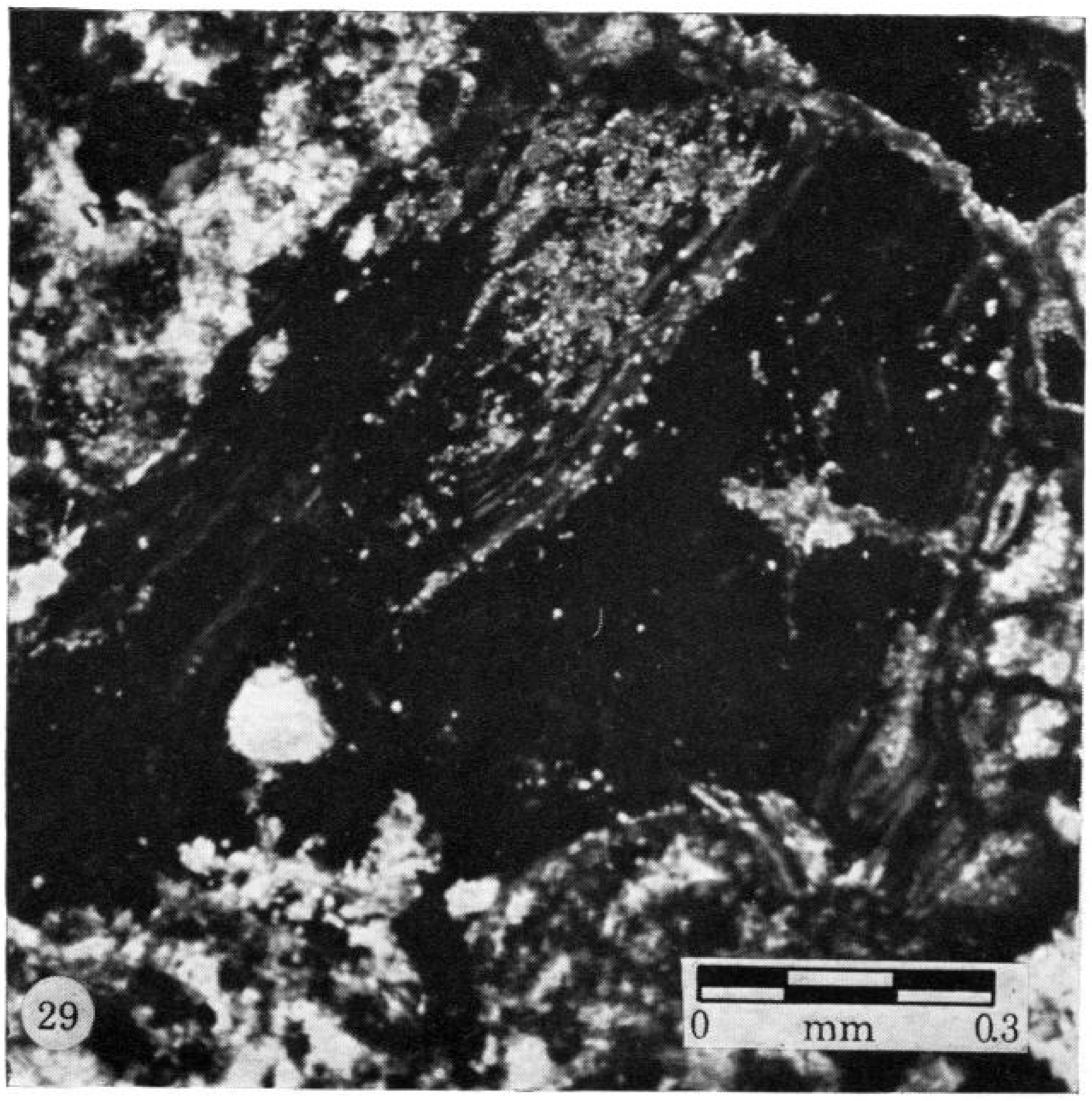

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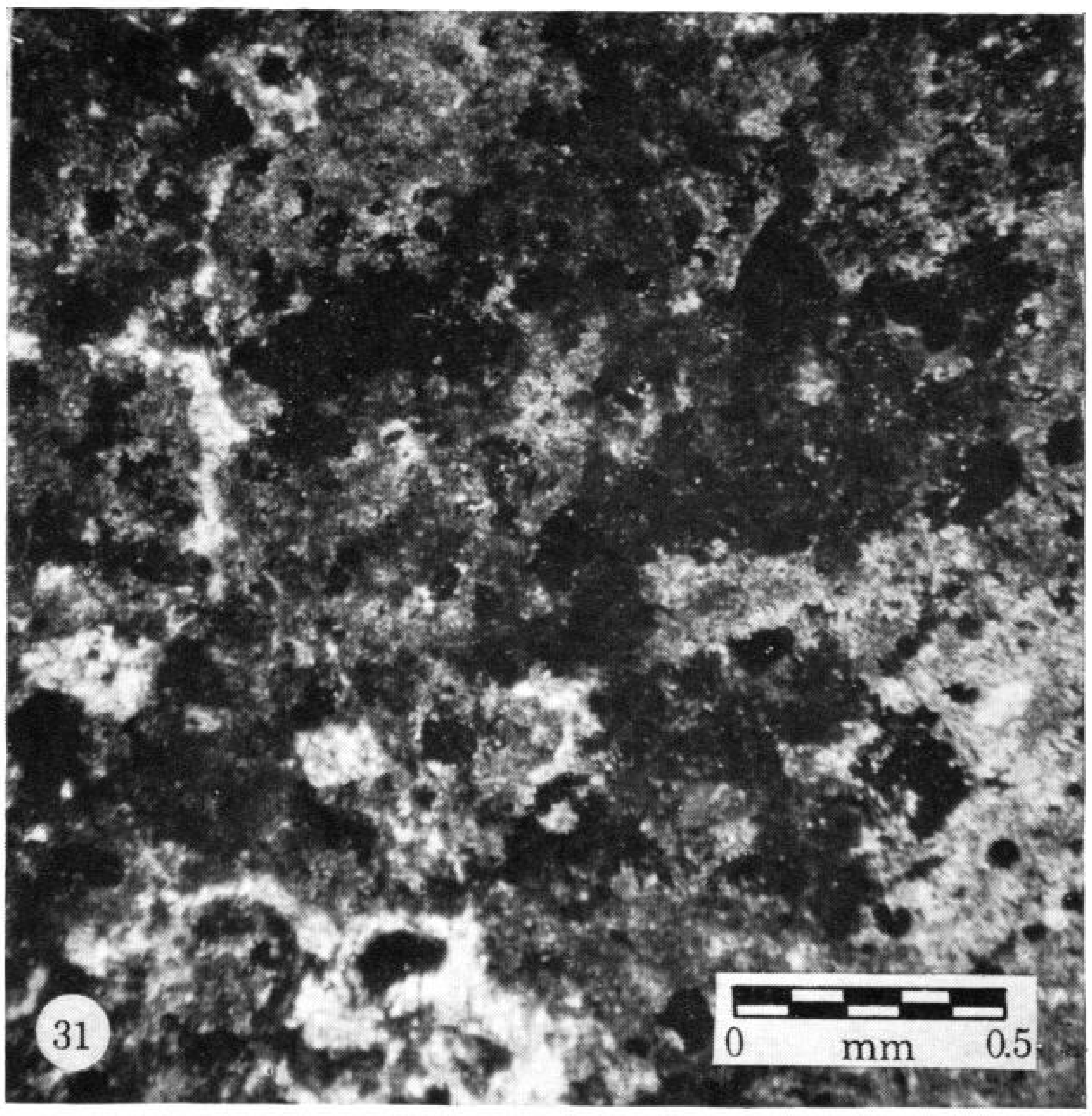

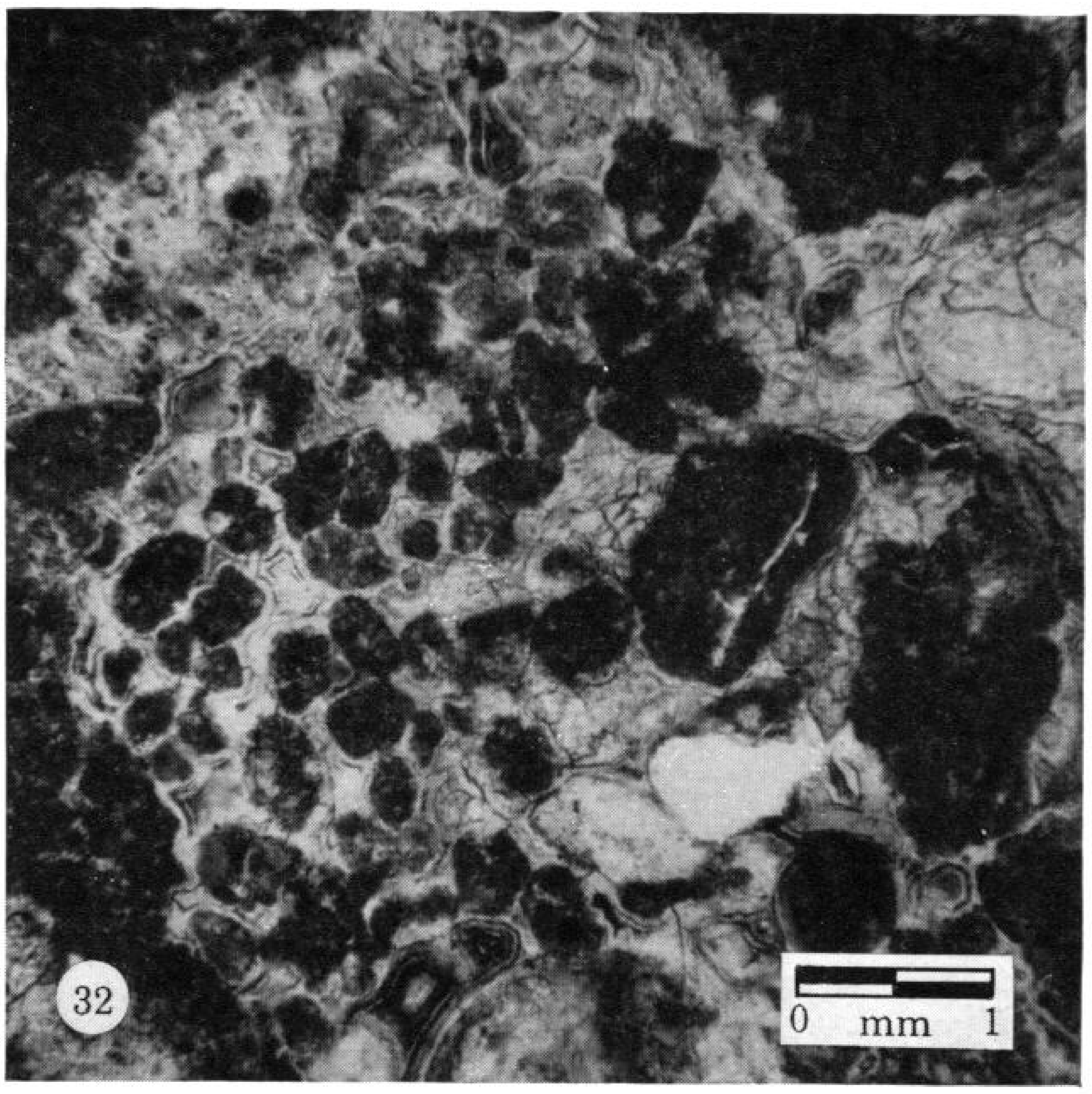

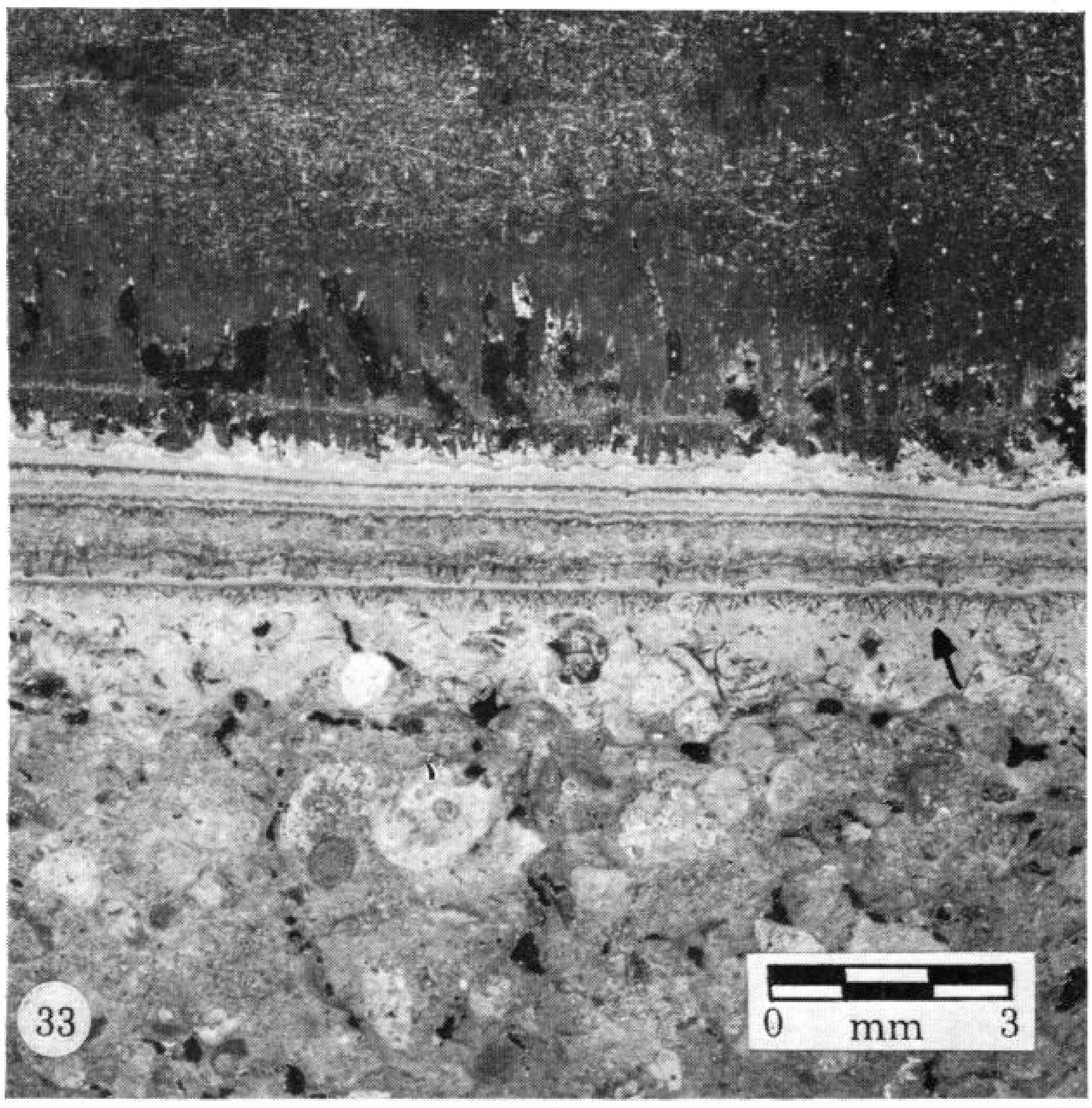

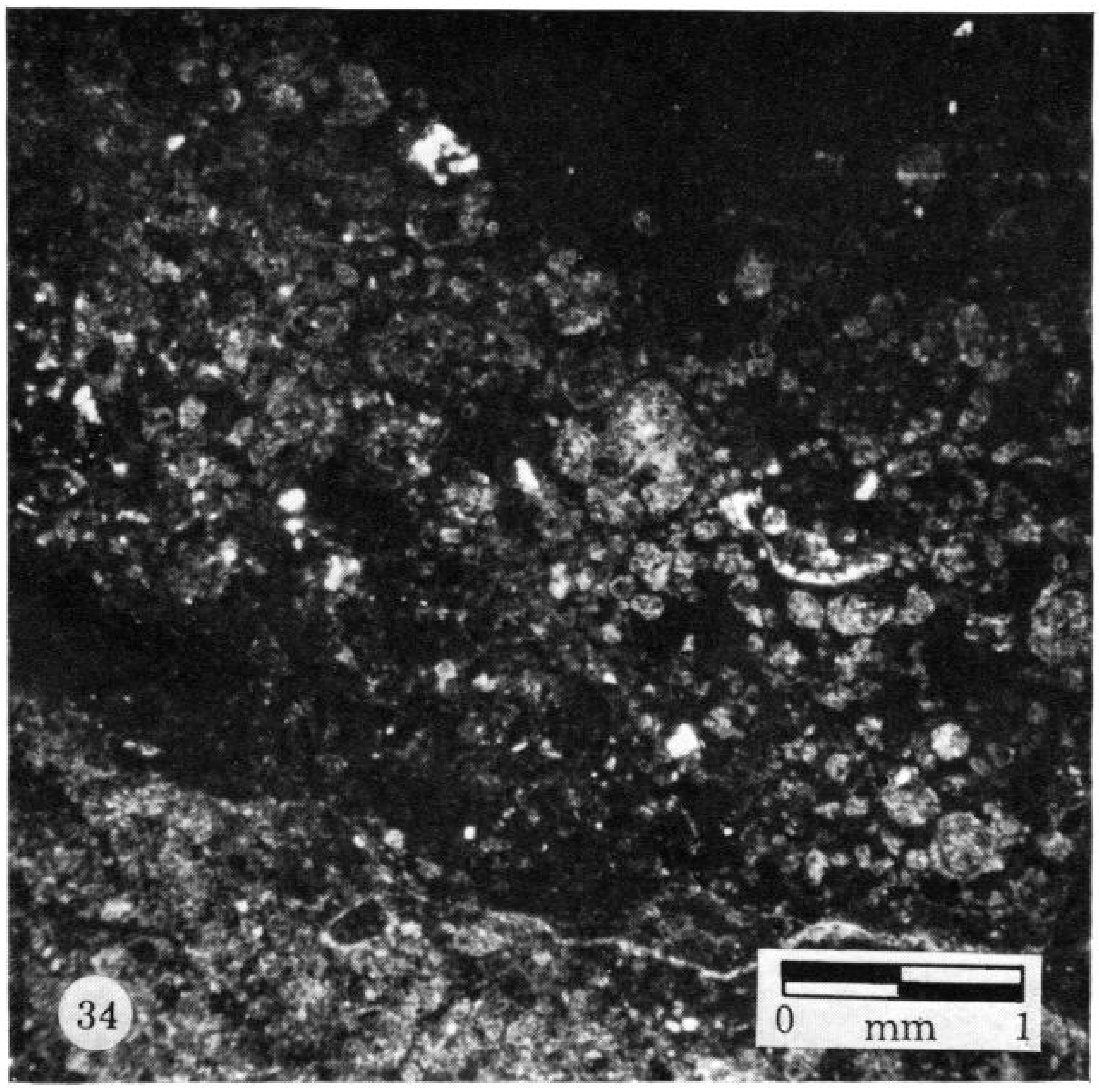

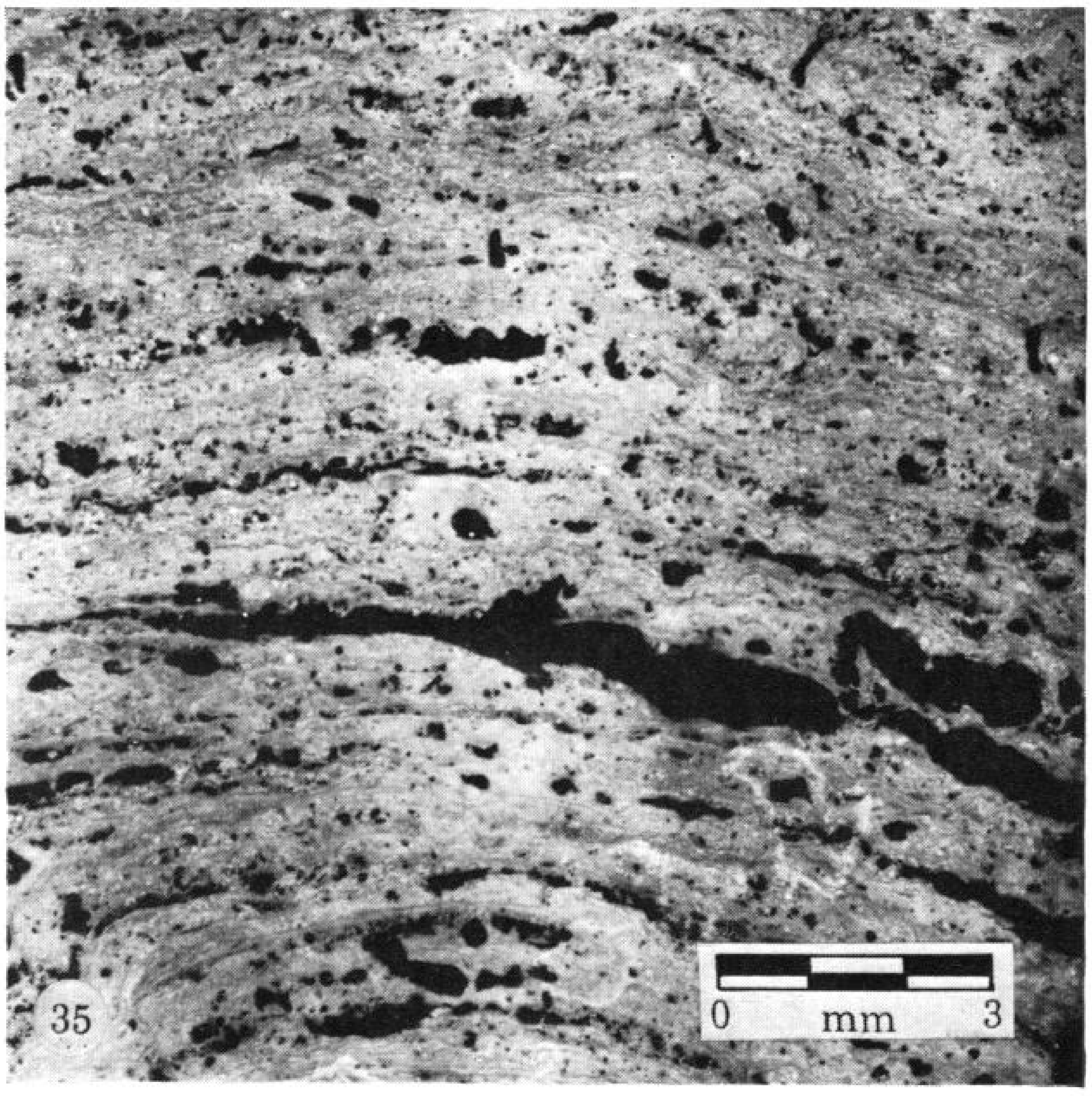

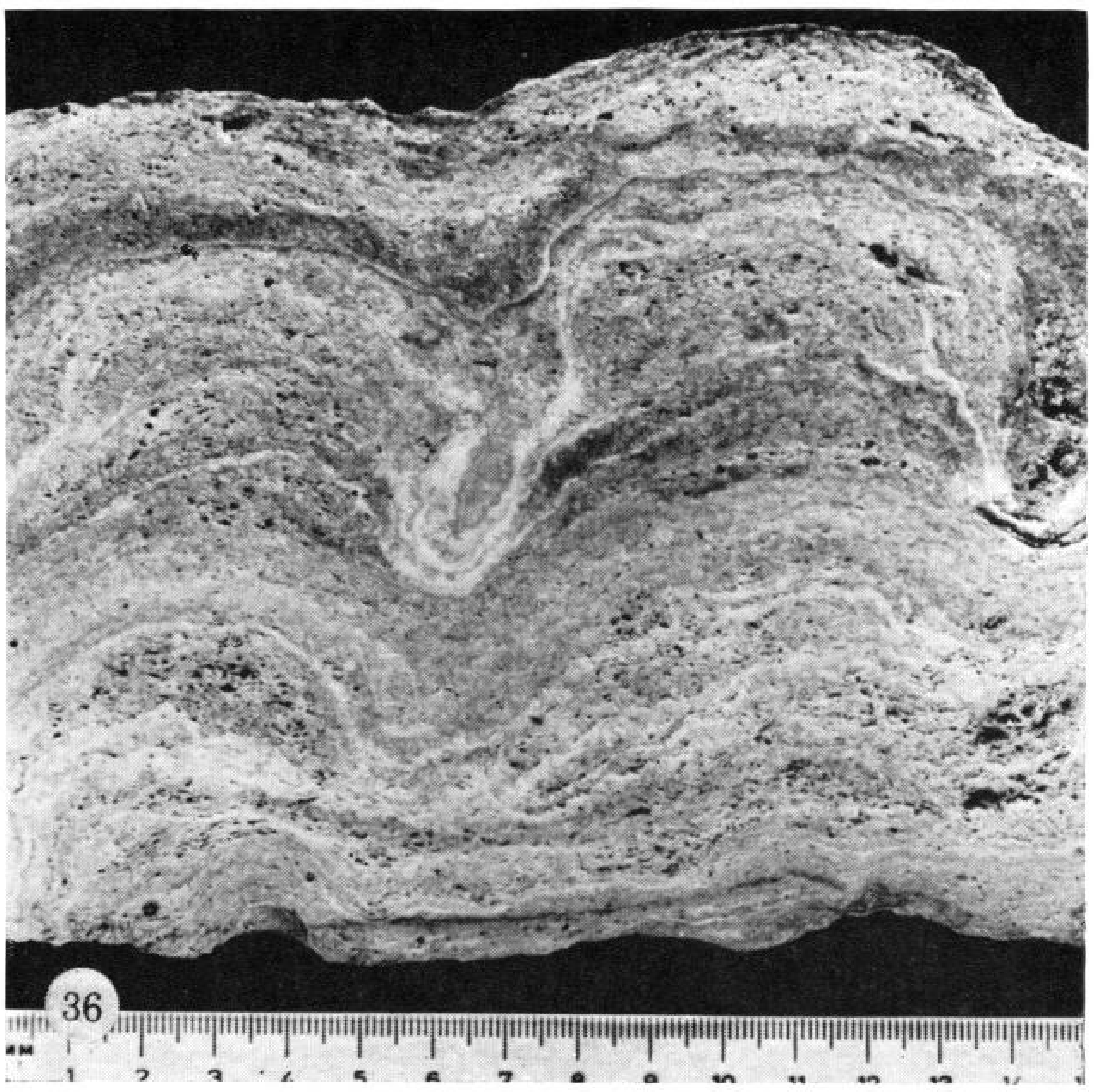

FIGURES 31–36. For description see opposite.