AN ELECTRON MICROSCOPIC STUDY OF THE UPPER PENNSYLVANIAN LIMESTONES OF KANSAS*

by

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(With 3 Tables, 16 Text-figures and 30 Plates)

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* Based on a doctoral dissertation submitted to Department of Geology and Mineralogy, Faculty of Science, Hokkaido University in 1973.

ABSTRACT

Through an investigation of about two hundred limestones, collected from the Upper Pennsylvanian of Kansas, mainly by means of an electron microscopic observations, revealed detailed features of these limestones. These features are described and interpreted through diagenetic as well as petrologic points of view. Amongst these descriptions and interpretations some important features are summarized as follows:

(1) There are systematic differences in the grain size of lime mud matrices of the limestones comprizing megacyclothem. Especially that of between upper and middle limestones of megacyclothemic successions evidently is delineated by factor analysis even though no significant difference is

depicted by partial statistics.

(2) The above difference probably is reflected by the difference of the environment of the depositional basin forming the two types of limestone. Since environmental difference must be extensively affecting to the type and amount of organisms, which would be utilized as the source of the lime mud.

(3) Most dolomites observed are considered as secondary origin, having euhedral shape and sometimes protruded into skeletal materials.

(4) Many euhedral quartz grains are revealed much more frequently observed than in thin sections. The apparent secondary origin of these grains also is evident.

(5) Most skeletal grains in these limestones were revealed finely comminuted and unabraded, probably fragmented rather by the action of scavenging organisms than by mechanical break-down such as agitation caused by wave and/or current.

(6) Even with the above fragmentation many skeletal microstructures are so well preserved that sometimes can not be distinguished from those of recent specimens, especially this is the case for brachiopod.

(7) Echinoderm fragments are exclusively containing numerous dolomitic inclusions in the skeleton. These dolomites probably are diagenetic products through enrichment of magnesium ions from that of originally contained in Mg-calcite of the skeleton.

(8) Fusulinid wall structure is extensively observed, and revealed porous nature of the spirotheca, though no difference other than grain size are depicted between keriotheca and tectum throughout.

(9) Most fusulinid which is revealed well preserved as seen in thin sections, generally failed to show distinct wall structure.

(10) Pellet is revealed as aggregate of extremely fine grained, less than 0.2 microns diameter, calcites. Some pellets appear as spherical. Also small amount of irregularly shaped pelletal aggregates scattered in between calcite grains of both lime mud and sparry cement.

INTRODUCTION

Much has been learned in the past two decades concerning the petrology and petrography of both Recent and ancient carbonate sediments. Principles gained from numerous studies of Recent sediments have been applied for interpreting the ancient rocks, and *vice versa.*

Although volumetric abundance of fine grain constituent in the stratigraphic records has been stressed, it has been pointed out by MATTHEWS (1966) that studies of Recent carbonate sediments generally have rather concentrated on the genesis and behavior of sand and coarser size particles than on those of the fine grain constituent. There has been, however, considerable amount of study discussing the genesis and origin of Reent lime mud, on the Great Bahama Banks (LOWENSTAM, 1955; LOWENSTAM and EPSTEIN, 1957; CLOUD, 1962, PURDY, 1963; etc.), on British Hondulas (MATTHEWS, 1966), on Florida (GINSBURG, 1956; STOCKMAN *et al.*, 1967; FORCE, 1969), and on many other similar areas.

On the contrary, numerous studies concerning the ancient carbonate rocks have been dealing with fine grain constituent extensively. However, it is rather striking that rarely the intrinsic characteristics, detailed nature and/or genesis of this constituent have been discussed, but this material has been mainly utilized to interpret current strength of the depositional basin. The presence, absence or relative abundance of fine grain constituent to sand and coarser size grains has been considered as of fundamental importance in petrologic study of carbonate rocks, since it serves as an index to current strength of the depositional basin (DUNHAM, 1962; REIGHTON and PENDEXTOR, 1962; PURDY, 1963; BISSEL and CHILINGAR, 1967). This quantitative treatment of the fine grain constituent, however, does not reveal the detailed natures of this material. Traditionaly it has been seldom discussed in detail, whereas other coarser constituents have been critically and extensively defined, described, diagnosed and discussed in respect to their origin, diagenetic changes and/or geologic bearings.

The scarcity of studies dealing with the intrinsic and detailed characteristics of fine grain constituent of ancient carbonate rocks may be partly because of the above approach to this material, but mainly because of the limitation due to resolving power of petrographic microscope (light microscope: L.M.) (HONJO and FISCHER, 1965; CHILINGAR *et al.*, 1967).

Theoretically the resolving power of L.M. should provide enough clarity for the investigation of this constituent, at least to a considerable extent. Overlap and superposition of mineral grains, caused by excess thickness of "ordinary" thin section, blurred the clarity of the image in the high magnification (x200 or more) work of L.M. Birefringence of mineral grains contributes to worsen the quality of the image (HONJO and FISCHER, 1965). Accordingly, the practical resolving power of L.M. in thin section study has been considered, even with the best optical system, not better than 4 microns (HONJO, 1969), although theoretically it attains approximately 0.5 microns. This practical limitation of resolving power of L.M. just lies at the size limit of FOLK's (1959) definition of micrite.

In eastern Kansas, Middle and Upper Pennsylvanian rocks cropout in a belt that extends diagonally through the state from northeast corner to the south-southwest direction. These strata are so well developed with no major break of deposition throughout the sequence that they have been considered as one of the type succession of Late Carboniferous stable shelf deposits. They have been, naturally, extensively and critically investigated from various points of view including stratigraphy, paleontlogy and sedimentolgy. Also cyclic nature of the lithology of the stratigraphic units, known as megacyclothem (MOORE, 1936), has no doubt attracted many investigations on these successions of rocks.

No less than 70 limestone members have been recognized (ZELLER, 1968), in this relatively thin successions of beds, approximately 800 m thick in the outcropping belt while it extends 300 kilometers or more laterally. Most limestones, many of which are existed in the Upper Pennsylvanian, also are as persistent as the belt. These amazingly thin but laterally widespread limestones, with the conjunction of cyclic nature of the lithology, naturally attracted sedimentological as well as petrologic and petrographic studies. Thus several limestone units in the Upper Pennsylvanian have been critically and extensively studied from the view-point of facies analysis. These studies successfully delineated lateral facies changes of these limestones along the outcropping belt. Many other limestones have been believed to show similar facies changes although not critically investigated in detail. Neverthless, depositional environments of these limestones as well as other lithologic units are thought to be so similar as expressed in successful repetition of the lithologic sequence. While laterally they are more or less variable represented in facies changes of some limestones.

This study primarily is intended to reveal the detailed morphologic features of fine grain matrices of the Upper Pennsylvanian limestones of Kansas using an electron microscope (E.M.). It is hoped to interpret relationships, if any, between the submicroscopic morphologies and the above megascopic features of these limestones. Descriptions of submicroscopic textures and structures of organic and inorganic constituents of these limestones also are one of the objectives of this study. Finally any diagenetic features revealed under E.M. are to be described and interpreted, if reasonably possible.

ACKNOWLEDGEMENTS

This study was accomplished under the direction and supervision of Professor Masao MINATO of Hokkaido University. The author wishes to express his sincerest thanks to Professor MINATO for his supervision, encouragement and valuable criticisms and suggestions throughout this study. The author is indebted to Professor Daniel F. MERRIAM of Syracuse University (formerly Geological Survey of Kansas) and Dr. William W. HUMBLETON, the Director of the Geological Survey of Kansas, both who have kindly arranged many special priveleges for the author to stay and investigate at the survey from 1969 to 1972, during when this study was mainly made. Professor MERRIAM's assistances in field works, discussions and suggestions are also helpful and are sincerely acknowledged. The author is also grateful to Drs. J.C. DAVIS and C.D. CONLEY, both of the Geological Survey of Kansas for their valuable discussions, suggestions and continuous encouragements.

Special gratitude is expressed to the following for reviews, comments, encouragements, criticisms and suggestions for the various stages in the research and preparation of the manuscript: Professor M. HUNAHASHI and Drs. M. KATO, S. UOZUMI, M. AKIYAMA, K. NAKAMURA and Y. FUJIWARA all of Hokkaido University, Professor W.W. HAY of the University of Illinois, Dr. P. TIEN of the University of North Carolina, Dr. D.F. TOOMEY of Pan American Petroleum Corporation, Professor F.W. PRESTON and Dr. A.J. ROWELL of the University of Kansas, Dr. P.H. HECKEL of Iowa State University, Dr. J.W. HARBAUGH of Stanford University, Professor P. TASCH of Wichita State University and Dr. S. HONJO of Woods Hole Oceanographic Institute.

Assistances of Messrs. S. KUMANO, S. OKADA and T. OHTAKE, Miss E. MIMA and Miss. K. UENO, all of Hokkaido University, for preparation of plates and draftings are gratefully acknowledged, also typing of manuscript was made by Miss MIMA.

PREVIOUS WORKS

No systematic investigation, primarily by means of an E.M., dealing with the Upper Pennsylvanian limestones of Kansas has been made previously. A preliminary report on the E.M. observation of some Winterset Limestone Member (Missourian) by FROST (1967), in connection with the development of a replication technique, is the exception. Tremendous amounts of studies have been made, however, concerning the Pennsylvanian System, either in its totality or parts of this system. Certain amounts of E.M. studies dealing with limestones of various ages, facies and localities have been reported, especially in this ten years.

Systematic stratigraphic studies concerning the Pennsylvanian in Kansas were begun as early as 1859 by MEEK and HAYDEN (*in* MOORE, 1949). Since then, a tremendous amount of studies has been made on this system or part of its from various points of view, including stratigraphy, sedimentology, paleontology, petrology and petrography. Actually, any geologic study concerning the state of Kansas deals with this system, more or less. It is far beyond the scope of this study to list the numerous publications dealing with the Pennsylvanian. Only some of these which are concerned with the basic stratigraphy and with petrologic or petrographic studies will be noted. Many comprehensive works covering the geology of Kansas or part of it can be reffered to, such as MOORE (1936, 1949); MOORE *et al.* (1951); JEWETT (1951); MERRIAM (1963); MERRIAM ed. (1964); ZELLER (1968).

Due to the comprehensive works of R.C. MOORE (1936, 1949), the status of Pennsylvanian stratigraphy in Kansas and the surrounding area has been one of the best established in the world. Although some revision on his designation of boundary between Virgilian and Missourian was made later (O'CONNOR, 1963, BALL et al., 1963), MOORE's comprehensive nomenclature and classification have long been adopted for use by the Geological Survey of Kansas. These divisions are still accepted throughout most of the outcropping Pennsylvanian rock units.

The well known concept of megacyclothem, cycle of cyclothems, had first been proposed in one of these comprehensive studies (MOORE, 1936). This concept was developed through extensive comparison of the cyclic features of Illinois' Pennsylvanian, where the concept of cyclothem had been originated (WELLER, 1930), and those of Kansas, especially the Shawnee Group of Virgilian Stage.

As far as petrologic studies are concerned, HARBAUGH (1959, 1960) first recognized and described the algal marine bank formation, which thicken locally and had been called reefs, buildups, or bioherms by various authors, but had not been precisely studied, in the Upper Pennsylvanian limestones. HARBAUGH (1959) pointed out the important role of phylloid algae as a biotic constituent and rock builder in the formations. Since then several similar structures have been revealed in many of the other Upper Pennsylvanian limestones throughout Kansas, by CROWLEY (1966, 1969) in the Wyandotte Limestone Formation, by MOSSLER (1970, 1971) in the Bethany Falls Limestone Member, and by FROST (1968) in the Dennis Formation, all of the Missourian Stage. In culmination of studies since HARBAUGH (1959), HECKEL and COCKE (1969) discussed some 23 features, which they called as mound complexes, in 16 limestone members of outcropping Pennsylvanian of the Midcontinent Region. They introduced a concept of facies belt, that is represented by geographic restriction of these features in successive units. Also according to this study, most mound complexes are limited in the two higher limestone units of megacyclothem, *e. g.*, the upper and super limenstones. On the other hand, the two lower limestone units, such as Leavenworth Limestone Member and Toronto Limestone Member, which were investigated precisely by

TOOMEY, (1964) and by TROWELL (1965, 1969) respectively, revealing marked differences in the petrology. Leavenworth Limestone Member is "unusually" homogeneous laterally throughout its extent, over 300 miles along the outcrop belt (TOOMEY, 1964). Toronto Limestone Member is revealed a marked facies change, both laterally and vertically, however, no algal mound is reported (TROWELL, 1965, 1969). It was suggested in HECKEL and COCKE's work (1969) that no development of algal mound complex appears in the two lower limestone units of the megacyclothem; there is one exception in the Captain Creek Limestone Member.

As far as E.M. Studies of limestones are concerned, F. KABELAC investigated Jurassic limestones as early as 1955 (*in* FLÜGEL *et al.*, 1968). Since KABELAC's study, E.M. has gradually been applied to clarify the detailed submicroscopic texture of limestones, including the nature of ultramicrofossils. Among the pioneer works is a study by SEELIGER (1956), which revealed some microtexture of Jurassic "lithographic" limestones. He also demonstrated the potential of the E.M. for investigating fine grained limestones.

In the study of the microfacies of Jurassic-Cretaceous radiolarian chert-bearing successions of the Central Alps, GRUNAU and STUDNER (1956) and GRUNAU (1959) successfully revealed the morphology of micro-organisms *Nannoconus,* which only individually separated specimens had been observed, even imbedded in indurated limestones. GRUNAU (1959) also revealed the detailed nature of "inorganic" ground mass of some limestones.

In the past ten years, E.M. studies of limestone have been made prosperously. GRÉGOIRE and MONTY (1962) revealed the cryptocrystalline nature of Visean stromatolite, which is composed mainly of tightly interloked mosaics of calcites less than a micron in size. SHOJI and FOLK (1964) and SHOJI (1964) investigated fractured surface of various limestone types which were classified according to FOLK's (1959, 1962) classification system. They were able to correlate many features observed with the E.M. and with those obtained by the L.M. No distinct fibrous and/or concentric structure of oolite and pisolite were revealed on the fractured surface of the limestones, as seen by E.M. According to their studies, significant morphological similarities of microcrystalline calcites (micrite) and microcrystalline quartz, which the latter had been revealed by FOLK and WEAVER (1952), were suggested. It was also suggested that environmental differences of the formation created surface features of some calcite, such as represented by the density of liquid(?) inclusions. Furthermore. significant differences in size of primary dolomite and replaced one, although both show similar rhomboidal shape, are suggested.

In a comprehensive study with many excellent E.M. photographs of limestones, ranging from Cambrian to Recent in age and various facies, FISCHER, HONJO and GARRISON (1967) made a major contribution to the study of limestones in this field. They described important details concerning the techniques of preparation, as well as the different fossils such as coccoliths, foraminifers, mollusca, "algal" filament, and *Tunicata.* The submicroscopic diagenetic fabrics such as zonal growth of dolomite, syntaxial rim cementation of fossils and "solution welding" are especially well revealed. They also recognized two fundamental fabrics of fine grain limestone, the amoeboid mosaic and the pavement mosaic, which forms irregularly interlocked grains and block-like grains, respectively.

In elaborate studies based mainly on E.M. observations of many "micrites" HONJO (1969a, b) suggested two basic types of fine grain matrix of limestones, "orthomicrite" and "nannoagorite". The former was suggested as represented by subhedral crystalline mosaic of calcite recrystallized from original inorganically precipitated aragonite. The latter was formed as a concentration of nannofossils, generally unaltered, in innumeral numbers. Each type is said characteristically dominant in Paleozoic and in the Jurassic or younger, respectively.

There have been many contributions toward the investigation of limestone by means of an E.M. other than the above mentioned. Many authors paid most attention to the submicroscopic fossils such as coccoliths and/or *Nannoconus* as rock builder or constituents of groundmass, which had not been able to be observed clearly enough by L.M. (*e. g.*, FARINACCI, 1964, 1968; HONJO and FISCHER, 1964, 1965; FLÜGEL, 1967, FLÜGEL and FRANZ, 1967 a, b; HONJO and MINOURA, 1967; MÜLLER and BLASCHEKE, 1971). On the contrary many other authors who investigated Paleozoic or older limestones discussed as a viewpoint of submicroscopic texture of grains, grain surfaces and physical characteristics (*e. g.*, GRÉGOIRE and MONTY, 1962; TEICHERT, 1965; HARVEY 1966).

A critical review made by FLÜGEL, FRANZ, and OTT (1968), dealing with many E.M. studies of limestones shed much light on the study of this field and clarified the status of knowledge to the date. According to this review the grain size of most "micrite" is rather uniform throughout the limestones studied and reviewed, though that of some Paleozoic algal limestones tend to have wider size range. Also they suggested that detailed study of diagenetic processes can be made by means of an E.M. more precisely.

Studies of detailed textures of fossils other than microfossils, are rather scarce, though many studies have been made on Recent molluscan shells (GRÉGOIRE *et al.*, 1955; GRÉGOIRE, 1957, 1959; WATABE and WADA, 1956; WATABE *et al.*, 1958). SASS (1967) and HARPER and TOWE (1967) studied detailed internal structure of some brachiopod species and revealed that important taxonomic diagnoses were clearly observable by E.M., but L.M. examination generally failed to clarify them. In a series of studies dealing with microtextures of various types of brachiopod, A. WILLIAMS and his associate, using both transmission and scanning E.M. successfully revealed phylogenic trends as well as the taxonomic features of this geologically and paleontologically important phylum (WILLIAMS, 1966, 1968 a, b, c, d, 1970 a, b, 1971; WILLIAMS and WRIGHT, 1970).

Recent advancement of scanning E.M. enables easier application of high magnification works in paleontological studies such as planktonic foraminifers (*e. g.*, HONJO and BERGGREM, 1967, KIMOTO and HONJO, 1968; HAY, 1968), and as coccoliths (*e. g.*, HONJO, MINOURA and OKADA, 1967; NOEL, 1967). Recently many investigations toward the textural as well as genetical features of limestones were made by this relatively newly developed and more convenient appratus (*e. g.*, HARVEY, 1967; MARGOLIS and REX, 1971).

BRIEF GEOLOGIC SETTING OF UPPER PENNSYLVANIAN OF KANSAS

In Kansas the Pennsylvanian period is divided into five stages in decending order: Virgilian, Missourian, Desmoinesian, Atokan and Morrowan. The first, following two, and the last one stages and stage are Upper, Middle and Lower Pennsylvanian, respectively.

The Upper and part of Middle Pennsylvanian, *i. e.* Virgilian, Missourian and Desmoinesian cropout in eastern Kansas (Fig. 1), whereas, the rest have been reported from southwestern Kansas subsurface (MERRIAM, 1963; JEWETT *et al.*, 1968). The Upper Pennsylvanian, in which the subject of this study belongs, overlie with marked unconformity on the Middle Pennsylvanian and is overlain by the Permain conformably (JEWETT *et al.*, 1968). Local disconformity, however, represented by channel cutting, was suggested between the latter boundary (MERRIAM, 1963).

Deposits of Missourian stage are subdivided as following groups in ascending order: Pleasanton Group, Kansas City Group including Bronson, Linn and Zarah Subgroups, and Lansing Group. Also Virgilian succession is subdivided into Douglas Group, Shawnee Group, and Wabaunsee Group lincluding Sacfox, Nemaha, and Richardson Subgroups in ascending order (Fig.2). The total thickness of outcropping Upper Pennsylvanian ranges from 500 meters to 650 meters and average thickness is accounted as nearly 600 meters (MOORE, 1949, JEWETT *et al.*, 1968).

The Upper Pennsylvanian comprise mainly with alternating of marine limestone, marine to locally nonmarine shale and sandstone (Fig.2) which show marked cyclicity of rhythmic sedimentation in their sequence. As many as fifty

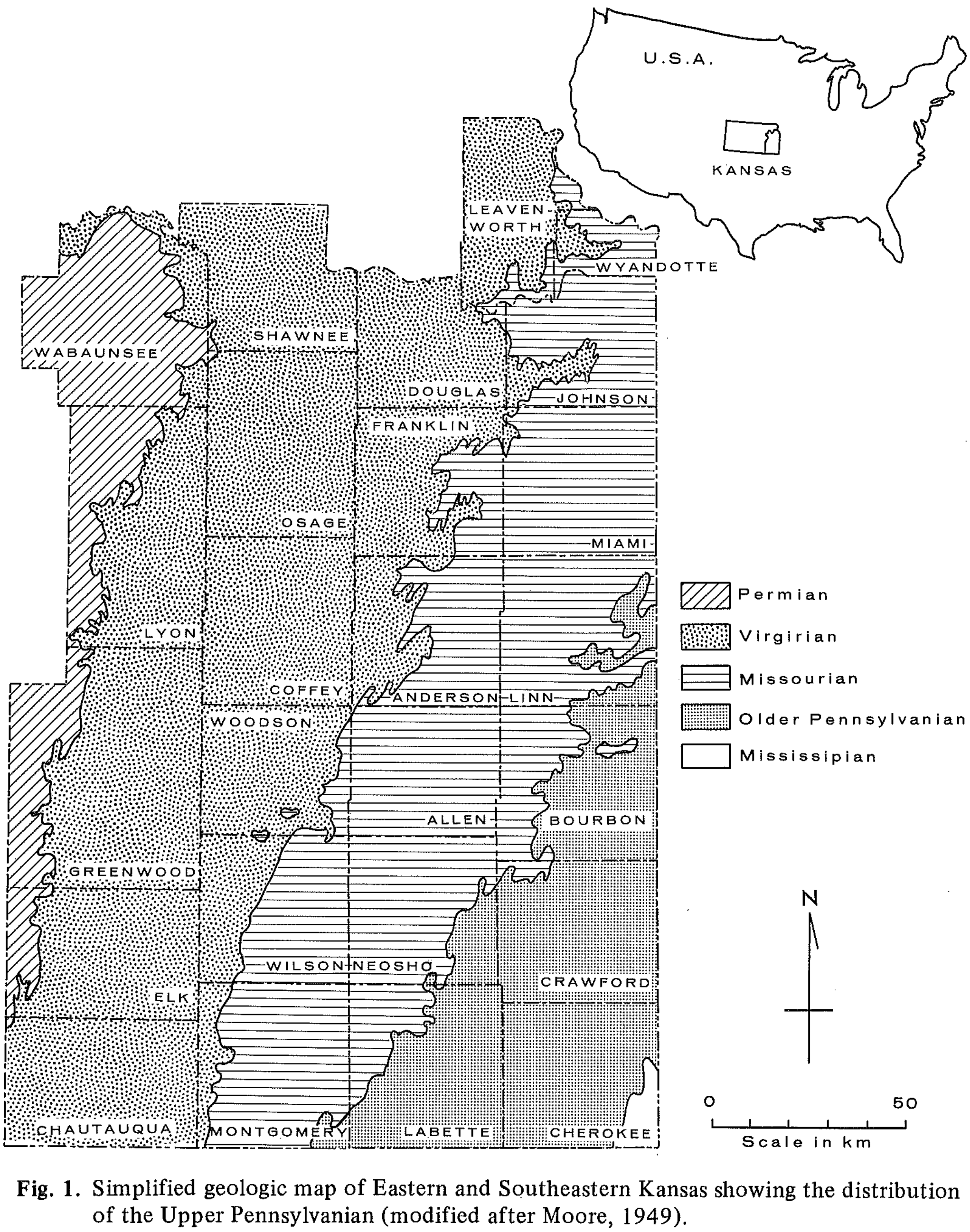

Fig. 1. Simplified geologic map of Eastern and Southeastern Kansas showing the distribution of the Upper Pennsylvanian (modified after Moore, 1949).

nine limestone members are included in this unit (ZELLER, 1968) which are generally persistent laterally, though some of they are lenticular or only locally known. These limestone members are mostly concentrated in Kansas City, Lansing, Shawnee, and Wabaunsee Groups. A few limestone members are reported both in Pleasanton and Douglas Groups, however, they are not widespread laterally.

Six megacyclothem sequences have been recognized by MOORE (1949) in the units of Missourian, four in Kansas City Group and two in Lansing Group. Four most representative megacyclothems have been designated in Shawnee Group. As many as fifteen simple cyclic sequences are recognized, but has not been considered as megacyclothem, in Wabaunsee Group (MOORE, 1949, 1950).

METHODS OF STUDY

FIELD WORKS

Field works were made several times for sampling the limestones during the study, throughout the outcrop area of the Upper Pennsylvanian in Kansas (Figs.1, 2 and 3). Mainly well-known or previously measured outcrops were visited, usually no measurement, except rough estimation of the sample horizons, was made.

Sample was collected with such a manner that at least one, generally two or more, up to fifteen vertically different samples, from a limestone member. The number of the specimen collected from a member was dependent on the thickness and variability of the lithology. Usually the interval between two samples collected was set about 50 to 80 cm, whenever the lithologic changes were frequent it was shortened. Basically all samples were collected from "micritic" or "aphanitic" parts, if possible, of the limestones. Some calcarenites, cherts and calcareous siltstone were collected, too.

More than one locality is visited for some of the limestone members. The distributions of the samples collected throughout the outcropping area, both lateral and vertical, were represented in Figs. 2 and 3.

Thus 179 samples, mainly "micritic" limestones, including some chert, dolomites, calcarenites and silty limestones from 46 limestone members, out of the 59 members present, in the Upper Pennsylvanian in Kansas (ZELLER, 1968), were collected and studied.

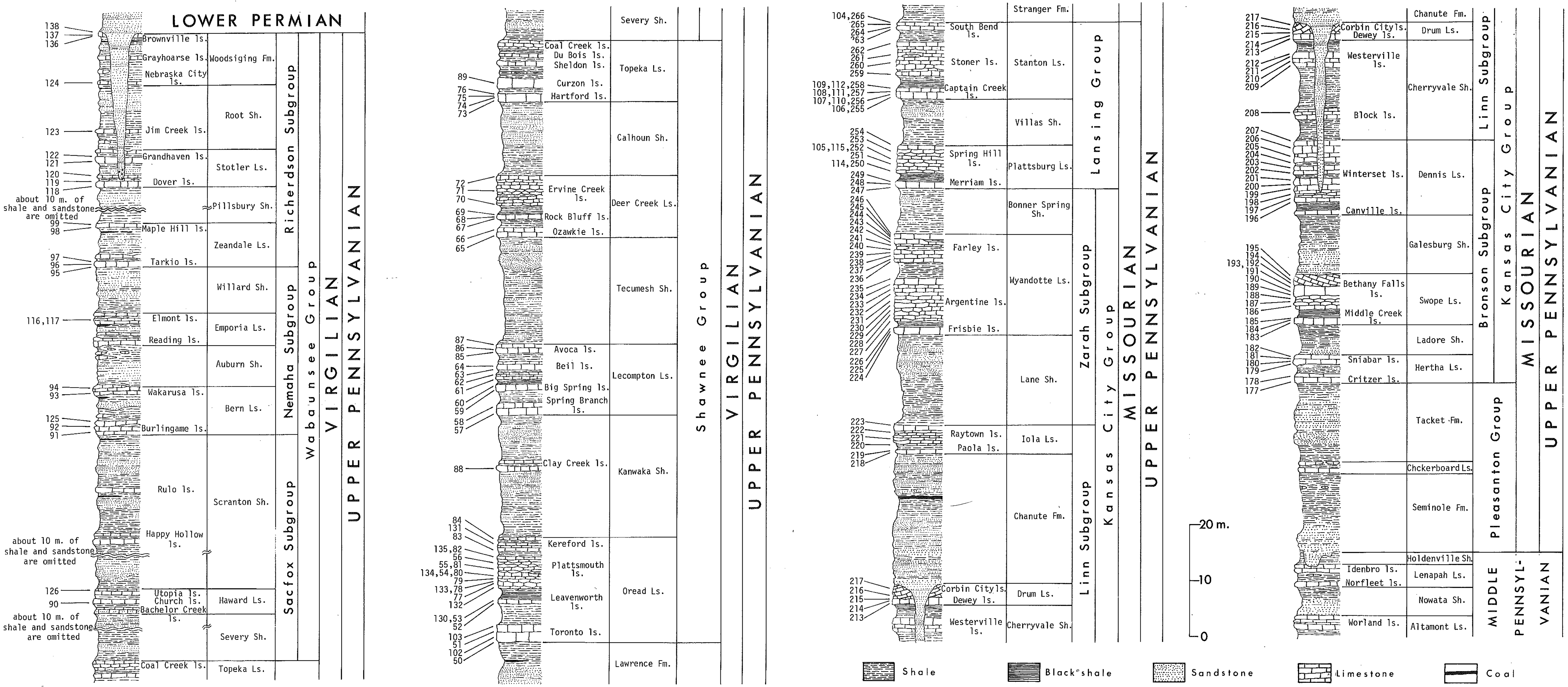

Fig. 2. Generalized columnar section of the Upper Pennsylvanian successions of Kansas. Numerals along the columns are sample numbers without the suffix P, indicating the horizons of the studied limestones. Douglas Group of the Virgilian stage (about 170 m thick, between Shawnee Group above and Kansas City Group below, consisting mainly of sandstones and shales) is omitted since no persistent limestone presents and no sampling was made in this study. (columns are modified after Moore, 1949).

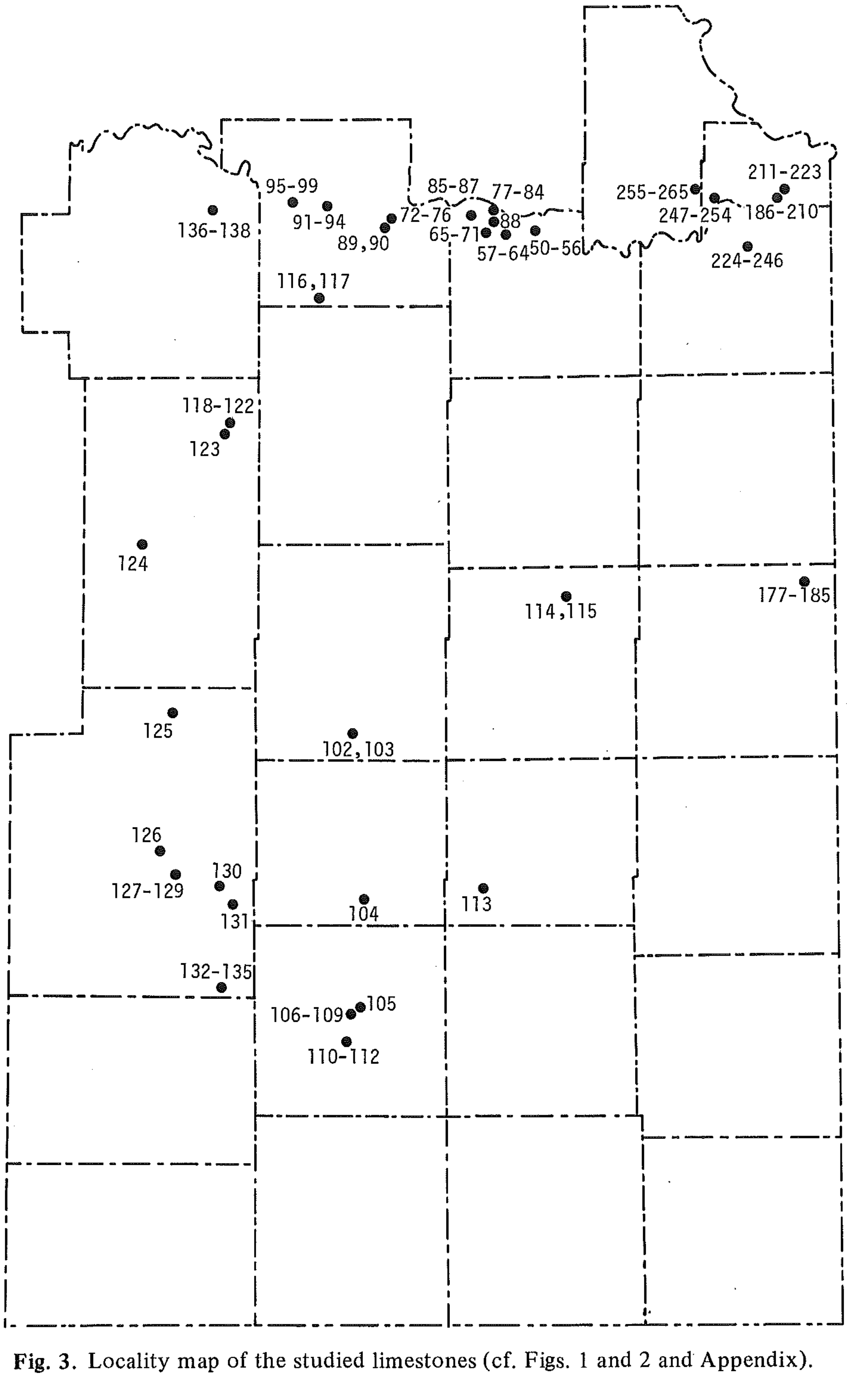

Fig. 3. Locality map of the studied limestones (cf. Figs. 1 and 2 and Appendix).

LABORATORY METHODS

General Procedure

All rock specimens colleted and brought to the laboratory were sawed into 3 x 2 centimeter thin-slabs and 1 centimeter cubes. The former are for thin sections and the latter for E.M. replication.

All thin sections were stained with alizalin red-S according to the procedure developed by FRIEDMAN (1964) to facilitate the identification of calcite and dolomite under L.M. After thorough L.M. examination, several thin sections were further ground carefully with #3,200 abrassives to obtain thinner than usual sections (less than 10 microns thick: U-section). These U-sections are utilized, with x250 and x400 magnification, to compare L.M. and E.M. observations more precisely.

Limestone cube, cut from same handspecimen utilized for thin section, was embedded into low viscosity epoxy resin with a vacuum impregnation technique (MINOURA and CONLEY, 1971). This plastic impregnated samples are processed to prepare two-stage replicas for E.M. examinations. During this process, two identical plastic replicas (*e. g.*, acetate peels) are prepared from a specimen, one for E.M. preparation and the other for L.M. observations.

Several acetate peels are made from polished and etched surface of uncovered thin sections. This allows comparative L.M. observation of thin section and E.M. observation simultaneously without much difficulty. This method also makes it possible to identify and confirm many minerals and skeletal grains as well as nonskeletal grains.

Generally, E.M. photographs are taken, at first, for the most representative texture of the matrix after an entire replicated 3x3 milimeter area is thoroughly observed. Some characteristic textural features, such as dolomite, quartz, skeletal textures, and textures revealing the diagenetic features, are photographed simultaneously. Usually five pictures are prepared for each sample, at a magnification of x1,400. Whenever interesting features are observed, both magnification and number of pictures are set appropriately. To represent the textures of the rocks as well as possible, serial E.M. photographs are frequently employed.

As a result, about 1,100 E.M. photographs are utilized and analyzed for this study.

Electron Microscopic Technique

Throughout this study, two-stage metal shadowed carbon replica method for ground, polished and etched (G.P.E.) surface of the limestone is adopted.

Basically this G.P.E. surface is utilized from epoxy resin embedded sample limestone according to a method described by HONJO and FISCHER (1965). In addition to the above, several G.P.E. surfaces of thin sections are also made as a modification of the method developed by KAHLE and TURNER (1964) and utilized for selected area replication (BRADLEY, 1965).

Although a vacuum impregnating technique (MINOURA and CONLEY, 1971) was applied and the etching was reduced for 20 seconds in 0.05 N. hydrochloric acid at 20°C, the detailed procedure was described by HONJO and FISCHER (1965) and it can be referred.

KAHLE and TURNER (1964) developed a replicating technique of thin section surfaces of various rock types. There was no treatment of polishing nor etching of them. Although replicating technique of the thin section surface is almost identical to that of embedded samples. Some precautions, however, must be made in various points. Thus the procedure of this method is briefly mentioned.

Polishing: Mount an ordinary thickness thin section, which has been finished with #3,200 abrasives and left uncovered, on a Thin Section Slide Holder*. Epoxy cement is preferred for the mounting medium of the rock chip to the slide glass because later application of replicating material, which will sometimes attack the lake-side cement.

The above mounted thin section is polished on a highspeed lap with Gamma Micropolish* suspended in distilled water. Texmet* seems to be most suitable as a polishing cloth. To prevent the chip-off damage of the edge of the thin section, the holder must be applied onto the lap as horizontal as possible. Since the weight of the holder gives sufficient pressure, hold it only not to be driven off. Excess pressure may cause breakage of the thin section occasionally. The holder should be applied on the lap for interval of less than 15 seconds at a time and this interval should be repeated 60 to 80 times. The surface of the thin section may show mirror-like luster after polishing. Polished thin section should be thoroughly cleaned and rinsed with distilled water.

Etching: After thoroughly dried, immerse the polished thin section, face up, into 20°C, 0.05 N hydrochloric acid for 20 seconds. Rinse the section immediately after the etching duration with distilled water, and then dry it thoroughly. Excess etching tends to cause breakage of the thin section when the replica is peeled off.

Replication: Put a few drops of Replicating Solution** on the G.P.E. surface

* Buehler, Ltd., 2120 Greenwood St., Evanston Illinois, U.S.A.

** Ladd Research Industries, Inc., P.O. Box 901, Burlington, Vermont, U.S.A.

and spread it with clean glass capillary tube over the entire specimen surface evenly. Immediately after spreading the solution, put a piece of Replicating Tape* large enough to cover the sample surface. Then press it firmly from an edge of the sample to avoid entrapping air bubbles. Hold the tape with the forefinger or flatsurfaced wood chip, approximately 10 seconds. After 7 to 10 minutes, peel off the plastic replica with forceps and mount it face up on a glass slide with a bit of adhesive tape. When peeling off the plastic replica, after prolonged drying, thin-section tends to be peeled off and damaged. Thus the drying time should not exceed 15 minutes. Repeat this replicating procedure and make two identical plastic replicas, one for L.M. observation and the other for shadowing and coating as E.M. replica. The methods for shadowing and coating of the plastic replica and mounting it to the E.M. specimen grid are identical to those described by HONJO and FISCHER (1965) and therefore, can be refered to.

CRITERIA OF MINERAL IDENTIFICATION

It is obvious that usual optical or crystallographic method is unapplicable in order to determine the mineral species in E.M. study of limestones, because a replica, previously mentioned, is required. Accordingly indirect evidences, such as bulk composition of the rocks, the habit of grains and their resistance to etching, therefore have been applied with no critical consideration. Actually the criteria for identification of mineral grains have been treated rather scarecely except that of FISCHER *et al.* (1967). This might have been partly because most authors have observed fractured surfaces preferentially, and partly because mainly textural features of microcrystalline calcite rather than genesis or diagenetic processes of it have been investigated (see FLÜGEL *et al.*, 1967). Composition of the limestone or accessory diagenetic mineral has been discussed very rarely, though rhomboidal dolomite (SHOJI and FOLK, 1964; HARVEY, 1965) and hexagonal authigenic quartz (GRÉGOIRE and MONTY, 1962) were reported.

In the rocks studied in this report, dolomite, silt-size quartz, chalcedonic silica and pyrite were found frequently in thin sections, and sometimes dolomite and/or chalcedonic silica consists of predominant parts of the rocks. Thus it is inevitable to establish criteria of identification of these minerals. For this purpose consistent criteria of mineral identification were established based on own procedure and that of described by FISCHER *et al.* (1967).

Certain rock specimen which contain fairly prominent amount of certain mineral was selected and the mineral was confirmed by X-ray spectrometry. The same specimen was carefully examined by L.M. with stained thin section

* Ladd Research Industries Inc. P.O. Box 901 Burlington, Vermont, U.S.A.

and acetate peel, which the latter is identical used for E.M. replica. Finally compared with E.M. photograph of same specimen, the following criteria and diagnoses were established and applied throughout this study.

Calcite

Readily identifiable from other minerals with more or less etched surfaces and deeply etched grain boundaries forming grooves, which throw the "shadow" behind them as seen in E.M. photographs. Generally this mineral forms interlocked subhedeal to anhedral mosaic of matrix. Also is comprising the most skeletal remains, (Pl.1, figs.1-6), although rhomboidal crystals are rarely found in chert, and sometimes are replacing, partly or wholy, after the dolomite rhombs.

Dolomite

Characterized with well developed many fine scratches on the etch-resistant surface, which form a prominent relief and cast the "shadow" on the front side of the mineral. These scratches probably are originated during the polishing of the samples and left because of more etch-resistant nature of this mineral (Pl.1, figs.3,5). Usually tend to form scattered rhomboidal euhedral crystals, which sometimes cut the boundaries of calcites and projected into organic textures. Even comprising the predominant part of the rock, this mineral sometimes forms rhomboidal shape.

Quartz

Characteristically smooth and clean appearance of this mineral led generally identifiable easily, though faint scratches are observed sometimes (Plate 1, fig.4). Double terminated euhedral crystals which have suturred pattern on the crystal surface may indicate presumably authigenic in origin. However, no growth pattern nor nucleic is observed by E.M., and may be due to the small size, nor by L.M. Irregularly shaped rough surfaced quartz, which may be mainly detrital in origin, are found rarely.

Chalcedonic Silica (Chert)

Generally surfaces appear smooth and clean as quartz above mentioned, though seems to tend to have more scratches than quartz. Mostly found as filling between other crystal grains such as calcite or dolomite, thus infinitive shape is characteristic. Sometimes small amount of this mineral is found associated with dolomite, probably as replacement after the latter.

Pyrite

Although volumetrically negligible, this mineral is easily identifiable by its distinctive framboidal or spheric shape of the aggregate. Cross section of the aggregate shows many faint scratches on it. Sometimes octahedral crystalline shape can be seen on the cross section and helpful for identification.

Clay minerals

Some of pseudo-replica appeared on E.M. photograph might be representing clay minerals, however, no attempt is made to determine the amount nor the composition.

PETROGRAPHIC OBSERVATIONS AND DISCUSSIONS

Although main objective of this study is to reveal and describe the fine grain matrices of the Upper Pennsylvanian limestones of Kansas using an E.M., it is obvious that even the fine grain constituent of the limestones can be revealed in detail, it is not sufficient enough to delineate the complex nature of this rock division. Therefore throughout the study most attention is payed on revealing the fine grain matrix of the limestones, other constitutents and diagenetic features of them also are observed, described and discussed.

Brief petrographic description (*e. g.*, classification and nomenclature) of all limestones studied are made by L.M., utilizing both thin sections and acetate peels (see Appendix). In this description, FOLK's classification system (1959, 1962) is followed, except no attempt is made critically differentiating the "micrite" and "microspar" of the matrix, partly because the basic difficulty to discriminate this size of material by L.M., and partly because, as will be discussed in detail later, no distinct difference other than grain size is appreciable even with E.M.

The description by means of an E.M. is treated in detail. Each textural constituent is described and discussed as a whole rather than describing and classifying the individual rocks. This mainly due to the extremely limited area of observation by E.M.*, which makes it difficult to represent the entire rock

* A specimen grid of E.M. covers a few square millimeters (about 2 mm diameter) area. Each E.M. photograph can cover less than 50 x 50 microns area at maximum, *i.e.*, with the lowest magnification available in the utilized E.M. This area is less than one four hundredth of a square millimeter.

observed. And partly due to some uncertainty of mineral and skeletal particle identification, which might casuse misinterpretation of observed rocks. To avoid these biases as well as possible, two, three, four or even five serial E.M. photograph is often employed. Consistent criteria for identifing mineral species are established, as previously noted, and are applied throughout this study.

Identification of skeletal as well as nonskeletal grains is made with following manner, utilizing an improoved selected area replicating technique of BRADLEY (1965) on G.P.E. surface of thin section. The selected area for the E.M. replica is marked on the L.M. photographs of x100 and x300 magnification taken from the thin section and the acetate peel, after thorough L.M. examinations of them. Most skeletal grains as seen under E.M., thus, can be compared with those appeared on these L.M. photographs by their shapes and relative positions. Accordingly, some nonskeletal grains also can be compared by the relative positions of them to the above identified skeletal grains.

TEXTURAL CONSTITUENTS OF LIMESTONES

Although there is considerable discrepancy on the terminology, on the difinition, and the subdivision of the constituents of limestones, it has been pointed out that most limestones can be, and really are, characterized by the types and relative amounts of the three major constituents. They are, (1) discrete carbonate aggregates, allochems of sheletal and nonskeletal origin, (2) sparry calcite cements, and (3) lime mud or "micrite" (MINOURA, 1969; SHOJI, 1971). It is noted that some types of limestones are characterized in addition to the above major constituents, by *in situ* organic framebuilder and/or pore spaces (FOLK, 1959; LEIGHTON and PENDEXTER, 1962), which are significant in a view point of petroleum geology but does not play an important role in the studied limestones.

Allochems are discrete particles capable of forming a rock framework and are therefore, similar to sand, silt and gravel grains in terrigeneous rocks. This constituent is subdivided into four types according to their origin and the other features, which are (1) intraclast: reworked fragments of penecontemporaneous carbonate sediment, (2) oolite, (3) fossils of various taxons and fragmental or whole, and (4) pellet: rounded aggregates of microcrystalline calcite, averaging 0.04–0.1 mm in diameter.

Sparry calcite cement is normally formed as a chemical precipitate that fills the space between the allochems and therefore, analogus to silica or calcite cement in a clean quartz sandstone. Generally this constituent appears as relatively coarse, clean, transparent, and crystalline calcite.

Lime mud (micrite)* are generally considered as particles analogus to clay in shale or clay matrix in a sandstone and also as once mud-like of either chemical or mechanical origin (LEIGHTON and PENDEXTOR, 1962). Traditionally this constituent has been defined and discriminated from other constituents arbitrarily by an upper size limit, in which great discrepancy exist such as 4 microns by FOLK (1959, 1962, 1965), 30 microns by LEIGHTON and PENDEXTOR (1962) and 60 microns by PLUMLEY *et al.* (1962).

This discrepancy of size limitation may partly be due to the purpose of the studies. Hence there may be no great advantage discussing this constituent in detail, as far as this is utilized as an index of the current strength of the depositional environment as previously mentioned. Since no significant difference in hydrodynamic characteristic can be expected in this size range of particles depending on these sizes. Therefore, it has quite reasonable that the size limitation may be conveniently decided depending on the resolving power of the microscope used in the studies.

It is to be realized, however, that once intrinsic morphologic as well as textural, diagenetic, and genetic characteristics of this material are to be revealed, this should be treated as a natural category, *e. g.* definition and characterization of this material must be made by diagnostic features of many point of view rather than by an arbitral size limitation.

Table 1. CLASSIFICATION OF CONSTITUENTS OF THE LIMESTONES STUDIED

ORTHOCHEMICAL CONSTITUENTS	ALLOCHEMICAL CONSTITUENTS
Lime Mud (Micrite)	Skeletal Grains (Fossils)
Sparry Calcite Cement (Spar)	brachiopod
Authigenic Minerals	bryozoa
dolomite	echinoderm
quartz	fusulinid
chalcedonic silica (chert)	trilobite
calcitized dolomite	mollusk
pyrite	ostracod
	Nonskeletal Grains
	oolite
DETRITAL CONSTITUENTS	coated grain
"silt size" quartz grain	pellet
sand and silt grain	intraclast

* The term micrite has been more widely accepted recently instead of the term lime mud. The writer uses the former term only to designate the limestone name.

The carbonate constituents classification utilized by the writer is shown as Table 1. In addition to the three major constituents mentioned above, various minor constituents such as dolomite, authigenic quartz, chert and calcitized dolomite are treated. Although in some limestones, *in situ* organic frame-work and pores are significent, these two constituents are not investigated in the study, since both of these are not present significantly in the studied limestones. Also intraclast is very rarely found in the studied limestones and the internal texture of this is naturally considered as similar to that of the limestone itself, because of the basic characteristics of this constituent. Intraclast, therefore, is not treated as an independent constituent, but it is felt that the other descriptions may cover the nature of this material well enough.

ORTHOCHEMICAL CONSTITUENTS

Orthochemical constituents of limestones include lime mud, sparry calcite cement and many diagenetic minerals such as secondary dolomite, quartz and chert (Table 1). Among these, lime mud and sparry calcite cement are of fundamental importance as textural constituents, since both they form matrices of limestones and comprise two basic limestone types (FOLK, 1959; 1962; TODD, 1966). All others are generally as of secondary importance as textural constituents but may play major roles to reveal diagenetic processes of limestones. During this study, most attentions were payed to reveal morphologic characteristics of fine grain matrix of limestones. However, due to the following considerations, detailed discussion will be restricted to the grain size analysis of this material, applying the principal components factor analysis using high-speed digital computer. Orthochemical constituents other than lime mud are also only briefly and simply described and discussed.

There have been varieties of replicating techniques employed for investigating limestones by E.M. Although different technique requires more or less different interpretations for the final E.M. images (FISCHER *et al.*, 1967), fundamental difference arises from what type of surfaces have been mainly utilized. One is freshly fructured (F.F.) surface and the other is G.P.E. surface, which the latter is employed throughout this study. It has been considered that the former is more favorable to investigate crystal surface and cleavage patterns and may provide better ideas about the porosities. Whereas G.P.E. surface is better suited to get direct informations on grain boundaries and on fossils (FISCHER *et al.*, 1967; FLÜGEL *et al.*, 1968). It is noted that investigators utilizing G.P.E. surface mentioned that more precise grain size measurement may be obtained on the F.F. surface (FISCHER *et al.*, 1967), while those who utilized F.F. surface did inversely (FLÜGEL *et al.*, 1968).

As a preliminary comparison, the author tried both surfaces, as FISCHER *et al.*, (1967) did and concluded that with G.P.E. surface more informations about the limestones, its constituents and its diagenetic processes can be obtained. Hence this surface allows direct comparison between the L.M. observation of thin section and E.M. observation of replica, using the selected area replicating technique, previously mentioned. In other words portion of the limestone being observed under E.M. is directly known, comparing the thin section and acetate peel L.M. photographs of the replicated area. While with F.F. surface it is hardly made.

If employing the selected area replicating technique of thin section surface, the G.P.E. surface also can provide more direct criteria for the identification of mineral species (see CRITERIA OF MINERAL IDENTIFICATION), whereas with F.F. surface, it is restricted to guess from indirect evidences such as bulk composition of the sample limestones and cleavage patterns of minerals. Furthermore, G.P.E. surface replica can be made from any desired orientation and portion of the sample. On the contraly only F.F. surface can be available from incidentally fructured portion of the sample.

Certain disadvantages, however, exist on utilizing the G.P.E. surface. The biggest of them is that the etching process required is hardly under precise control. Thus reproducibility of the etched surface patterns may be low. Application of etching tends to yield artificial material on the surface, which can be imprinted to the final replica even with careful cleaning and blank replication, therefore sometimes complicating the interpretations of these patterns. Grinding and polishing procedure rather contributes to complicate this situation, since mechanical alterations caused by these processes may add more or less indifinite effects onto the behaviours of mineral grains to the etching solution. The other is tediousness of the preparation procedures to get high quality surface consistently. The last disadvantage can be eliminated since this factor does not affect on the quality of the final image and may be easily improved, at least certain extent, by an orderly way of the preparation procedures.

Nonthless, with G.P.E. surface more valuable informations can be obtainable than with F.F. surface. During E.M. observation of the limestones, knowing what part of the sample being observed is of fundamental importance. Without knowing this, even with selected area replicating technique of either G.P.E. or F.F. surface, granular texture of certain skeletal material such as fusulinid or trilobite tends to be misinterpretted as granular matrices of the limestones. To the writer's knowledge, there has been no study discribing finely fragmented skeletal material of the limestones on the F.F. surface using E.M. Only exception is large fragments of crinoidal columnals (SHOJI, 1964; SHOJI, and FOLK, 1964) and coccoliths and related nonnofossils (FLÜGEL *et al.*, 1968). This scarcity may be due to the above mentioned difficulty of knowing what part of the sample is being observed under E.M. when utilizing F.F. surface.

With the above considerations and comprisons, G.P.E. surface was utilized throughout this study. Most mineral species and skeletal and nonskeletal grains, accordingly, were able to be identified and discriminated, if they could be identified in thin sections. While reproducibility of the surface patterns was more or less sacrificed. Therefore, although various surface patterns and grain shapes of matrices of the limestones were recognized during the E.M. observations, no extensive effort was made on classifying the former. On the contrarly grain shapes and boundries can be considered, at least certain extent, as having higher reproducibilities than that of the surface patterns. Thus most attention was payed to reveal characteristics of the grain size and shapes of grain boundaries.

Lime Mud (Micrite)

Surface Morphologies: No extensive efforts have been made here to classify each limestone according to its surface morphology because of the low reproducibility of etching, as above mentioned. Actually, although very rarely, in hand specimen or even in a replica, distinctively different surface structures are recognizable, or after a type of surface was recognized in a certain specimen, occasionally other pattern is appreciable when the same specimen is replicated and observed. Furthermore, it is likely that not only etching causes this difference but the thickness of shadowing and coating material, which precise control is hard, if not impossible, also may be responsible. Neverthless, no less than three distinctively different surface morphologic types are commonly recognized in the studied limestones. These three types are briefly described.

Most commonly and frequently appeared type is represented with flat and smooth surface such as shown in Plate 2, fig.1, 2 and 3. Although these E.M. photographs appear slightly different each other, all the grain surfaces are resembling each other with evenly and smoothly etched patterns. All calcite grains are etched so evenly that entire area of these photographs appear as if with no appreciable topography except grain boundaries and some etch-resistant minerals. Some surfaces are very finely wrinkled, which is also characteristic of this type while no other type shows this feature. Although few appear on the grains of fig.1, these calcite grains are almost devoid of etch-pits, which probably are fluid inclusions.

Grain boundaries of this type are so distinct that they can be precisely defined and traced. These boundaries, directly traced on the E.M. photographs, are shown as line-drawings in Fig.7, A–C, respectively. Although detailed characters are not exactly seen on these line-drawings, it can be noticed that some boundaries are curve-linear and abruptly bent. Others are more or less zig-zag shaped or irregularly curved. Some coarse (4 microns long and more) grains seem to contact each other with the former boundaries while the latter boundaries are predominating the remaining finer grains.

Another morphologic type is represented with rather irregularly etched surface than the above (Plate 3, figs.1 and 2). This type of surfaces are so roughly and irregularly etched that most grains appear "dirty". Actually this type of texture sometimes contain appreciable amount of pseudoreplicas between grain boundaries, to which dirty appearance may partly due. Almost devoid of inclusion, as the former type texture, on the surface, also is characteristic. Grain boundaries associated with this type texture are said rather obscurred. They are irregularly zig-zagged and no curve linear boundaries is appreciable throughout.

The last and least common type of the three is represented with abundant inclusions on the etched surfaces (Plate 3, fig.3). Calcite grains of this type seem to be etched little deeper at their bundaries than those of the first type, thus appear rather roughly topographed as a whole, while individual surface is as flat and evenly etched as that of the first type, excepting abundant inclusions. Grain boundaries are mixture of curve-liner and irregularly curved, also resembling to the first type. It should be noted, however, that no distinct fine wrinkle is recognized. Also noted is that some grain boundaries are rather unclearly appreciable than the first type.

Grain Size: Grain size measurements are made on 24 limestones. These 24 samples consist of 3 super limestones, 11 upper limestones, 7 middle limestones, and a lower limestone of the megacyclothem (MOORE, 1936). In addition to the above, two are choosen from limestones which have not been assigned to comprize megacyclothemic feature, though their megascopic characteristics are rather similar to those of the middle limestone.

The grain size is defined arbitlarily as the average of the longest dimension and that perpendicular to it. The counting are made on fixed area of the limestone, rather than counting the fixed number of grains as usually employed (FLÜGEL *et al.*, 1968). This is simply achieved by counting the all grains in identical magnification E.M. photograph of each sample. Although some measurements are made on serial photographs of two, while others are made on two individual photographs and added together. Also all the counting actually are made on line-drawings of grain boundaries made directly from E.M.

photographs, such as shown as Figs.7-11.

Actually the author wished to make this analysis on Shawnee Group megacyclothems, which have been assigned as most representative and well developed (MOORE, 1936). Many limestones in this group, at least those observed, however, are so intensively dolomitized or silicified than any other limestone that no grain size measurement could be made with enough accurasy and consistensy. Accordingly, limestones in Missourian stage megacyclothems, which have been assigned as less representative but considerably well developed by MOORE, (1936), are mostly selected for this analysis. Even with the above possible biases, interesting results were obtained through this analysis, especially on relationships between the grain size distributions and the megacyclothemic features.

Table 2. GRAIN SIZE COUNTINGS ON 24 LIMESTONES

Sample (μ)	0~ 0.5	0.5~ 1.0	1.0~ 2.0	2.0~ 3.0	3.0~ 4.0	4.0~ 5.0	5.0~ 6.0	6.0~ 7.0	7.0~ 8.0	8.0~ 9.0	9.0<	TOTAL
P-87	20	20	48	48	32	24	14	13	10	2	3	234
P-265	24	118	174	57	35	17	9	6	3	2	6	451
P-245	26	81	122	101	63	28	5	3	2	0	1	432
P-261	35	59	121	55	20	16	8	5	3	4	4	330
P-253	50	94	123	76	31	12	14	6	2	2	7	417
P-250	19	45	54	31	16	11	9	5	7	2	11	210
P-231	11	21	11	13	16	10	13	6	3	5	12	121
P-223	21	59	74	38	32	11	15	8	8	5	6	277
P-222	24	66	122	67	29	25	14	5	3	0	6	361
P-205	38	119	196	80	32	9	10	6	3	0	8	501
P-202	5	30	75	54	19	20	7	14	7	0	4	235
P-198	18	71	88	44	22	14	5	5	1	2	10	280
P-195	7	24	23	17	14	14	9	4	6	4	10	132
P-187	5	8	14	14	17	9	5	7	4	2	8	93
P-257	80	134	304	103	20	25	5	2	3	0	0	676
P-255	19	62	90	69	23	14	6	6	2	2	4	297
P-247	47	95	168	95	52	29	8	3	1	0	0	498
P-226	39	78	109	77	34	40	6	3	4	2	4	396
P-219	57	56	76	76	46	28	10	5	3	2	5	364
P-218	81	275	474	113	41	15	4	4	2	0	5	1014
P-183	27	92	180	95	56	30	14	5	1	1	2	503
P-89	21	49	103	82	38	16	12	3	2	0	5	331
P-216	62	163	166	108	50	14	3	2	3	2	3	576
P-214	105	332	227	52	27	9	5	2	1	0	4	764

All the grain size counting data are shown in Table 2. The grain size distribution histograms and cumulative frequency curves of the all 24 samples, super limestones, upper limestones and middle limestones are shown as Fig.4, A–D respectively. From these cumulative curves and frequency histograms the followings can be noted: the upper limestones are, as average, somehow coarser than any other type of limestones, which is likely due to the fairly prominent

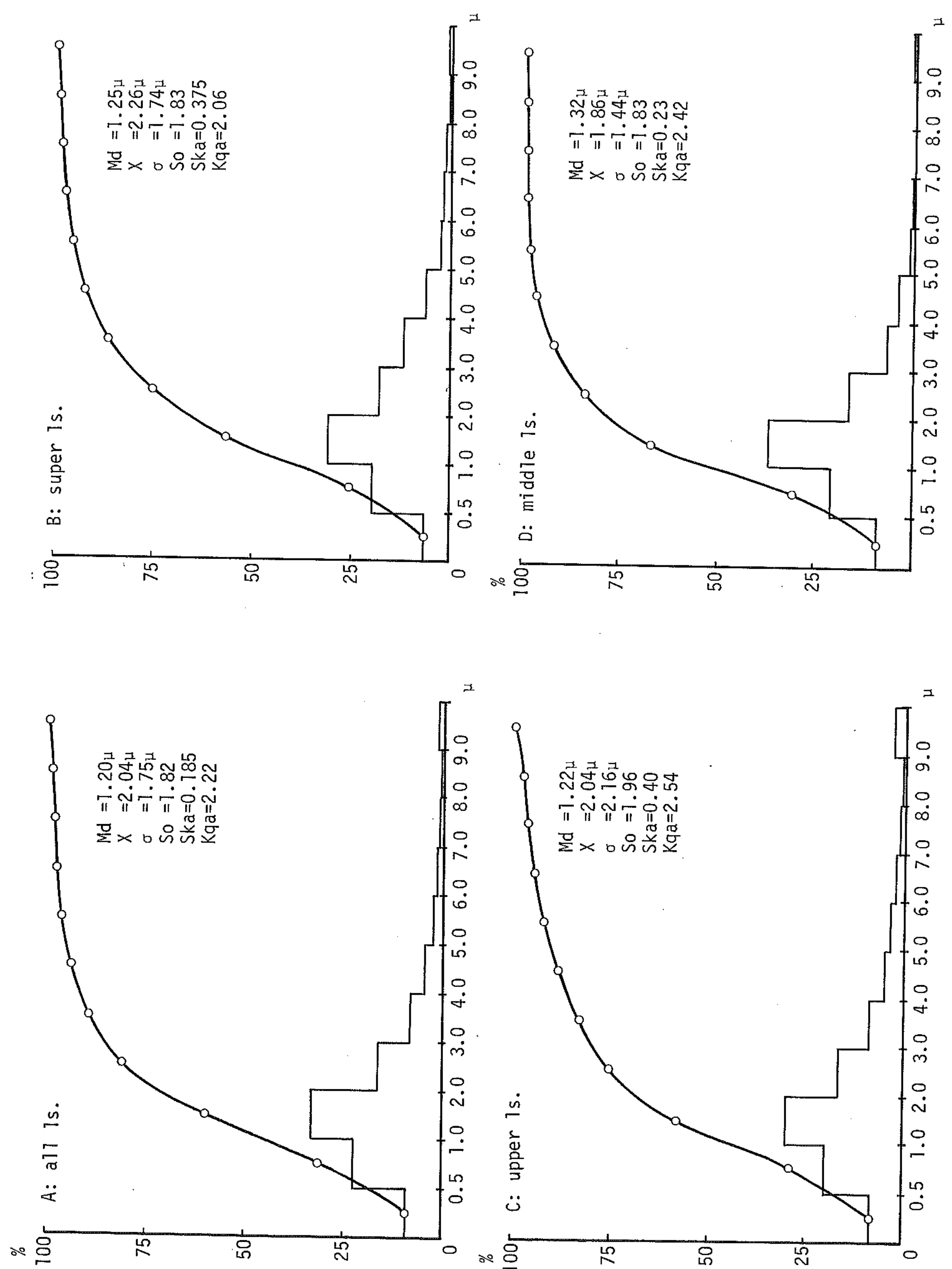

Fig. 4. Graphical representation of the lime mud grain size counting data tabulated as Table 2, including frequency histograms, cumulative frequency curves and partial statistics.

amount of the coarsest fractions (9 microns and more). While the other types of limestones contain lesser amount of this fraction; inversely the middle limestones can be characterized by the prominence of the finer (0–3 microns) fractions; the super limestones can be said to be a median of these two types.

It should be noted that the above differences are insignificant statistically. Also noted is that they may be due to the difference of the total number of the grains counted in each sample. Since the number of the grains of the upper limestones are consistently less than that of other types in general, which results higher relative frequency of the coarser fractions, although amount of these fractions is nearly same throughout all types. And the reverse is possible for the middle limestones.

The sorting indicates that all types are very well sorted though the sorting of these material does not mean mechanical separation of grains, but is only the result of competition between space and grain growth (FLÜGEL *et al.*, 1968). The kurtosis is rather agreeable to the sorting; the better sorted sediment has higher peakedness. The standard deviation may also have same bearing in this concern. The skewness is interpreted as rather higher frequency of the coarser fractions in the upper limestones than the other, which indicates more skewed to the coarser side with the order of middle, super, and upper limestones.

Although no graphic representation is given for the other type of limestones, they are similar to the super limestones in every aspect. This

Table 3.

A. Scores of principal components factor analysis.

I	II	III
−1.131	1.803	2.359
−0.038	−0.167	0.023
1.071	1.406	−1.012
−0.352	−0.386	−0.364
−0.088	−0.296	−0.191
−1.163	−0.815	0.223
−1.663	−0.973	−1.281
−1.270	0.228	0.685
−0.066	0.679	−0.252
0.186	−0.607	0.555
−0.859	1.005	2.460
−0.449	−1.032	−1.008
−1.436	−0.738	−0.710
−1.193	−0.712	−0.170
1.422	−0.232	0.856
−0.170	−0.199	−0.270
1.195	1.149	−0.732
0.396	1.005	−0.752
0.243	0.841	−0.705
1.938	−1.309	1.512
0.737	1.594	−0.851
0.169	0.430	−0.916
1.112	−0.405	−0.325
1.410	−2.270	0.865

B. Scores of varimax rotation of factors.

I	II	III
−0.48	0.79	3.04
0.07	−0.16	−0.02
−0.44	1.78	−0.88
−0.25	−0.51	−0.29
−0.02	−0.29	−0.22
−0.31	−1.34	0.42
−1.36	−1.73	−0.72
−0.66	−0.55	1.18
−0.51	0.52	0.02
0.71	−0.40	0.22
0.16	0.29	2.77
−0.33	−1.09	−1.00
−1.02	−1.42	−0.25
−0.59	−1.27	0.13
1.56	0.61	0.08
−0.16	−0.26	−0.22
−0.09	−0.64	−0.77
−0.59	1.06	−0.50
−0.60	0.84	0.45
2.78	0.02	0.11
−0.69	1.74	−0.55
−0.56	0.46	−0.73
0.82	0.31	−0.86
2.55	−1.06	−0.53

C. Primary factor loadings matrix

I	II	III
0.802	0.341	0.192
0.768	0.489	0.246
0.829	0.238	0.303
0.883	0.314	0.013
0.633	0.529	−0.223
0.359	0.773	−0.141
−0.466	0.373	−0.035
−0.609	0.332	0.618
−0.643	0.243	0.568
−0.688	−0.174	−0.258
−6.685	−0.538	−0.196

situation can be seen in the statistical analyses of all 24 samples using the factor analysis technique.

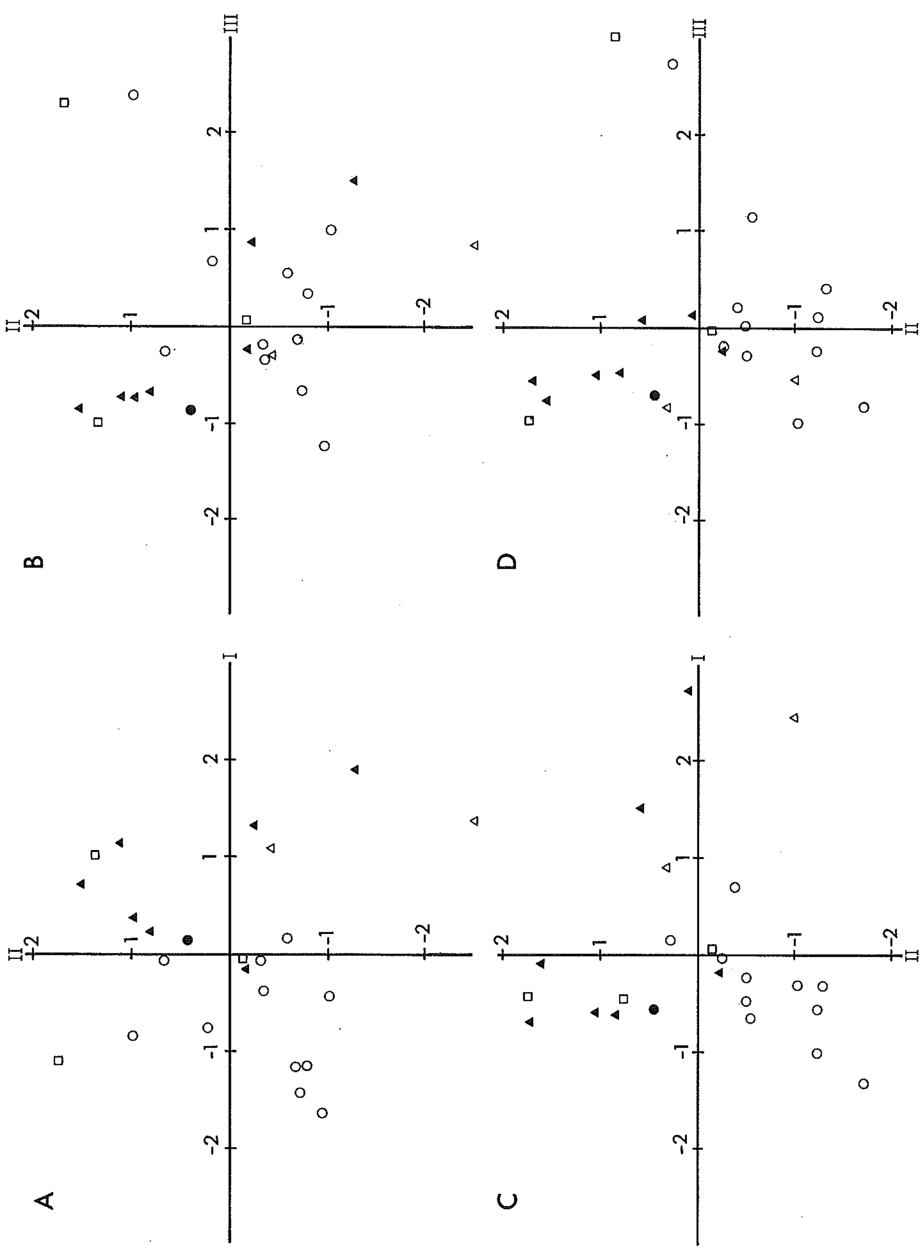

Fig. 5. Plots of the scores of principal components factor analysis (A and B) and those of varimax factor rotation (C and D). Open squares are super limestones, open circles are upper limestones, solid triangles are middle limestones, solid circle is lower limestone, and open triangles are unclassified limestones.

Statistical Analyses: The grain size measurement data, made on 24 limestones and shown as Table 2, are directly analyzed with R-mode principal components factor analysis and varimax factor rotation. The resulted scores of both analyses are tabulated as Table 3. The primary factor loading matrix also is included in the Table 3. These scores and matrix are graphically represented in Fig.5 A and B, Fig.5 C and D, and Fig.6, respectively.

According to the plots of the total 24 samples along the three factor axes (Fig.5 A and B), in which explain more than 75 persent of the total variance of all variables. It is obvious that the upper and middle limestones are distinctively separated from each other. The upper and middle limestones are characterized mainly by minus scores and plus scores along factor I, respectively. The minus score is indicating more coarser fractions of variables 8-11 (Fig.6). While the plus value is interpreted as more finer fractions of variables 1-4 (Fig.6). The wide range of the scores along factor axis II for both limestone types indicating widely variable amounts of the middle size fractions present in these two types. Since the factor II is characteristically indicating the middle size variables of 4-8, which size ranges from 2 to 7 microns (Fig.6).

Although the factor III explains less than 10 percent of the total variance of the variables, this factor may indicate higher amount of the coarse fractions

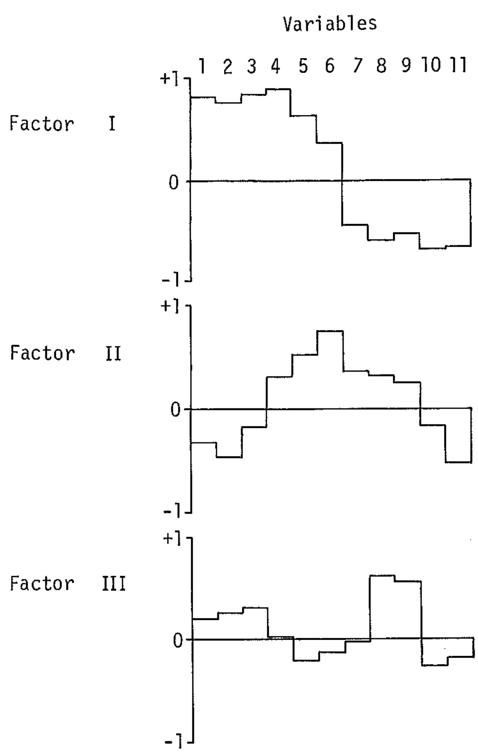

Fig. 6. Graphical representation of primary factor loading matrix shown as Table 3-C.

of variable 8 and 9 or fine fractions of variables 1-3. Therefore this factor likely is indicating the sorting coefficient of the each limestone.

From this factor analysis and primary loading matrix the following can be concluded; (1) variance of the amount of fine fractions and coarse fractions, which is represented by the scores along Factor I (Fig.6), mostly characterizes each limestone; (2) upper and middle limestones are distinctively grouped mainly by respective minus values and plus values along Factor I; (3) the amount of middle size fraction does not significantly characterize each type of limestones nor does sorting coefficient.

The most significant features of this analysis, however, can be detected through the clustering of the upper and middle limestones. They are three dimensionally distributed nearly perpendicular each other, which means opposite tendency of the distribution of each variable.

The varimax rotation of the above factor analysis is unlikely improve the clustering of the scores significantly (Fig.5 C and D). This may indicate that all limestones are rather widely scattered along three dimensional factor axes, which also is indicating individual limestone as a whole is widely variable, even though they are obviously clustered as upper limestones and middle limestones.

Discussions: Based on the grain size analyses of more than 200 thin sections made by L.M., FOLK (1965) noted two sizes of distribution maxima, which were 1-2 microns and 4-8 microns. The former finer grains were said more predominating than the latter grains. He also suggested in the study that limestones interbedded with frequent shale beds generally consisted of coarser grains than thickly bedded limestones. Even with this grain size fructuation in limestones of different occurences, all limestones show somewhat bimodal grain size distribution.

FLÜGEL *et al.* (1968) analyzed many grain size of lime mud based on their own measurements and compilations of the published E.M. studies concerning to this material. According to this study, there seems to be several lime muds which consist of more or less bimodal distributions of grain size suggested by FOLK (1965). It is rather obvious, however, that 1-2 microns fraction is predominating in most limestones. Their analysis indicated that all lime mud grains are well to moderately well sorted. No distinct frequency maximum has been indicated, however at the sizes of 5 microns and larger.

The measurement of grain size frequencies of lime mud made in the present study is fairly agreeable to the observation made by FLÜGEL *et al.* (1968). Also agreeable is including the sorting, mean grain size and range of grain sizes. It should be pointed, however, that the grain size distribution revealed in this study is accounted in limestones formed in almost identical depositional environments.

This difference of grain size distribution likely is rather systematic one *e. g.*, the difference is more significantly obvious as a group than as individual limestone. This difference exists in group may mainly reflects to that between middle and upper limestones of megacyclothem. With respect to this systematic difference of grain size frequency between upper and middle limestones, it is interesting to consider FOLK's (1965) suggestion that the lime mud of interbedded with shale tends to have coarser grains than the thickly bedded limestones. Since the limestones examined in the present study are all alternations with shale though the thickness is rather systematically changing (Fig.2). Upper limestones are thick as total but thinly bedded and shaly partitions frequently exist between layers. While middle limestones are thickly and massively bedded and thin as total thickness, in which generally has no partition nor lense of shaly material. Although the exact cause of the difference of grain size distribution of interbedded and non-interbedded limestones is not well understood, FOLK (1965) suggested catalytic action of shale for the formation of coarse calcite grains.

Another interesting feature concerning to the presently examined limestones is that there are distinct differences between the limestone types existing in each megacyclothem. These are included fossil contents and its ratio, type of organisms contained, macroscopic characters such as color, bedding nature all as pointed by MOORE (1936). These differences are mostly appreciable between limestone types, while limestones grouped as a type show rather common characters.

The above common nature existed in a type and differences observed in different limestone types are quite suggestive for depositional condition of each type. Accordingly slight difference of depositional environment could be existed during the formation of limestones of different type. Also these difference might be systematical one, which is reflected to the cyclicity of sedimentary sequences of the Upper Pennsylvanian of Kansas and neighboring states.

Accordingly, the systematic difference of grain size distribution revealed in the Upper Pennsylvanian Limestones examined and analyzed probably is considered as reflection of that of depositional environment (TOOMEY, 1964; TROWELL,1965), rather than that of diagenetic processes. Since this difference might cause that of organisms, which most likely are source of original material of lime mud, lived in the environment, while no systematic difference might be expected operational during diagenetic processes.

Although it is still open to question that the difference of grain size distribution patterns revealed in the lime mud is caused by the catalytic action of clays in shale during the diagenesis (FOLK, 1965). Or by reflection of the difference of original material of lime mud, which might be expected by that of the depositional environment. The author is highly tempted to favor the latter interpretation, since grain size distribution pattern changes so systematically, although mostly revealed in the upper and middle limestones of mega-cyclothems, that well coincides with cyclicity of the sedimentary sequence.

Another supporting fact of the above interpretation, although indirect and will be discussed in the later section, is that most skeletal material is fragmented, very little amount of fine grained one (less than 5 microns, for example) is revealed. This scarcity of fine skeletal remain probably is caused by recrystallization of this size material due to higher reactivity of finer grained carbonate, which must be produced by the fragmentation with prominent amount comparing to coarser one. The higher reactivity of the fine grain skeleton is also evidenced by the poor preservation of skeletal microstructure of this size grains, which will be described latter.

Micrite and Microspar: During the L.M. observation of thin sections, it is rather strongly felt that many limestones examined, especially upper limestones, are having rather course matrices, though do not appear so coarse as common sparry cement. Actually most of these matrices are revealed as fine as original difinition of micrite size (FOLK, 1959) as seen under E.M.

The frequency of micritic fractions (less than 4 microns) of all limestones measured (Fig.4, A) is not so high as has been noted by FOLK (1965), and no frequency maximum at microspar range exists. Actually the grain size changes from the finest to the coarsest so gradually that no abrupt change at any size range is appreciable.

There is unlikely any appreciable difference of shape, etching pattern, or grain boundary between micrite and microspar excepting that of arbitralily designated size. It is interesting to note that many detrital or allochemical grains, which are not contact each other, appear as being embedded in micrite and microspar (quartz grains of Plate 3, fig.3, skeletal grains of Plate 6, fig.1 and Plate 10, fig.3, pellet of Plate 30, fig.3). These grains originally had to be supported by muddy material otherwise they had to be come to contact each other before lithification.

These observations clearly indicating the same origin of micrite and microspar. While microspar and sparry cement might be quite different in origin. Actually they show different morphologies, such as microspar has zig-zag grain boundaries, as micrite does while spar has rather straight ones as BATHURST(1964) described (Plate 1, fig.2, Plate 10, figs.1 and 6). Also the etching surface of spar is quite smooth and almost devoid of inclusion exclusively while micrite and microspar is roughly surfaced and sometimes contain abundant inclusions, though there are many exceptions in respect to these characters.

As a conclusion, micrite and microspar have so common characters and origin that can not be distinguished each other other than by their arbitralily disignated size difference. While sparry cement can easily be distinguished from both micrite and microspar, by shape, grain boundary, size and/or surface morphology. Also no size difference based on appreciable natural category is noticiable, therefore, it is rather strongly felt that micrite and microspar must not be treated as different constituents of the limestones. But they might be better treated and discussed as only arbitralily differentiated constituents, which both comprize the fine grain matrix of limestones.

It should be noted they possibly are products of slightly different original material, as discussed in the proceeding section, while the diagenetic processes forming them are considered as almost identical. Thus forming nearly identical morphology excepting gradual size difference, of which difference of the original material probably is reflecting.

Sparry Calcite Cement (Spar)

Sparry calcite cement (spar) forms another type of matrix of limestone. This constituent usually is associating with abundant allochem, forming allochemical rocks, which is characteristically occurred in depositional environment under influence of aggitation by current or wave actions (FOLK, 1965). This constituent appears as precipitation filling original void spaces such as chambers of skeletal material and/or spaces between grains.

The limestones studied mostly contain lime mud as matrix while few limestones are sparritic. This fact may suggest that during the formation of limestones, depositional basin was quiet condition while intermittent agitation was operational in exceptional time and space. This interpretation also is strongly supporting the well preserved and nonabraded fossils, though highly fragmented, contained in most limestones.

Accordingly not so many spars have been observed intentionally except those of filling original void space. Also the fact that most attention were payed on revealing the nature of lime mud contributing to this scarcity of the observation of spars. However, quite few spars, which are associated with skeletal materials, with void, and with recrystallization have been observed not intentionally. Some of they are described briefly and simply.

Sparry calcites formed in original void spaces such as chambers of foraminifers, spaces between bivalved skeletons or zooecial openings of bryozoas are easily recognized during the detailed observation of these skeletal material. Also these spars generally are forming characteristic features such as radial orientation (Plate 1, fig.6, Plate 15, fig.5), bladed growth (Plate 11, fig.4, Plate 15, fig.3) or growth patterns (Plate 7, fig.1, Plate 11, fig.2, Plate 30, fig.1), therefore are easily recognized.

Even original void filling nature can not be detected, most spars show rather straight and/or sharply bent boundaries, as described by BATHURST (1964), (Plate 1, fig.2, Plate 14, fig.1). Smoothly etched surfaces of these calcites are sometimes quite helpful to identify them (Plate 14, fig.1), although there are many exceptions such as shown in Plate 1, fig.2. General large size of this material sometimes fails to identify it.

Coarsely grained lime mud, or microspar sometimes can not be distinguished from sparry cement only by their morphology, since both they sometimes show quite similar shape, size, grain boundary or surface. They can be distinguished rather by whole texture of limestones such as dencity of allochems, and/or relations between them.

Authigenic Minerals

Several types of authigenic minerals, including dolomite, quartz, pyrite, and calcitized dolomite, are frequently seen in many limestones studied. They generally constitute no more than a few percent in amount, except some dolostones and chert. These authigenic minerals are briefly described.

Many clay minerals might be authigenic in origin, they can not be precisely identified nor depicted, though pseudoreplicas appeared on many E.M. photographs represent clay minerals more or less. Therefore, they are not mentioned here.

Dolomite and Calcitized Dolomite: Most dolomite appeared in the studied limestones presumably considered as secondary in origin. Since many of these protrude into skeletal materials without disturbing the skeletal structure (Plate 9, figs.1 and 2, Plate 15, fig.2). Also euhedral rhomboidal shapes of most dolomite suggesting their authigenic origin (Plate 1, figs.3 and 5, Plate 5, figs.1 and 3, Plate 7, figs.1-5, etc.).

This mineral appears both embedded in lime mud matrix and in sparry calcite cement (Plate 1, fig.5, Plate 7, figs.1 and 5). This fact is suggesting that formation of this mineral, at least some of them, is later than that of sparry cement. Also sometimes this mineral cut boundaries of both lime mud and spar (Plate 1, fig.3, Plate 7, fig.5) thus the above interpretation of this mineral is strongly supported.

Many tiny dolomites are observed in echinoderm fragments (Plates 19-21). These dolomites are not known either original ones or secondary, although no true dolomites have been reported in recent echinoderm. In this concern, it is interesting to note that echinoderm skeleton originally consists exclusively of Mg-calcite, which the content of magnesium ranges from a few percent to more than 15 percent (DODD, 1967). It is highly probable, therefore, that this magnesium can be the source of magnesium ions to form these dolomites.

Sometimes dolomite is cut by silica cement (Plate 7, fig.3). This fact obviously indicates that cementation by silica is later than the formation of the former mineral. Also some dolomites are replaced by silica (Plate 8, fig.1) partially or wholy, which may have same bearing on the sequence of the formation of these minerals in the limestones, though silica cement and that of replacing dolomite are either diagenetic product of same stage or not is unknown.

Dolostones are very few in the studied limestones, since no such rock is intentionally avoided for collecting as samples. Some example of them collected unintentionally and observed show rather interesting character of this type of rocks (Plate 8, figs.5 and 6). Mineral dolomites seen in these dolostones appear as rhomboidal shape embedded in silica cement (Plate 8, fig.5) or in silica and/or argillaceous matrix (fig.6). Another interesting feature as seen in these is growth lines of dolomite, in which silica cement fills between them (Plate 8, fig.6). Although many dolomites seen in thin section sometimes reveals growth patterns by difference of the amount of iron in them (MOSSLER, 1970) or by growth lines of concentric shape, only E.M. observation of G.P.E. surface can reveal such a fine structure as 0.3 microns thick silica layer in between the growth lines of this mineral.

These observations tempting the author to convince the secondary origin of this type of mineral and the later cementation by silica. Either these are true or not it can be noted that the formation of dolomite evidently is earlier than silica in most cases.

Calcitized dolomites (EVAMY, 1967) are found abundantly in a limestone stained strongly by ferrugenious material, of which the lower limestone of megacyclothem is characterized (Plate 8, fig.3). Many other limestones contain this type of near-surface latest diagenetic products (EVAMY, 1967), though not so abundantly as lower limestone does (Plate 8, figs.2 and 4). This fact is indicating that the processes staining the limestone also is opperative for calcitization of dolomite, by which ground water has been suggested, as EVAMY (1967) noted.

Calcitized dolomites are also found in some echinoderm fragments (Plate

20, fig.1, Plate 21, fig.1) as calcite replacement after dolomite, which are commonly contained in this skeletal material as inclusions. This fact may be indicating the calcitization of dolomite is not restricted phenominan but is rather common one, though the chance to be calcitized or not may depend on the amount, nature and habit of the groundwater. Since even in a limestone or in a fragment of echinoderm skeleton, some dolomites are calcitized partially or wholy while remaining dolomites are unaffected at all. Also the degree of the calcitization is widely variable as apparently seen in Plate 8, figs.2-4.

As far as this study concerned, no apparent primary dolomite is observed and most dolomites observed reveal more or less euhedral or subhedral shape, by which secondary origin is suggested, although not prooved. Many euhedral dolomites protruded into skeletal material are more strongly indicating the secondary origin of it.

Quartz and Silica Cements: Both authigenic and detrital quartz grains are identified very often in thin sections. Amount of these grains in the limestones generally ranges from a few to several percent. Many limestones, which contain quartz grains of neither authigenic nor detrital origin as seen in thin sections, reveal this mineral in them, as seen under E.M., although the amount may be negligible as a constituent, less than a percent. Most of this mineral found in such a limestone are euhedral or subhedral. Same phenominan is depicted for silica cement or chalcedonic silica, although no euhedral nor subhedral grains naturally can not be found among this type of mineral.

These two type of silica mineral are briefly described and discussed. Although self-evidently detrital quartz are not authigenic, they also are briefly mentioned here since many supposed "silt size" quartz, as seen in thin sections, are revealed mostly euhedral to subhedral as seen under E.M. This fact may have some bearing on the origin and nature of quartz grains in the limestones.

Shown in Plate 1, fig.4 and in Plate 10, figs.1-4 are all euhedral quartz grains in various lime mud and sparrytic matrices. Among these most interesting one is that shown in Plate 10, fig.2. Although this euhedral quartz appeared is actually a mold of it extracted during blank replication, it reveals sutures on the surface of the mineral. These sutures are interpretted originally protruded into the mineral grain. Thus the entire quartz grain may be appeared as composite crystal, as aggregates of fragments, as seen as an individual extracted mineral. Also these sutures seem to be coincide with grain boundaries of the lime mud matrix surrounding it.

Therefore, this quartz is considered as grown in lime mud matrix with such a manner that portions contact to the crystal faces of the calcite grew slightly more rapidly while along grain boundary the growth was slightly slower. Thus boundaries of calcites are left as shallow grooves or sutures. This obviously is indicating the secondary origin of this quartz.

Another quartz (Plate 1, fig.4) shows same sutures, though very faintly. Thus has same bearings as above mentioned. Many euhedral quartz grains reveal same feature, and therefore, all they apparently are secondary origin.

Abundant pits on the surface of euhedral quartz grain (Plate 10, fig.3) probably were caused by same processes as the above sutures.

As far as the studied limestones are concerned, quartz grains which is revealing rather euhedral to subhedral shape, as seen under E.M., is much more commoner than those of apparently anhedral detrital quartz (Plate 10, fig.5 and 6), though naturally the latter type is seen abundantly in sandy limestones, which several are collected. Sometimes quartz grains protrude into skeletal grains without distrubing the skeletal microstructure, as previously mentioned dolomite grains (Plate 9, fig.4, Plate 15, fig.1).

These facts as above described are suggesting that euhedral quartz grain in limestones are secondary origin and many "silt size" quartz revealed by L.M., possibly are also this type of euhedral grains.

Silica cement (chalcedonic silica or amorphous silica) also is often appeared. Naturally it appears as abundantly as exceeding 50 percent of whole rock in chert, which some limestones contain commonly. Many limestones appeared as devoid of silica or quartz as seen under L.M., reveal slight amount of silica cement filling original void spaces (Plate 9, figs.5 and 6). Interestingly enough many calcites around this original void apaces show euhedral rhomboidal shape, while no other calcite in these limestones except calcitized dolomite reveals euhedral shape. This fact obviously is indicating the filling of silica cement into the void space was later than the formation of these euhedral calcites of sparrytic nature.

Sometimes silica cement protrudes into skeletal material without disturbing the skeletal microstructure (Plate 9, fig.3), though sometimes it does (Plate 15, fig.5).

It is apparently concluded from the above descriptions and discussions that many quartz grains are authigenic origin even though they appear as "silt size" quartz as seen by L.M. Also apparent is that filling of void spaces by silica cement is considered as rather later stage of diagenesis.

Pyrite: This mineral is not so commonly seen as the other authigenic minerals are. And those observed are considered as pyrite by its crytalline shape and by coincidence with opaque minerals as seen in thin sections. Therefore it might include hematite or limonite pseudomorph after pyrite, as usually seen in thin sections.

Pyrites observed under E.M. mostly appear as aggregates of spheric shape (Plate 1, fig.5, Plate 11, figs.3 and 5), in which hexahedral or octahedral crystal shapes sometimes are seen on the surface of the spheric bodies. Only a pyrite aggregate other than spheric shape has been observed (Plate 11, fig.6). This aggregate interestingly reveals that it is cut probably by silica cement, while it cuts grain boundaries of coarse grain lime mud and protrudes to it.

Relationship between pyrite and dolomite is not evedently revealed though the former protrudes to the latter is most likely considarable (Plate 1, fig.5).

ALLOCHEMICAL CONSTITUENTS

Varieties of allochemical constituents are frequently appeared in the limestones studied. Various taxons of fossils are most commonly present and predominant in them. As a matter of fact, limestone containing no fossil remain is very uncommon in the studied limestones, though the amount is widely variable. The degree of preservation of these fossil fragments also widely deffers depending on taxons, on limestone types and even on an individual fragment.

Allochemical constituents other than fossils are rather scarce and uncommon. Oolite is contained in several limestones, but only very few limestones contain this material as main allochem type. This fact can be evidenced indirectly by the fact that matrices of most limestones are micritic. No more than 10 percent of the studied limestones contain predominantly sparry cement which is precipitated after washout of lime mud under the influence of moderately to strongly agitated current (PLUMLEY *et al.*, 1962). Thus most limestones studied can be safely concluded as formed in quiet condition, which is unfavorable for the formation of colite.

Pellet is contained in many limestones. Not many of these limestones contain this material dominantly. In fact, although most limestones contain this material more or less, no more than 10 limestones can be definitely classfied as pelletal.

Apparent intraclast is very uncommon throughout the studied limestones. This fact, like the scarcities of oolite and sparry cement, also is indicating the formation of most limestones probably in quiet condition.

Accordingly three of the above four types of allochemical constituents, fossils, oolite, and pellet are observed mainly and, therefore, are described and discussed hereafter. Most effort, however, is naturally focussed on nature, characters and diagnoses of various taxons of fossils, which are most predominant allochems in the studied limestones. Others are briefly mentioned since only very few observations on these uncommon constituents are made during this study.

Fossils

Throughout the studied limestones, skeletal limestones containing diverse amount and taxons of organic remains are the commonest rock type (Appendix). Although many limestones are classified as biomicrite or, less commonly, biosparite according to FOLK's classification system, after which this study follows, it should be noted that the amount of skeletal remains is rather low. Limestones containg more than 20 percent of fossil fragments are quite uncommon. Actually most limestones are mud supported and therefore can be better characterized as mudstones and wackestones of DUNHAM's (1962) classification system, whereas packstone or grainstone is rather scarse and exceptional.

Most shelly fossils contained in the studied limestones, with exception of fusulinid and ostracod, are extensively comminuted. As a result of this fragmentation, discrimination between certain taxons is hardly made even in thin sections. Generic identification of brachiopod, bryozoa, and echinoderm, which are most extensively fragmented generally and are comprising the most abundant organic constituents in the studied limestones, is not made. As a matter of fact, only few brachiopod and bryozoa fragments can be identified even at the level of family, whereas most echinoderm are unidentifiable even at the level of order or higher.

Varieties of skeletal remains are frequently observed during E.M. examination of these limestones. Most of they can be confirmed as certain taxons but some are not. This is partly due to the above mentioned fragmentation of fossils and the resulting difficulty of identification of them by L.M. The major difficulty, however, arises from the preparation and observation by E.M.

A final replica of E.M. contains numerous tiny fossil fragments scattered throughout. Thus, even they can be identified as certain taxons by L.M., finding the identical fragment during E.M. examination is very difficult, if not impossible. Since no architectural outline of the fragments can be observed at a time due to the limitation of the field of observation of E.M., as previously mentioned.

On the contrary, thorough L.M. examination of an acetate peel identical used for E.M. replication is made. This procedure sometimes make it possible to find an identical portion photographed by E.M., if the portion is characterized by any of distinct texture or shape such as protruding of authigenic minerals into shell fragment or characteristic shape of sparry cement surrounding the shell. This is most favorably applicable for tiny skeletal remains present independently in matrix, though identification of it in thin section or in acetate peel is sometimes made not certainly.

In other words, generally E.M. observation can not be made for an identical portion predetermined by L.M. even if selected area replication technique is utilized, but sometimes subsequent L.M. observation can determines the portion photographed by E.M. by certain distinct features appeared in E.M. photograph.

Fusulinid, however, is easily recognized during the preparation procedure by unaimed eye. Therefore selecting it as a separate single replica is easily made. Since it usually is contained as unfragmented skeleton, and its size is large enough to cover an entire area of replica of about 2 x 2 mm square.

Under E.M., several taxons of organic remains are examined and identified by the above two methods. These are brachiopod, bryozoa, echinoderm, fusulinid, trilobite, mollusc and ostracod. These are briefly described.

Although brief paleontologic considerations are made on fusulinid, descriptions and discussions on the other taxons should be restricted to the preriminary diagnoses or criteria for the identification of them under E.M., as rock constituents of the limestones. Hence observations are made on limited portions of organisms in random orientations. Also the taxonomic identification can not be certainly made for many of them even during L.M. examinations.

Brachiopod: Brachiopod fragments, together with bryozoa and echinoderm fragments, comprises the commonest skeletal constituent of many of the studied limestones.

Brachiopod and its spine can easily be distinguished in thin section during the L.M. observation, by their shape and characteristic two layer microstructure, though they are finely comminuted generally. As a result of the fragmentation, generic identification of these shell fragments is difficult and most cases it is impossible.

Two of three groups of brachiopod skeletal microstructures are commonly observed in thin section: impunctate and pseudo-punctate forms. Both microstructures are composed of two carbonate layers of thin outer (primary) layer and thick inner (secondary) layer.

The outer primary layer consits of thin fiber-like prisms, which usually appears in thin section as highly transparent bright rind on or around the inner secondary layer. The thin fiber-like prisms commonly appear as if oriented normal to the shell surface, but some of they seem to be granular with no orientation. This layer is frequently abraded and not preserved, and therefore, apts to be lacking on many of fragmental brachiopod observed.

The inner secondary layer of impunctate shell is either composed of closely and dencely packed thin fibers, which appears, in longitudinal section, as bundles of a hair, or of slender geometric fibrous prisms parallel or slightly inclinid to the shell surface. The transverse section of fibrous prisms of this layer appears as pseudorhombic or rectangular, depending on orientation, of various size. Some of secondary layer of impunctate shell show multilayered laminar structure, of which two differently oriented fibrous prisms constitute.

The secondary layer of pseudopunctate brachiopod is composed of thin flat prisms similar to those of impunctate one. This microstructure is distinctive by presence of taleolae, which is composed of clear nod of calcite transecting the secondary layer. The fibrous prisms of this laer is bent and folded at and around the taleolae consisting a pseudopunctae, after which this microstructure was named. In an oblique section, pseudopunctate structure appears as convergence or whirlpool of folded fibrous calcite around the nod of the clean calcite of taleolae.

As seen under E.M., brachiopod fragment and its spine are readily identifiable by their orderly arrangement of fibrous calcite prisms or by the slightly wavy prismatic calcite. Sometimes, however, certain bryozoa microstructure closely resembles to that of wavy pseudopunctate brachiopod. Usually bryozoa microstructure, as will be described in the next section, shows stronger and frequent folding than brachiopod. Skeletal architecture of bryozoa also shows many branching, thus led to their identification as bryozoa.

Plate 12, fig.1 represents almost longitudinal section of impunctate brachiopod secondary layer, which is composed of 0.1-1 micron thick and infinite length fibrous calcite prisms. Several of these ifbrous prisms seem to form a bundle of 2-3 microns wide, probably, composite crystal, which may appear as unit fibrous prisms when observed by L.M. Fig.2 of the same plate reveals both primary and secondary layers. The primary layer of this fragment is appeared as granular texture, which consists of 1-2 microns calcite granules. This primary layer hardly shows any orientation or elongation of the constituent calcite, though this layer has been believed composed of fibrous prisms oriented normal to the shell surface (MAJEWSKE, 1969).

The secondary layer of this specimen is composed of finer fibers than those of fig.1. The width of individual calcite fiber is 0.1-0.2 microns and quite uniform throughout. The length of this fiber is variable, commonly 2-3 microns but few are infinite. This variability of the length probably is due to slightly oblique, though close to longitudinal, section. Several calcite fibers likely are comprising a bundle of 1-1.5 microns wide composite crystal, as that of fig.1 of the same plate.

Transverse section of impunctate brachiopod shell microstructure represents elongate pseudorhomboidal shape of fibrous calcite prisms (Plate 12, fig.3). Individual calcite prism is 2-3 microns wide and 5-10 microns long, which is much larger than that considered from figs.1 and 2. The size of individual prisms much differ among genera (MAJEWSKE, 1969), therefore, this difference of the size may reflects the generic difference of these specimens rather than that of sectional orientation.

The elongated and normaly oriented calcite prisms at upper right portion of fig.3 are fibrous prisms of the primary layer (MAJEWSKE, 1969). Strangely enough the size of individual prisms of the primary layers of figs.2 and 3 does not seem much differ, though that of the secondary layers does drastically.

A multi-layerd laminar structure of impunctate brachiopod secondary layer (Plate 13, fig.1) shows difference of the orientation of prismatic calcite consisting of each layer. The lowermost layer of this fragment appears as faint pseudorhombic shape, indicating being cut obliquely. The next layer is cut nearly longitudinally, thus appears as long fibrous prisms with infinite length. The remaining layers are consisted with parallel alternation of these two layers. The thickness of each layer is 1-10 microns and uniform throughout this fragment. It is likely, therefore, that the long axis of each layer exists in almost parallel planes but slightly crosses each other. The uppermost granular layer of this fragment is not known either primary layer or a portion of secondary layer cut obliquely.

Pseudopunctate brachiopod microstructure shows variable texture according to the orientation of the section, to the part of the shell, and probably to genera. A nearly longitudinal section through a taleolae (Plate 13, fig.2) exibits large prisms of the secondary laer bent at the portion of the taleolae. The taleolae is composed of granular calcite, which the size ranges from 2 to more than 7 microns. It transects the entire thickness of the secondary layer but not the primary layer. The calcite prisms of the layer are 2-3 microns wide and more than 10 microns long. Some of prisms are infinite in length and appear as long pseudorhombic. These fibrous prisms show downward (inward) deflection at the taleolae, which is characteristic to pseudopunctate microstructure, while endopunctate one, though very rarely present in the studied limestones, shows upward deflection (MAJEWSKE, 1969).

An oblique section (transverse to the direction of taleolae) of two pseudopuncta reveals wavy microstructure of fibrous prisms of the secondary layer (Plate 14, fig.2). Each fibrous prism of this fragment appears as more or less pseudorhombic or rectangular in shape. Hence the downward deflection of prisms at around the taleolae, as above mentioned, probably causes these prisms as if being cut transversely.

The other part of this shelly fragment is appeared as rather granular, to which the orientation of this section may due. More or less disordered arrangement of the prismatic calcite may due to the same reason. The taleolae of this fragment is not clearly revealed, but entire pseudopunctae evidently is composed of convergence or wirlpool of prismatic calcite around the taleolae.

Shown in Plate 14, fig.1 is slightly oblique but nearly transverse section of productid brachiopod external spine. The outer layer of this spine consists of granular, rather fine grain calcite of 0.1-1.2 microns diameter. It is gradually increasing the size toward the inside of the spine. The thickness of this layer is about 5 microns and uniform throughout. The granular habitat of this layer apparently due to normaly oriented prisms cut tangentially.

The secondary layer of this spine consists of 2-4 microns long and 0.5-1.2 microns wide thin, slender fibrous prisms, which appears as composite crystal, as previous specimens, of a bundle of 0.2-0.3 microns wide unit crystal. The boundary between these two layers is sharp and well parallel to the shell surface throughout.

Several examples of brachiopod shell microstructure, in which wide size variation of unit fibrous prismatic calcites is clearly appreciable, are presented in Plate 15. Fig.1 of the plate is a slender, less than 6 microns thick, fragment of probably productid spine cut nearly longitudinally. The thickness of unit fibrous prismatic calcite of the secondary layer is infinite. Although no distinct primary layer is apparent, some fine granular calcites on the outer surface of the spine possively is part of this layer.

The sharply shaped, smooth surfaced and depressed minerals (center and lower middle right) likely are quartz, which the central one is quite euhedral. This euhedral quartz, as previously mentioned, is evidently indicating the secondary origin of this type of mineral. Apparently this mineral transects the shell wall and therefore strongly support the above interpretation.

Fig.2 is an oblique section of a spine, which is revealing deeply protruded euhedral dolomite. Although this is a mold of dolomite extracted during blanc replication, it is apparently, like the euhedral quartz, secondary origin.

The individual fibrous calcite prism of the secondary layer, no primary layer is seen, is extremely thin, less than 0.2 microns, and infinitely long. The entire layer thus appears as though consisting of bundles of hairs arranged nearly parallel. Tiny pits on the hairlike prism may be inclusions, which the origin and nature is not well known. Although the other type of inclusions are seen in brachiopod prisms (Plate 12, fig.3), etched patterns of organic fragment can hardly be interpretted generally. Since the etching behavior of the calcites consisting these fragments are more or less affected by organic matters inherently preserved in shell fragments.

Fig.5 is another oblique section of a spine. Inside the spine (middle to upper left) is filled with sparry calcite, typically showing radial orientation grown normal to the wall and inward increase of the size, as described by FOLK (1965). The outside of the spine is amorphous silica, in which contains small amount of dolomite (lower center to lower left). This silica protrudes to the spine, thus indicating the secondary precipitate or replacement.

Fig.3 and 4 are other secondary layers of brachiopod shell, which the taxon is not identified. Fig.3 is a portion of presumably impunctate brachiopod secondary layer cut nearly longitudinally. The fibrous prisms are 1.5-2 microns wide and 2 to more than 10 microns long. This size is intermediate of between those of Plate 12, fig.1 and fig.2. The elongate large calcite crystals around the shell surface are bladed calcite (FOLK, 1965) precipitated.

Fig.4 represents two brachiopod fragments, in which difference of microtexture is quite evident. The nearly horizontal one (central right to left) is almost longitudinal section with 0.5-1.5 microns thick and 2-4 microns long prismatic fibrous calcites constitute. The vertical one (middle center to upper) is also longitudinally cut section but with much larger prisms of 0.5-3 microns wide and 4-8 microns long. These two fragments are evidently representing difference of microtexture of brachiopod shell rather on genera than on orientation of the section.

Bryozoa: As a skeletal constituent, this taxon is as common as brachiopod or echinoderm in many limestones examined. Numerous lacy bryozoa are sometimes scattered on the weathered surfaces of the collected limestones. These genera, naturally are most frequently seen in thin sections, although no generic nor specific identification of this taxon is intended during the study.

Bryozoa are exclusively colonial animals and therefore the colony appear as wide range of shapes depending on genera, species, on the substrata, or on the sectional directions. In thin sections they appear as rows of small beads, as lacy networks, as thin encrustation on other fossils or substrata, as triangles, wheels or discs, and sometimes as massive screw-like objects or branching trees. During the L.M. examination of thin sections or peels, bryozoa can be discriminated from other taxa by shape of colonial habit and by laminated or granular microstructure of the skeleton. Characteristic cone-in-cone structure appearing on some bryozoan longitudinal section is quite helpful for the identification of this taxon.

Finely comminuted brachiopod fragments are sometimes hard to be distinguished from bryozoan fragments. They can be distinguished if architectural shape of the latter, which generally is fine enough to be revealed even in 0.05 mm size fragment, is carefully considered. Also bryozoan fragments usually are appearing slightly darker than brachiopod in thin sections and showing yellowish color in peels. The skeletal architecture of network-like shape is rather characteristic to bryozoa, although some colonial tabulate coral, which is very uncommon in the studied limestones, superficially resembles to it. They can be distinguished each other by relatively small size of colony, finer grained skeletal microstructure, and presence of small openings distributed on the skeleton such as mesopores and acanthopores, all of bryozoa.

No less than three types of bryozoan wall microstructure have been recognized (HOROWITZ and POTTOR, 1971). They are (1) laminated, (2) granular and (3) fibrous structures. These three types of microstructure are distributed in various combination in different bryozoan groups, although laminated and granular types are predominantly seen in the studied specimens. The laminated structure appears fibrous in cross section and sometimes structureless in sections parallel to the laminae. The granular structure is generally very fine grained and thus appears darker or translusent in thin sections.

During the sampling of the limestones throughout the outcropping Upper Pensylvanian of Kansas, fenestellidae bryozoa such as *Fenestella, Polypora,* and *Archimedes* are recognized on many of weathered surfaces of the limestones, as previously mentioned. In thin sections it is rather strongly felt that bryozoa is, as same as most other taxa, generally finely comminuted. Therefore some bryozoa fragments in thin sections can be identified to the above genera. For most other fragments, however, identification to certain general is hardly made. This difficulty of the identification may not only due to the fragmentation of the skeleton, which generally makes taxonomic identification very difficult and sometimes impossible, and to randomness of the orientation of thin sections, but certainly due mainly to the author's unfamiliality to this taxon.

On the course of the E.M. observation, bryozoa fragments are seen frequently, although not so as brachiopod or echinoderm fragments are. Bryozoa can be certainly distinguished from other taxa by small size of skeletal architecture, which is sometimes small enough to be traced in one or two fields of observation of E.M. As a matter of fact, some bryozoa fragments are revealed to be branching even in a serial E.M. photograph of two (Plate 16, fig.1, Plate 17, fig.1). This fact certainly is contributed by relatively small size of individuals of bryozoa. Whereas skeletal architecture of other taxa sometimes seen requires much wider area, at least four serial E.M. photographs, to be even partially revealed.

The most common skeletal microstructure of bryozoa is characterized by laminated structure which two types are recognized. One type is composed of two outer slightly fibrous layers and an inner structureless layer, of which single calcite crystal may consists. Thus this type appears as though sandwich of the latter bwtween the former (Plate 16, fig.1, Plate 17, figs.1 and 2) and can be said as thickly laminated. The other type of microstructure appears rather more commonly than the former type. This type of structure consists of alternation of bundles of 5-15 microns thick fibrous layers, which each layer is less than 2 microns thick or consists of numerous alternation of thin fibrous layers as above (Plate 16, fig.2, Plate 18, fig.4). This type of structure can be named as thinly laminated. The former thickly laminated structure presents as thin wall of usually less than 20-30 microns thick (Plate 16, fig.1, Plate 17, figs.1 and 2), therefore likely is partition of zooecial openings such as cystiphragm, diaphragm, or vesicular tissue. Whereas the thinly laminated structure presents as thick wall of the skeleton, which may be shell wall between the zooecia.

The size of individual calcite grains of the fibrous layer of both thickly and thinly laminated structures seem to be almost same, of 1-2 microns wide and 3-5 microns long, although some are longer (leftest portion of Plate 16, fig.2), and some are shorter, appearing more or less granular (center of Plate 17, fig.2, center of Plate 18, fig.4). This variation of the size probably is caused by difference of the orientation of sectioning.

The direction of lamination of the thinly laminated skeleton likely is nearly parallel to the shell surface (Plate 16, fig.2, Plate 18, fig.4). The thickly laminated one also shows same orientation. Therefore, at around the branching of the skeleton, the inner structureless layer is branching and thus appears as "Y" shape. While the outer layers are only slightly curving in accordance with the shell surface and appear as if lining the opening or the surface of the skeleton (Plate 16, fig.1, Plate 17, figs.1 and 2). Each fiber comprizing the layer is oriented almost parallel to the surface. It is felt, however, that the above orientation of lamina and fibers is not so regular and uniform as that of brachiopod. Thus can be considered as a diagnosis to distinguish these two taxa, even if the architectural shape of bryozoa can not be clearly seen during the E.M. investigation.

Thickness of the inner layer of the thickly laminated bryozoa varies widely though that of the outer one seems to be uniform. It ranges from 50 percent of the total thickness (Plate 17, fig.1) to less than 10 percent (Plate 16, fig.1). The variation may due to the orientation of the section, since this layer comprising the core of the wall and thus variability of the thickness appeared may depend on which portion is cut.

Thinly laminated wall sometimes reveals rather characteristic nod, turbulence, or crumpling of fibrous layer, of which the laminae is comprized (Plate 16, fig.2). This structure could never been clearly observed during the L.M. observation of neither thin section nor peel. This is so characteristic to bryozoa that it can diagnose this taxon during E.M. observation, though its exact paleontologic meaning is not well understood to the author.

Fibrous bryozoan microstructure sometimes resembles to that of brachiopod. Microstructures of Plate 18, fig.2 (bryozoa) and center of plate 15, fig.4 (brachiopod) may not be distinguished each other. Although surface morphologies such as size, shape, and orientation are much differ, the etching patterns of the former also closely resemble to those of brachiopod (Plate 12, fig.3 and upper parts of Plate 15, fig.4). Bryozoa can be distinguished from brachiopod by change of fibrous layer to granular one at both sides of the former. While brachiopod usually does not show such change of microstructure.

Granular texture of bryozoa such as seen in Plate 18, fig.1 could be misidentified as brachiopod secondary layer cut obliquely (Plate 14, fig.2), or primary layer cut transversely (Plate 12, fig.3, Plate 14, fig.1). The former structure appears, however, rather disordered than the latters, or sometimes shows almost no arrangement of the constituent grains. Thus can be distinguished if both microstructures are carefully compared. Also brachiopod primary layer is so thin that can be discriminated from bryozoa easily.

Shown in Fig.3 of Plate 18 is a bryozoa fragment with unusual slightly angular grains. This fragment has been thought as bryozoa during the E.M. examination, with conspicious feeling. Following thorough L.M. examination of the identical peel used for E.M. replica confirms it as bryozoa by its skeletal architecture. Thus these angular grains are considered products of partial recrystallization. Tiny grains, with rectangular to rhomboidal shape and flat surface, therefore appears blighter, probably are silica mineral impregnating into void space between the calcite grains. This fact may be supporting the above recrystallization interpretation of angular calcite grains. It is rather surprizing that even with the recrystallization, the entire skeleton shows somehow irregular orientation of grains characterizing bryozoan microstructure.

Echinoderm: As of brachiopod and bryozoa, echinoderm comprises one of the commonest skeletal constituents of many limestones examined. Echinoderm skeleton, of which numerous calcite plates consists, apts to disarticulate and scatter soon after the death of organism. Therefore, thin section is more likely to contain individual calcareous plates, spines and their fragments than the entire skeleton. Thus almost no architectural characteristic of the skeleton, on which generic and specific identification is based, can be seen in the section. As a result, no generic identification can be made, nor is discrimination on the level of family or higher.

Each individual plate and spine of echinoderm skeleton, acts as a single crystal of calcite, which extincts as a whole at a single position under crossed nicols. This characteristic feature distinguishes echinoderm from other taxa easily. Many body fragments exhibit numerous tiny pores, which gives "dirty" appearance on the central area of the single crystal of calcite.

Among echinoderm fragments, crinoid columnals and plates are predominant in the studied limestones. While echinoid spines and fragments of plate are not uncommon. Some of these fragmental material exhibit syntaxial rim cementation (BATHURST, 1959), which is formed by calcite cement overgrowth, with optical continuity over a nuclei of echinoderm fragment.

When examined by E.M., most echinoderm fragments appear as extremely large single crystal of calcite, which generally beyond the entire field of observation of E.M. (Plate 19, 20 and 21). This large size of the crystal sometimes makes it difficult to distinguish it as skeletal fragment.

Most of the etched surfaces of the calcite crystal appear clean and smooth, even numerous inclusions are scattered on them (Plate 19, fig.1, Plate 20, fig.1, Plate 21, figs.1, 2, 3 and 4). Some surfaces appear rather roughly and dirty, not with irregularly distributed inclusions but with randomly contoured surface topography (Plate 19, fig.2, Plate 20, fig.2).

The above extremely large size of calcite crystal with smooth and clean or with dirty and rough surface, together with the presence of numerous inclusions on it, characterizes echinoderm. Echinoderm, therefore can be distinguished from large inorganic calcite crystals, such as sparry cement or recrystallized calcite, by the above characters.

Two types of inclusions are exclusively recognized on the etched surface of all echinoderm fragments. One is etch-resistant mineral inclusion and has larger size of 1.5-5 microns, whereas the other is smaller, usually less than 1 micron diameter. The latter inclusion is well etched and appears as a pit under E.M. Well etched nature of this type inclusions is strongly indicating it as void space or fluid filled, therefore is not likely mineral, but probably is fluid inclusion.

The former inclusion sometimes shows rhomboidal shape and has numerous scratches on it, therefore is identical to the diagnostic feature of dolomite as previously mentioned. Corresponding sized "dirty" inclusion is not stained by alizalin red-S when examined by L.M., thus also strongly indicating dolomitic composition of it. Sometimes this dolomitic inclusion is partially or wholy replaced by presumably chalecedonic silica (Plate 21, figs.1 and 2). Calcitized dolomite, which is calcite pseudmorph after dolomite (EVAMY, 1967) is rarely seen in this type of mineral inclusions (Plate 19, fig.1). The shape of original dolomite is preserved as rhomboidal shape of calcite grains, which is a lump of granular grains presents in an extremely large single crystal of host echinoderm skeleton (middle center of Plate 19, fig.1). Numbers of tiny dolomite grains

(0.3-1.5 microns diameter) also are sometimes outlining the rhomboidal shape of original dolomite (upper center to lower center of Plate 19, fig.1).

These tiny dolomites probably are indicating partial replacement of calcite after dolomite inclusions, although calcitized dolomite possibly is being replaced by dolomite again. Another possible interpretation is that they act as nuclei of rhomboidal dolomite as they concentrate magnesium ion from surrounding echinoderm skeleton, which has been considered as magnesium rich, Mg-calcite, exclusively (DODD, 1967). Since calcitezed dolomite is a product of near surface diagenesis, where ground water and weathering are effective agents (EVAMY, 1967). It is most likely that the difference of the degree of calcitization is caused by difference of freshness of the sample, which sometimes appreciable even in a milimeter scale.

The dolomite inclusions above discussed coincide with the "dirty" inclusions on some echinoderm fragments examined by L.M. Also they are likely coincide with the "monadonocks" on the fractured surface of crinoidal columnals reported by SHOJI (1964) and by SHOJI and FOLK (1964) by size and distribution of them. Although they reported them as calcite inclusions of different orientation than the host columnal, it is clearly revealed that this type of inclusions, at least those observed in this study, are dolomitic in composition.

Although the origin of this dolomitic inclusions is not certainly understood yet, nor is the objective of this study to investigate it in further detail, following brief discussions are made.

During the examination of echinoderm skeletons by E.M., it is strongly felt that they are mostly containing this mineral as inclusions more or less. While no such mineral has been revealed in Recent specimens investigated by E.M. (TOWE, 1966; NISSEN, 1969) nor by X-ray diffraction (DONNAY and PAWSON, 1969). Therefore it is most likely that the dolomite inclusions are secondary in origin, though no such dolomite has been reported ever in echinoderm fragment.

Although many skeletal material other than echinoderm are observed, as described throughout this study, no other taxon contains dolomite as abundantly and frequently as echinoderm does. It is quite certain that dolomites are closely associated only with echinoderm, which the original skeleton has been considered as Mg-calcite exclusively (CHAVE, 1954; DODD, 1967; WINLAND, 1969; WEBER, 1969). This close association of both minerals may suggest that magnesium ions of the former have been supplied from these of Mg-calcite.

Mg-calcite is thermodynamically unstable under the normal pressure and temperature. Especially in aquatic condition this mineral dissolves to water and recrystallize or reprecipitates as aragonite and finally as most stable low Mg-calcite. While no recrystallized nor reprecipitated structure of echinoderm skeleton is revealed through this study. This is superficially indicating no appreciable such reactions have been in operation on these skeleton.

According to FRIEDMAN (1964), change of unstable Mg-calcite to stable low Mg-calcite is solution deposition on a microscale, which does not alter fine internal skeletal structures. Conducting an experimental investigation, LAND (1967) noted rather interesting result that Mg-calcite undergoes incongruent solution with production of low Mg-calcite and a magnesium enriched solution. Therefore it is likely that this magnesium enriched solution might precipitate the dolomite while solution deposition or incongluent solution is in operation on the echinoderm skeleton without altering the microstructure. Also it is quite possible that the dolomite formation in skeletal material is at early stage of diagenesis since the change of skeletal Mg-calcite to low Mg-calcite, which supply magnesium ions for the formation of the dolomite has been noted exclusively as quite early stage of diagenesis (WINLAND, 1968).

As a summary, echinoderm fragments exhibit rather simple microstructure of extremely large calcite crystal. Only some variations which are represented by difference of the amount of inclusions, by mineral composition of them and by roughness of the surface, but no orientational difference, are strongly noted during the E.M. observations. Also as a conclusion the above discussed secondary dolomite and extremely large size single calcite crystal, by which is sometimes given nonskeletal appearance, composing the skeleton are considered as mostly characterizing echinoderm fragment.

Fusulinid: In the studied limestones, several fusulinid genera, including *Triticites, Staffella, Wedekindellina* and *Waeringella,* are identified in thin sections. Among those, *Triticites* is found most frequently. The remaining genera are rarely found in several limestones. Thus the genus *Triticites* is examined in detail, as a representative of fusulinids, by E.M. and described below. This genus is found throughout the Missourian and Virgilian strata.

In thin sections, *Triticites* is characterized by relatively large size, bluntly pointed poles, a wall structure that is usually well preserved and distinctive, consisting of a tectum and keriotheca containing pronounced alveoli, single and straight tunnel, dense, distinct and symmetrical chomata, small proloculus and fluting of septa mainly in the polar regions and extending to the central portion.

All L.M. observations are made on randomly oriented thin sections, in which not all of the above features are observed simultaneously. Thus it is highly possible that closely resembling genus *Kansanella* might be misidentified as genus *Triticites*. Therefore the latter genus discussed below might include the former, though not so much difference on the microstructure might be likely between these two genera.

In any orientation of the specimen in thin sections, this genus is characterized distinctively by the pronounced wall structure of spirotheca. It is sometimes noted in acetate peel made from G.P.E. surface of thin section, that this distinct wall structure seen in thin section is difficult to be revealed clearly

When examined by E.M., the fusulinid shell shows various degree of clarity of the microstructure which exclusively is granular. As a general, the distinct wall structure seen in thin sections and/or acetate peels is more or less blurred, excepting some of exceptionally well preserved specimens, when examined by E.M. It is felt that the difference of the microtexture of the skeleton as seen in thin section is likely due to that of grain size of the calcite crystals composing it. Also, calcite grains consisting spirotheca and septa are unlikely arranged orderly, even though they appear so when seen in thin sections. This randomness of the microstructure characterizes *Triticites*, and probably most other fusulinid genera. It is also the most distinct character to discriminate fusulinid from other taxa, of which variable orderly oriented calcite grains consist.

An exceptionally distinct microtexture examined by E.M. is shown in Plate 22. The identical specimen seen in thin section and in acetate peel is shown in Plate 26, figs.4 and 2, respectively. A simplified line-drawing made from E.M. photograph representing grain boundaries is also shown as Fig.11. This may be helpful to distinctively differentiate shape and size of grains consisting the skeleton.

E.M. examination definitely reveals that the alveoli* of this specimen is composed of pore-filling calcite spar, since some of they are apparently continuous from that of inside the chamber as seen at lowermost left portion. Some of these pore filling spar of alveoli continuing to those of outer chamber (uppermost). On the contrary, the keriotheca* consists of finer calcites than those of alveoli. The shape of these calcite seems to be subangular to subround and some appear as rather rectangular, with the long axis parallel to the direction of the wall. These differences can be apparently seen in the line-drawing presented as Fig.11. The width of the keriotheca differs one another. This difference probably is caused by the orientational direction of

* Although the term keriotheca specifies a layer of the wall inside the tectum including the alveolar structure. As a convenience, this term is used hereafter for the darker portion of this layer normal to the wall. The term alveoli, therefore, is used as the portion between the keriotheca, here defined, where appears as bright, transparent and normaly oriented structure to the wall.

the section and by the portion of the keriotheca transected. Accordingly the wide one may be cut at nearly center of the keriotheca, while narrower one may be at perifery of it.

Tectum is thin, about 10 microns thick. This layer is composed of the finest grains, though change of grain size from keriotheca to tectum seems gradual. No arrangements on the grains of tectum is seen apparently. As previously mentioned, some pore-filling sparry calcites of alveoli penetrate through the tectum, *i. e.*, alveoli penetrates through the entire wall. Although it is not well known, at the stage of this study, either all or some of alveola penetrate the tectum. It is clearly revealed that tectum is discontinous and porous, at least partially, even if it appears to be dense and continuous layer when examined in thin sections, and sometimes even in E.M.

Shown in Plate 23, fig.1 is different part of the specimen discribed above (Plate 26, figs.1 and 4 represent the same specimen seen in acetate peel and in thin section, respectively). Upper portion of the spirotheca probably is replaced or recrystallized by large calcite single crystal. In this part of the specimen the pore filling nature of the alveoli is certainly obvious, though some alveola appear as being discontinuously transected by the keriotheca (*cf.* Fig.12) and no obvious tectum can be seen.

The keriotheca of this specimen appears as rather granular without distinctive orientation, except that of lower left portion, where several rectangular grains are apparently seen. At this part, keriotheca is appeared as divided by pore filling spar of alveoli. This division of keriotheca and the above mentioned alveoli transected by the keriotheca, which means the latter is divided by the former, are suggesting keriotheca is winding or its width is changing abruptly along the direction of it. The height of alveola is rather differing one another, to which thining of this structure at the upper part of the spirotheca may due.

Cross cut sections of different portions of a spirotheca as seen in an obliquely cut specimen are shown in Plate 23, fig.2 and in Plate 24. The identical specimen seen in thin section and in acetate peel are presented in Plate 26, figs.5 and 7, respectively. Line-drawing of grain boundaries seen on the E.M. photograph are shown as Fig.12B and Fig.13. From these plates and figures, arrangement of alveoli and keriotheca and that of calcite grains consisting these structures are clearly revealed.

As seen on Plate 23, fig.2, there are apparently two types of calcite grains consisting the spirotheca. One is large (ranging 10-20 microns diameter) and appearing subround to subangular. The other type is smaller (less than 5 microns) and rather granular and elongated, and appearing as though embedding the space between the former grains. Also the latter grains seem to be oriented normal to the former grains. Thus the former grains appear as though "birds eye" between the latter grains. These difference are more easily noticiable in Fig.12-B. It is obviously seen from Plate 26, fig.7 that the former grains correspond to alveola and the latter to keriotheca. The above observation on keriotheca and alveola are quite agreeable to those of Plate 22, though the pore filling of alveola is not clearly revealed. The grains of keriotheca elongates almost parallel to the wall as seen on the longitudinal section, naturally appears radially oriented around the alveola when this structure is cross cut.

The thickness of the keriotheca seems to be rather uniform of 5-6 microns though the size of alveola is variable, ranging 10-20 microns diameter. The thickness of the keriotheca is fairly agreeable to that measured on Plate 22. The size of alveola also is quite agreeable to that measured on Plate 22 and Plate 23, fig.1.

Outermost portion of the same specimen (Plate 24, Plate 26, fig.7), reveals no alveolar structure but radially oriented keriotheca, which appears as fusiform. The finer grained layer of about 5 microns thick (lower right portion), may be representing the tectum. This layer shows no distinct orientation nor arrangement. No alveoli apparently penetrates this presumable tectum. Some larger calcite grains of 5-6 microns diameter appeared on the portion of the tectum, however, are possibly representing alveoli (upper lower right).

Another specimen, which shows distinct structures as seen in thin section (Plate 26, fig.3) but not so obvious in acetate peel (Plate 26, fig.6), examined by E.M. is shown in Plate 25. This specimen reveals no distinct wall structure other than the difference of grain sizes composing the keriotheca and alveoli (*cf.* Fig.14), which the latter seems to be rather irregularly distributed. This difference of grain sizes is unlikely to be arranged in an orderly fashion. The discrimination between the keriotheca and tectum is rather distinct than that of the former and alveoli. A portion of a septum adjacent to the wall (upper right) consists of coarser calcite than that of the wall. No distinct arrangement of mineral grains in septum are obvious. A boundary between the septum and the tectum can be clearly defined by the differences of grain size and rather well oriented calcite of outermost tectum. Another septum shown in Plate 27, fig.1 reveals no orderly texture in this portion of the fusulinid shell, as of the above specimen.

A sprirotheca which shows no appreciable wall structure when observed by E.M., is most common in the studied limestones (Plate 27, fig.3). In this specimen there are unlikely any difference between supposed keriotheca and alveoli. Also no tectum can be seen in the wall. The boundaries between the wall and the chambers of both sides are rather blurred. Part of spirotheca of another specimen reveals no distinct structure in keriotheca, even though the boundary between the wall and the chamber is very distinct (Plate 27, fig.2).

As a matter of fact, throughout the E.M. examination of fusulinid shell, the wall which shows distinct structure is rather exceptional case (Plates 22, 23, 24 and 25). While fusulinid shell which shows no texture in any orientation (Plate 27) is more commonly seen. Also in any orientation of the section there is unlikely any appreciable microstructure in a septum exclusively (Plate 25).

Discussions on the fusulinid wall microstructure: The structure of spirotheca has been considered as one of the most reliable criteria for the differentiation and classification of many of the fusulinaceans, and is highly complicated. GUBLER (1934, 1935 *in* THOMPSON, 1948, 1964) had interpreted the keriothecal texture as a masonry-like structure, in which the alveoli are coarse crystals of calcite cemented with a finer calcite impregnated with organic material, the latter less transparent material serving as "mortar". The tectum was interpreted as being composed of fine grained calcite and includes organic material.

On the other hand, many fusulinid specialists judged this texture as being porous, passing through all layers of spirotheca, based on many thin section observations and published excellent illustrations (HENBEST, 1937; DUNBAR and SKINNER, 1937; DUNBAR and HENBEST, 1942; THOMPSON, 1961).

E.M. observation of *Triticites,* as above described, clearly revealed the pore filling nature of alveoli (DUNBAR and HENBEST , 1937), some of which are continuous from inside the chamber to the outside. It is clear that some parts of tectum is also filled by pore filling calcite (Plate 22). The difference between the tectum and keriotheca is most obviously observed, thought it seems to be more or less gradual, except that of grain sizes. (Plate 25). The organic material impregnated nature of less transparent parts of keriotheca and tectum (GUBLER, 1934; 1935) is uncertain. However, it is unlikely that there exists appreciable organic material in fossilized shells.

On the other hand it should be noted that fusulinid specimens with distinctive structure, such as shown in Plates 22-25, appear rather "dirty". This means not only calcite grains consisting the wall but pore filling sparry calcite also reveal more or less indistinct grain boundaries, also the grain surfaces are appearing "dirty" with dusty material of unknown nature. While those without distinct microstructure show "clean" appearance (Plate 28). It is not certainly known that this difference of appearance is caused either by that of preservation of skeleton or by that of preparation procedure, which exact control is almost impossible.

The texture of the septa seems to be homogeneous, composed of a little coarser calcite than that of the tectum, through all observed specimens of *Triticites*, the porous nature of chomata passed through from spirotheca (HENBEST, 1937) is uncertain because no obsercation by E.M. was made on this structure. It is certain that all of these textures show various degree of textural alteration, which sometimes makes it hard to distinguish if the observed texture is original one or not.

Trilobite: Although trilobite is not so abundant volumetrically as brachiopod, as bryozoa or as fusulinid, several trilobite carapace fragments and spines are observed in thin sections. They are highly transparent and therefore, appear very bright in thin sections. No structural elements are visible in ordinary light. Between crossed nicols, however, the skeleton extinguishes as if composed of submicroscopic calcite prisms oriented normal to the shell surface.

The microstructure of trilobite carapace and spine is, therefore, has been considered as homogeneous prismatic (MAJEWSKE, 1969; HOROWITZ and POTTER, 1971). This microstructure is distinctive and makes it easy to distinguish trilobite from most other taxons. Also characteristic architectural shape of trilobite carapace readly led to its identification.

Trilobite microstructure examined by E.M. is characterized by densely packed very fine granular calcite unlikely with definite arrangement or orientation (Plate 28), thus appearing structureless. It should be noted, however, that the outermost (lower left portion) surface of the skeleton appears as a layer consisting of a little finer grain calcite (0.1-0.4 microns) granules than those of the other parts. This layer is about 2 microns thick as a whole. The other part of the skeleton consists of rather granular fine grain calcite of 1-3 microns diameter. Some of these calcite seem to be elongated and faintly oriented normal to the shell surface. It is not certainly known that indistinct feature of these calcite grains is either due to the original microstructure of the chitnous composition of the skeleton, which is heavely inpregnated with calcite and varying amount of calcium phosphate (VINOGRADOV, 1953; HARRINGTON, 1959) or to etching habitat of these grains. It is noted, as previously mentioned, that highly transparent primary layer of brachiopod shows, at some orientations, resembling very fine grained microstructure, though the latter is composing apparently prismatic structure. No prismatic submicrostructure suggested by MAJEWSKE (1969) is likely observed excusively on the trilobite carapace excepting very few elongate calcite grains, which possibly is appearing prismatic.

Mollusca: This taxon is seen rather rarely comparing to other taxa, in the studied limestones. Molluscan shell generally is finely fragmented, as most other taxa are, and therefore not only specific but generic identification could not be made. Actually, only the identification at the level of class or higher can be made, by skeletal architecture of fragmented shell, sometimes in thin sections.

Although skeletal microstructures, which are mostly multi-layered and no less than 8 types have been recognized (HOROWITZ and POTTER, 1971), are helpful to distinguish this taxon from other taxa. Most of the shell fragments in the studied limestones are recrystallized in various degrees and no microstructure can be seen generally. Fragments appeared as coarsely crystalline calcite in micritic or sparritic matrix are most commonly seen and those with ghost of relict structure are not uncommon. Molluscan shell showing detailed microstructure is very rarely seen in thin sections.

Although very rarely recrystallized shell fragments of this taxon can be identified certainly under E.M., by dirty appearance of crystalline surface or presence of abundant pseudoreplica on it. They can not be distinguished from sparry calcites generally. Only several molluscan fragments with finely preserved microstructure are observed by E.M. Though they show many different microstructure, one of them which are most frequently seen, is crossed lamellar structure and is shown as Plate 29, fig.1. Each lamellar is composed of 1 to 1.5 microns thick and infinite length fibers. Some fibers appeared on upper portion seem to be 4 to 6 microns long and thus appear as if prismatic. Each lamellar is crossed at nearly right angle each other. The thickness of each lamellar is variable but most commonly is 40-50 microns in this specimen, though imcompletely appeared on this E.M. photograph. Entire skeleton of the shell, although fragmented, consists of alternation of numerous lamellars crossed with nearly right angle, when cut tangential, to the direction of lamellars.

No discussion on molluscan shell microstructure can be made here, since limited numbers of presumably well preserved specimen has been observed. It is felt, during the E.M. observation, that molluscan shell generally is severaly recrystallized by which discriminating it from crystalline sparry calcite is hardly made. And also that the microstructure of the shell of this taxon is rather complicated and many types can be identified, when well preserved specimens were observed.

Ostracod: Ostracod carapace can easily be distinguished in thin sections by its small size, by overlap of valves and by fine prismatic structure which sometimes appears as homogeneous. Ostracod is contained in many limestones examined but the amount usually does not exceed a few percent of whole skeletal grains at most. Although no point counting has been conducted, it is felt during L.M. observation of thin sections that this taxon comprising less than a percent of skeletal material generally.

As seen under E.M., ostracod is rarely seen and is distinguished from other taxa by its thin wall thickness and by entire skeletal architecture, which sometimes small enough to be seen in a few fields of observation of E.M. The microstructure of this taxon generally seen is prismatic one as noted by HOROWITZ and POTTER (1971). This microstructure consists of prisms oriented normal to the wall. These prisms are streched to the entire thickness of the wall and are 1-3 microns wide and 10-20 microns long. Prisms of more than 20 microns long are not uncommon, depending on the thickness of the wall.

Another type of microstructure is rarely seen on ostracod carapace. This structure is granular one, which possibly is the above prismatic structure cut obliquely and thus appears as though granular. The specimen shown in Plate 29, fig.2, certainly is ostracod since the entire skeletal architecture is bivalved, and overlap of valves are obviously seen (center). The whole microstructure appears as rather granular, although some prismatic granules are seen (center to central left). Since no granular texture of ostracod has been recognized (HOROWITZ and POTTER 1971: MAJEWSKE, 1969), this structure possible is recrystallized homogeneous prismatic one recognized by MAJEWSKE (1969). The rest of this carapace is rather granular, therefore, it is also possible that some ostracod has granular texture although the above interpretations can not be denied. Although no discussion on the microstructure of ostracod is made, it is rather strongly felt this granular texture is not so uncommon than prismatic one.

Discussions on Fossils

As above described, numerous skeletal remains are observed in many of the limestones studied, both by L.M. and by E.M. Most of they are finely comminuted, excepting fusulinids and ostracods, as previously mentioned. This fragmentation, which makes taxonomic identification of these remains very difficult, may be attributed to the activity of scavenging organisms rather than to agitation by current and/or wave action. Since fossil fragments in the limestones with fine grain matrices, which are predominant, are angular and anabraded generally, while those in limestones with sparry matrices apparently are moderately to well rounded. These angular fragments are seemed not to be sorted, consisting of various size of fragments ranging from silt to corse sand size and larger, whereas rounded fragments are generally rather well sorted.

Furthermore, usually unabraded and unbroken fusulinids (Plate 26) and ostracods support the above interpretation of the fragmentation Since remains of these orgainisms are discarded tests and molted carapace rather than dead individuals, therefore, they would have been lacking fleshy residues, which would have attracted the scavenging organisms (PAYTON, 1966).

Even with the above fragmentation, these skeletal remains are revealed, by E.M. observations, amazingly well preserved. Especially brachiopod microstructures are so well preserved that many of they can not be distinguished from those of recent specimens (WILLIAMS, 1968, 1970; etc.) by their microstructures. Most of these shelly fossils are, excepting phylloid algae and some molluscan shells, not recrystallized. Whereas phylloid algae and some molluscan shell (Plate 29, fig.1) are generally recrystallized as coarse sparry calcite and those with ghost of the lamellar structures, respectively.

These skeletal remains are finely fragmented probably by the activity of the scavenging organisms as above discussed. Resulted fragments preserved and observed in these limestones are, however, seemed to have peculiar grain size distribution, although no measurement was made, that most of they are coarser than coarse silt size. Naturally skeletal remains in these limestones can have size range up to the whole shell, a few centimeters or more depending on the dimension of the taxa. While fragments finer than coarse silt size (30 microns) are very rare and exceptional.

Actually, fossil fragments of even a skeletal unit, which generally in less than a micron, are exactly identifiable by E.M., if present and preserved. Very few fragments composed of a few units or less are observed in the studied limestones. Fragments of coarser than coarse silt size are unnumerably observed by E.M. and by L.M., whereas those finer than this size are seen under E.M. very rarely. Interestingly enough, these small size fragments revealed under E.M. (Plate 8, fig.4 and Plate 10, fig.2) show rather poorer microstructures preserved than those of predominant and amazingly well preserved coarser fragments. They are, therefore, entirely impossible to be identified as certain taxon by their microstructures.

Two interpretations are possible for the above scarcity and poor preservation of small size fragments comparing to the coarser fragments. One is that fragmentation of skeletal remains by the activity of the scavenging organisms did not produce much of this size fragments. And even though some had been produced, they were recrystallized and no organic textures are recognized. Although it is possible, this interpretation seems highly unprobable. Since by any activity, distruction of skeletal material must yield rather prominent amount of lime mud than coarse fragments (KLEMENT and TOOMEY, 1967; FORCE, 1967; GINSBURG *et al.*, 1967). Also this interpretation seemed to fail to interpret the poorer preservation of these small size fragments comparing to that of larger fragments. The other interpretation is as follows: although dominant amount of finer fragments, of finer than coarse silt size or less, were produced by the activity of the scavenging organisms previously mentioned, but recrystallization eliminated micro-structures of these skeletal fragments.

The second interpretation seem to be more likely interprets the observed limestones. Since finer fragments have higher surface to volume ratio than the coarser one, thus causes high chemical reactivity, tends to recrystallize much easier than the coarser ones (BATHURST, 1971). This high reactivity more suitably interpret the poor preservation of these smaller fragments. Furthermore, this interpretation is supported by the fact that fossil fragments in the most studied limestones are mud supported, not contact each other, which means they were originally embedded in predominant amount of mud size constituent. The mud size constituent probably recrystallized to the fine grain matrix of limestones after burrial.

Nonskeletal Allochems

Nonskeletal allochems such as oolites, pellets and coated grains commonly present in many limestones examined. Although they are contained in the studied limestones as frequently as fossils, the amount of the former generally is quit lesser than that of the latter. Actually only few limestones contain nonskeletal allochem as a main constituent.

Pellets are contained as frequently as fossils, but few limestones can be correctly named as pelletal though several limestones are classified as pelmicrite or pelsparite (Appendix). Oolite is not so frequently contained as pellet is, but several oolitic limestones are recognized. When oolite predominates in a limestone, it sometimes exceeds 80 percent of the total allochems. Also it occupies more than 50 percent of the whole limestone, which no other allochem, even conbining all fossils, generally does attain. Coated grains are recognized in only two sample limestones. Although it superficially resembles to oolite, E.M. observation reveals different microstructures between them. These three nonskeletal allochems are briefly mentioned as a whole, since not so many observations on these grains have been made by E.M. as on the other allochemical grains.

Several limestones examined contain oolites as main allochem type. These limestones are predominantly with sparritic cement. Therefore observation of oolite by E.M. should be easily attained, since oolite appear with well preserved microstructure, which is highly contrasted with crystalline sparritic matrices as seen by L.M. Nonthless, observation of oolite by E.M. is made rather sporadically because of most oolites shows rather crystalline microstructure consisted with 5-10 microns calcite. While many sparritic calcites attain this size rather commonly. Sometimes discrimination between these two types of crystalline calcite is hardly made.

Very rarely oolite with extremely fine granular microstructure is seen under E.M. (Plate 30, fig.1). The specimen shown in this E.M. photograph reveals extremely distinct oolitic structure such as concentric and radial structure in yellowish to brownish calcite without appreciable granularity or crystallinity as seen in thin section. Therefore this specimen is likely preserving original microstructure, or at least is not severely altered.

From this E.M. photograph, it is apparently seen that this oolite is fringed by granular calcites of 5-10 microns diameter (upper center to lower right). Outside of these granular calcites is extremely large sparry calcite whose size exceeds 30 microns. Inside the oolite consists of extremely fine grain calcite of less than 0.5 microns diameter and is gradually increasing its size inwardly up to 2 microns. It is not well understood that the granular calcite with medium size is either component of oolite or sparry cement. However it is noted that one of the calcite grain (round one at lower right) of this size reveals distinct zonal growth lines, which is suggesting partial recrystallization or neomorphic alteration (FOLK, 1965).

Also noted is that fine granules consisting this oolite seem to be faintly oriented normal to the surface. The size difference between the outermost portion and inner portion may be reflecting the concentric structure of this oolite as seen in thin section.

Shown in fig. 2 of Plate 30 is a coated grain, which only this specimen has been observed by E.M. during this study. The specimen is coated around a crystalline calcite nucleus, as seen in thin section. The whole coating consists of alternation of 20-30 microns thick layer of fine grain calcite (lower left to upper center) and nearly same thickness layer of coarse calcite grains (upper left). Sparritic calcite seen outside the fine grained layer is sparry cement embedding void spaces between coated grains.

Calcite grains consisting fine grained layer appears gradually decreasing its size inward. While the coarse grain abruptly changes its size. Thus it is likely that the coating starts with precipitation of fine grain calcite on the nucleus, increasing its size gradually. Then may seizes precipitation abruptly. And sometime later repeat this type of precipitation onto the formerly formed layer. This process can be said as inverse of growth of voidifilling sparry calcite, which is decreasing its size opposing to the substratum. It should be noted, however that the former precipitation has no orientation of grains while the latter shows distinctive normally oriented crystals to the substratum. In the same coated grain several euhedral quartz, by which secondary origin is suggested, are observed. They are giving no disturbance to the microstructure of it. These quartz, therefore, may suggesting that the formation is as early diagenetic as formation of coating.

In thin section pellets appear as rounded objects of usually less than 40 microns diameter. The microstructure has been considered as extremely fine grained, which L.M. observation generally fails to reveal it. As seen under E.M. pellet appears as rather irregular shape and as aggregate of less than 0.2 microns diameter granules (Plate 30, figs.3 and 4).

Interesting thing being revealed is that small amount of pelletal materials are imbedded between sparry calcite (upper left of fig.2). Also they are sometimes scattered around the large pellet (center left, upper right and right lower-right of fig.4). Furthermore, the pellet shown in fig.3 seems to have supposed nucleus of about 1 micron diameter crystalline calcite.

Many other pellets have been observed during this study, most of they appeared as being scattered as 20-50 microns diameter aggregates consisting of extremely fine grain calcites, though with definite shape is rarely seen. Some pellets are composed with a little coarser grain than those shown.

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(Manuscript received on April 1, 1974)

PLATES 1 ~ 30 AND EXPLANATION

Explanation of Plate 1

(Most plates are E. M. photographs of same magnification, thus scale-bar at the lower right corner represents 5 microns for all figures of the plate, otherwise indicated)

Fig. 1: Representative lime mud consists exclusively of anhedral calcite crystals. All grain boundaries are deeply etched and forming grooves, which throw shadows behind them. Some crystals are smoothly etched while others show rough surfaces, especially those of fine size ones. Note crystal size ranges widely, less than 0.2 microns to nearly 10 microns. Also all grain boundaries are irregular and somewhat zig-zag shaped.
Sample: P-208, middle of Block Ls.

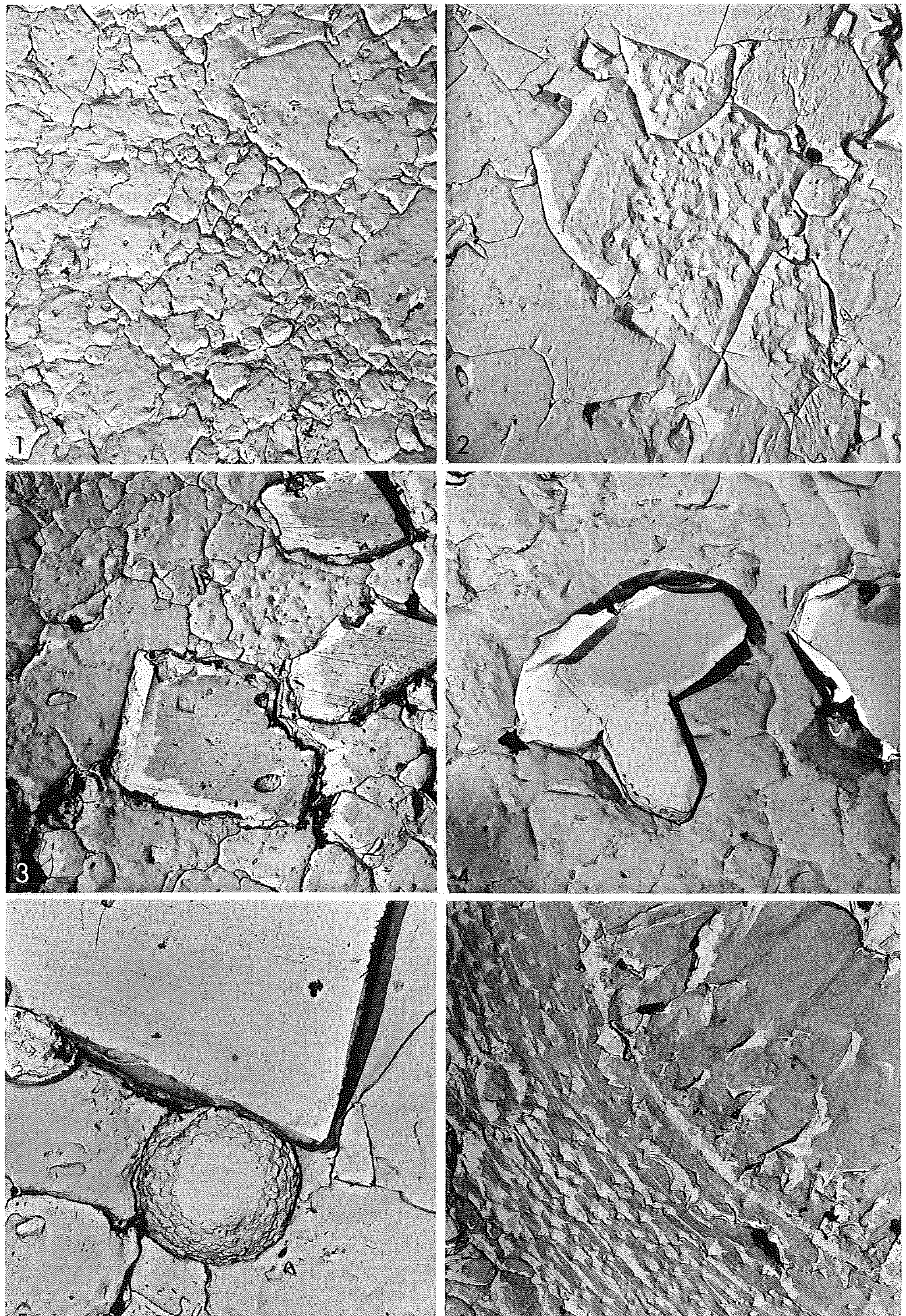
Fig. 2: Sparry calcite cement impregnating the space between allochemical grains. Deeply etched grain boundaries throw shadows behind them, as those of fig.1. Both smoothly and roughly etched surfaces exist, while the former show fine wrinkles. Note the differences of grain boundaries and size of this figure and those of fig.1.
Sample: P-234, 2.4 m above base of Argentine Ls.

Fig. 3: Euhedral dolomites scattered in lime mud matrix. Scratches on the surface and long shadow are characteristic. Note the serrated grain boundaries of the calcite of the matrix.
Sample: P-210, 1.0 m above base of Winterset Ls.

Fig. 4: Euhedral quartz grown in a matrix of rather coarse lime mud. Smooth surface and euhedral shape of the quartz are prominent.
Sample: P-186, base of Bethany Falls Ls.

Fig. 5: Spheric pyrite aggregate, part of euhedral dolomite and sparry calcite. Hexagonal shape of pyrite crystals and euhedral shape and scratches of dolomite are distinctive.
Sample: P-63, 1.5 m above base of Beil Ls.

Fig. 6: Skeletal calcite (upper left to lower right) and sparry calcite cement precipitated in the void space of the skeleton (upper right).
This skeletal texture probably is productid spine cut nearly transversely. Note fine microstructure of the spine, difference of shape, size, and grain boundaries of lime mud (lower left corner) and sparry cement.
Sample: P-137, 0.6 m above base of Brownville Ls.



Explanation of Plate 2

Fig. 1: A typical lime mud microstructure. Note the difference of the amount of inclusions appeared on various size grains and zig-zag grain boundaries.
Sample: P-255, 0.1 m above base of Captain Creek Ls.

Fig. 2: Another representative lime mud microstructure. Aggregate of very fine grain calcites at central portion of the figure possively is a pellet. Note difference of grain boundary patterns of fine and coarse grains.
Sample: P-214, 0.6 m above base of Drum Ls.

Fig. 3: Representative of somehow coarsely grained lime mud. Note some calcite grains have rather curve-linear boundaries. Also some grains reveal cleaved surfaces. Prominent mineral grain (center upper right) probably is an euhedral quartz.
Sample: P-216, 2.2 m above base of Drum Ls.

Fig. 7. Drawing to accompany Plate 2 showing grain boundaries of the matrices of the limestones. Minerals other than calcite are stippled and pseudo-replicas are diagonally ruled.

Fig. 7

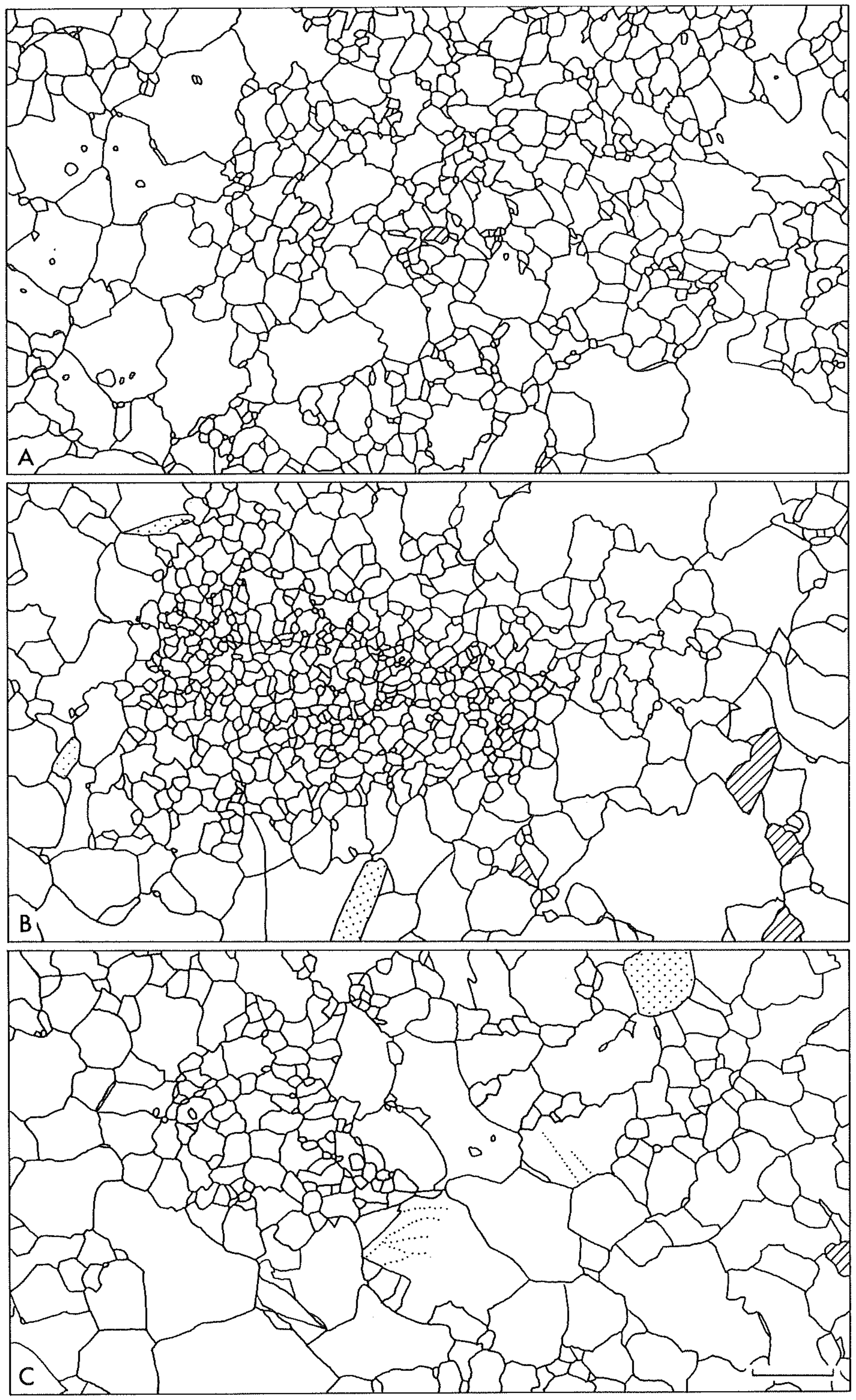
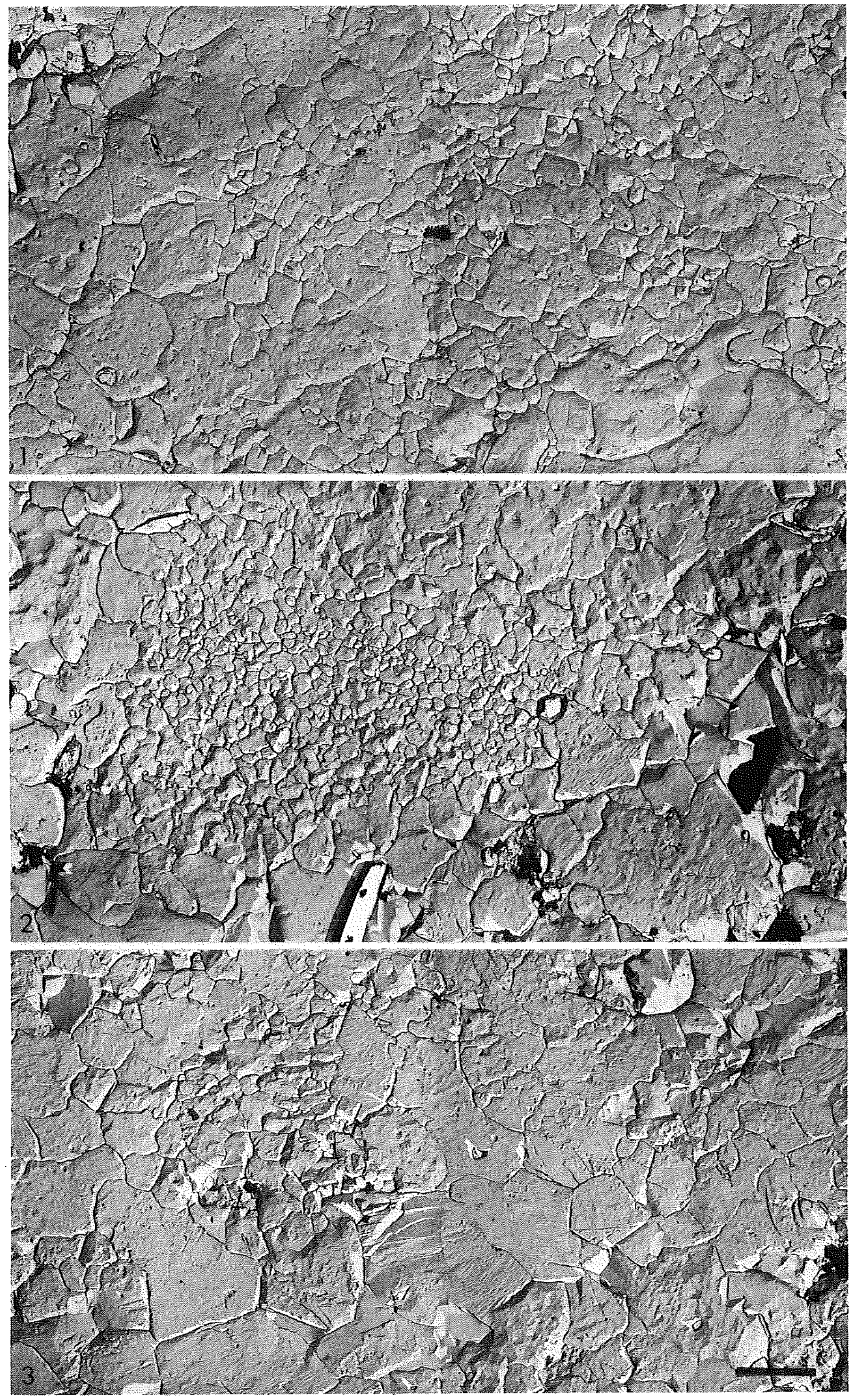


Plate 2



Explanation of Plate 3

Fig. 1: Representative lime mud microstructure with somehow obliterated grain boundary and with almost no inclusion on the etched surface. Brightly appeared minerals impregnating between calcite crystals probably are silica cement.
Sample: P-89, middle part of Curzon Ls.

Fig. 2: Another representative lime mud microstructure with more obliterated grain boundaries and with roughly etched surfaces of calcites.
Sample: P-87, 0.6 m above base of Avoca Ls.

Fig. 3: Lime mud microstructure with clear grain boundaries as shown in Plate 2, but with much more inclusions on the etched surface. Note prominent grains at upper left and lower right, both of which may be detrital quartz grains.
Sample: P-219, 0.5 m above base of Paola Ls.

Fig. 8. Drawing to accompány Plate 3 showing grain boundaries of the matrices of the limestones. Minerals other than calcite are stippled and pseudo-replicas are diagonally ruled.

Fig. 8

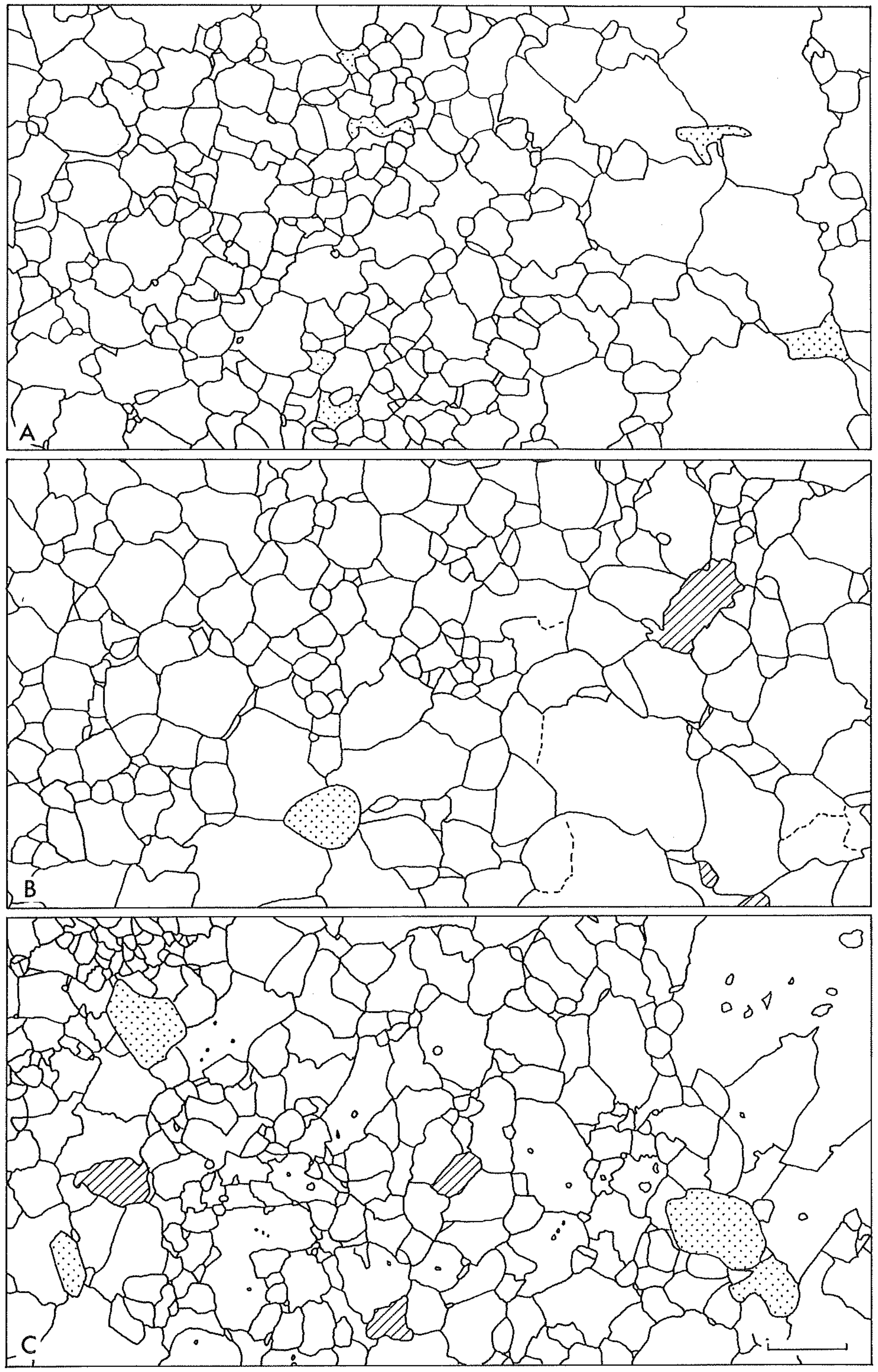


Plate 3

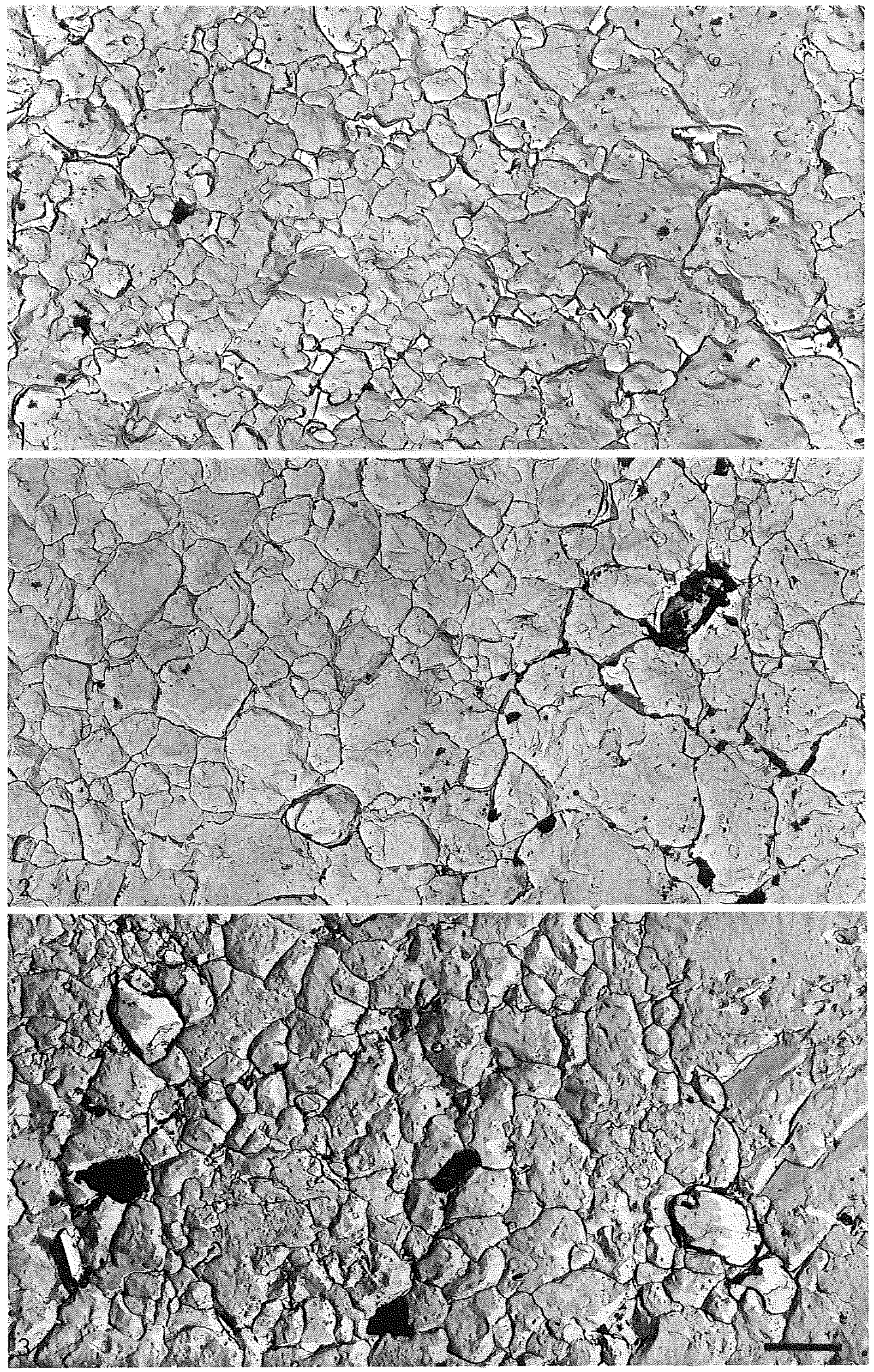


Fig. 9. Drawing to accompany Plate 4 representing grain boundaries of the matrices of the limestones consisting the Iola Megacyclothem. Minerals other than calcite are stippled and pseudo-replicas are diagonally ruled.

Explanation of Plate 4

Fig. 1: Lime mud of the upper limestone of the Iola Megacyclothem. Elongated grain at lower center probably is a skeletal grain, which is so severely altered that the taxon can not be surely known.
Sample: P-223, 1.5 m above base (top) of Raytown Ls.

Fig. 2: Somehow coarsely grained lime mud of the upper limestone of the Iola Megacyclothem. Note difference of grain sizes of calcites at upper left corner and the remaining parts.
Sample: Same as fig.1.

Fig. 3: Somehow finely appearing lime mud of the upper limestone of the Iola Megacyclothem. Zig-zag grain boundaries are characteristic.
Sample: P-222, 0.8 m above base of Raytown Ls.

Fig. 4: Coarsely grained lime mud microstructure of the upper limestone of the Iola Megacyclothem. Prominent large grain at lower left probably is a secondary quartz. Note highly serrated grain boundaries of the lime mud.
Sample: Same as fig.3.

Fig. 5: Very fine grain lime mud of the middle limestone of the Iola Megacyclothem. Zig-zag or serrated grain boundaries and a calcite crystal appearing as "birds eye" (center left) are prominent.
Sample: P-218 base of Paola Ls.

Fig. 6: Same as fig.5, but slightly coarsely appears. Abundant fine wrinkles on the surfaces are prominent.
Sample: Same as fig.5.

Fig. 9

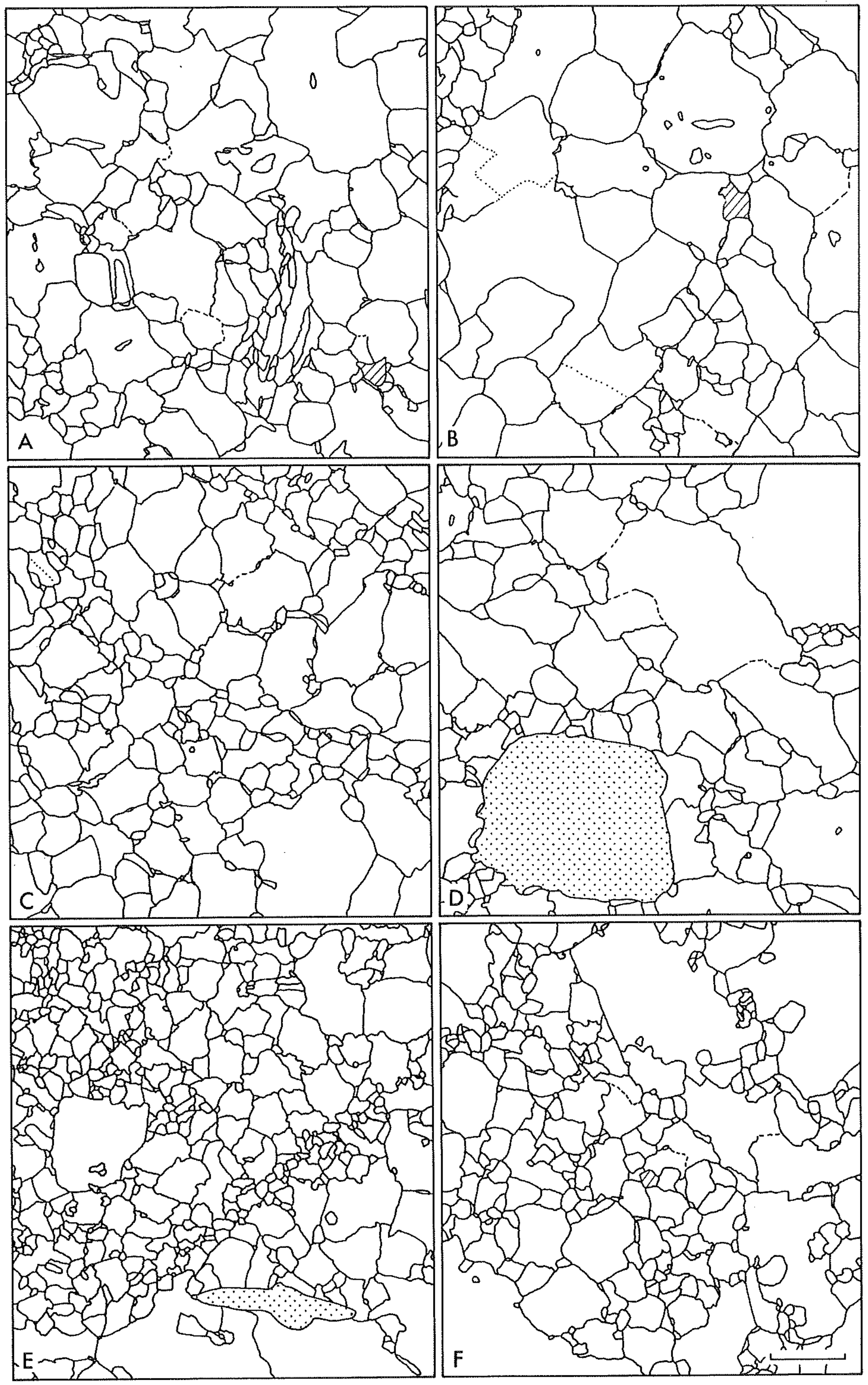
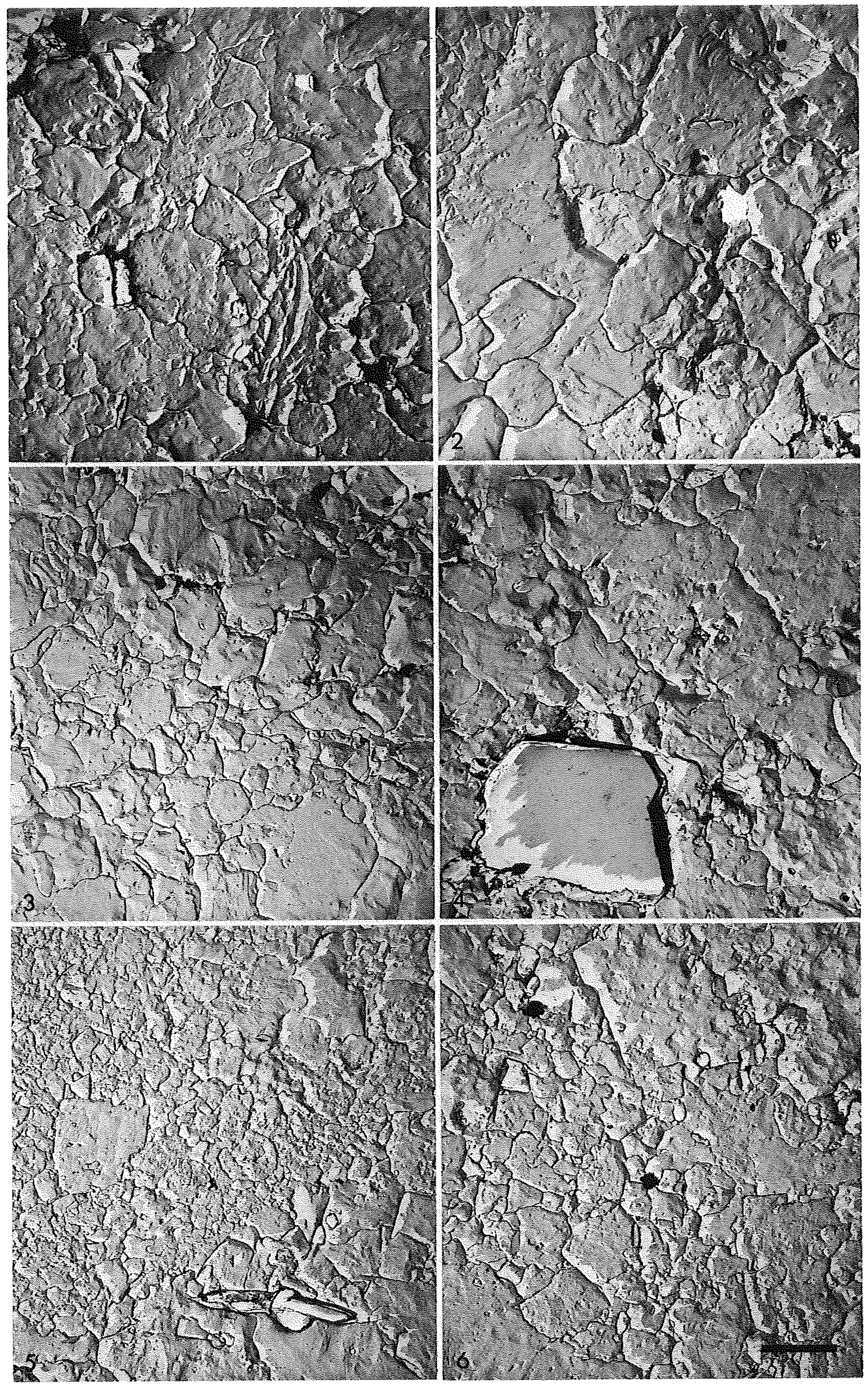


Plate 4



Explanation of Plate 5

Fig. 1: Lime mud matrix of the upper limestone of the Plattsburg Megacyclothem. This microstructure appears somewhat crystalline and rather coarsely grained as a whole. Some calcite crystals show apparent twin lamellae (lower left center and center left) on the surfaces. Curve-linear grain boundaries are also prominent. Large crystal at lower center is a secondary dolomite.
Sample: P-253, 1.4 m above base of Spring Hill Ls.

Fig. 2: Another lime mud matrix of the upper limestone of the Plattsburg Megacyclothem. Coarse crystalline appearing calcites (upper left corner) abruptly change to fine ones (remaining parts).
Sample: Same as fig.1.

Fig. 3: Coarsely appearing lime mud of the upper limestone of the Plattsburg Megacyclothem. Silica cement (upper left) and a prominent dolomite (left lower center) are distinct.
Sample: P-250, 0.3 m above base of Spring Hill Ls.

Fig. 4: Same as fig.3 with dolomite crystals and obliterated skeletal material (center) of unknown taxon. Note characteristically curve-linear grain boundaries of lime mud.
Sample: Same as fig.3.

Fig. 5: Lime mud of the middle limestone of the Plattsburg Megacyclothem. Several dolomite grains (upper left and lower center) are seen. Note mostly serrated grain boundaries. Also all calcite crystals are roughly etched. Tiny hexagonal shape mineral at center may be cross cut section of an euhedral quartz.
Sample: P-247, 0.6 m above base of Merriam Ls.

Fig. 6: Fine grain lime mud of the middle limestone of the Plattsburg Megacyclothem. Extremely large dolomite (left) is prominent. Etched surfaces of the calcite crystals of the lime mud are as rough as those of fig.5.
Sample: Same as fig.5.

Fig. 10. Drawing to accompany Plate 5 representing grain boundaries of the matrices of the limestones consisting the Plattsburg Megacyclothem. Minerals other than calcite are stippled and pseudo-replicas are diagonally ruled.

Fig. 10

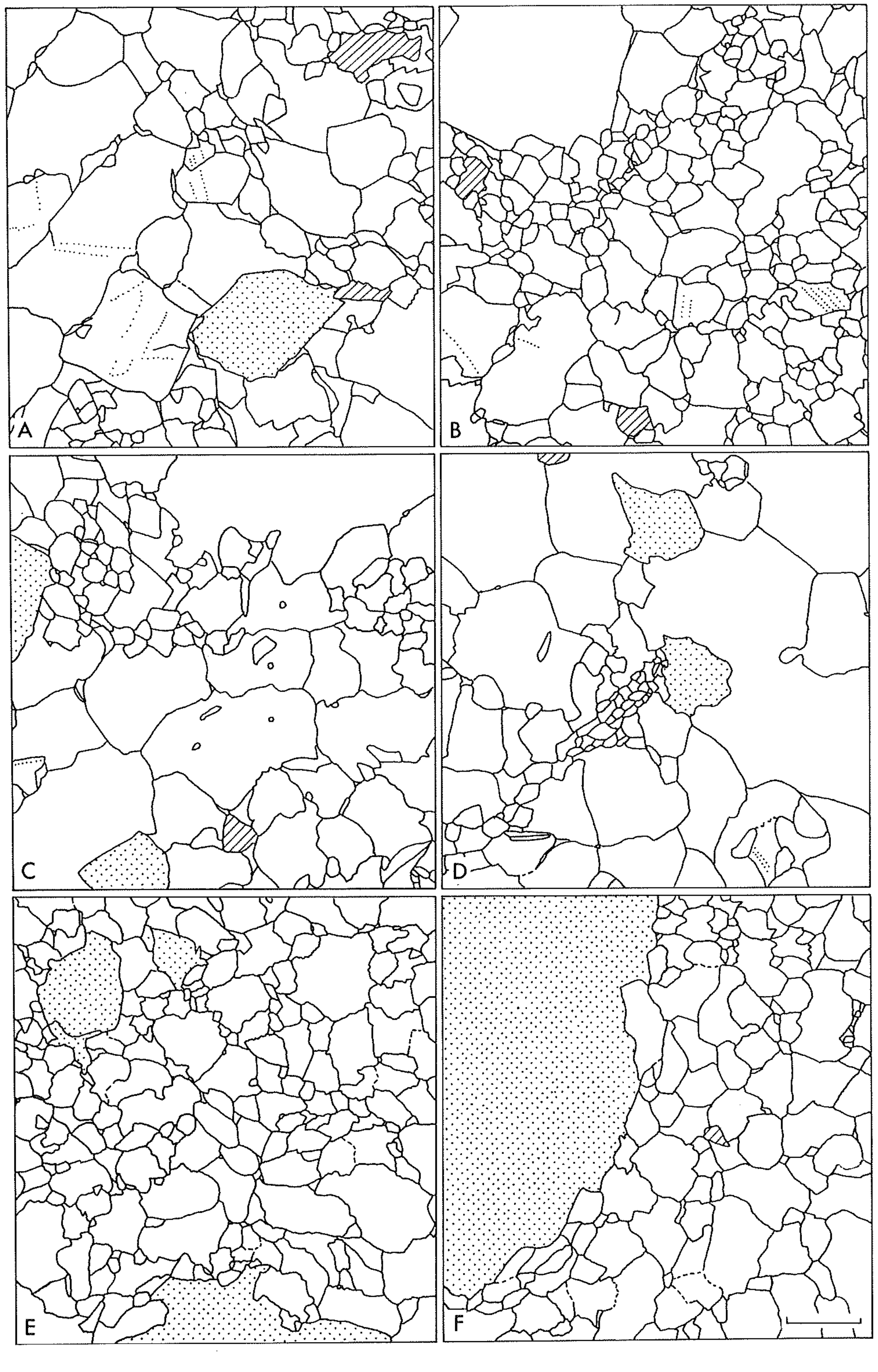
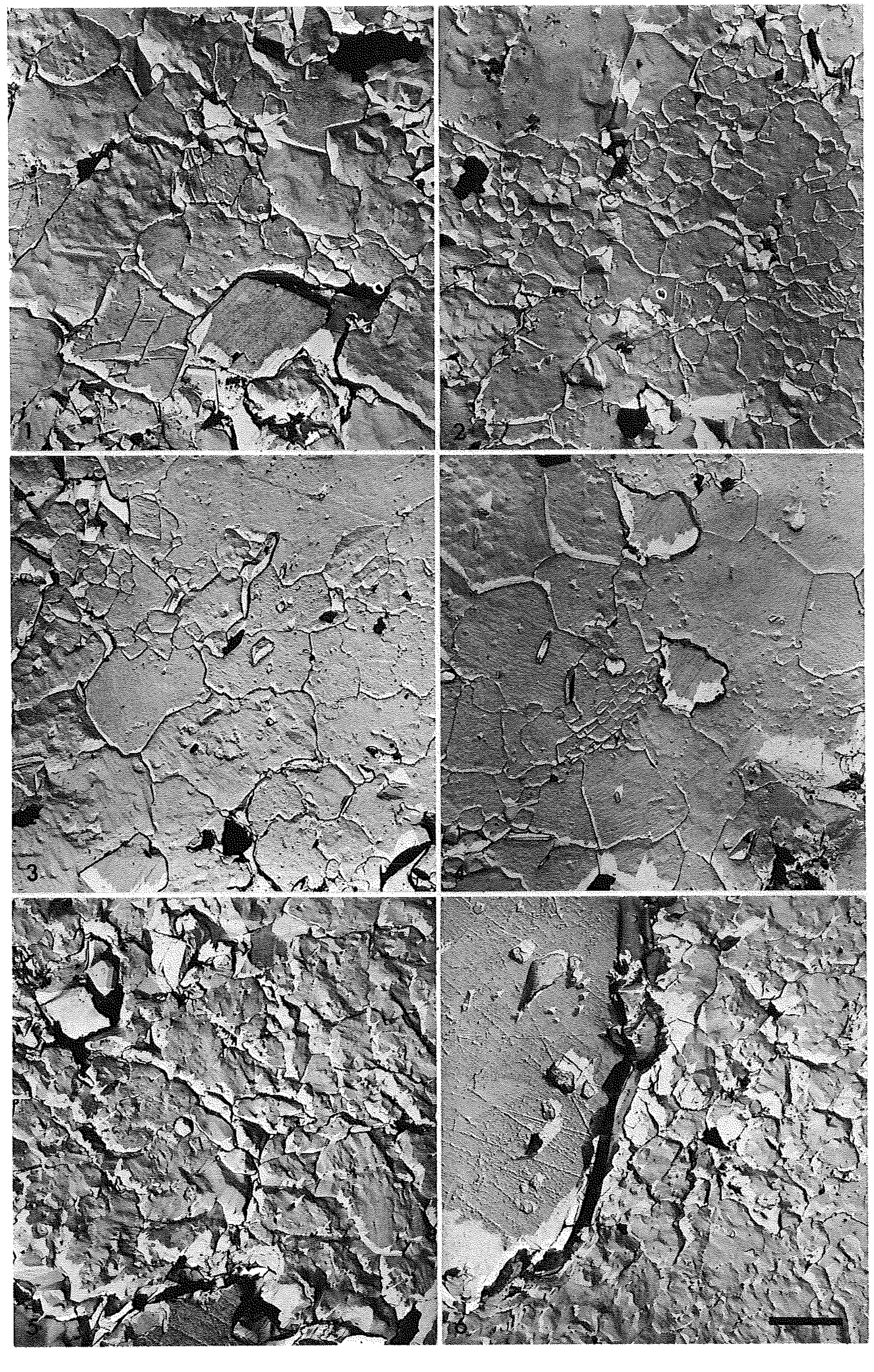


Plate 5



Explanation of Plate 6

Fig. 1: Lime mud microstructures of the super limestone of the Stanton Megacyclothem. Extremely serrated grain boundaries and greately different size of calcites are distinctive. Also abundance of inclusions on the calcite surfaces is characteristic.
Sample: P-265, 0.8 m above base of South Bend Ls.

Fig. 2: Medium to coarse grain lime mud of the upper limestone of the Stanton Megacyclothem. Serrated and straight grain boundaries of medium and coarse grains, resprectively are obvious. Whitish part at center probably is silica cement.
Sample: P-261, 1.2 m above base of Stoner Ls.

Fig. 3: Coarse grain lime mud of the upper limestone of the Stanton Megacyclothem. Mostly serrated grain boundaries of calcite is prominent.
Sample: Same as fig.2.

Fig. 4: Lime mud matrix of the middle limestone of the Stanton Megacyclothem. Homogeneously appearing microstructure is characteristic. Prominent mineral at just below center is euhedral quartz and that at above center probably is a detrital grain of unknown mineral.
Sample: P-257, 0.7 m above base of Captain Creek Ls.

Fig. 5: As same as fig.4. Highly zig-zag grain boundaries, especially at lower right portion is apparent.
Sample: Same as fig.4.

Fig. 11. Drawing to accompany Plate 6 representing grain boundaries of the matrices of the limestones consisting the Stanton Megacyclothem. Minerals other than calcite are stippled and pseudo-replicas are diagonally ruled.

Fig. 11

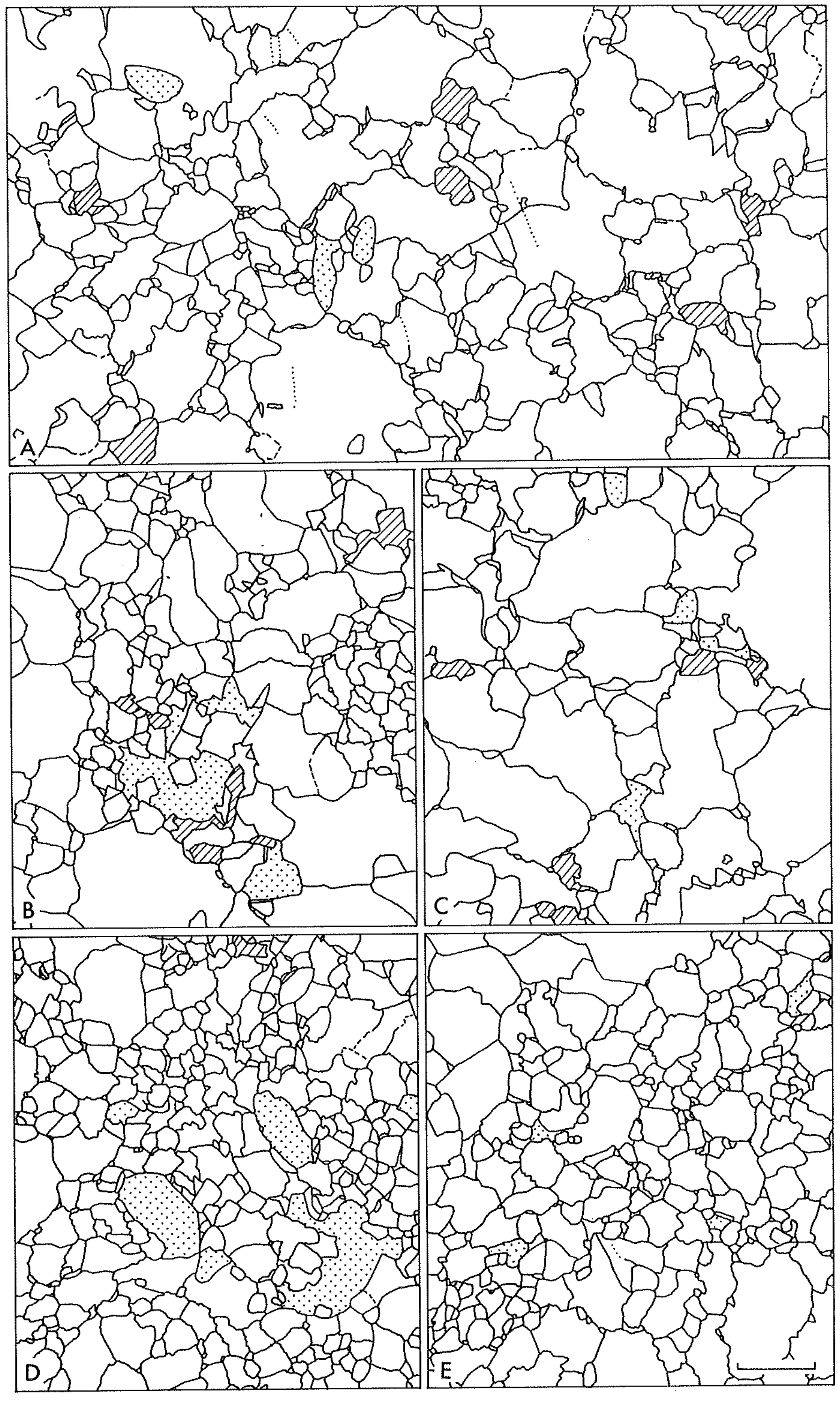
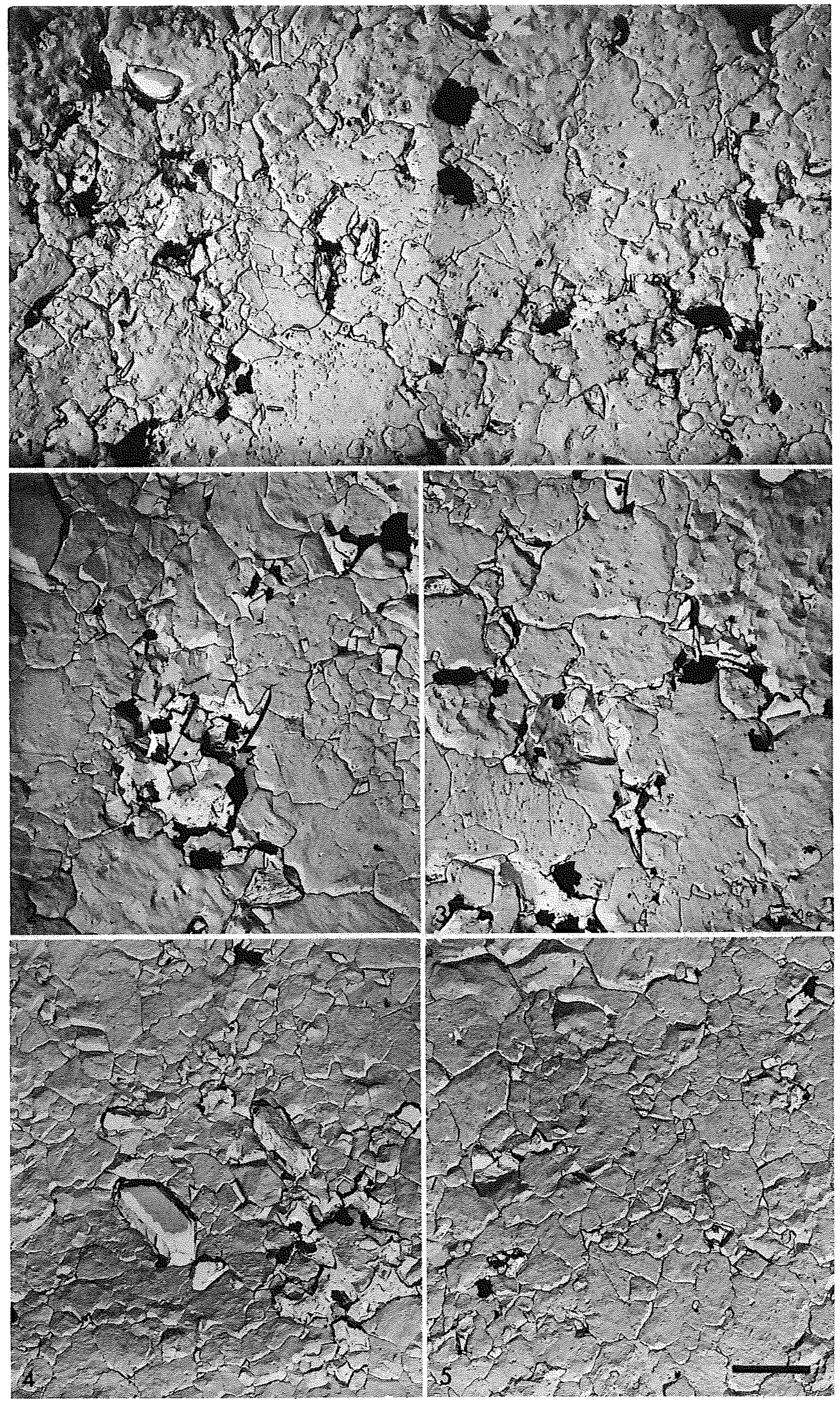


Plate 6



Explanation of Plate 7

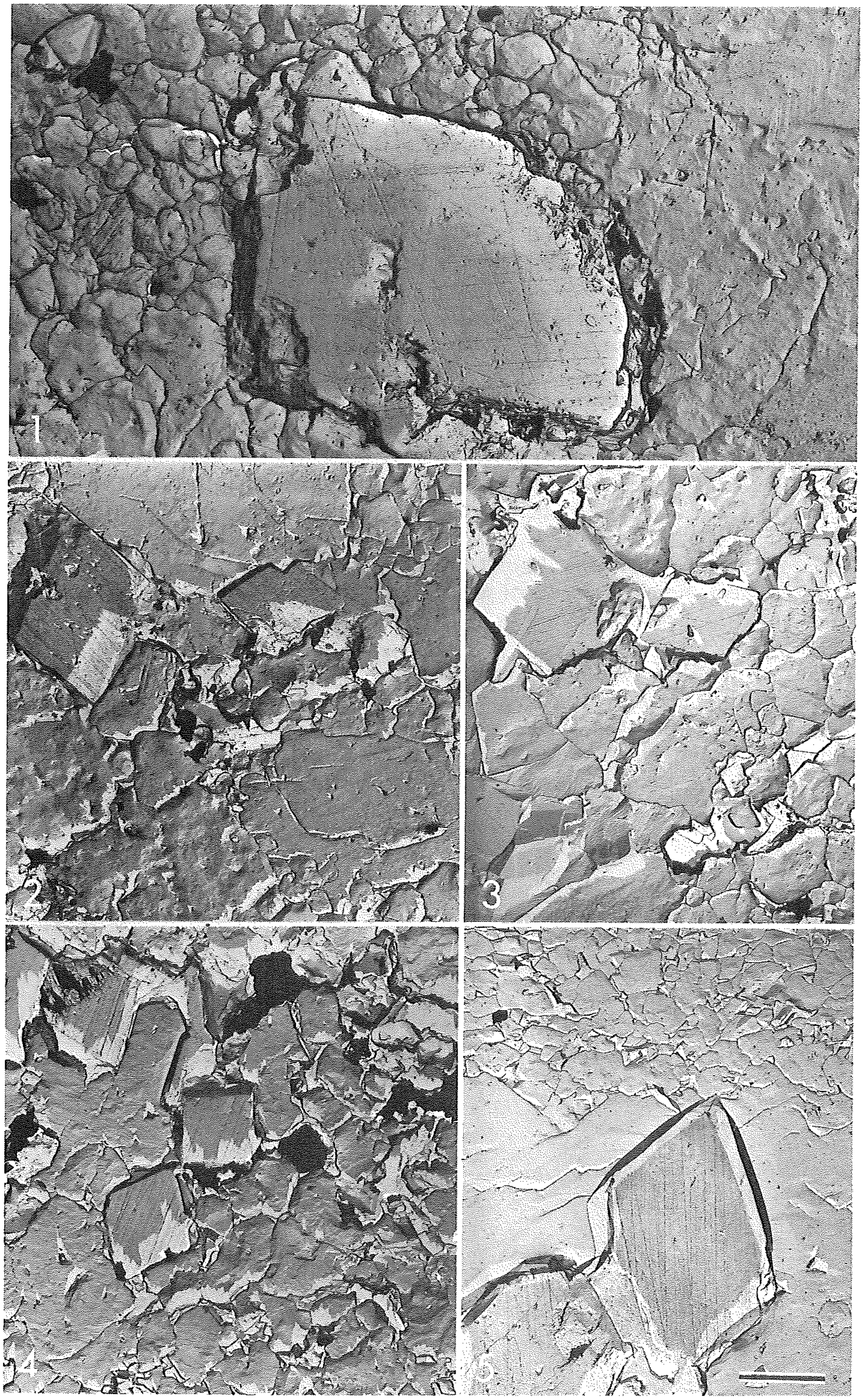
Fig. 1: A large euhedral dolomite crystal embedded in between lime mud (left) and spar (right). Note apparent growth lines (upper right corner) and extremely serrated grain boundaries (lower right) of the sparry calcite cement.
Sample: P-53, 0.3 m above base of Leavenworth Ls.

Fig. 2: Euhedral dolomite crystals scattered in sparry calcite grain (lower right) shows rhomboidal shape, which possibly is calcitized dolomite.
Sample: P-253, 1.4 m above base of Spring Hill Ls.

Fig. 3: Euhedral dolomites with silica cement impregnating into and between the dolomite (upper left). Some calcites show zig-zag boundaries while others are rather curve-linear.
Sample: P-249, 0.9 m above base (top) of Merriam Ls.

Fig. 4: Dolomite crystals scattered in the lime mud, with which silica cement impregnates. Some calcite of the lime mud appears as somehow euhedral, by which suggesting secondary growth into the original void space, in which later cementation by silica filled (upper center left).
Sample: P-251, 1.0 m above base of Spring Hill Ls.

Fig. 5: Large euhedral dolomite crystals embedded in sparry calcite. The center one cuts tangentially thus appears having very sharp corner angle. Transition from sparry calcite (lower portion) to micrite (upper portion) is rather abrupt.
Sample: P-259, 0.05 m above base of Stoner Ls.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Explanation of Plate 8

Fig. 1: A dolomite partially replaced by silica cement. The rhomboidal shape of original dolomite appears as roughly same shape of silica. Note difference of the surface of silica and dolomite.
Sample: P-235, 2.8 m above base (top) of Argentine Ls.

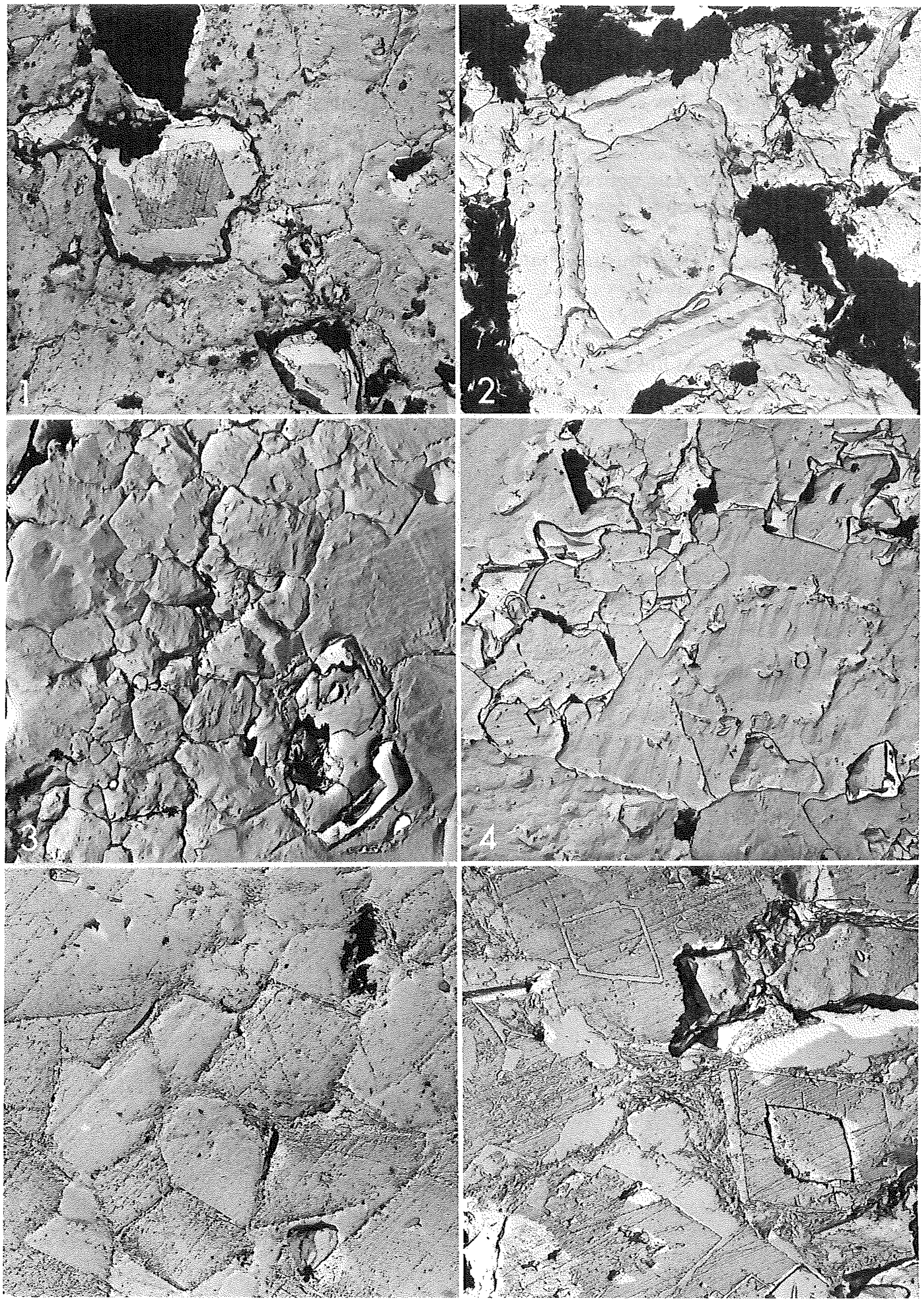
Fig. 2: A completely calcitized dolomite. Rhomboidal shape of original dolomite is seen as growth line of the calcite.
Sample: P-179, base of Sniabar Ls.

Fig. 3: Partially calcitized dolomite in micritic matrix. Relict of dolomite indicates original rhomboidal shape, but calcite grains migrate to the matrix and show no original shape.
Sample: P-51, 1.2 m above base of Toronto Ls.

Fig. 4: As same as fig.1, but growth pattern shows some relict of dolomites or inclusions. Whitish parts between apparent calcite grains probably is silica cement.
Sample: P-261, 0.8 m above base of Stoner Ls.

Fig. 5: A representative dolostone. Rhomboidal shape dolomites are embedded in probably silica cement. Note differences of scratches on silica and those on dolomite.
Sample: P-73, base of Hartford Ls.

Fig. 6: Another dolostone with small amount of calcite (upper right). Cementing material impregnating between dolomites consists of hairly appeared clay minerals and smoothly surfaced silica or silicate minerals. Also some silica cement is impregnating along the growth line of rhomboidal dolomite.
Sample: P-212, 1.8 m above base (top) of Westerville Ls.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Explanation of Plate 9

Fig. 1: An euhedral dolomite intrudes into a skeletal grain of probably fibrous layer of brachiopod shell. Note roughly surfaced sparry cement surrounding the shell.
Sample: P-64, 3.0 m above base (top) of Beil Ls.

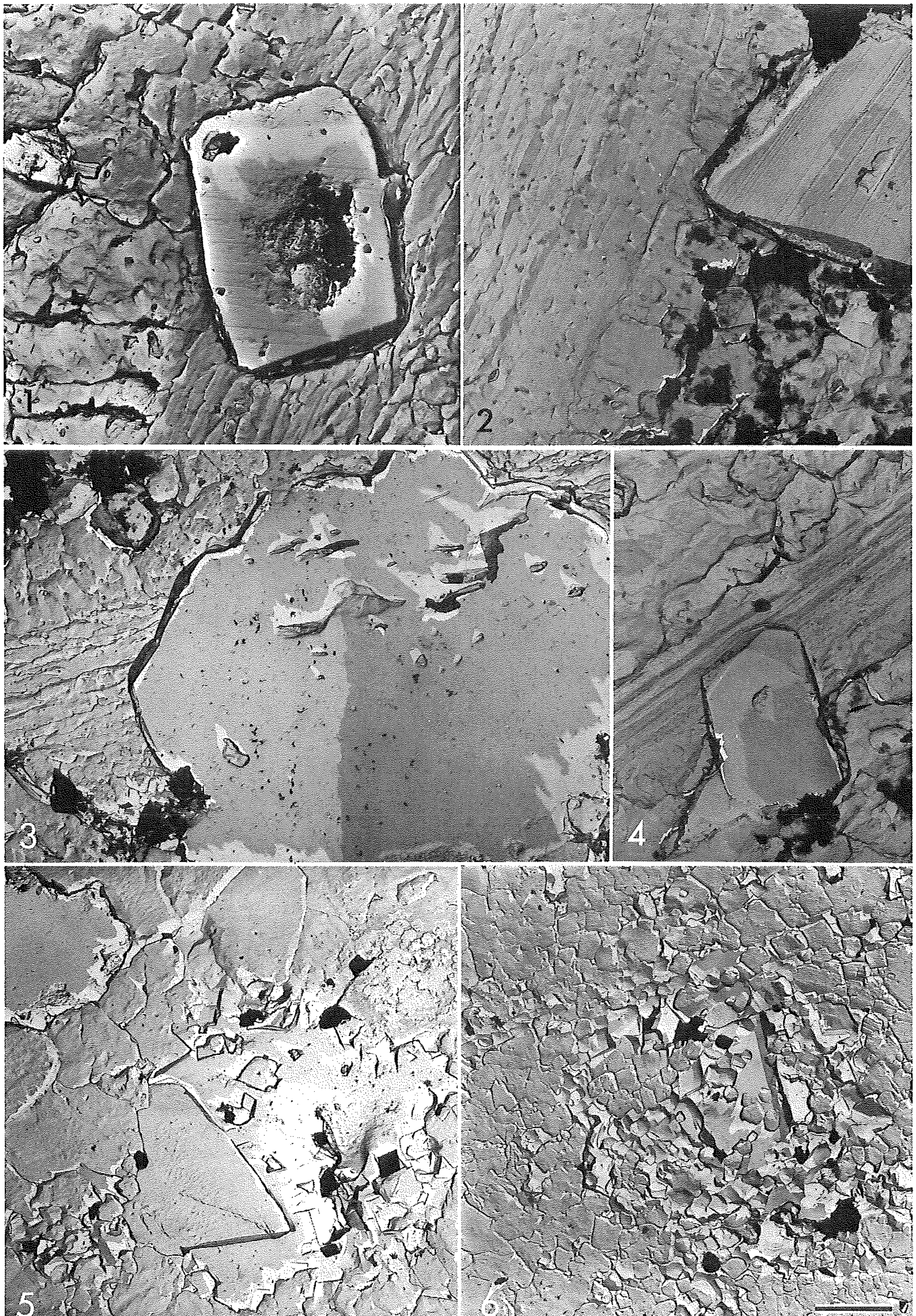
Fig. 2: Another euhedral dolomite intrudes into probably a brachiopod shell, but with somehow coarse lime mud matrix.
Sample: P-129, top of Ervine Creek Ls.

Fig. 3: An euhedral quartz intrudes into a skeletal grain of unknown taxon. Note large inclusions in the quartz.
Sample: P-213, base of Drum Ls.

Fig. 4: A skeletal grain of unknown taxon intruded by probably euhedral quartz.
Sample: P-129, top of Ervine Creek Ls.

Fig. 5: Silica cement apparently filling original void space between calcites. Note euhedral shape of calcite, which strongly indicating secondary growth into an original void space.
Sample: P-260, 0.8 m above base of Stoner Ls.

Fig. 6: Silica cement and loosely packed fine grain calcite. Many calcite crystals with more or less euhedral shape is suggesting secondary growth in void space, by which silica cement filled. Note some highly serrated grain boundaries of calcites (lower left).
Sample: P-253, 1.4 m above base of Spring Hill Ls.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Explanation of Plate 10

Fig. 1: Euhedral quartz grains scattered in the transitional portion of sparry calcite and lime mud. Sutured pattern of quartz grain at left is apparent.
Sample: P-182, 1.5 m above base (top) of Sniabar Ls.

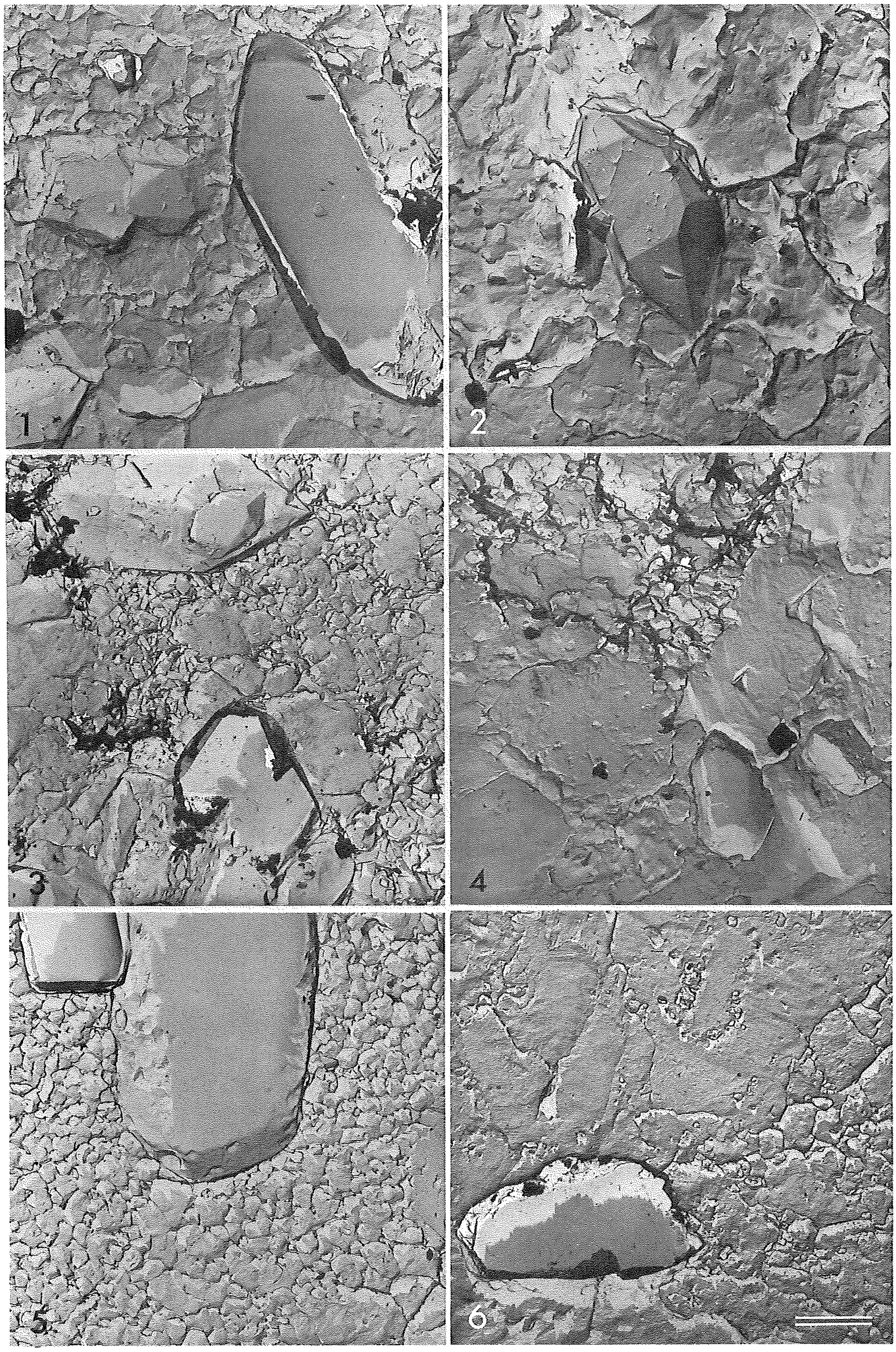
Fig. 2: An euhedral quartz, which is both terminated, grown in a rather coarse lime mud matrix. Note the sutured nature of the crystal as fig.1. Also roughly etched surface and abundant inclusions of the lime mud matrix of somewhat coarsely appearing.

Fig. 3: Euhedral quartz grains grown in a lime mud matrix composed of mixture of very fine and coarse calcite grains.
Sample: P-176, 0.5 m above base (top) of Critzer Ls.
Sample: P-132, 0.1 m above base of Plattsmouth Ls.

Fig. 4: Another euhedral quartz grown in coarse lime mud matrix. This quartz, as that of fig.2, is both terminated and has sutures on it. Note the great size difference of calcite grains at lower left to upper right and those of upper center.
Sample: P-207, 7.5 m above base (top) of Winterset Ls.

Fig. 5: Presumably a detrital quartz embedded in uniform size very fine grain lime mud matrix. Note depressed patterns on left side of quarts grain at upper center.
Sample: P-182, 1.5 m above base (top) of Sniabar Ls.

Fig. 6: Another presumable detrital quartz embedded in rather coarse grain matrix of sparry calcite. Note serrated grain boundaries of these calcite grains.
Sample: P-218, base of Paola Ls.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Explanation of Plate 11

Fig. 1: A limestone matrix representing grain boundary of lime mud and sparry cement. Note abrupt change of grain size from the former to the latter. Also difference of the grain boundary patterns.
Sample: P-190, 2.8 m above base of Bethany Falls Ls.

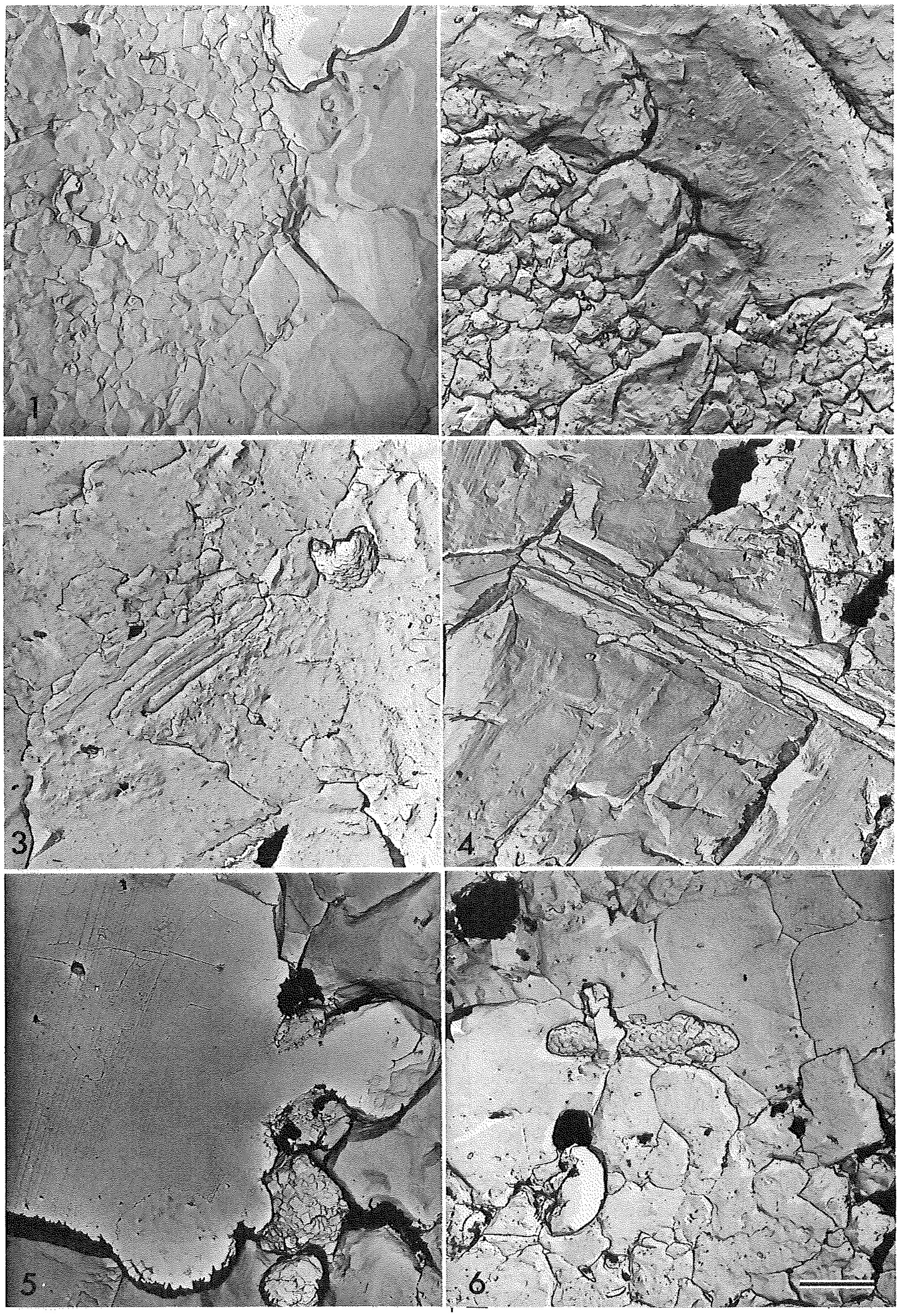
Fig. 2: As same as fig. 1, but both types of grain show rather rough surface. Probable growth patterns of a sparry calcite are obviously seen (upper right).
Sample: P-84, 0.4 m above base of Kereford Ls.

Fig. 3: Saprry calcites which show rather serrated grain boundaries. Rounded grain at near upper right corner is pyrite aggregate. The central fine grain part is skeletal material of unknown taxon. Note highly obliterated skeletal microstructure.
Sample: P-80, 2.0 m above base of Plattsmouth Ls.

Fig. 4: Sparry cement grown on skeletal grain of unknown taxon. The normal arrangement of spars to the skeleton is obvious. Also the obliterated microstructure of the latter is characteristic.
Sample: P-138, 1.2 m above base (top) of Brownville Ls.

Fig. 5: Large dolomite crystal and spheric pyrite aggregates in a sparry matrix. Note difference of surface smoothness of the dolomite and pyrite aggregate. Also the latter apparently replaced the former mineral.
Sample: P-63, 1.5 m above base of Beil Ls.

Fig. 6: A pyrite aggregate and quartz grains in a rather coarse lime mud matrix. Secondary origin of the former two minerals is apparent. Also apparently a quartz grain (upper left) cuts the pyrite aggregate.
Sample: P-247, 2.5 m above base of Farley Ls.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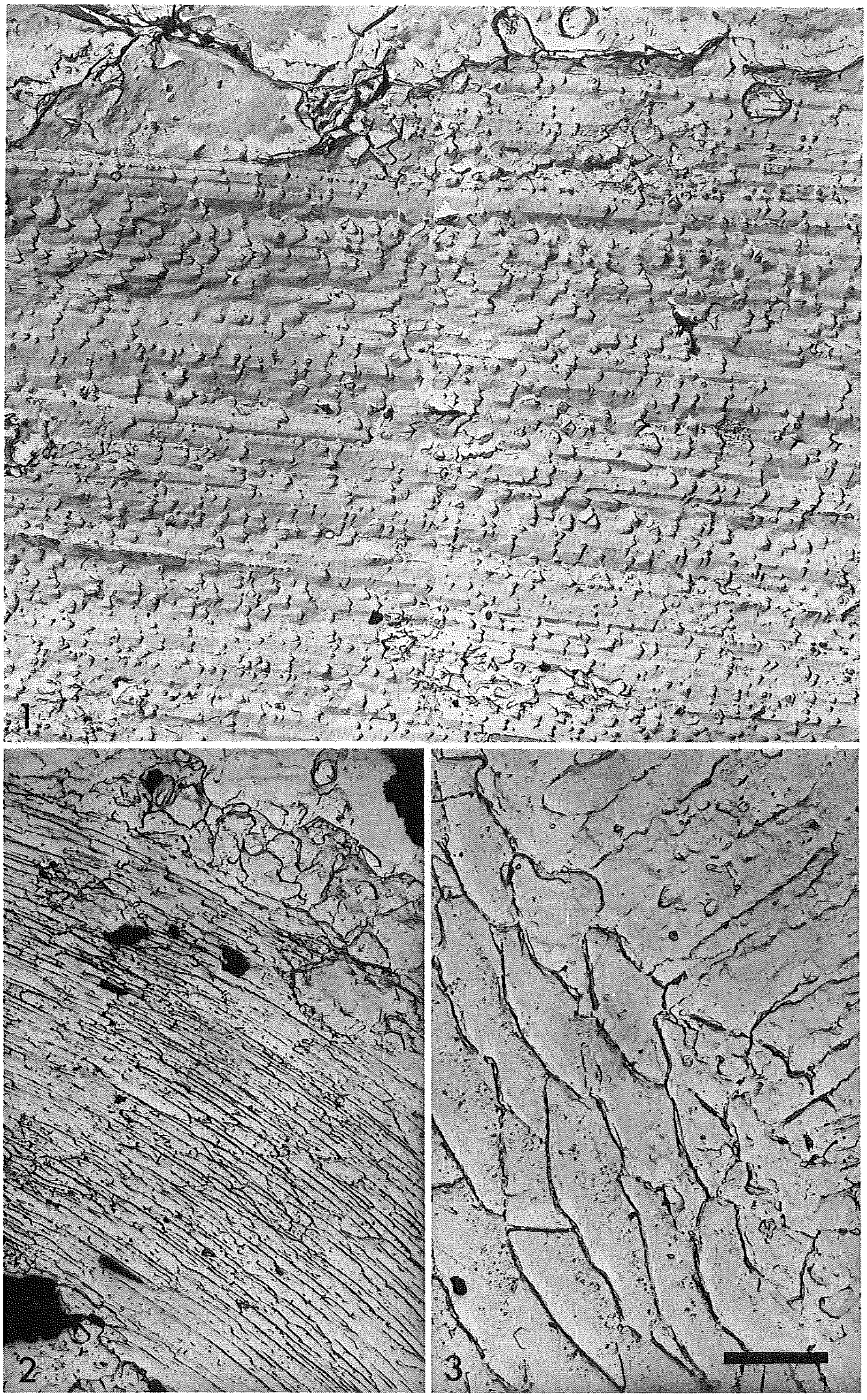
Explanation of Plate 12

Fig. 1: Longitudinal section of an impunctate brachiopod secondary layer. Individual fibrous prisms are very thin, less than 0.2 microns, and infinitely long.
Sample: P-90, Church Ls.

Fig. 2: Nearly longitudinal section of primary and secondary layers of an impunctate brachiopod shell. The prisms of the primary layer appears as granular. The secondary layer consists of hairly thin prisms almost parallel to the shell surface.
Sample: P-123, middle of Jim Creek Ls.

Fig. 3: Transverse section of an impunctate brachiopod shell revealing both primary and secondary layers. The latter consists of pseudorhomboidal calcite of 2-3 microns thick and 5-10 microns wide. The primary layer also consists of prisms of 2-3 microns wide and more than 15 microns long, probably normal to the shell surface. Note numerous tiny inclusions on the right hand side of each prism of the secondary layer.
Sample: P-93, 0.2 m above base of Wakaruusa Ls.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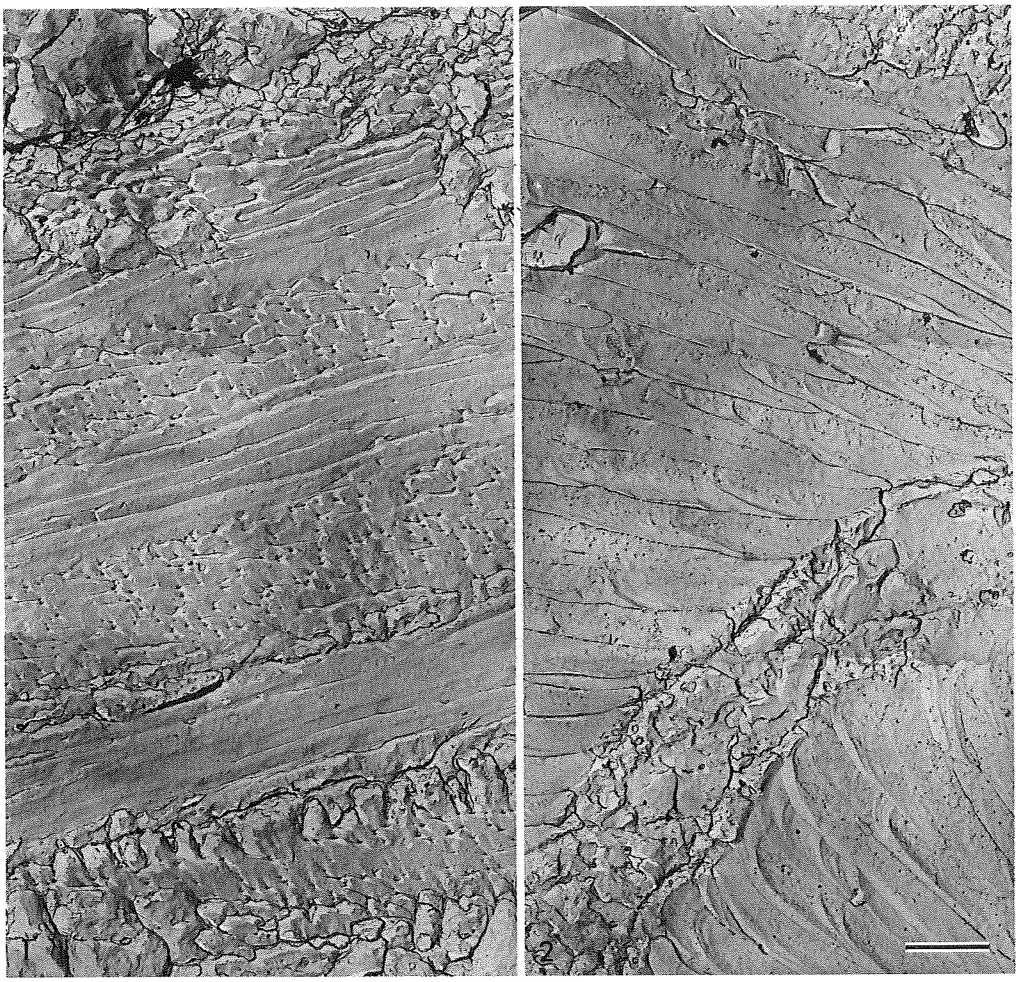
Explanation of Plate 13

Fig. 1: Laminated structure of an impunctate branchiopod shell as seen in almost longitudinal section. The primary layer (uppermost portion) appears as being composed of granular calcite. The secondary layer consists of parallel stucking of 4-7 microns thick fibrous prismatic layers.
Sample: P-94, 0.4 m above base of Wakaruusa Ls.

Fig. 2: Almost longitudinal section of a pseudopunctate brachiopod shell fragment, revealing secondary layer and a taleolae. The fibrous prisms of the secondary layer are large and some are infinitely long. The taleolae seems to be composed of granular calcites of various sizes.
Sample: Same as fig. 1.



Explanation of Plate 14

Fig. 1: Nearly transverse oblique section of a productid spine. Granular layer at right is a primary layer. Hair-like prisms of the secondary layer appear as comprising composite crystals. Note Suture-like pattern on each composite crystal.
Sample: P-86, middle of Avoca Ls.

Fig. 2: An oblique (nearly transverse to the direction of taleola) section of secondary layer of a brachiopod. Whirlpools of prisms at around the taleola are apparent.
Sample: Same as fig. 1.

Explanation of Plate 15

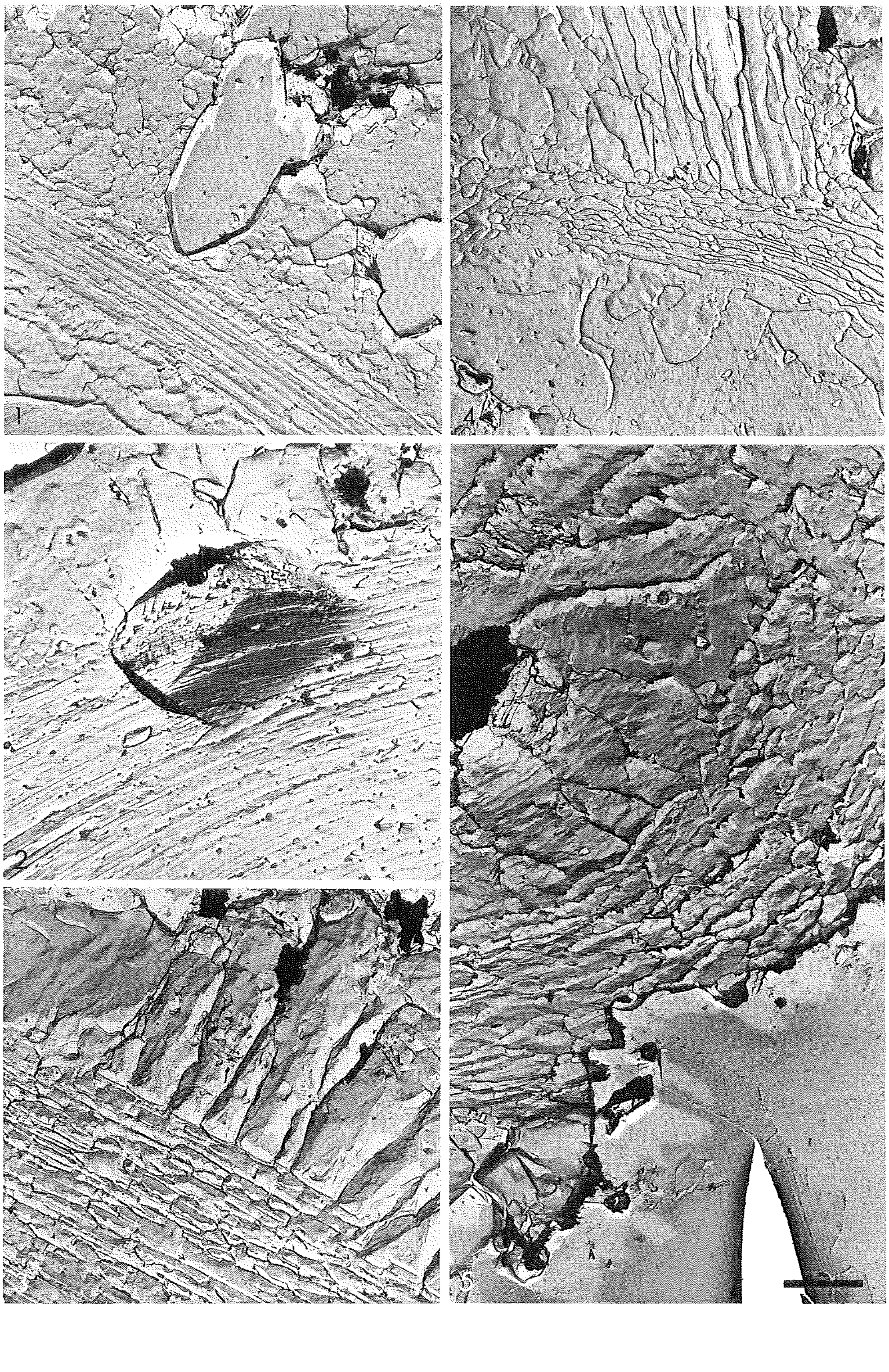
Fig. 1: A nearly longitudinal section of a slender productid spine (left center to lower right), with hairly appearance. An euhedral quartz intrudes into the skeleton (center). Note the difference of sizes, shapes and grain boundaries of calcite grains inside (lower left corner) and outside (above) the skeleton.
Sample: P-258, 1.2 m above base (top) of Captain Creek Ls.

Fig. 2: A nearly longitudinal section of brachiopod Secondary layer. Very thin hair-like prisms with infinite length are characteristic. Rhomboidal shape at near center of the figure is a mold of a dolomite, which has been extracted during blanc replication.
Sample: P-64, 2.8 m above base (top) of Beil Ls.

Fig. 3: A nearly longitudinal section of brachiopod. Fibrous prisms of secondary layer are apparent. Large calcite grains normal to the shell may be sparry calcite precipitated into original void space.
Sample: P-138, 1.2 m above base (top) of Brownville Ls.

Fig. 4: A brachiopod fragments of unknown part cut nearly longitudinally. Difference of size of prisms composing the sheleton is apparent. Note obliterated boundary between the lower sheleton and presumable sparry cement inside it.
Sample: P-220, base of Raytown Ls.

Fig. 5: An oblique section of probably a productid spine. Inside the spine are composed of radially oriented sparry calcite cement. Outside the skeleton is silica cement. Note the intrusion of silica cement into the skeleton.
Sample: P-60, 0.1 m above base of Big Spring Ls.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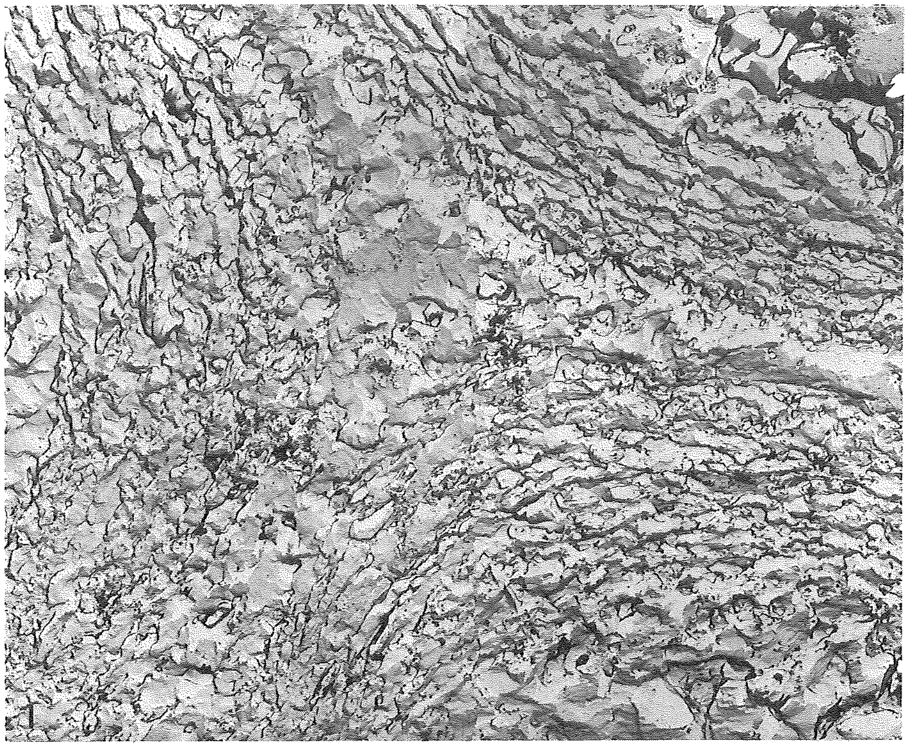
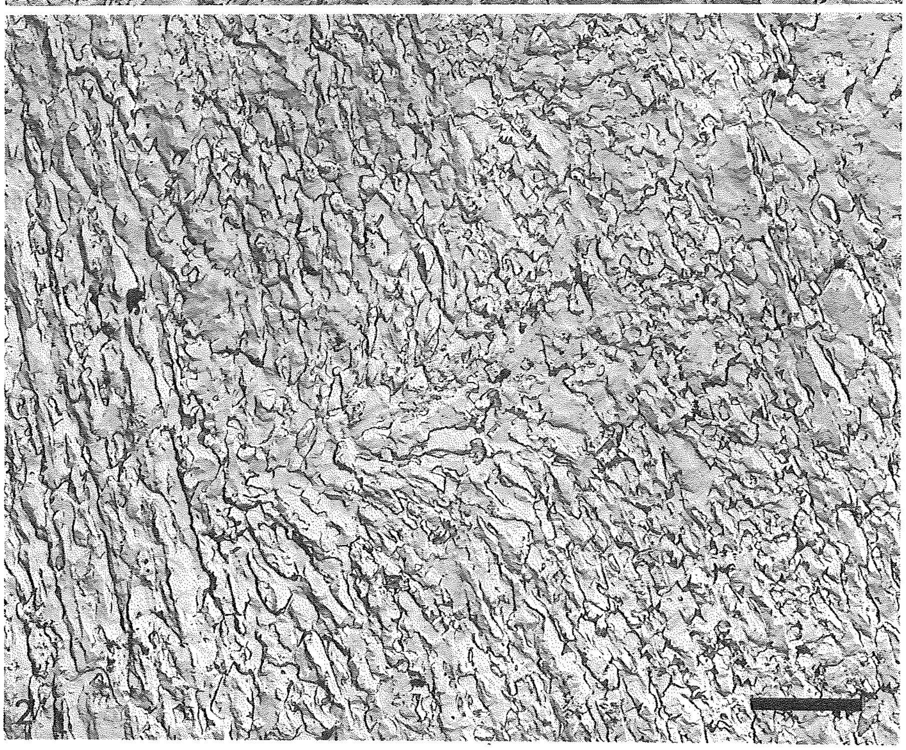
Explanation of Plate 16

Fig. 1: A cross cut section of presumably skeletal partition of bryozoa zooecial opening. Sandwich-like texture of laminated structure is obviously seen. Numerous inclusions and rough and dirty appearance of the inner structureless layer are also obvious.
Sample: P-85, lower part of Avoca Ls.

Fig. 2: A presumably longitudinal section to the direction of layers of a bryozoan skeleton. Note nearly straight orientation of fibrous grains at both sides of the wall surface, while some turbulences are seen at near center of the skeleton.
Sample: Same as fig. 1.





Explanation of Plate 17

Fig. 1: A rather irregularly appearing bryozoan skeleton with turbulances of the orientation of the fibrous calcites (lower right and upper left). Note rather weak arrangements of all fibers. Grains at lower right and upper right corners may be quartz.
Sample: P-85, lower part of Avoca Ls.

Fig. 2: A granular microstructure of a bryozoa. Extremely roughly etched surface and dirty appearance are characteristic.
Sample: Same as fig. 1.

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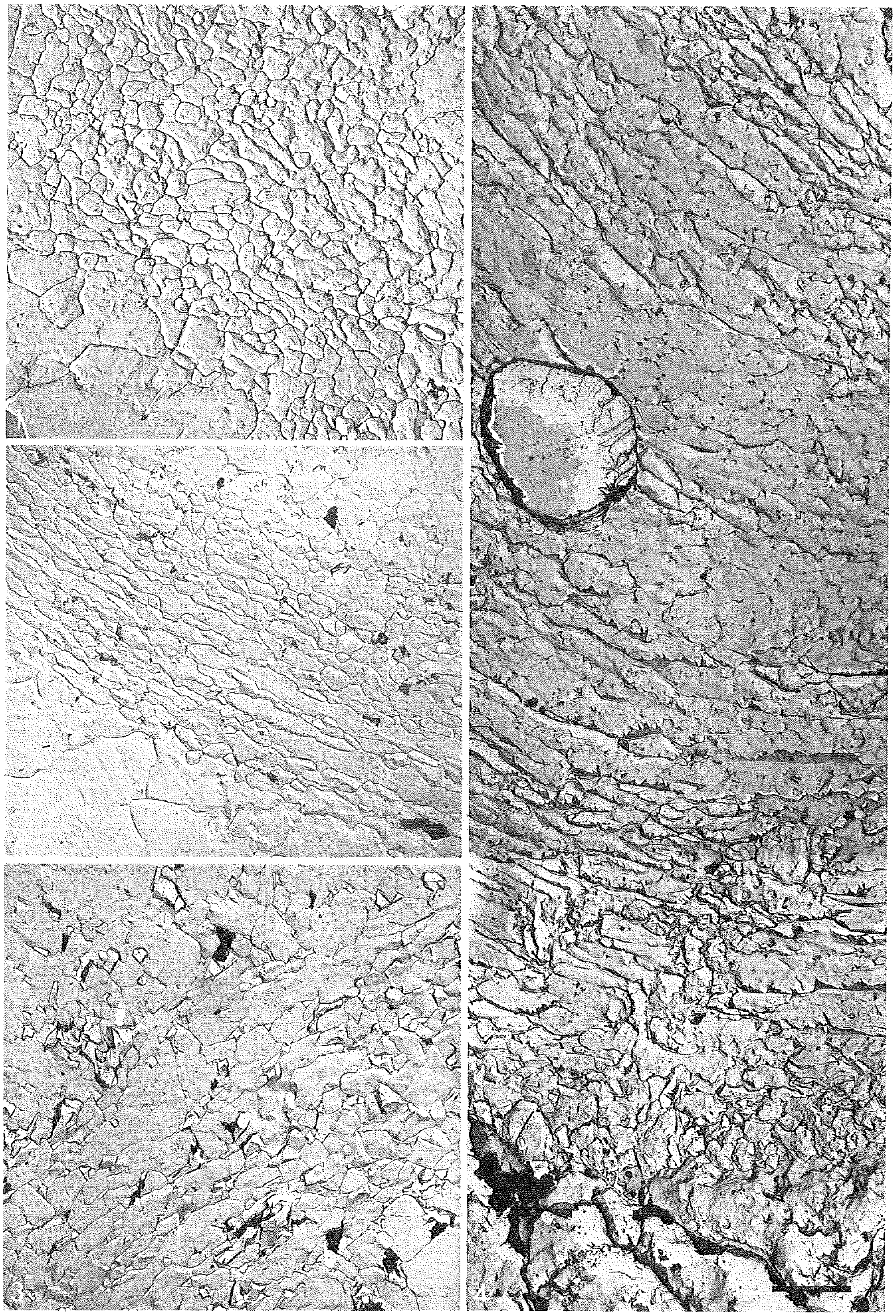
Explanation of Plate 18

Fig. 1: A granular microstructure of bryozoa, in which show rather irregularly arranged calcite grains. Clean appearance is characteristic on this fragment.
Sample: P-230, 0.8 m above base of Argentine Ls.

Fig. 2: A nearly longitudinal section of fibrous bryozoan microstructure. Note the resemblance of this structure to a brachiopod one such as shown in Plate 15, fig.4.
Sample: P-233, 2.0 m above base of Argentine Ls.

Fig. 3: A rather obliterated granular microstructure of a brachiopod fragment. Somehow oriented grains revealing skeletal structure, but more or less rhomboidal shape of individual calcite grains, by which recrystalization probably is caused, gives rather nonskeletal appearance.
Sample: P-259, 0.05 m above base of Stoner Ls.

Fig. 4: A laminated microstructure of a bryozoan skeleton. Prominent grain at just above left center probably is a detrital grain, which possibly is secreted into the skeleton during the formation of it.
Sample: P-93, 0.2 m above base of Wakaruusa Ls.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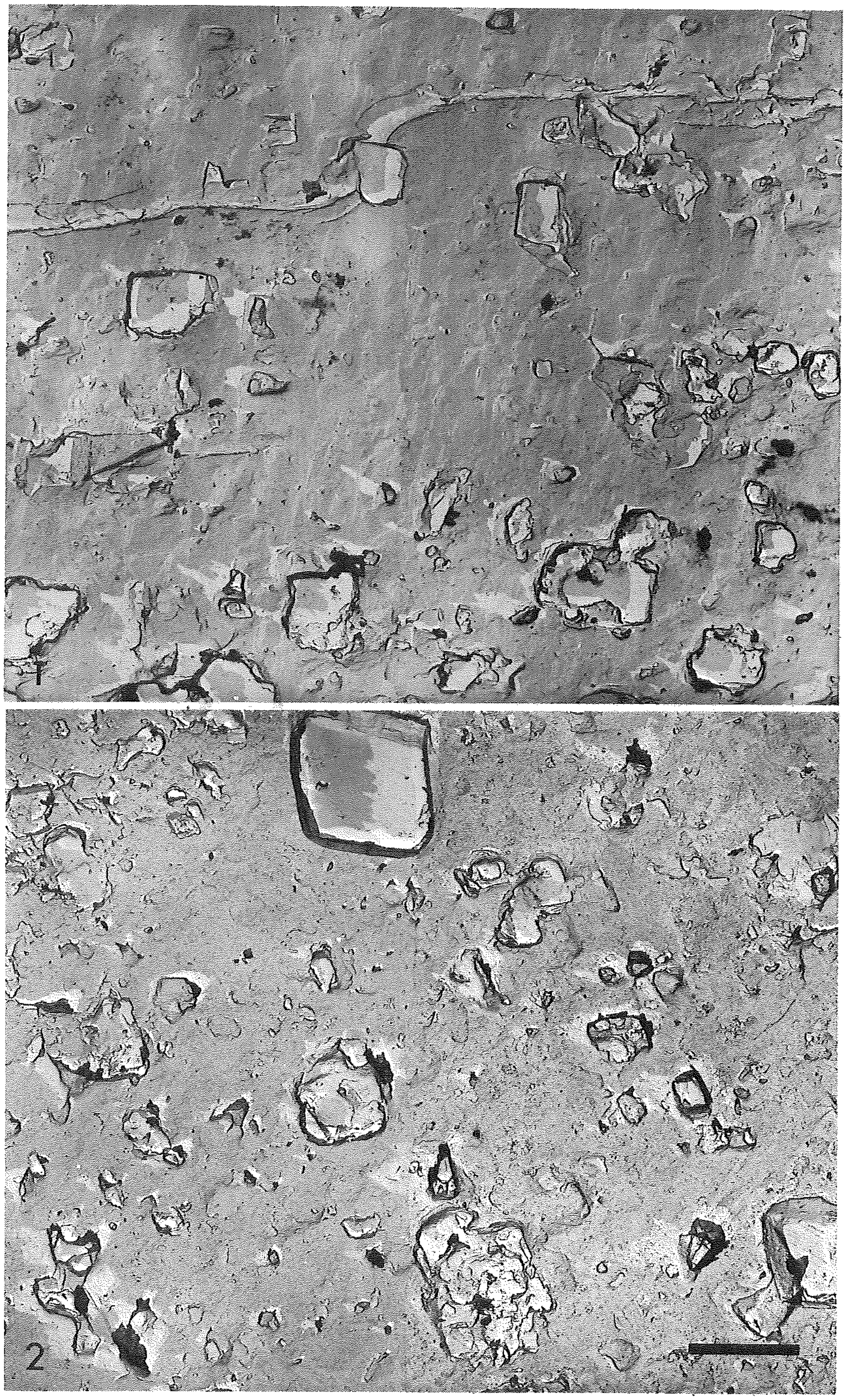
Explanation of Plate 19

Fig. 1: A section of an echinoderm fragment revealing many inclusions, which are probably relicts of calcitized dolomite (left center) and of dolomite (upper center and lower center).
Sample: P-220, base of Raytown Ls.

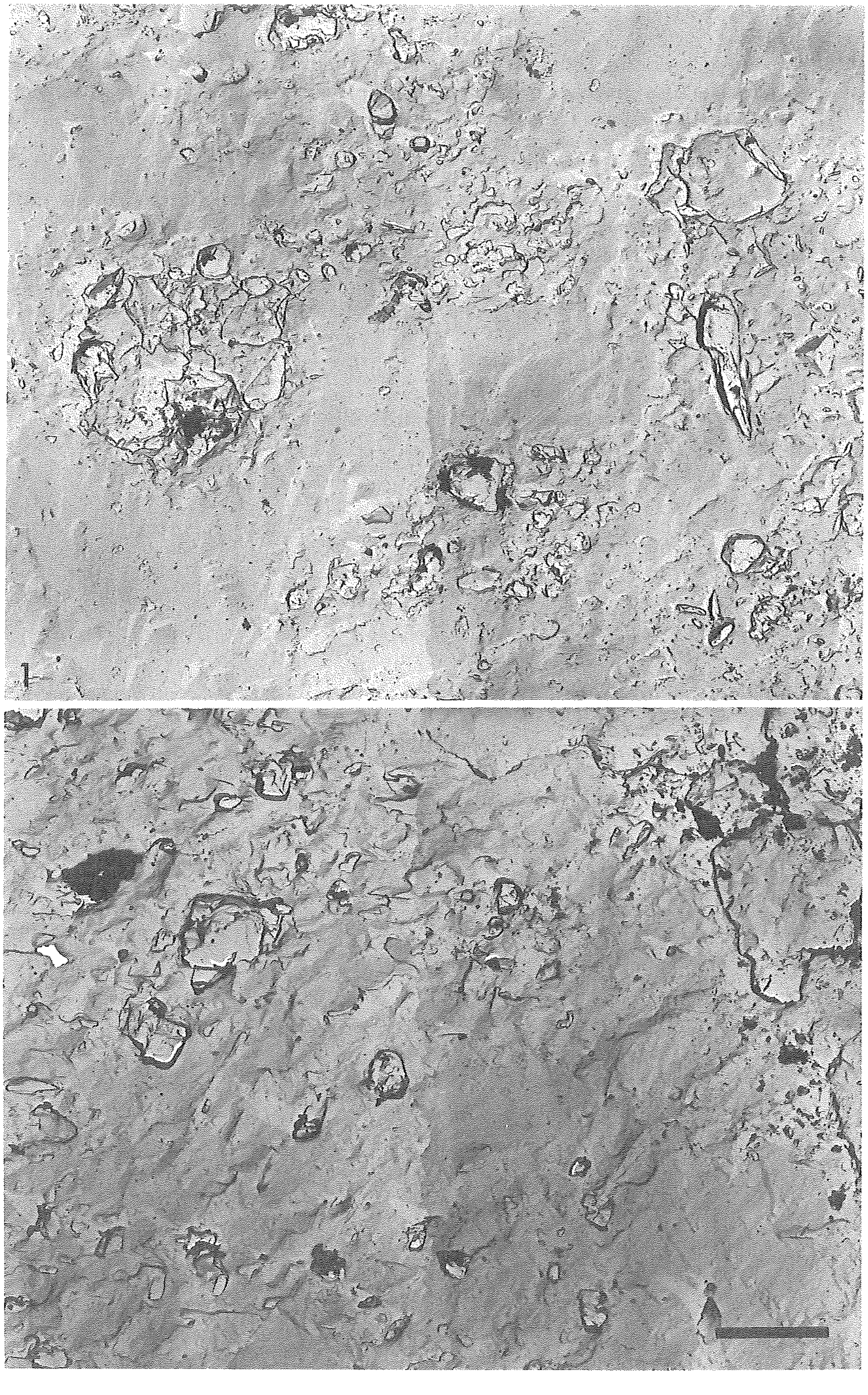
Fig. 2: Another echinoderm fragment with dolomite inclusions in it. Roughly surfaced etching pattern is apparent.
Sample: P-84, 0.4 m above base of Kereford Ls.



Explanation of Plate 20

Fig. 1: Echinoderm skeletal microstructure with numerous dolomitic inclusions. Smoothly etched surface of typical echinoderm is apparent. Note no scratches on the dolomite surface, by which possibility of replacement by silica is suggested.
Sample: P-220, base of Raytown Ls.

Fig. 2: Another echinoderm with numerous dolomitic inclusion.
Sample: P-86, middle of Avoca Ls.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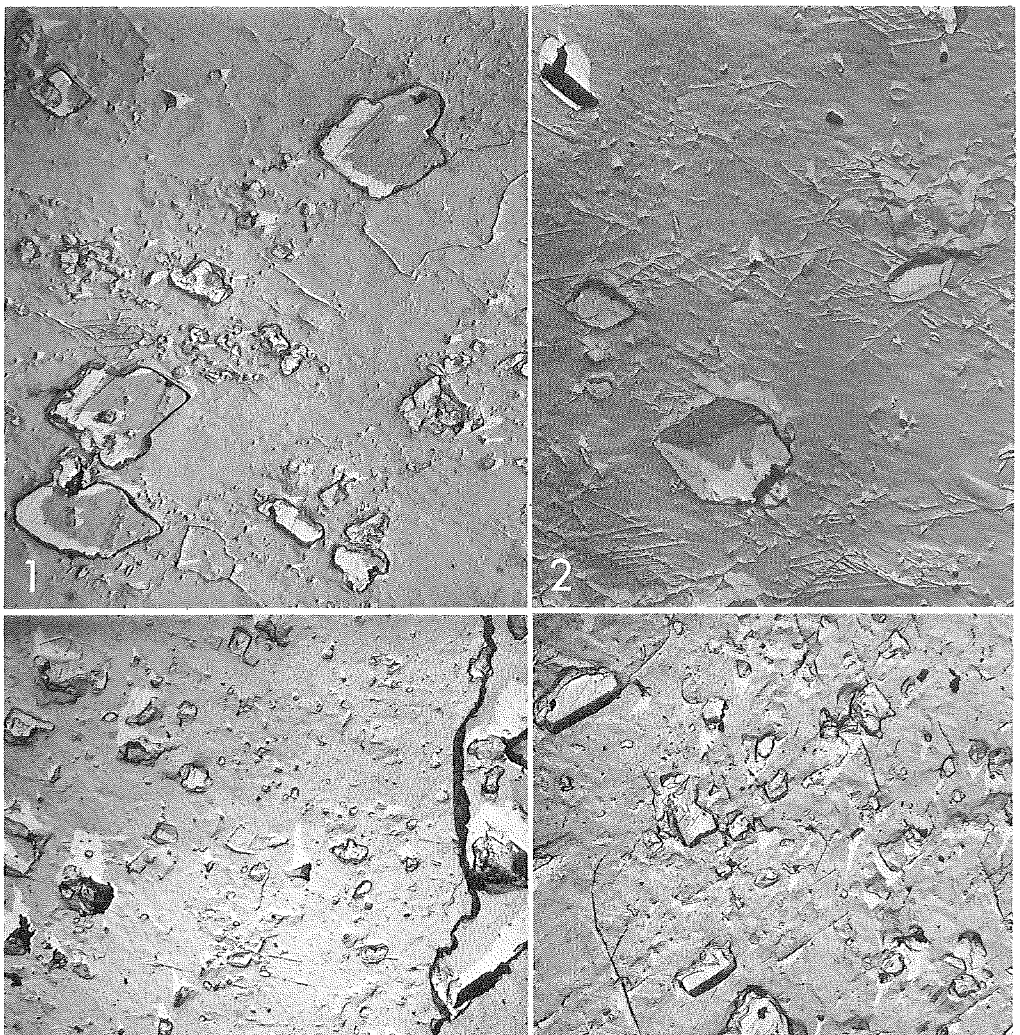
Explanation of Plate 21

Fig. 1: Dolomitic inclusion in echinoderm fragment apparently replaced partially by silica (upper right). Also probable calcitized dolomite, which is indicated by arrangement of relict structure, is seen (center left).
Sample: P-220, base of Raytown Ls.

Fig. 2: Possible echinoderm fragment with dolomite inclusions. Straight lines on the surface probably indicating shearing of this fragments (FISCHER et al., 1967).
Sample: P-253, 1.4 m above base of Spring Hill Ls.

Fig. 3: Another possible echinoderm fragment with numerous tiny inclusions, which probably are fluid inclusions.
Sample: P-267, middle of Drum Ls.

Fig. 4: Echinoderm fragment with two different sizes of inclusions.
Sample: P-236, base of Farley Ls.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Explanation of Plate 22

A nearly saggittal section through a wall of *Triticites*. Pore filling nature of alveoli is apparent. The pore filling calcite penetrates all through the spirotheca. Size difference of the calcite grains composing tectum (uppermost 20 microns thick layer) and keriotheca is slightly appreciable. Note somehow oblong shape of calcite grains of keriotheca. Also noted is rather "dirty" appearance of the entire skeleton. The corresponding specimen as seen in an acetate peel and in a thin section are shown in Plate 26, figs.2 and 4, respectively.
Sample: P-85, lower part of Avoca Ls.

Fig. 12. Drawing to accompany Plate 22 showing grain boundaries of *Triticites* wall microstructure. Pseudo-replicas are diagonally ruled.

Fig. 12

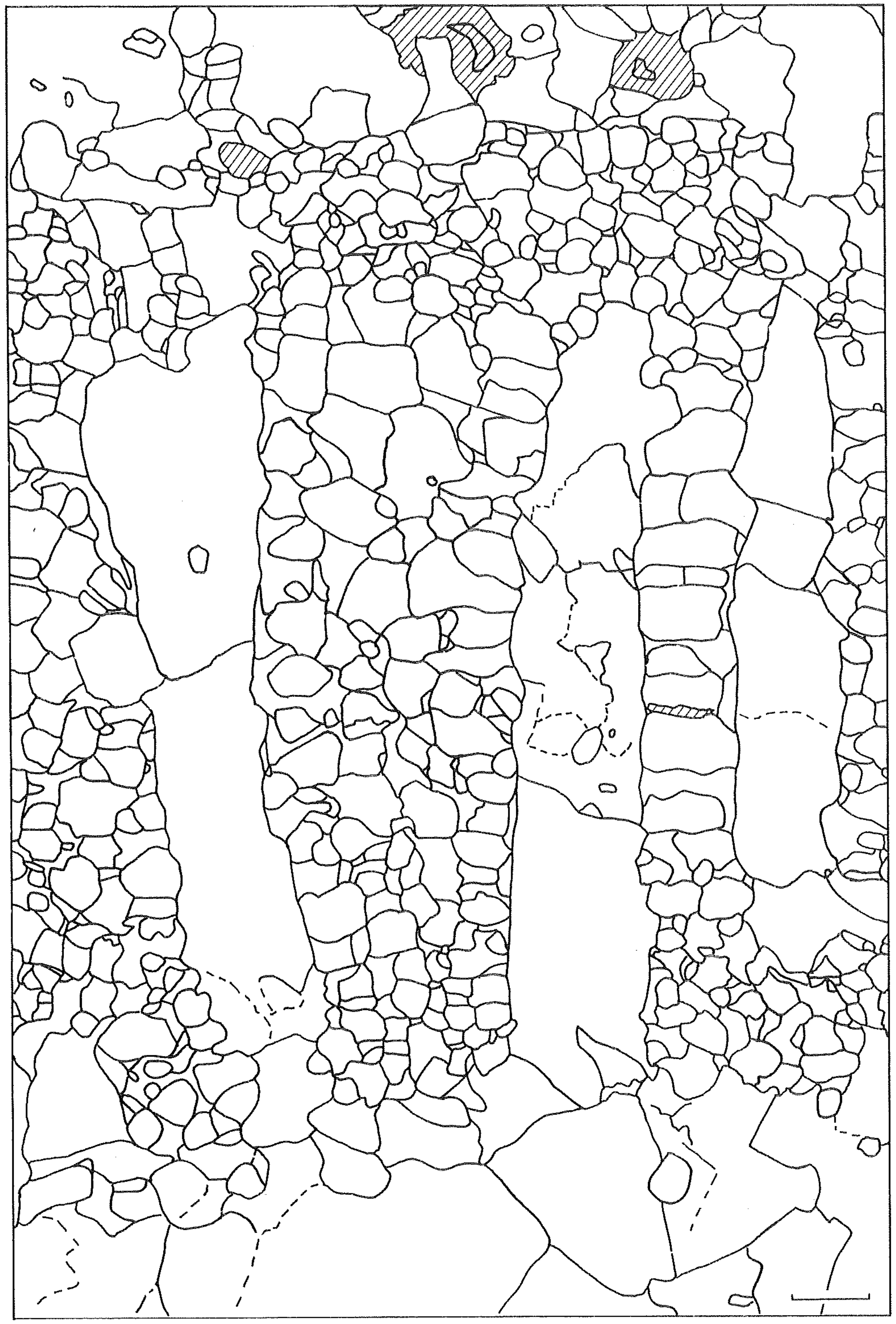


Plate 22

Explanation of Plate 23

Fig. 1: Another part of the *Triticites* shown in Plate 22. The keriothecal and alveolar structure are evidently seen. Tectum is completely obliterated by growth of sparry cement. Prominent grain at upper center probably is a quartz of unknown origin. The respective area as seen in an acetate peel is shown in Plate 26, fig.1.
Sample: P-85, lower part of Avoca Ls.

Fig. 2: An oblique section of *Triticites* which is revealing nearly transverse microstructure of the spirotheca. Large prominent grains may be pore-filling calcite of the alveoli. Somehow oblong grains oriented nearly normal to the above large calcite may be keriotheca. Note the radial arrangement of keriotheca around the alveoli. The respective specimen seen in an acetate peel is shown as Plate 26, fig.7.
Sample: Same as fig.1.

Fig. 13. Drawing to accompany Plate 23 showing grain boundaries of *Triticites* wall microstructure. Mineral other than calcite is stippled and pseudo-replicas are diagonally ruled.

Fig. 13

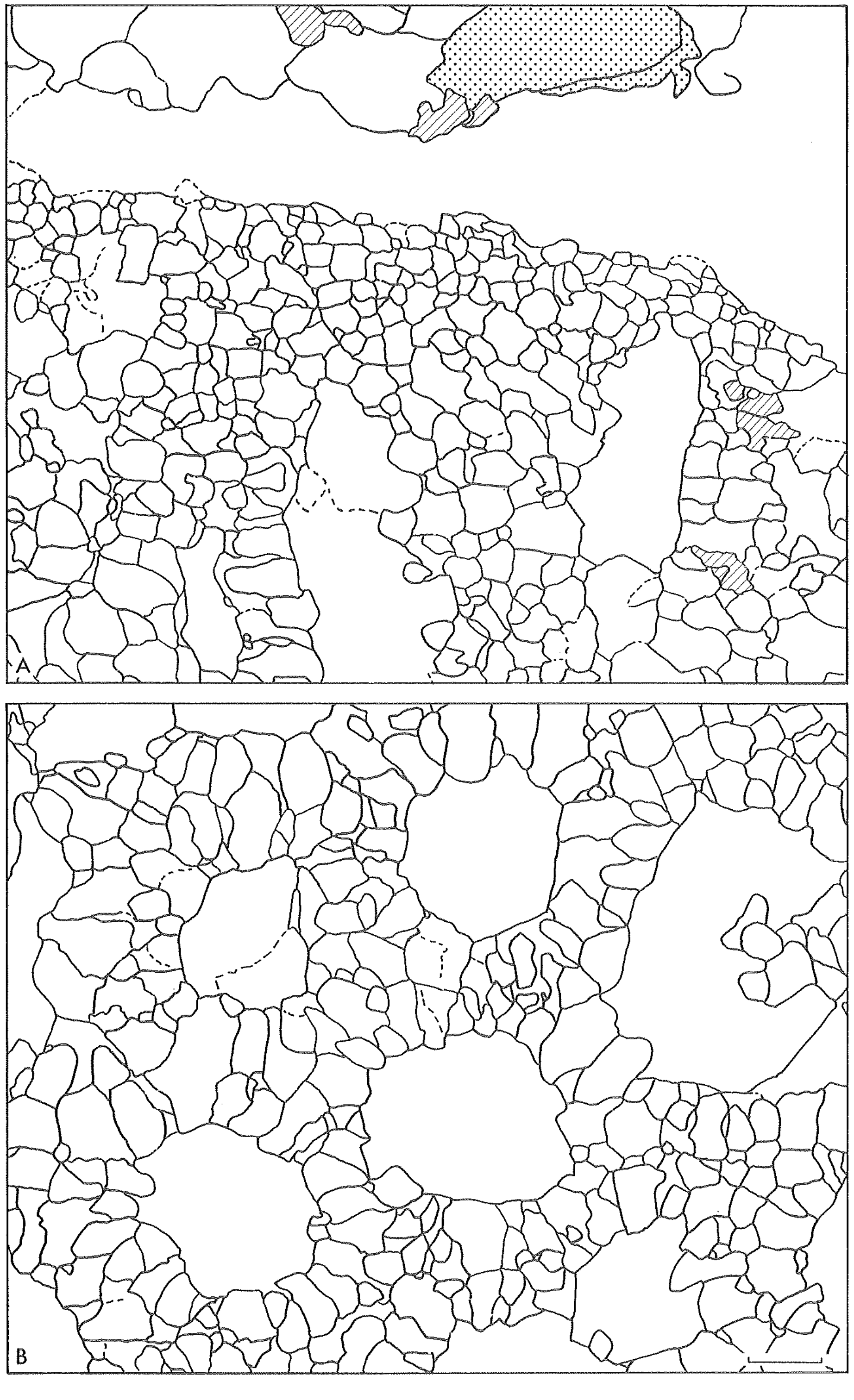
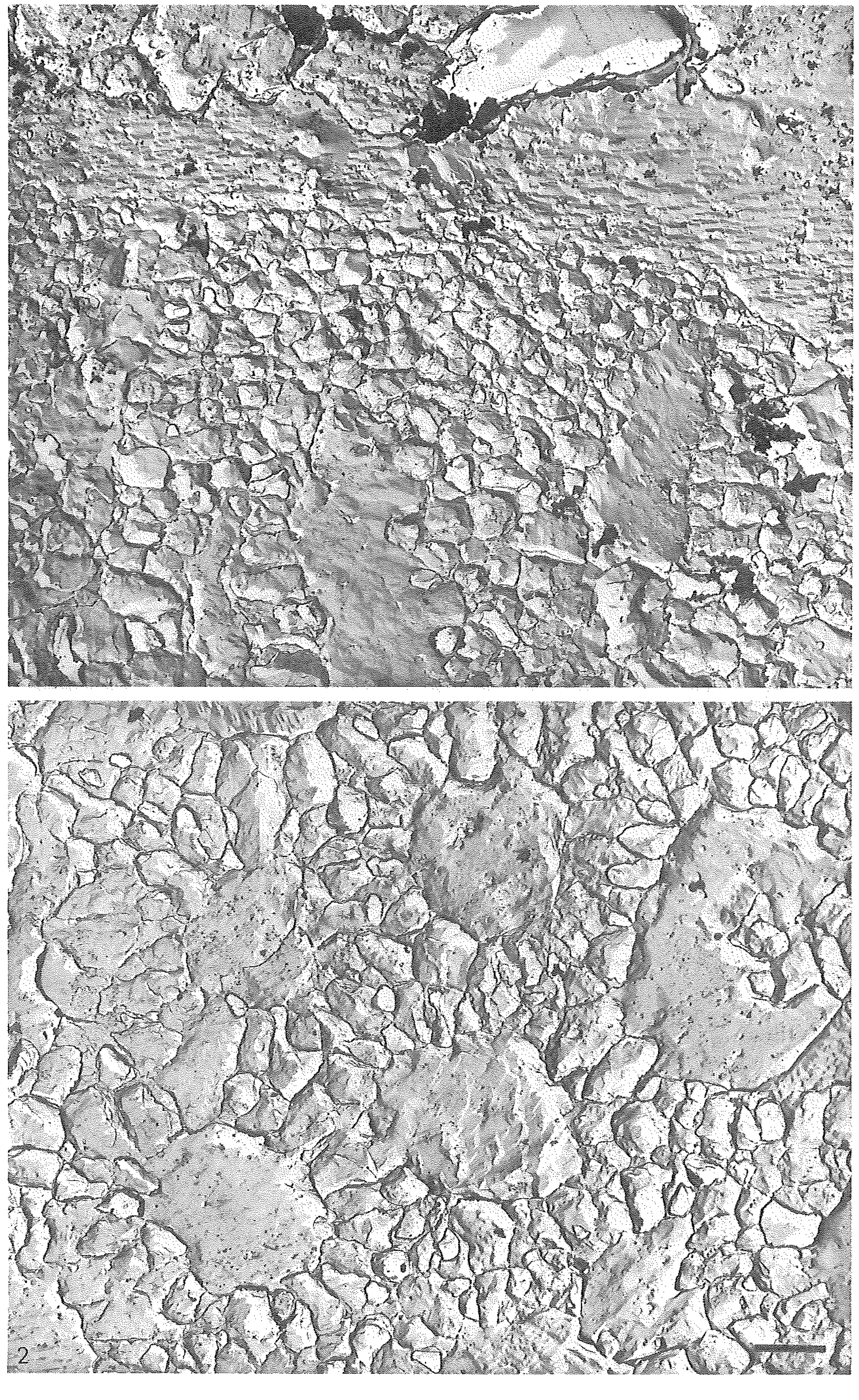


Plate 23



Explanation of Plate 24

An oblique section of a little outer side of the spirotheca shown in Plate 23, fig.2, reveals radial arrangement of keriotheca consists of oblong to oval grains. No alveolar pore filling obviously is seen. Some large grains at upper right corner may be this type of calcite. Somehow fine grain layer of lower center to center left probably is tectum. Corresponding specimens seen in a thin section and an acetate peel is shown in Plate 26, figs.5 and 7 respectively.
Sample: P-85, lower part of Avoca Ls.

Fig. 14. Drawing to accompany Plate 24 showing grain boundaries of *Triticites* wall microstructure.

Fig. 14

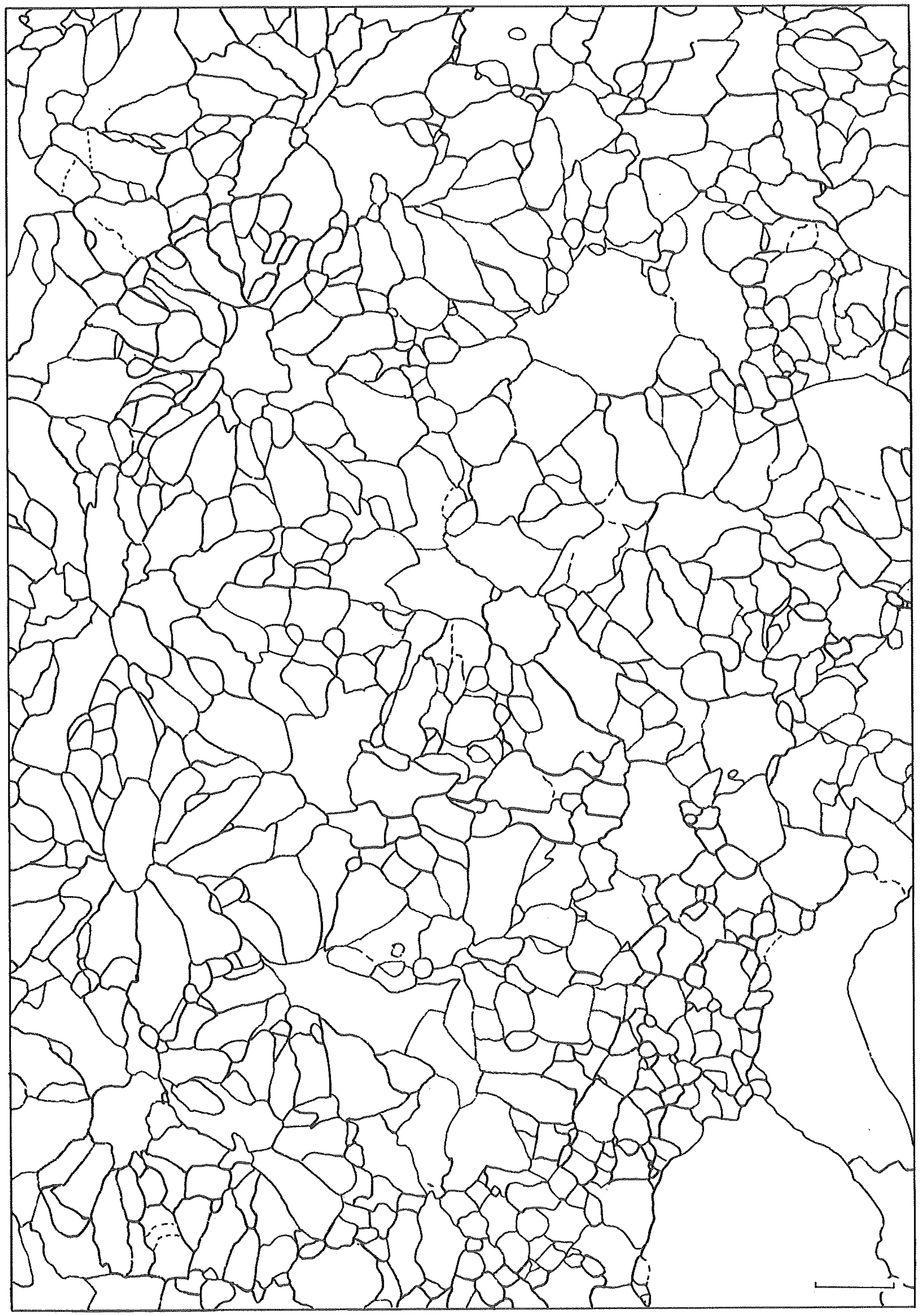
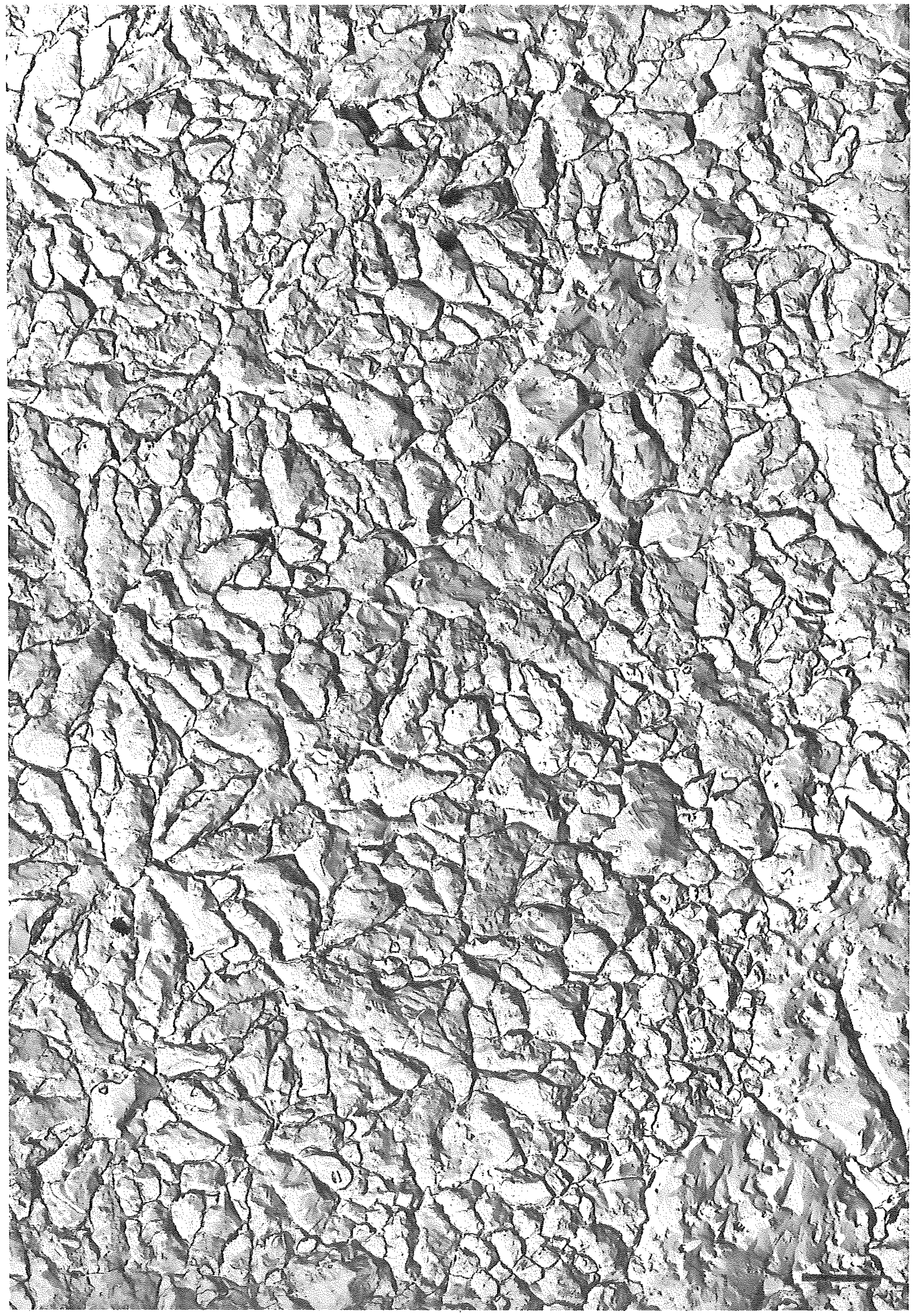


Plate 24



Explanation of Plate 25

Another *Triticites*, which reveals distinctive wall structure as seen in thin section (Plate 26, fig.3) but more or less obliterated structure in acetate peel (Plate 26, fig.6). E. M. observation reveals somehow obliterated spirothecal structure, but tectum can be well definable by rather finer grains composing this layer than the other parts of the spirotheca. Part of septum reveals coarse grain structure (upper right part).
Sample: P-85, lower part of Avoca Ls.

Fig. 15. Drawing to accompany Plate 25 showing grain boundaries of *Triticites* wall microstructure. Minerals other than calcite are stippled and pseudo-replicas are diagonally ruled.

Fig. 15

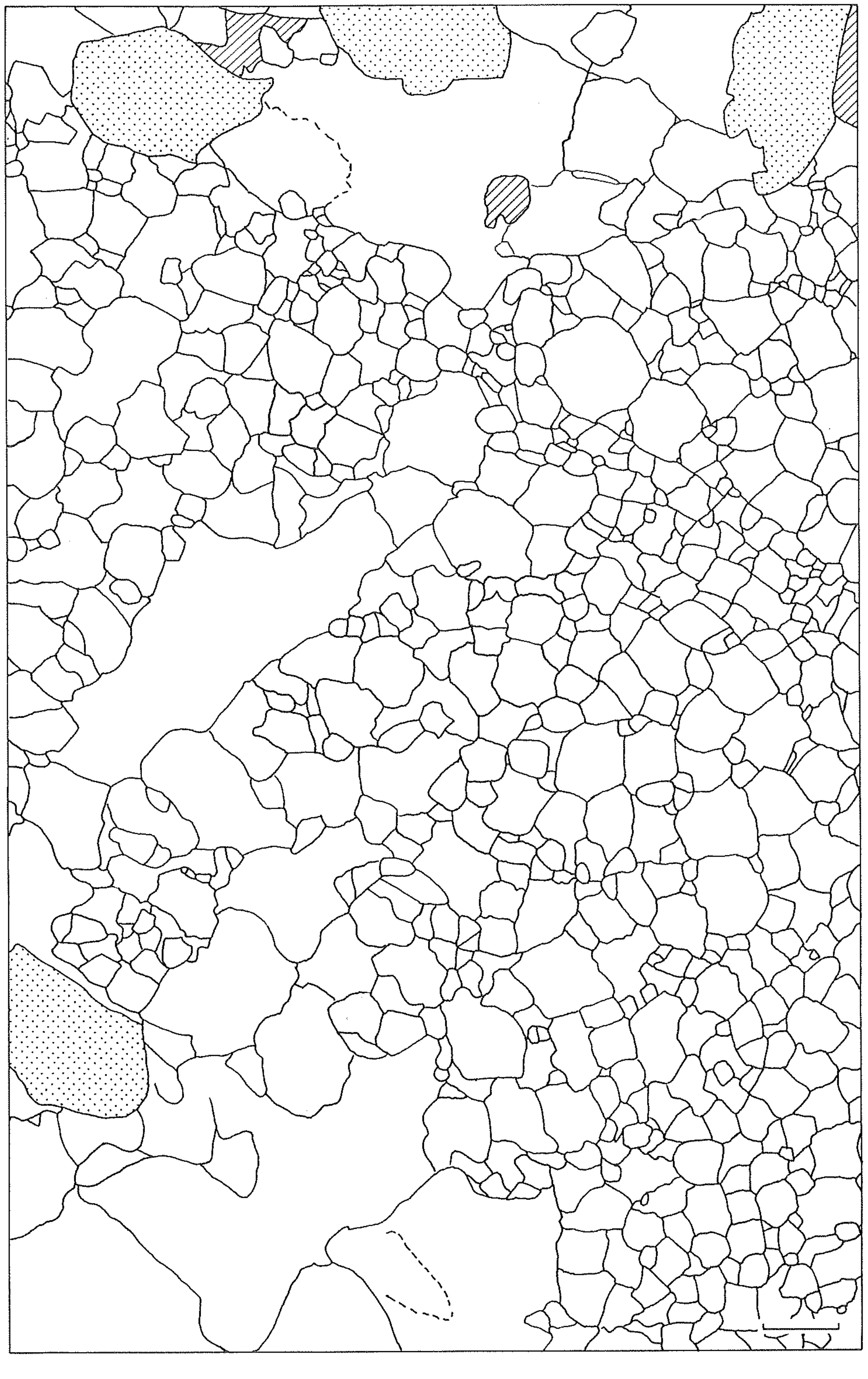


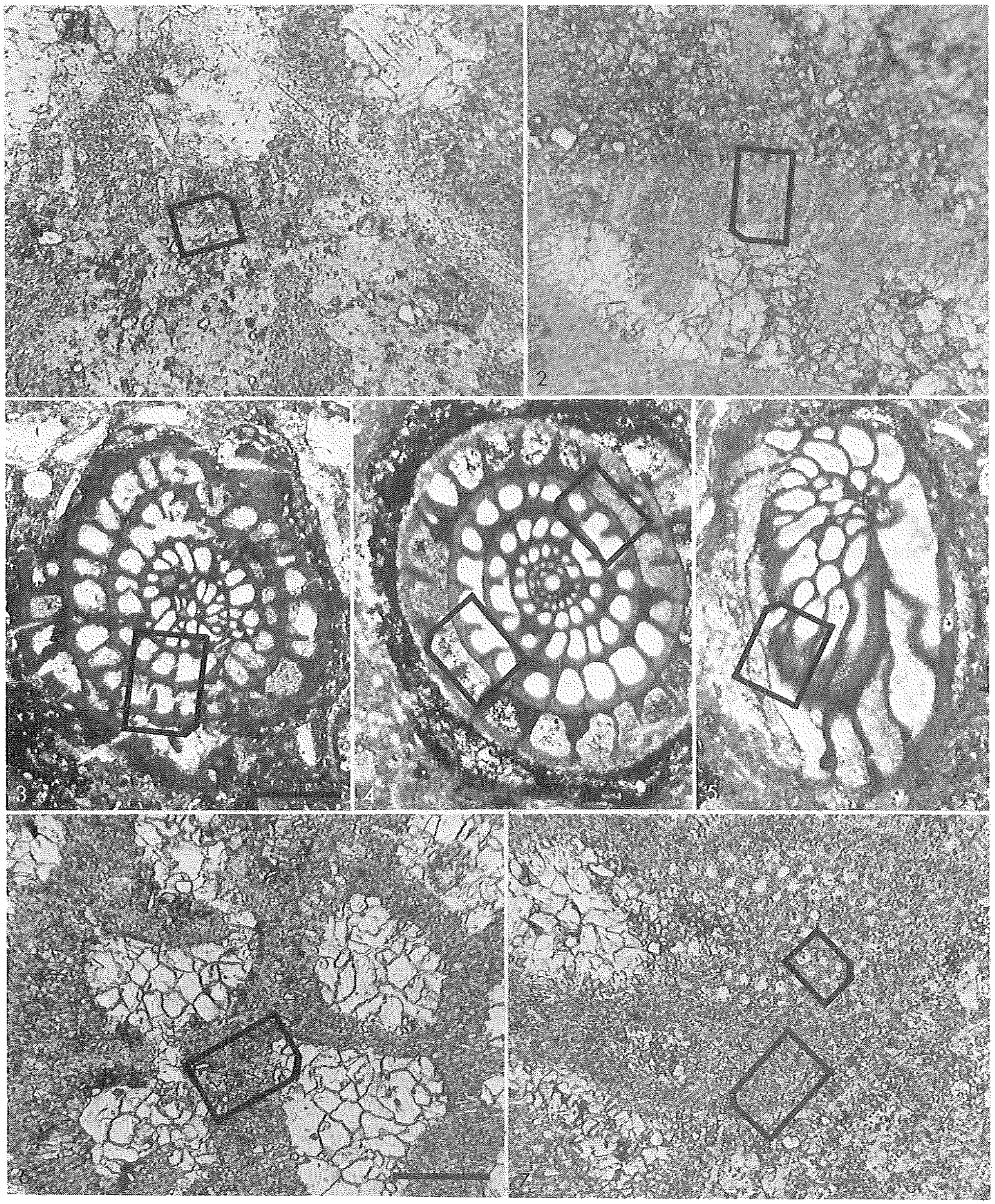
Plate 25

Explanation of Plate 26

All figures are L. M. photographs of acetate peels (figs.1,2,6 and 7) and of thin sections (figs.3,4 and 5). Scale bars on figs.3 and 6 indicates 0.5 mm and 0.1 mm for figs.3,4 and 5, figs.1,2,6 and 7, respectively. Also squares in thin sections indicate the areas shown as acetate peels, and those in the latter indicates the areas shown as E. M. photographs. The cut-off corner of the squares indicate lower left corners of the corresponding photographs. All specimens are identified as *Triticites* of different sectional orientation in a sample limestone.

Square in fig.3 indicates the area of fig.6, and that of the latter corresponds to Plate 25. The square of lower left of fig.4 indicates fig.1 and upper right does fig.2. That of fig.1 corresponds to plate 23, fig.1 and that of fig.2 does Plate 22. The area of fig.7 is indicated by the square of fig.3. Lower one of fig.7 corresponds to Plate 24 and the upper one does to the area of Plate 23, fig.2.

Sample: P-85, lower part of Avoca Ls.



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Explanation of Plate 27

Fig. 1: A cross cut section of a *Triticites,* which show no spirothecal structure as seen in E. M., while distinct structure is observed in thin section.
Sample: P-88, Clay Creek Ls.

Fig. 2: Another *Triticites,* which show no distinct wall structure, although difference of the wall and the chamber is distinct.
Sample: P-267, Drum Ls.

Fig. 3: A fusulinid specimen, probably *Triticites,* which reveals no wall structure at all. Note the wall runs from lower left corner to the upper right corner. No difference of outer wall (lower side) and inner wall (upper side) can be seen.
Sample: P-86, middle part of Avoca Ls.

Fig. 16. Drawing to accompany Plate 27 showing grain boundaries of fusulinid wall microstructure.

Fig. 16

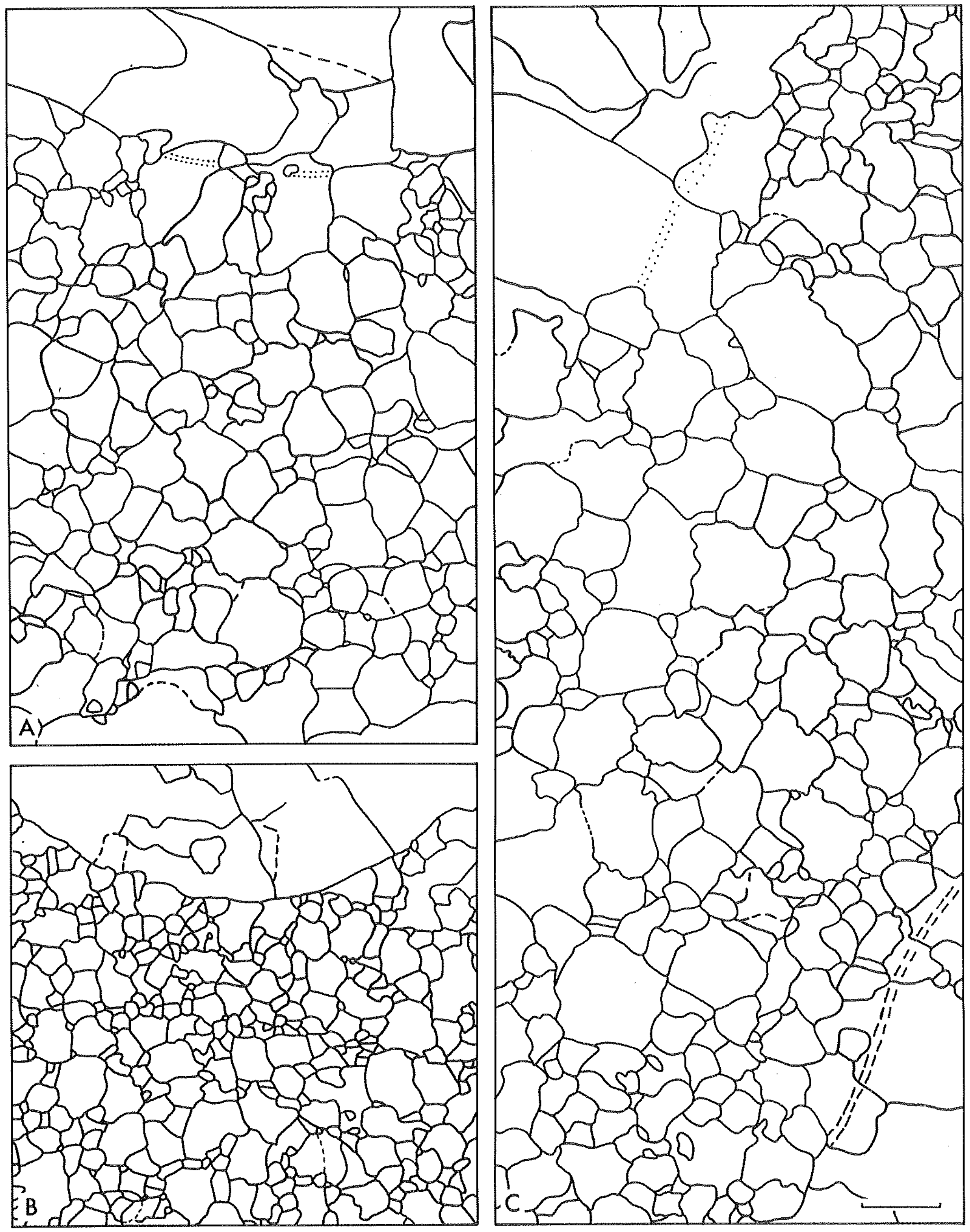
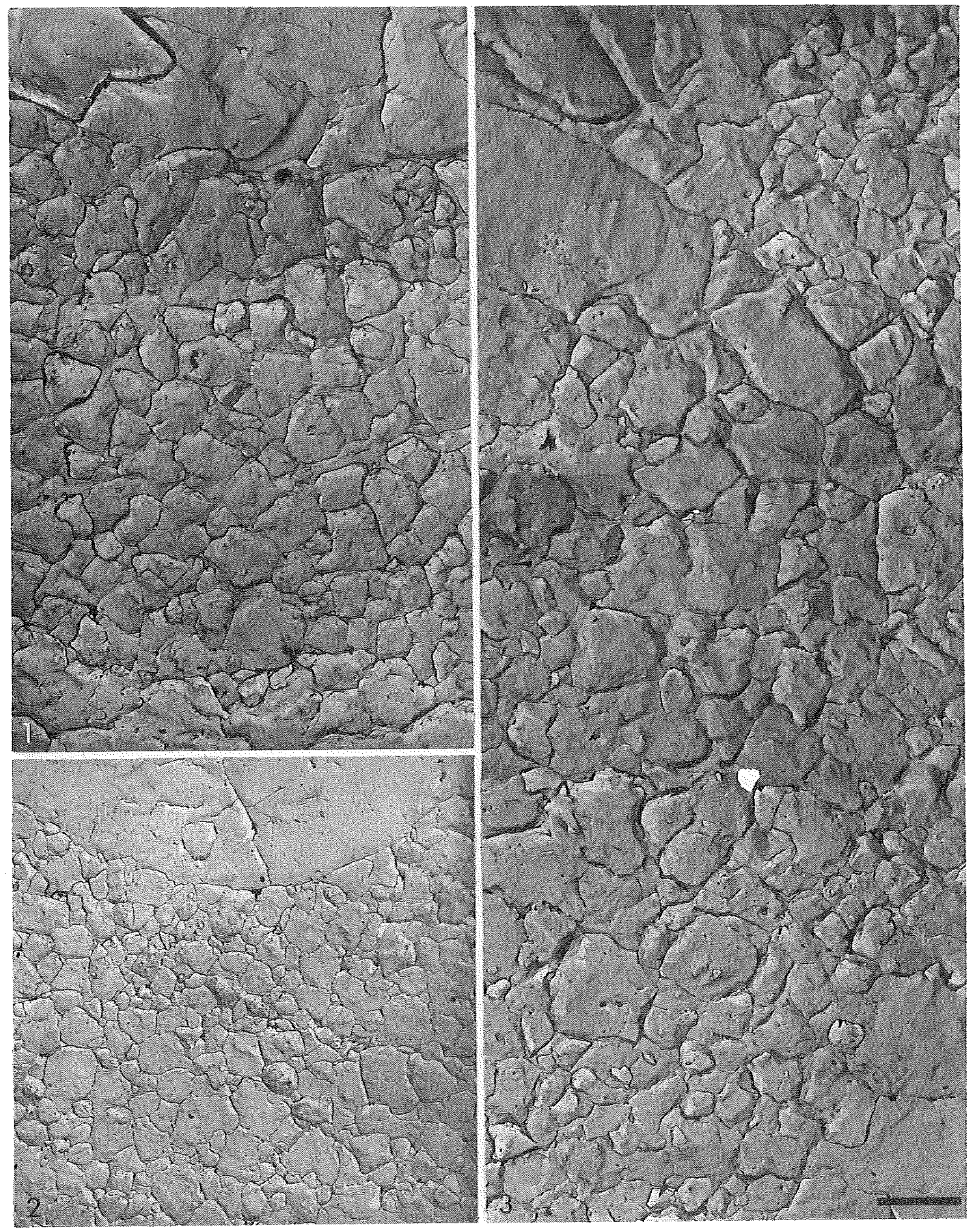
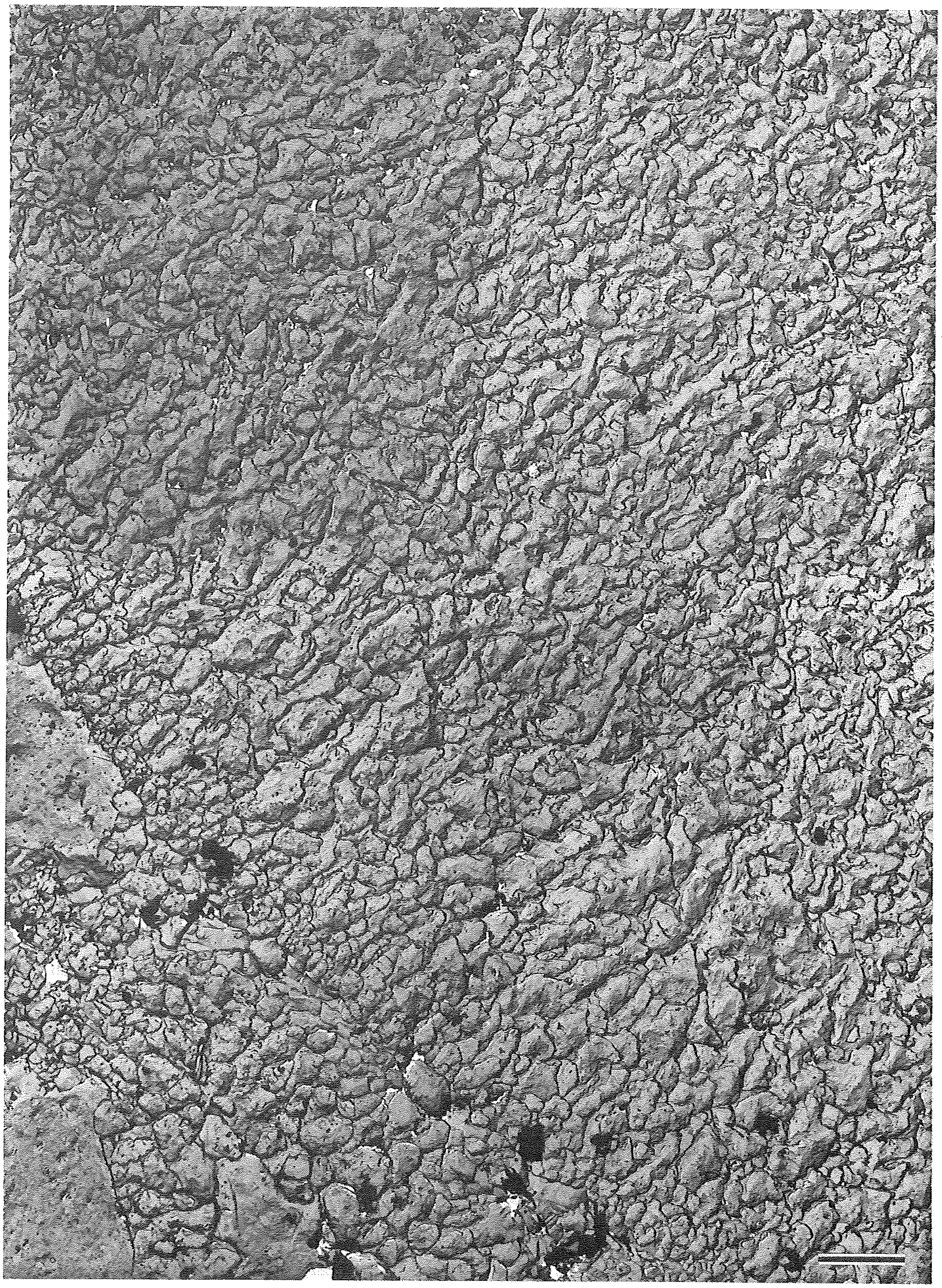


Plate 27



Explanation of Plate 28

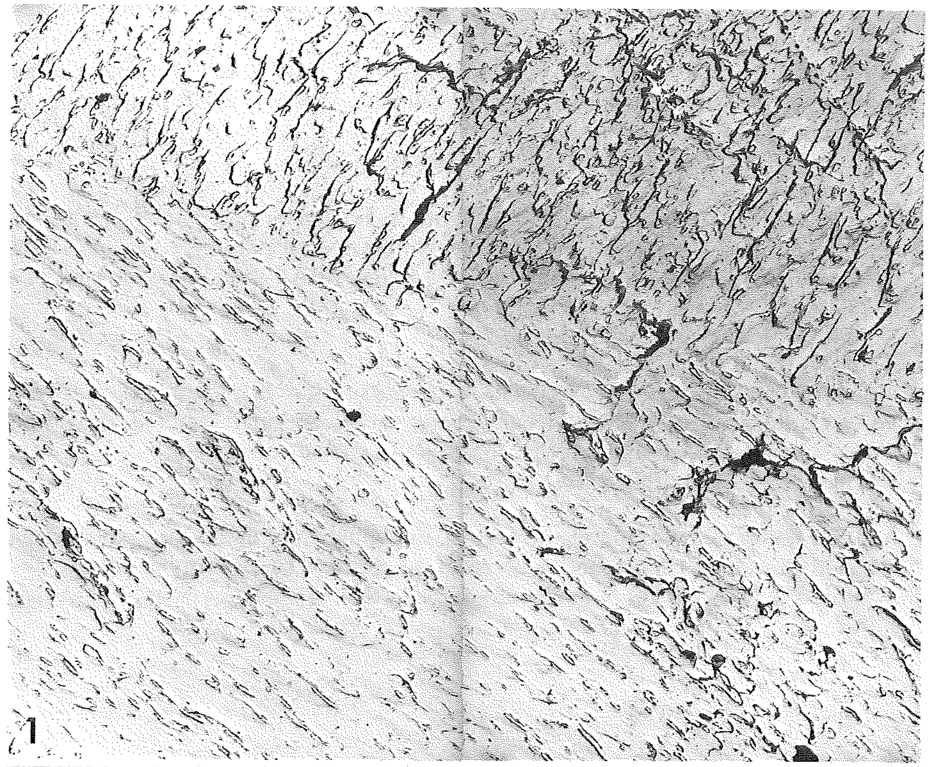
Probably outermost portion of a trilobite carapace, which shows rather disordered arrangement of prismatic(?) calcite consisting the skeleton. Only exception is very fine grained layer of about 3 microns thick consisting the outermost part of the skeleton.
Sample: P-93, 0.2 m above base of Wakaruusa Ls.



Explanation of Plate 29

Fig. 1: A cross cut section of a molluscan shell fragment, which is of unknown taxon. Cross lamellae structure of fibrous prisms is obvious.
Sample: P-86, middle part of Avoca Ls.

Fig. 2: An ostracod carapace showing granular texture and overlap of the shell. Note extremely thin shell of this ostracod. Inside the shell (upper portion) consists of sparry calcite cement precipitated into the original void space.
Sample: P-94, 0.4 m above base of Wakaruusa Ls.



Explanation of Plate 30

Fig. 1: Outermost portion of an oolite. Extremely fine grained calcite (left) gradually changes to needle-like calcite of rather radially oriented. Note probable growth patterns on a grain of matrix (lower right).
Sample: P-97, 0.6 m above base (top) of Tarkio Ls.

Fig. 2: A portion of an colitic coated grain, consists of layers of granular calcites with gradual and rapid size change alternatively. No radial orientation is revealed as seen in oolite. But the concentric structure may be represented by the size difference of the layers.
Sample: P-66, top of Ozawkee Ls.

Fig. 3: Probable pellet in a rather coarse lime mud matrix. Very fine grain calcite consisting pellet is characteristic. Many pellets show rather irregular shape as shown here. Ovoid shape mineral at upper center likely is an aggregate of pyrites.
Sample: P-218, base of Paola Ls.

Fig. 4: Another pellet with round shape and in fine grain lime mud. Note some pelletal material appeared as impregnating between the grains of matrix (upper left).
Sample: P-219, 0.5 m above base (top) of Paola Ls.