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PRELIMINARY REPORT ON THE PETROLOGY AND PETROGRAPHY OF LIMESTONES FROM THE FITZROY BASIN

By

J.E. Glover

CANBERRA.

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TABLE OF CONTENTS.

	Page
INTRODUCTION	1
DETERMINATION OF COMPOSITION	1
1. General remarks	1
2. Etching	1
3. Staining	2
4. Microscopy	2
5. Chemical analysis	2
6. Summary	2
DESCRIPTION OF SPECIMENS	2
ORDOVICIAN DOLOMITES	2
MIDDLE DEVONIAN LIMESTONES	3
1. Winjana Gorge	3
a. Biostromal limestones	3
b. Calcarenites	4
c. Environment of deposition and post depositional changes.	5
2. Menjou's Gap	5
a. Calcarenites	5
b. Calcilutites	6
UPPER DEVONIAN LIMESTONES	6
a. Biohermal limestones	6
b. Calcarenites	6
c. Petrological descussion of calcarenites	8
CONCLUSION	9
BIBLIOGRAPHY	9

INTRODUCTION

This preliminary report deals with examination and classification of Ordovician, Middle and Upper Devonian limestone samples collected in the Fitzroy Basin during August, September and October of 1953. The geology of the area has been recently described by Guppy (1953). Rocks are designated by their field numbers, as geologists of West Australian Petroleum Limited, in conjunction with whom the collection was made, have retained the numbers for reference. For purposes of petrographic discussion, the nomenclature of clastic limestones as set out by Condon (1953) is used. Calcarenites are considered to range in grain size from 0.06 mm. to 4 mm., grading by decrease in grain size to calcilutites, and by increase into calcirudites. Condon's nomenclature for bioherm is also followed. Biostrome is quoted by Condon as "a bed consisting mainly of tests of benthonic organisms," but organic material in the Middle Devonian biostromes of the Fitzroy Basin is mainly of colonial organisms (stromatoporoids) that have grown in situ. In this respect they resemble algal biostromes briefly described by Shrock (1948, pp. 281-293).

Basic information sought in investigations of most limestones concerns:

1) Composition: distinction between calcite and dolomite is important.

2) Origin: the origin of many limestones is very complex, but division into clastic, organic or chemical limestone should be attempted. Texture, both as observed under the microscope and in handspecimen is very useful, but in some cases (especially bioherms) field evidence supplies the only criterion.

This paper has two main sections. The section on determination of composition describes techniques for distinction between calcite and dolomite, and the section on description of specimens incorporates suggestions about origin and environment of deposition where these logically arise from examination of textural or other features. 78 thin sections were examined, and textures typical of of limestones of the area are illustrated by photomicrographs (photography by G. Reid, Bureau of Mineral Resources).

DETERMINATION OF COMPOSITION

1. General Remarks

Although there are many carbonate minerals, calcite and dolomite constitute the great bulk of most limestones, and distinction between them is important. Some indication may be had from colour - dolomite is white or grey but more commonly pink or brown from oxidation of ferrous iron in the dolomite crystal or of siderite in the rock, whereas calcite is more commonly white or grey though it may also be pink and brown. Dolomite (S.G. = 2.87) is heavier than calcite (S.G. = 2.71) and slightly harder. Dolomitic limestones have a more sugary or crystalline texture than most calcitic limestones, and fossils in the former are commonly but not universally, obliterated. Calcite effervesces in cold, dilute HCl, dolomite does not, and whereas this supplies a rough field test, solubility in fact is the basis for more precise tests (etching and staining tests, described below). According to Rodgers (1940, p.788) orthorhombic carbonates except cerussite (i.e. aragonite, strontianite, witherite) react like calcite with weak acid, and rhombohedral carbonates (i.e. ankerite, magnesite, siderite, smithsonite) react like dolomite. In the isomorphous series calcite-rhodocrosite, pure calcite and material high in manganese can be distinguished.

2. Etching

Etching techniques depend on the greater solubility in acid of calcite than dolomite. The procedure adopted in this investigation involves grinding a smooth surface on a small limestone fragment, which is then placed in 2N formic acid for about 15 minutes. In a rock containing dolomite and calcite, calcite dissolves leaving flat-bottomed valleys about 1 mm. below the original smooth surface,

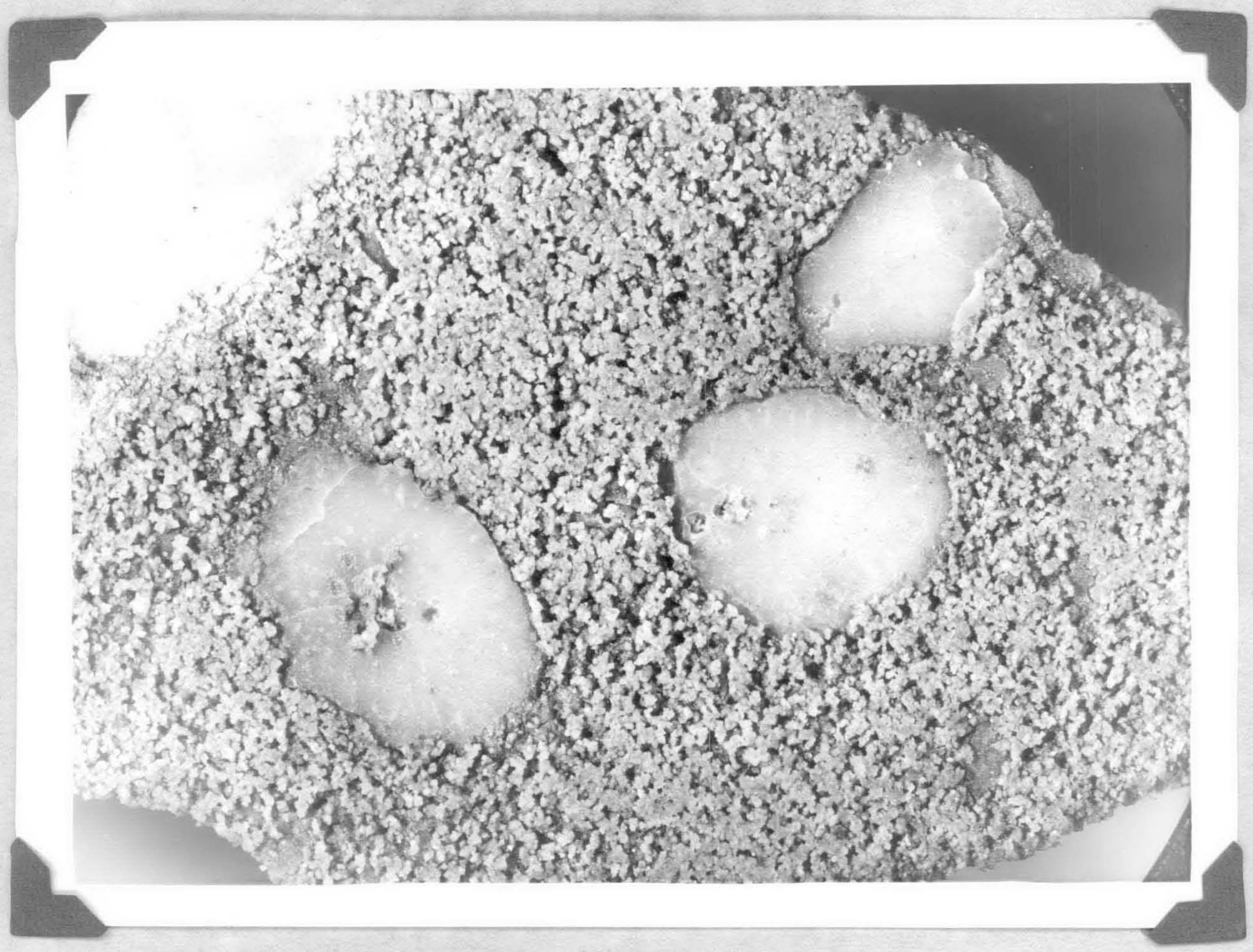

FIGURE 1. Etched biostromal limestone. X8.

dolomite remains as flat topped hills. Examination of etched surfaces with a hand lens or binocular microscope best reveals the interrelationship of the minerals in fine-grained rocks. Fig. 1 shows an etched biostromal limestone. The rock consists of stromatoporoids (calcite) separated by a calcite matrix containing dolomite rhombs. After etching, rhombs stand out with relief of the order of 1 mm., and calcite both of fossils and matrix, forms the floor on which the rhombs rest.

3. Staining

An effective staining method (Rodgers, 1940) involves use of a molar solution of $Cu(NO_3)_2$ on polished limestone surfaces: calcite stains blue, dolomite stains only after prolonged immersion. The molar solution of $Cu(NO_3)_2$ is prepared by dissolving in water 188 grams $Cu(NO_3)_2$ or 255 grams $Cu(NO_3)_2 3H_2O$ or 332 grams $Cu(NO_3)6H_2O$ and making up to one litre. Specimens are immersed in the solution so that the polished surface is not against the floor of the vessel, and care is taken to prevent adherence of bubbles to the polished surface. According to Rodgers, immersion should be for 5 or 6 hours at room temperature, or $2\frac{1}{2}$ to 4 hours for specimens high in calcite. The specimen is removed and immediately immersed for a few seconds in NH_4OH. It is then washed and rubbed before drying to remove excess precipitate, and is ready for study.

Staining is not as precise as etching in fine-grained rocks, for blueness overlaps from calcite to adjoining dolomite grains.

4. Microscopy.

Calcite commonly shows lamellar twinning, said usually to be absent from dolomite (Winchell, 1946, p.75). Moreover, the habit of calcite crystals in limestone is anhedral, rarely rhombohedral, that of dolomite is commonly rhombohedral. Distinction and determination from refractive indices can rapidly and easily be made. Calcite and dolomite are uniaxial, so true omega can be measured in all grains whatever their orientation in the immersion medium (ω for calcite = 1.658, for dolomite = 1.681). Omega for other common uniaxial carbonates is far higher (ankerite 1.698+, magnesite 1.700, rhodocrosite 1.817, siderite 1.830+, smithsonite 1.849) (Data from Larsen and Berman, 1939). True value of the remaining index epsilon is difficult to measure but is necessary only where complete optic data are required.

5. Chemical analysis.

This method, though precise, is long and expensive.

6. Summary.

Refractive indices can be used to determine and distinguish between calcite, dolomite and other carbonates. Etching and staining tests have the advantage of revealing distribution of the two minerals over relatively large surfaces (several square inches if necessary) of composite limestone. Knowledge of distribution so revealed may reveal factors such as the selective nature of dolomitization. Etching and staining methods, though not capable of absolute mineralogic determination are therefore very useful: moreover they are adaptable for field use.

DESCRIPTION OF SPECIMENS

ORDOVICIAN DOLOMITES

Five Ordovician limestones from the Gap Creek Dolomite (specimens 42, 44, 45, 51, 52), all subsequently determined as dolomites, were examined. Four are texturally similar, the other (52) being an intraformational limestone conglomerate. Specimen 44 is typical and is now described in detail. It is a dense granular rock, grey on fresh surfaces with irregularly distributed pink patches about 1 mm. in diameter, and weathers brown. The

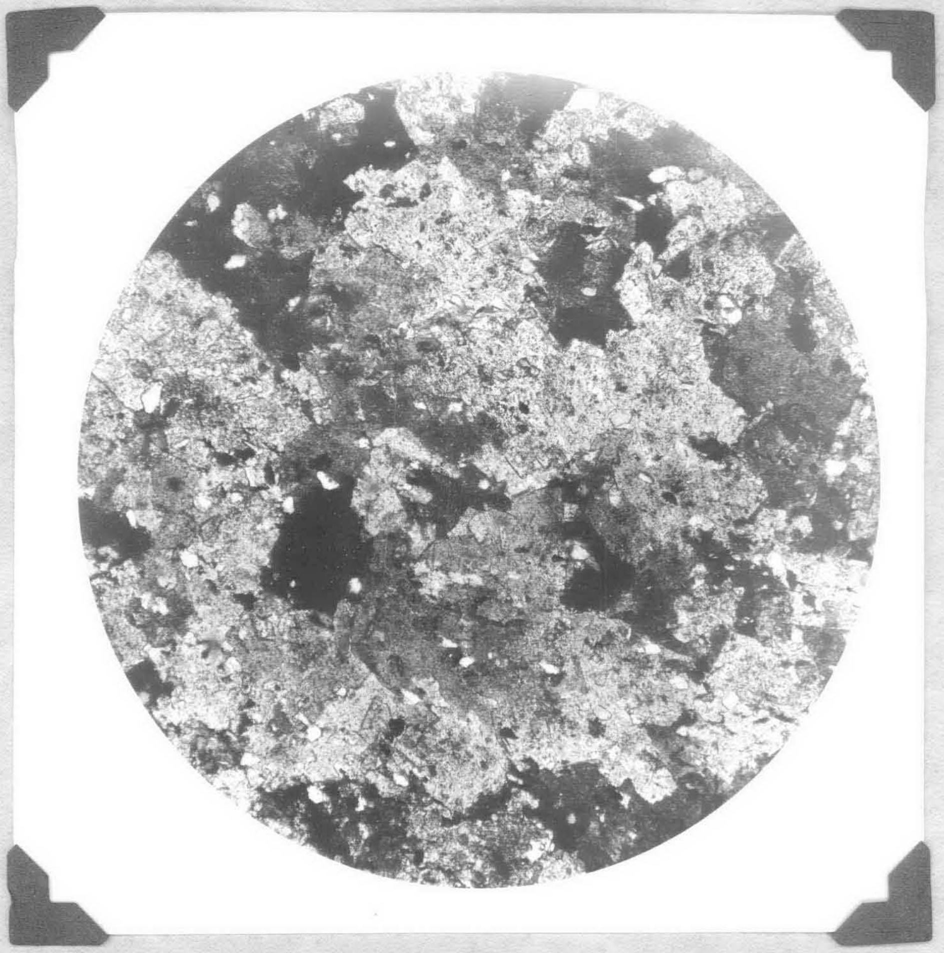

FIGURE 2. Ordovician dolomite. Small white grains are quartz. X30, X nicols.

bedded aspect of the rock in the field is consistent with clastic origin. Under the microscope (fig. 2) the rock is a mosaic of anhedral and subhedral grains of average diameter 0.25 mm.: a few grains are rhombic. Red iron oxide thinly impregnates the rock, and is locally concentrated to give the red spots visible in hand-specimens. Absence of twinning, negative reaction to etching and staining reagents, and refractive index ($\omega = 1.682 \pm .001$) prove dolomite.

Small quartz and plagioclase grains (average length 0.05 mm.) constitute 10% by weight of the rock. Many apparently anhedral quartz grains, when separated and examined in oils, show development of minute crystal edges, and probably 90% of the quartz can be demonstrated to have undergone authigenic growth. Most plagioclase is perfectly euhedral, and is authigenic: there are also a few rare grains of authigenic tourmaline. Many writers (Reynolds (1929), Tester and Atwater (1934), van Straaten (1948), Topkaya (1950)) believe authigenic silicates form in sediments at least after their partial solidification, by precipitation from percolating ground-waters, and Topkaya in particular presents strong evidence for their formation in lithified rock: if so, porosity sufficient for passage of these solutions through the Ordovician dolomites must have been present. Other writers however believe formation occurred at low temperature before lithification. Useful bibliographies are given by Daly (1917), Boswell (1933), Honess and Jefferies (1940) and Topkaya (1950).

Minute black granules are scattered through the rock. Mineragraphic examination (by W.M. Roberts, Bureau of Mineral Resources) of specimen 42 where they are more abundant, indicated a manganese mineral, possibly pyrolusite.

MIDDLE DEVONIAN LIMESTONES

1. Winjana Gorge

One of the best exposures of Middle Devonian biostromal and clastic limestone is found at Winjana Gorge, where the two alternate in a thick section. A description follows of selected specimens of typical lithologic types, together with a short summary of environmental and diagenetic conditions probably leading to their formation.

a. Biostromal Limestones

The constant thickness of biostromal layers, at least over lateral distances of several hundred feet, contrasts with the mound-like shape of biohermal reefs. Biostromal limestone has a framework of reef-forming organisms that have grown in situ, and which, at Winjana Gorge, form 15 to 90% of the rock. Space between the framework is filled with finely divided carbonate usually at least partly dolomitized and in places consisting mainly of dolomite. With diminution in amount of organic framework, biostromal limestone grades laterally into calcilutite or dolomite.

Microscopic appearance of a typical biostromal limestone (specimen 239) is shown in fig. 3. The handspecimen has a pink finely granular matrix that weathers tan to buff, and on weathered surfaces the small rhombs making up much of the matrix are visible with a hand lens. The remainder of the rock (about 30%) consists of white branching stromatoporoids.

Microscopy, etching and staining reveal the texture and mineralogy. The pink matrix consists of dolomite rhombs whose average length along the greatest diagonal is 0.25 mm., set in finely divided interstitial calcite. The rhombs are coated with a film of red iron oxide that imparts pinkness to the matrix in handspecimen, and one index (ω) was determined as $1.682 \pm .001$. Stromatoporoids are calcite ($\omega = 1.658 \pm .001$) and are not dolomitized but their edges are penetrated by rhombs growing from the adjoining matrix.

Where the matrix is only slightly dolomitized, its original

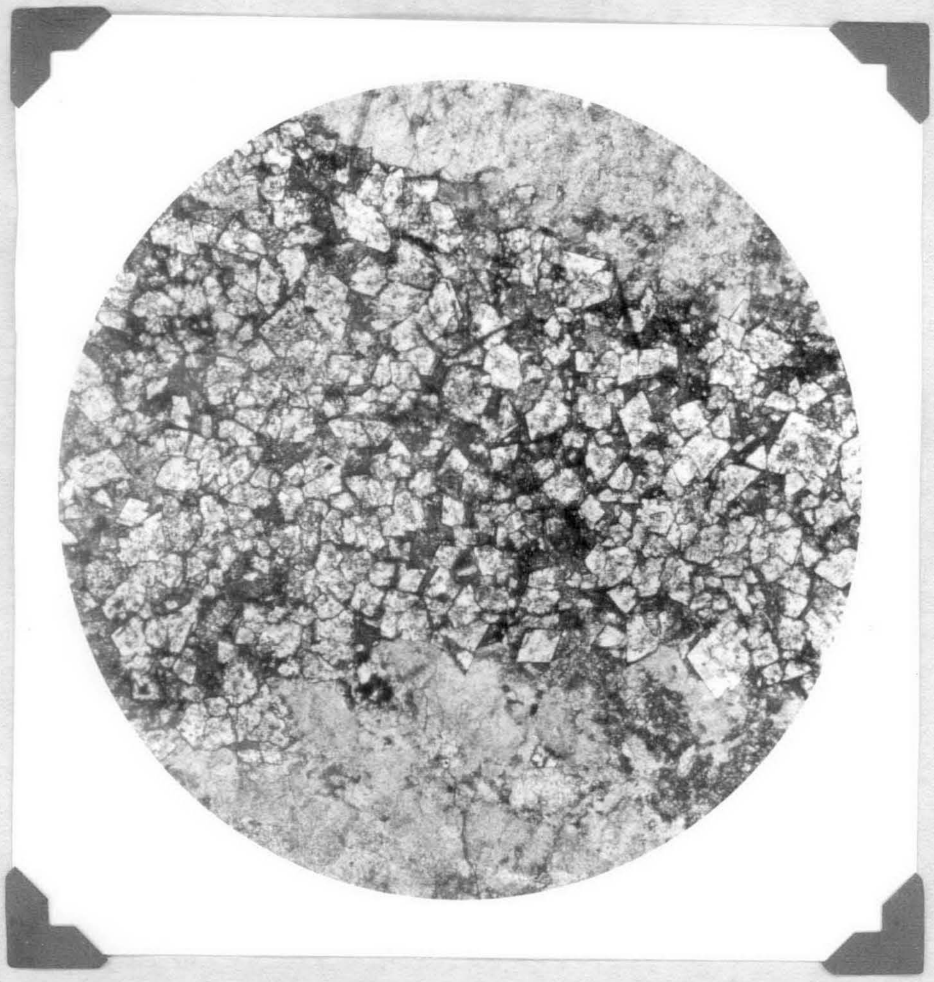

FIGURE 3. Middle Devonian biostromal limestone showing calcite reef building organisms (top, bottom) and dolomite rhombs in a calcite matrix (centre) X33.

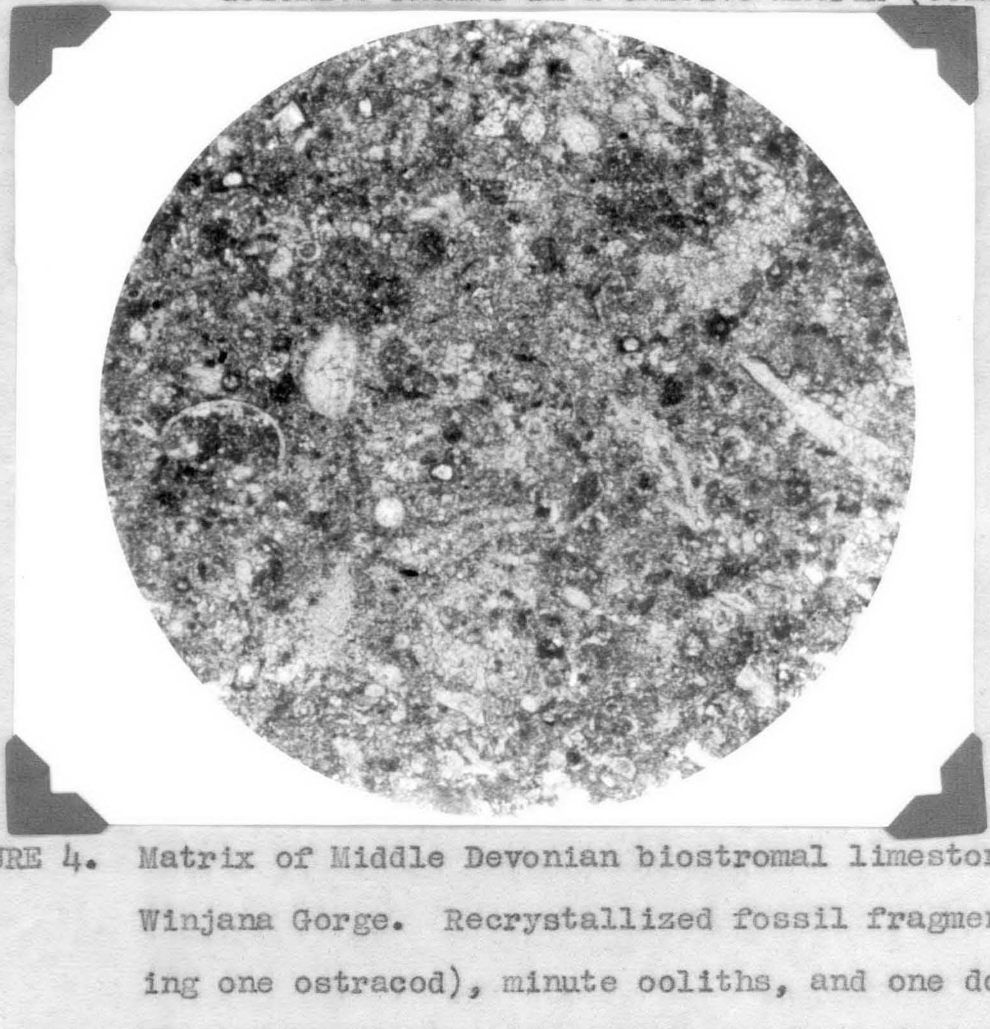

FIGURE 4. Matrix of Middle Devonian biostromal limestone from Winjana Gorge. Recrystallized fossil fragments (including one ostracod), minute ooliths, and one dolomite rhomb in a finely divided, grey calcite matrix. X32

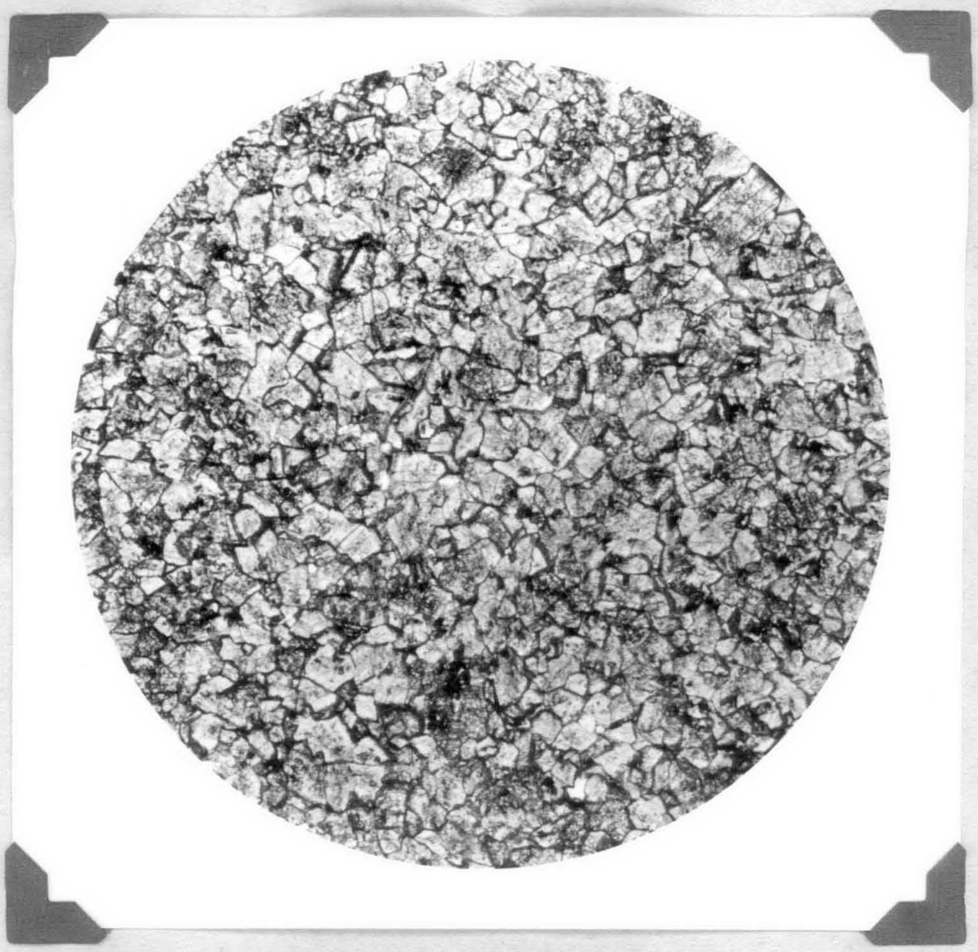

FIGURE 5. Dolomitized calcilutite from a lens in Middle Devonian biostromal limestone at Winjana Gorge. Note the rhombic shape of dolomite crystals. X30.

FIGURE 6. Middle Devonian calcarenite from Winjana Gorge. The grain near the upper centre of the photomicrograph is mica. Also near the centre are 3 ooliths. Other dark grains are calcilutite, white grains are quartz. Cement is calcite. X18.

texture is evident. Fig. 4 shows the microscopic appearance of the matrix of a slightly dolomitized pink biostromal limestone, with white reef building organisms (not shown in photograph) forming about 20% of the rock. The pink matrix is calcilutite, and consists of minute recrystallized oolites and ostracod and other organic fragments in a finely divided, slightly iron-stained calcite base. A few dolomite rhombs are scattered throughout the calcilutite, and rarely, rhombs are observed in the stromatoporoids. The calcilutite is probably lithified lime-mud, and various interpretations of its origin can be advanced. It may arise in the littoral zone from fine comminution of organic structures by abrasion, then to be carried out into deeper water: it may be coral or other detritus consumed in great quantities by holothurians, sea urchins and worms, and reduced by digestive action to fine paste: or it may be chemically precipitated from sea water. Perhaps all factors have contributed to some lime-muds. A useful summary of ideas on lime-mud, together with references, is given by Crickmay (in Ladd and Hoffmeister, 1945, pp.233-235).

In some biostromal limestones complete recrystallization prevents identification or even recognition of reef building organisms, but their nature is assumed from comparison with less recrystallized fossils nearby. The calcilutite matrix appears unaltered in such rocks. Authigenic silicates are sparingly distributed in many calcilutites.

Fig. 5 illustrates the microscopic appearance of a granular light brown rock that weathers grey, collected from a lens in biostromal limestone. The rock is dolomite, and is an even-grained mosaic of subhedral dolomite crystals with here and there a grain of authigenic quartz. The brown colour is due to thinly disseminated iron stains. This rock (specimen 259B) represents the end stage in dolomitization of calcilutite.

b. Calcarenites

Calcarenites at Winjana Gorge vary from grey through brown to red, and normally weather grey and brown. Mineralogically they grade from almost pure carbonate through sandy and micaceous calcarenite to calcareous sandstone. In many places calcarenites grade vertically in a few inches into biostromal limestone.

Calcarenites are normally recognizable under the hand lens, but such determination is not always easy. Presence of quartz and mica assists diagnosis, but where sand-sized, clastic carbonate fragments have uniform appearance, and are the same colour as carbonate cement, careful observation is needed to distinguish calcarenite from calcilutite. A dampened, fresh rock surface is best for observation.

Fig. 6 shows the microscopic appearance of a typical sandy micaceous calcarenite (specimen 259A). The rock contains irregularly shaped to subrounded, moderately to poorly sorted clastic grains of grey calcilutite, angular quartz, a few ooliths and mica flakes and clear crystalline calcite cement. The diameter of grains varies mainly between 0.1 and 2 mm. Calcilutite fragments are finely divided grey calcite containing a few minute angular granules of quartz (diameter 0.05 mm.) and some recrystallized fossil fragments. The raggedness of quartz grains in the calcarenite, and of quartz granules in calcilutite fragments strongly suggests diagenetic solution. Some quartz grains and a few calcilutite fragments have a narrow rim of calcilutite as though they had rolled in lime-mud before incorporation in the rock. The clear crystalline calcite cement, for reasons set out later in the petrological discussion of calcarenites, is assumed to be precipitated, and not recrystallized lime-mud.

Many clastic grains in the calcarenite suite at Winjana Gorge are derived from the Precambrian basement: these include quartz, biotite, muscovite, orthoclase, chlorite and rare hornblende and mica schist fragments. Carbonate detritus comprises calcilutite fragments, ooliths and fossil fragments that are commonly completely recrystallized (ostracods, stromatoporoids, brachiopods and probable crinoid stems have been recognized). Cement varies from clear

FIGURE 7. Poorly sorted Middle Devonian calcarenite from Menjou's Gap. Cement is finely divided grey calcite, fragments are mainly organic, with some calcilutite grains. X28.

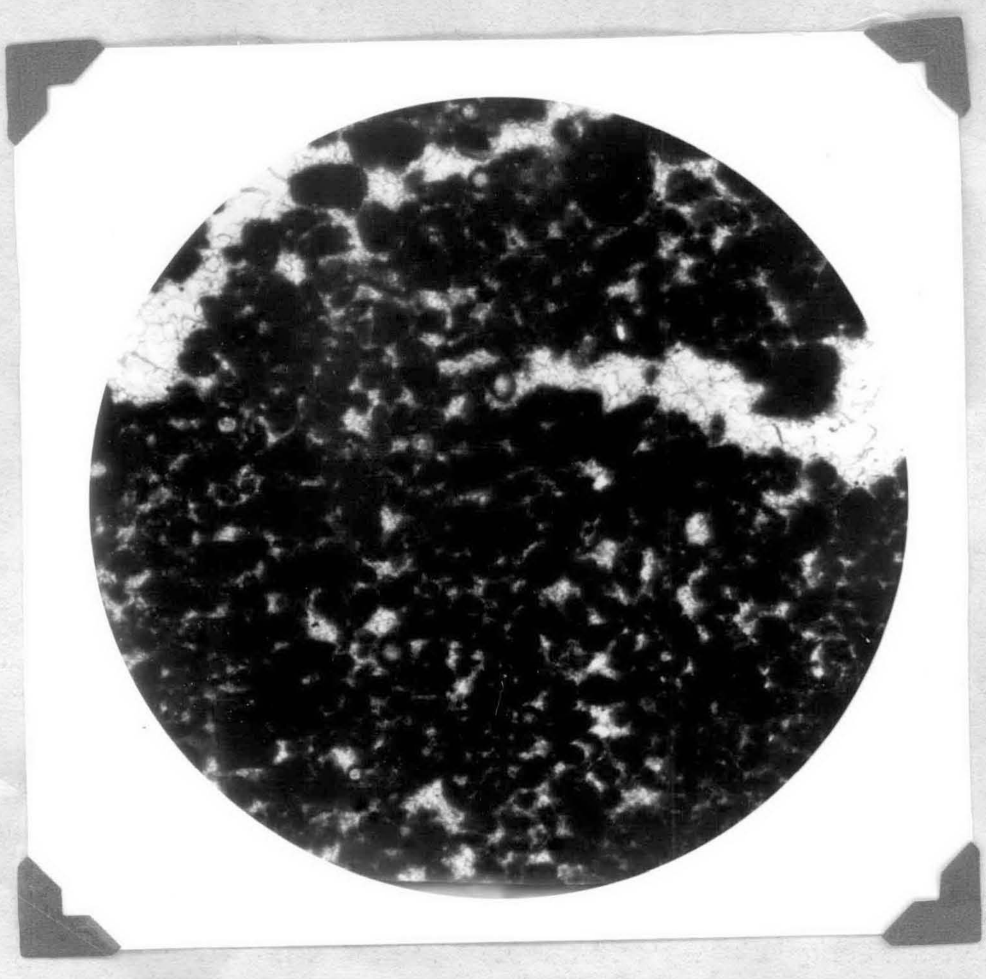

FIGURE 8. Very well sorted Middle Devonian Calcarenite from Menjou's Gap. Cement is clear calcite. X30.

crystalline calcite to finely divided cloudy calcite, the latter representing lime-mud.

c. Environment of deposition and post depositional changes.

The matrix of some biostromal limestones contains sand-sized clastic fragments, and locally small lenses of coarse sandy micaceous calcarenite. However, the matrix of most biostromal limestones is now represented by all stages between calcilutite and dolomite, and was originally lime-mud, so that its depositional environment was presumably quiet rather than turbulent. Calcarenites, with their coarser grain size, local small scale cross bedding and moderate sorting with the winnowing out of most lime mud (see page 8[redacted]) point to a shallower or less protected environment with stronger wave action. A section through the rocks at Winjana Gorge therefore indicates alternating periods of strong current action with dominant clastic sedimentation, and quieter waters with dominant reef growth. This could reflect cyclic climatic changes with variation in rainfall and hence of erosion, or repeated oscillations in position of the shore line.

Dolomite at Winjana Gorge has replaced calcite, and except where prevented by interference from adjacent dolomite crystals, forms perfect rhombic metacrysts. Dolomitization in 17 etched specimens of biostromal limestone was confined to the calcilutite matrix between the fossil framework of calcite, and was therefore selective. Thin sections of 6 calcarenites contain no dolomite.

It is not certain that the calcarenites at Winjana Gorge were derived partly from pre-existing, lithified, near shore, Middle Devonian biostromal limestones and calcarenites, but it is likely. Calcilutite fragments in the calcarenites resemble calcilutite from biostromal limestone, and both locally contain minute grains of authigenic quartz and feldspar. Absence of dolomite rhombs in calcilutite fragments in the 6 calcarenites studied microscopically is notable. If further investigation sustained present findings, it would suggest, but not prove, that authigenic silicates formed during or shortly after lithification, and that dolomitization occurred later.

2. <u>Menjou's Gap</u>

The Middle Devonian sequence at Menjou's Gap includes alternating biostromal limestones, calcilutites and calcarenites. Few specimens were studied in detail, but the three rocks described below (2 calcarenites, 1 calcilutite) provide good examples of micro-textures encountered.

a. Calcarenites

Two calcarenites, one very poorly sorted (specimen 77) and one excellently sorted (specimen 71A) are described.

Specimen 77 is pale brown, medium to coarse-grained and is made up of grey poorly sorted fragments up to 2 mm. long in a pale brown matrix that is indistinct under the hand lens and varies between aphanitic and finely granular. Microscopy emphasizes the poor sorting (fig. 7). Crinoid and ostracod remains, other organic fragments and calcilutite grains are set in a matrix mainly of brown, finely divided calcite (lime-mud) and partly of clear crystalline calcite. Association of lime-mud with very poorly sorted fragments is typical in calcarenites.

Specimen 71A as seen under the hand lens is a very well sorted, fine-grained, light grey calcarenite flecked with irregularly shaped patches and streaks of clear crystalline calcite. Some streaks are 5 mm. long and 1 mm. wide. Microscopic examination (fig. 8) shows that the rock is made up of rounded cloudy grey grains between 0.1 and 0.2 mm. diameter, and clear calcite cement. Lime-mud was probably winnowed out of the rock before lithification, and clear calcite was precipitated in the porous, even-grained limestone. The drusy outer fringe of crystals in many clear crystalline aggregates points to growth inward from borders of a

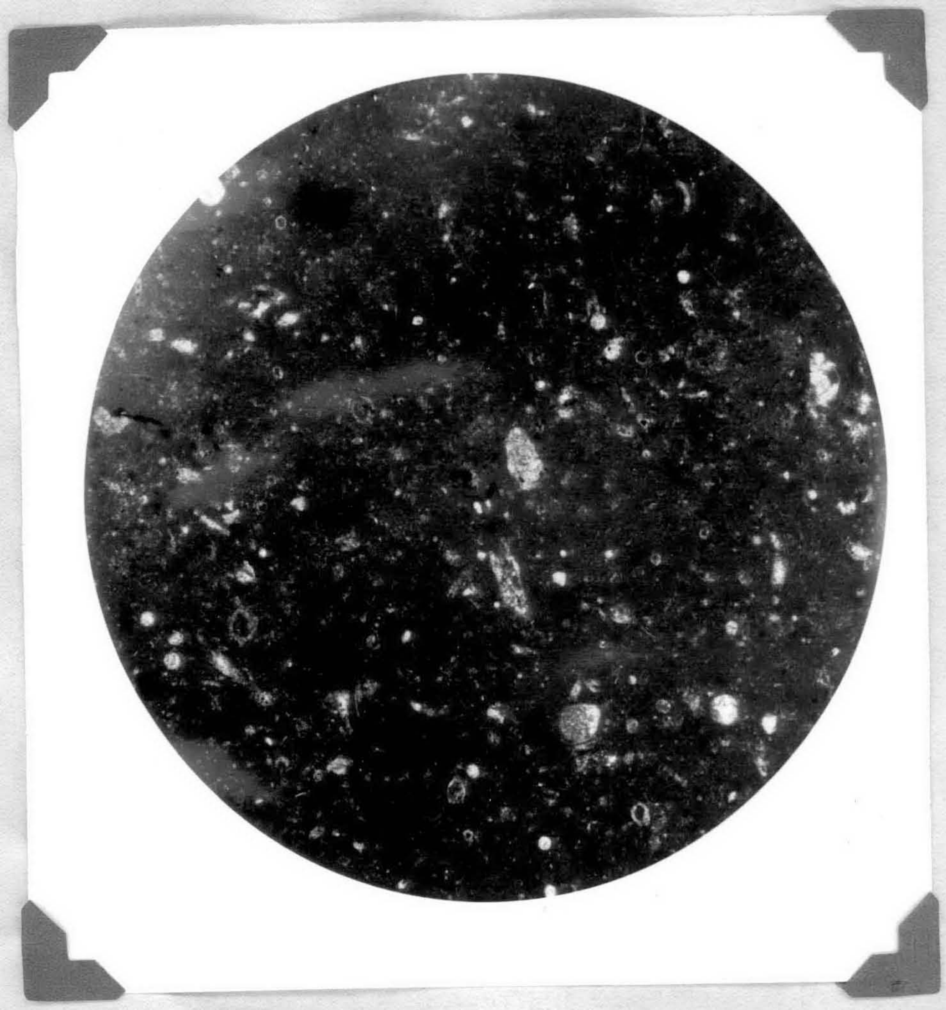

FIGURE 9. Middle Devonian calcilutite from Menjou's Gap. X20.

FIGURE 10. Stromatoporoid from Upper Devonian biohermal limestone. X18.

void. Where precipitation was excessive, clastic grains have been pushed apart by crystal growth until they no longer touch: clear calcite masses so formed are the calcite flecks observed in hand specimen. Well sorted clastic grains and clear crystalline calcite cement form a typical association in calcarenites (contrast with specimen 77, fig. 7).

b. Calcilutites

Microscopic appearance of a typical calcilutite (specimen 72B) is illustrated in fig. 9. Small fossil fragments and minute recrystallized ooliths are set in a fine calcite paste constituting over 90% of the rock. The handspecimen is light grey and aphanitic.

UPPER DEVONIAN LIMESTONES

Comprehensive petrographic examination of Upper Devonian limestones was not attempted. Petrography of biohermal limestones and calcarenites (including oolites) is discussed briefly below.

a. Biohermal limestones.

Bioherms are elongate, mound like reefs whose criteria for recognition are found in the field rather than the laboratory. They are strongly indurated, mostly grey on weathered surfaces, light grey on fresh surfaces, and include a wide range of textures. Stromatoporoids, brachiopods, crinoid stems and algae are recognized in some, but recrystallization has obliterated diagnostic fossil characters in most. Many bioherms contain angular pockets several inches long, of grey, tan and red-brown, finely banded and fine-grained carbonate. A thin section of such banded rock reveals crystalline carbonate, probably dolomite, containing about 5% quartz, mostly authigenic.

Eight thin sections of biohermal limestone studied include a section of stromatoporoid (fig. 10), oolith bearing calcarenite containing fossil fragments, crystalline limestone containing apparent remnants of algae, and limestone so completely recrystallized that the original nature of the rock cannot be decided. Authigenic silicates are common in some thin sections examined, dolomite is sparse or absent.

Microscopic data are consistent with both precipitated and clastic limestone having been deposited in cavities in a reef mass built of the skeletons of lime secreting organisms, the whole having been welded together by recrystallization. Recrystallization in many bioherms has destroyed obvious organic structure.

b. Calcarenites

There are all gradations between calcarenites almost entirely made up of ooliths and cement, and calcarenites containing few ooliths. Most but not all very well sorted calcarenites are very oolitic, and all are cemented by clear crystalline cement, whereas less well sorted calcarenites contain few ooliths, abundant fossil detritus and fragments of pre-existing limestone, and cement that is partly composed of lime-mud.

The term oolite has been used by different workers both for individual entities and rock composed mainly of such entities. Oolith has been used in a similar double sense, and for clarity oolith is here retained for the entity and oolite for calcarenite 80% or more of whose grains are ooliths. Some typical calcarenites from the Upper Devonian are described below.

Specimen 155 is a grey to pink, bedded oolitic limestone that weathers grey. It is stylolitic and locally fossiliferous, and evenly sorted, concentrically ringed ooliths set in clear cement are visible with the hand lens. The rock is an oolite. Under the microscope (see figs. 11,12) it comprises grey and grey-brown concentrically ringed ooliths of average diameter 0.5 mm. in a clear crystalline carbonate matrix. A few angular to subrounded grains of quartz and calcilutite and rare fossil fragments are also present.

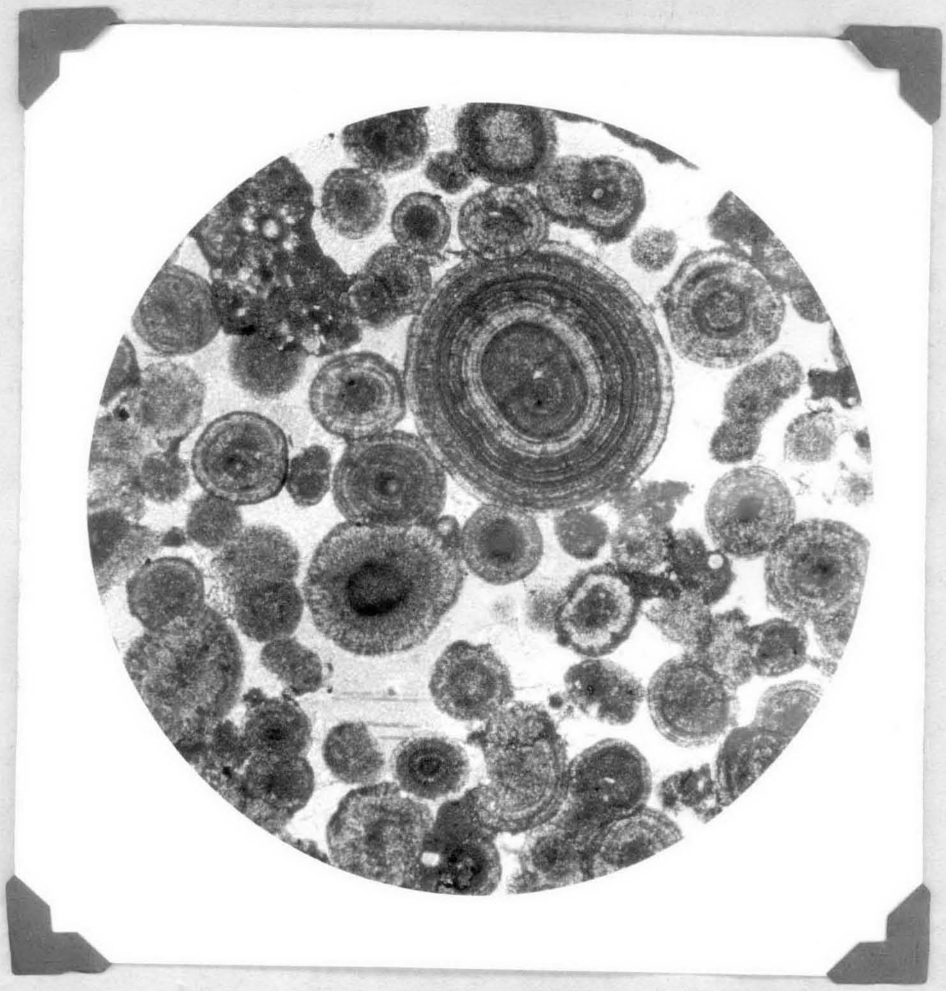

FIGURE 11. Upper Devonian oolite containing a mixture of unchanged and reorganized ooliths in clear calcite cement. Note pre-existing limestone fragment (top left), broken oolith (bottom) X25.

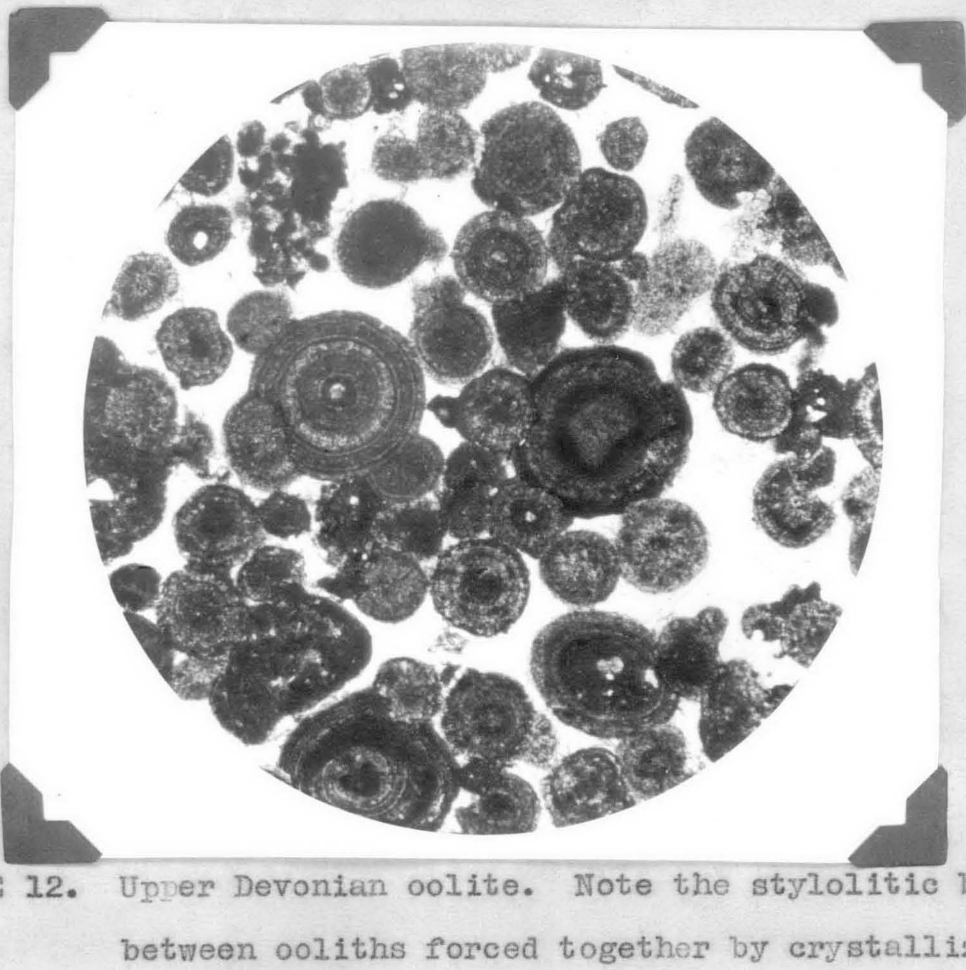

FIGURE 12. Upper Devonian oolite. Note the stylolitic boundary between ooliths forced together by crystallization of the introduced, clear calcite cement. X31.

Quartz is the core of a few ooliths but brown carbonate is far more common. Nine points concerning ooliths in this and other specimens are notable:

1) The calcite matrix, for reasons set out later is believed to have been precipitated, and does not represent recrystallized lime-mud.

2) Many grains and ooliths are not in contact with each other, and they were probably moved apart by the force of crystallization of the calcite matrix. The peripheral layer of some ooliths is partly peeled off, and some parts of the layer have been broken away by the force of crystallization so that they no longer touch any part of the oolith.

3) Some ooliths penetrate each other, probably due to pressure accompanied by solution at their contact. The stylolitic appearance of the contact, demarkated by limonite, bears this out.

4) Not all ooliths are complete. Breakage probably occurred during transportation before incorporation in the sediment.

5) Ooliths may have grown by accretion during the rolling of nuclei on the sea floor in a lime-mud environment, as assumed by Bergenback and Terriere (1953, p.1022). The obviously clastic origin of some nuclei, and the resemblance of concentric layers to lime-mud supports this. Not all ooliths have an obvious nucleus however. A few, but not many ooliths are compound, with two nuclei; it may be that two small somewhat plastic ooliths, fortuitously pressed to-gether on the sea floor, would in time become welded and later roll about as a single unit, continuing to grow by accretion.

6) Many ooliths have been reorganized. Initially, reorganization causes a fuzzy appearance with superimposition of radial structure on the original concentric structure: finally the oolith appears as a brown, structureless, spherical mass of finely divided carbonate not everywhere easily distinguishable from calcilutite fragments. Graf and Lamar (1950, p.2330) notice a similar effect in the Fredonia Oolite of Southern Illinois and state "The recrystallization is not the result of the alteration of aragonite to calcite, as indicated from the fact that unaltered parts of partly recrystallized oolites do not give X-ray reflections for aragonite". Bergenback and Terriere (1953, p.1022) note a random mixing of reorganized and unaltered ooliths within single thin sections from the Scurry Reef, Texas and suggest that ooliths may have been reorganized before final deposition. Such a random mixing is present in limestones from the Fitzroy Basin.

7) Most ooliths in specimen 155 are slightly stained, presumably by iron oxide. The ooliths take copper nitrate stain more strongly than the matrix, and etch in formic acid more rapidly. The matrix is however undoubtedly calcite ($\omega = 1.658 \pm .001$) so its slightly slower solution may be due to its granularity, which is coarse compared to the submicroscopic granularity of ooliths. Concentric layers within ooliths dissolve at unequal rates in formic acid. A rough analysis of specimen 155 made by I. Reynolds (BMR) after this report was written, gave the following results: $CaCO_3$ 93.3%, $MgCO_3$ 1.8%, Fe_2O_3 0.1%, insoluble 4.2%.

8) Some ooliths are cut by white calcite veinlets. The veinlets also cut the calcite cement, with which they are in optical continuity, but through which they can be traced by slight colour difference. Veins of precisely the same appearance cut ooliths and calcite cement in the Fredonia Oolite (Graf and Lamar, 1950, p.2334).

9) The concentrically ringed ooliths of calcarenites differ remarkably from ooliths in calcilutites. The latter are far less common, much smaller (average diameter about 0.1 mm.) and are homogeneous, consisting of white calcite with radial structure that gives a dark cross under crossed nicols. They may have a different origin from larger, concentrically ringed ooliths.

Specimen 159B is light grey and well bedded, and under the hand lens appears to be composed of very well sorted rounded fragments and ooliths. Under the microscope ooliths, quartz (a little of which is authigenic), calcilutite fragments and crystalline

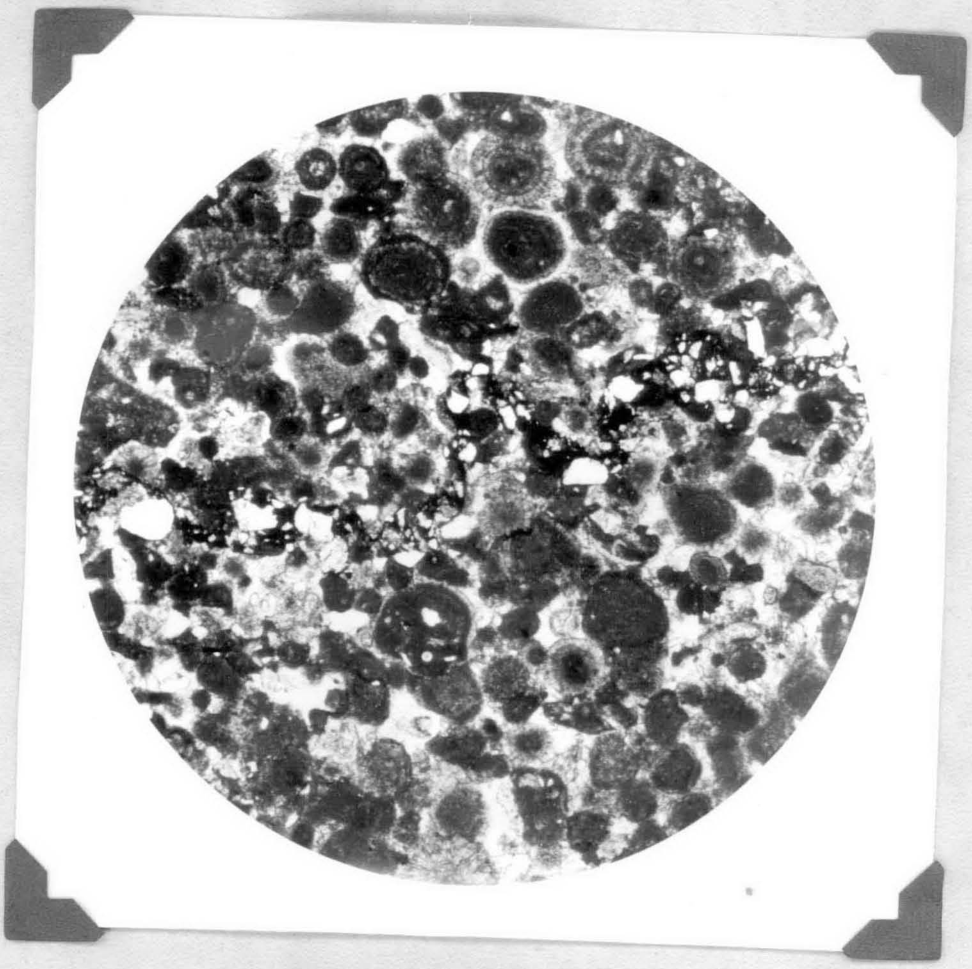

FIGURE 13. Upper Devonian calcarenite with microstylolite (see text). X31.

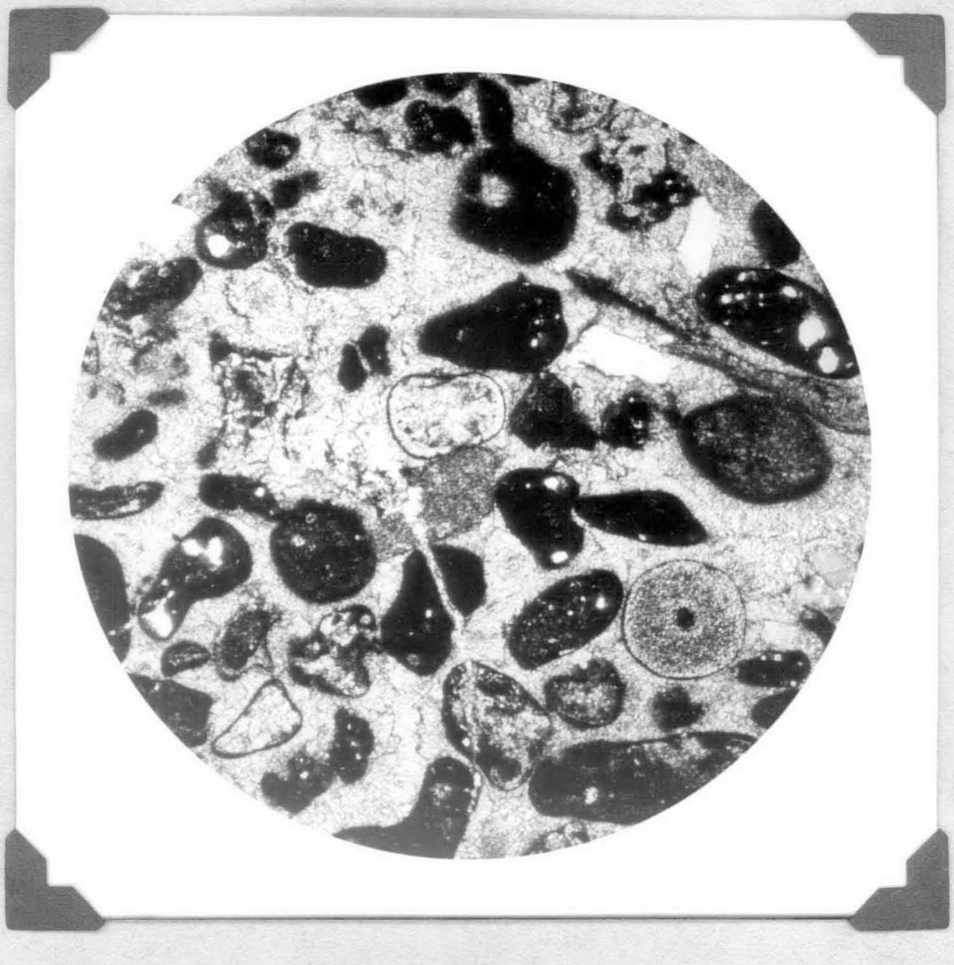

FIGURE 14. Upper Devonian calcarenite. Note calcite vein cutting calcilutite fragments and clear calcite cement. X30.

calcite cement are seen. A microstylolite is present, and the two parts of the rock on either side of it have been forced together with simultaneous solution and removal of calcite. The concentration of quartz, compared to its relatively sparse distribution in the rock, indicates movement of the order of 1 mm. (See fig. 13). Dark material delineating the stylolite is most likely an insoluble residue of clay minerals and iron oxide.

Fig. 14 illustrates a fairly well sorted calcarenite (specimen 133) unusual for its paucity of ooliths. Grains are quartz, fossil detritus (mainly crinoidal) and calcilutite fragments, set in clear crystalline calcite cement.

Fig. 15 shows a poorly sorted calcarenite of special type (specimen 211). Dark calcilutite fragments from an earlier limestone are scattered throughout but most detritus is crystalline crinoid debris. Calcite cement, as usual in such rocks (called encrinites by Pettijohn (1949, p.301)) has crystallized in optical continuity with crinoid fragments.

c. Petrological discussion of calcarenites

In the light of data accumulated in this investigation, brief petrological discussion of the calcarenite suite is possible. Evidence concerning the origin of cement is briefly set out and a suggested sequence of events in the formation of many calcarenites is presented.

It has been assumed throughout that the finely divided, grey calcite cement found in some calcarenites was once mud, and that the clear crystalline calcite cement was precipitated. Finely divided calcite cement has the same appearance as calcilutite, and its origin is not doubted. Arguments in favour of precipitation of clear crystalline calcite cement, instead of its formation by recrystallization of lime-mud cement, are now summarized.

1) The calcilutite matrix is not reorganized in calcilutites and biostromal limestone containing recrystallized fossil fragments.

2) The calcilutite fragments of calcarenites would surely recrystallize if a lithified lime-mud cement (calcilutite) recrystallized to give clear calcite cement. On the other hand in specimen 259A (fig. 6) many grains have a border of lime-mud probably adhering to them after rolling on the sea floor, and this should have recrystallized if conversion took place before lithification.

3) There are few quartz granules and no relict structures of fossil fragments in the clear crystalline calcite cement, and these would be expected in a reorganized calcilutite matrix.

4) Well sorted calcarenites (including oolites) generally contain only crystalline calcite cement. Good sorting is consistent with finer material being winnowed out by current action. Poorly sorted calcarenites commonly contain some calcilutite (mud) cement.

5) Many ooliths and clastic grains have a drusy fringe of calcite crystals, suggesting growth in a primary interstitial void.

A remarkably similar series of observations has been made by Bergenback and Terriere (1953) concerning the crystalline calcite matrix of calcarenites in the Scurry Reef, Texas.

The following sequence of events leading to formation of moderately to well sorted calcarenites is suggested:

1) Accumulation of sorted debris (quartz and other minerals, ooliths, fossil detritus, fragments of pre-existing limestone) in water subject to wave and current action, with contemporaneous elimination of mud by winnowing out and removal to quiet waters, leaving a porous lime sand.

2) Precipitation of clear calcite cement in voids between grains, greatly reducing porosity, lithification.

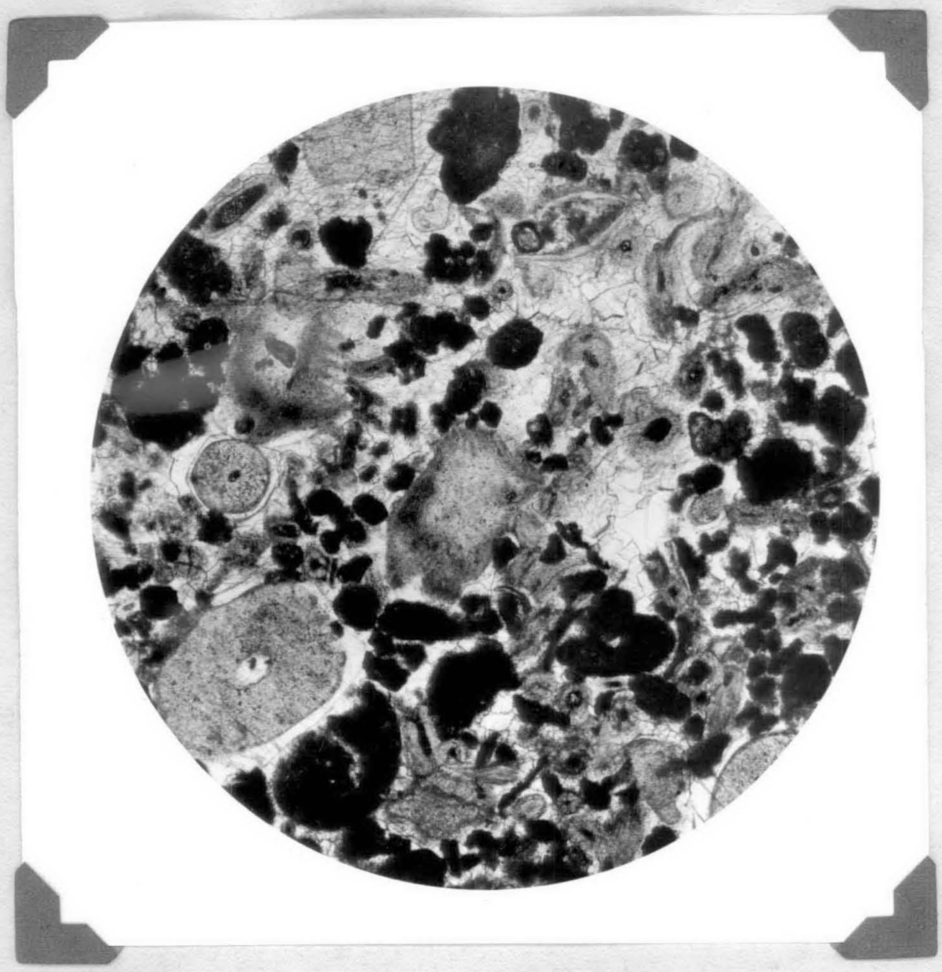

FIGURE 15. Upper Devonian calcarenite made up of crinoidal detritus and calcilutite fragments in clear calcite cement. Cement has grown in optical continuity with some crinoid fragments.

3) Minor calcite veining, formation of stylolites, jointing, etc.

CONCLUSION

Petrographic and petrologic work described above was rather hurried, and does not pretend to be exhaustive. Some rocks, notably limestone breccias and fine-grained rocks described in the field as calcareous siltstones, have not been dealt with. It is felt however that the descriptions of mineralogy and texture given above will serve as a preliminary guide to classification of limestones from the Fitzroy Basin, for no detailed laboratory investigation of them has hitherto been attempted.

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