Limestone Classification

Two of the most popular limestone classifications are those of Folk (1959, 1962) and Dunham (1962). These are summarized in Tables 3 and 4 and Fig. E.

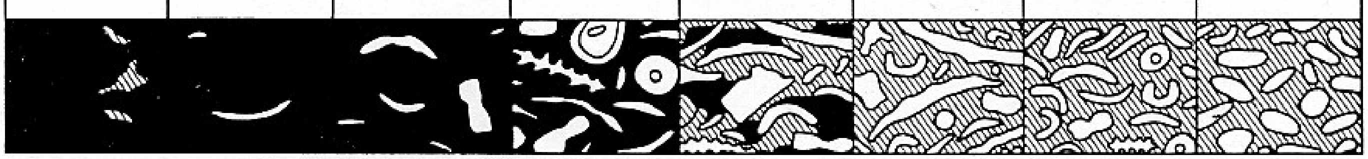
Original components not organically bound together during deposition				Components organically bound during deposition
contains carbonate mud			no carbonate mud	
mud-supported		grain-supported		
< 10% allochems	> 10% allochems			
MUDSTONE	WACKESTONE	PACKSTONE	GRAINSTONE	BOUNDSTONE

Table 3. Classification of limestones according to Dunham (1962) Rock names are in capital letters

volumetric allochem composition			> 10% allochems: Sparry calcite > Micrite	> 10% allochems: Micrite > Sparry calcite	< 10% allochems: 1–10% allochems (Most abundant allochems)	< 10% allochems: <1% allochems	Undisturbed reef and bioherm rocks
> 25% Intraclasts			INTRASPARITE	INTRAMICRITE	Intraclasts INTRACLAST-BEARING MICRITE	MICRITE, or if sparry patches present DISMICRITE	BIOLITHITE
< 25% Intraclasts	> 25% Ooids		OOSPARITE	OOMICRITE	Ooids OOID-BEARING MICRITE		
< 25% Intraclasts	< 25% Ooids; Volume ratio, bioclasts: peloids	3:1	BIOSPARITE	BIOMICRITE	Bioclasts FOSSILIFEROUS MICRITE		
< 25% Intraclasts	< 25% Ooids; Volume ratio, bioclasts: peloids	3:1 to 1:3	BIOPELSPARITE	BIOPELMICRITE			
< 25% Intraclasts	< 25% Ooids; Volume ratio, bioclasts: peloids	1:3	PELSPARITE	PELMICRITE	Peloids PELOID-BEARING MICRITE		

Table 4 Classification of limestones based on the scheme of Folk (1959, 1962) Rock names are in capital letters

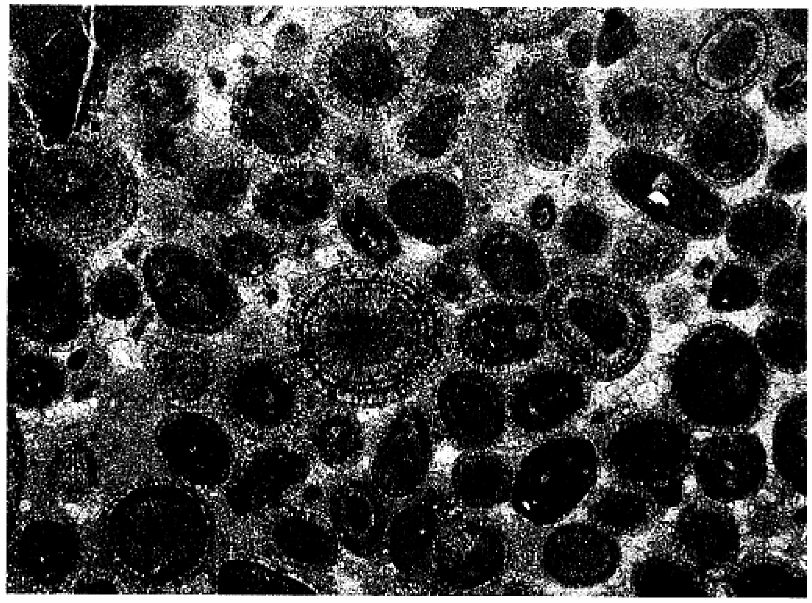
Over ⅔ micrite matrix				Subequal spar & micrite	Over ⅔ spar cement		
0–1% Allochems	1–10% Allochems	10–50% Allochems	Over 50% Allochems		Sorting poor	Sorting good	Rounded & abraded
Micrite & dismicrite	Fossiliferous micrite	Sparse biomicrite	Packed biomicrite	Poorly-washed biosparite	Unsorted biosparite	Sorted biosparite	Rounded biosparite

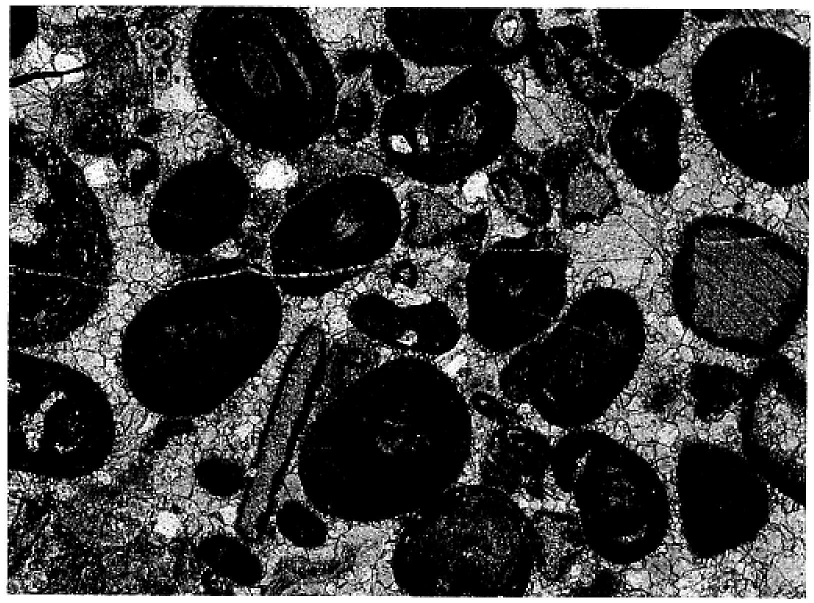


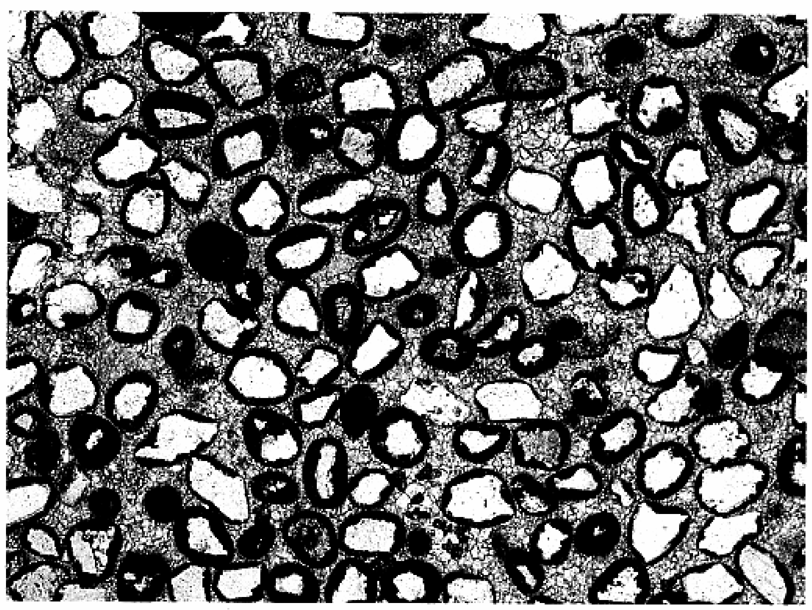
Micrite matrix Sparry calcite cement

Fig. E The range in textures shown by carbonate rocks, illustrated using the rock names of the Folk classification (after Folk, 1959)

Ooids







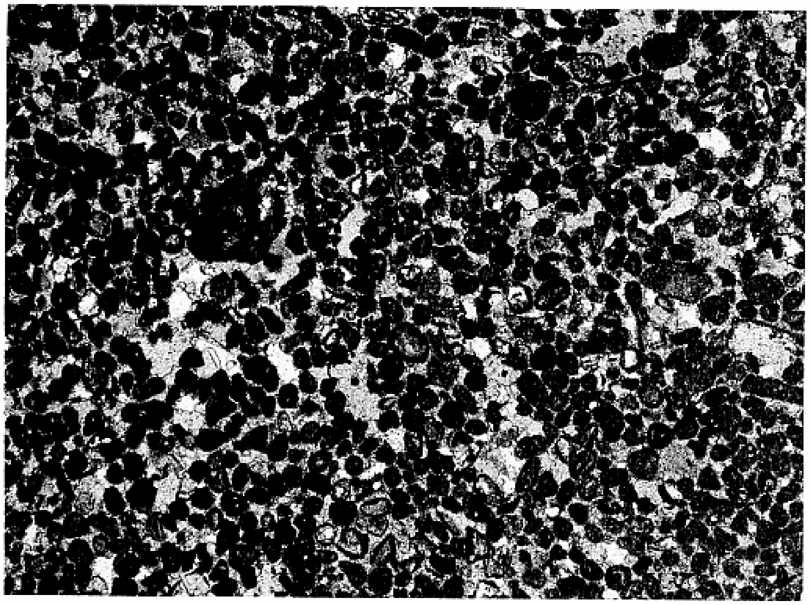
Ooids or *ooliths* are spherical or ellipsoidal grains, less than 2 mm in diameter, having regular concentric laminae developed around a nucleus. Ancient ooids often show both the concentric laminae and a radial structure. It is not always certain whether the radial structure is primary, or formed during the inversion of aragonite to calcite.

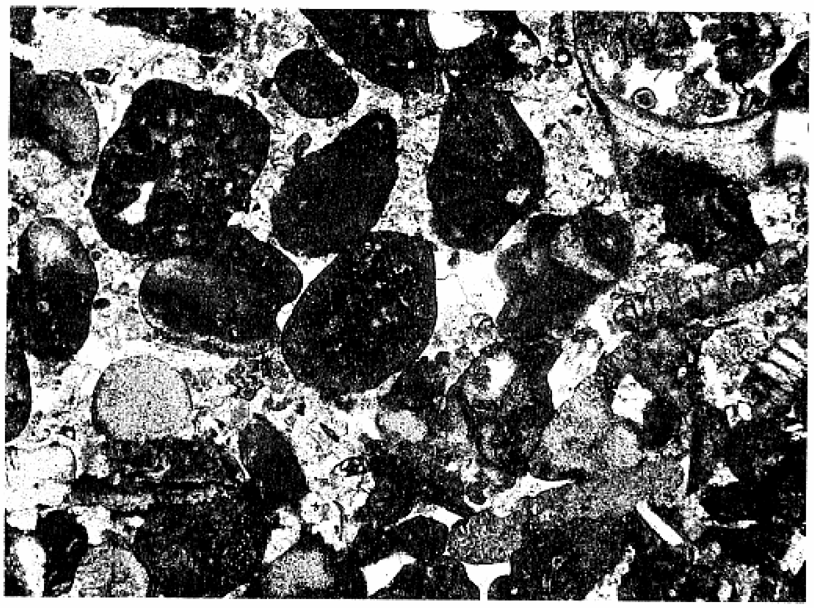
72 shows ooids with well-developed radial and concentric structures. The nuclei are micritic carbonate grains. The sample shows a range of ooids, from those with a small nucleus and thick cortex (the oolitic coating), to those with a large nucleus and a single oolitic lamina. The latter are called *superficial ooids*. The matrix between the ooids is a mixture of carbonate mud and sparry calcite cement.

73 illustrates ooids with a rather poorly-preserved concentric structure. The structure may have been partly lost by micritization (p. 54). The speckled plates with thin micrite coatings are echinoderms (an example can be seen half way up the right-hand edge). The pink-stained cement is non-ferroan sparry calcite. The unstained grains with low relief are secondary (authigenic) quartz replacing calcite.

74 shows ooids with relatively thin cortices coating detrital quartz nuclei. Note how the early ooid laminae fill in depressions on the surface of quartz grains and are absent from angular corners. The cement is pink-stained non-ferroan sparry calcite.

72: Stained thin section, Upper Jurassic, Cap Rhir, Morocco; magnification × 31, PPL.
73: Stained thin section, Hunt's Bay Oolite, Lower Carboniferous, South Wales; magnification × 43, PPL.
74: Stained thin section, Carboniferous Limestone, Llangollen, Clwyd, Wales; magnification × 27, PPL.
Ooids can also be seen in **125**, **127**, **137**, **146**, **147** *and* **155**.





Peloids and Intraclasts

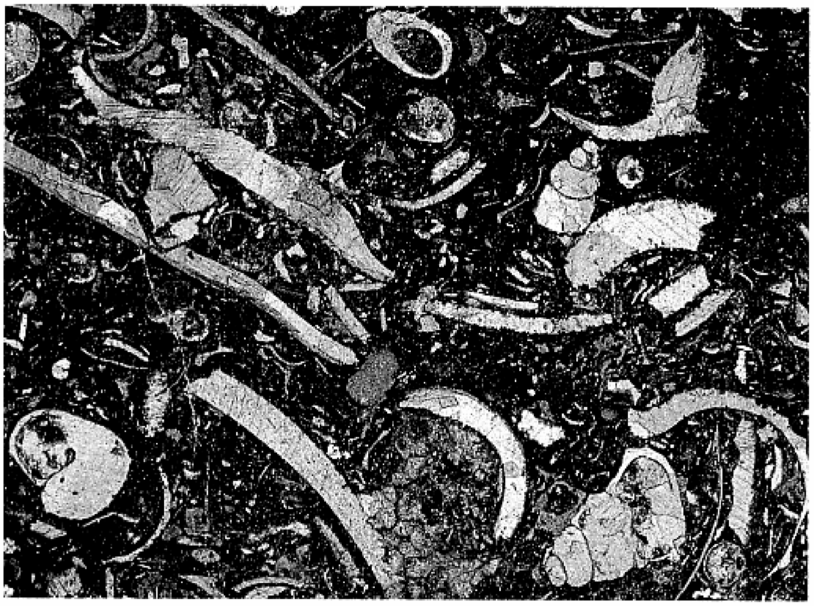
A large proportion of the allochems in limestones are grains composed partly or entirely of micrite, but having no concentric laminae in their outermost zones. Various terms have been used to classify these grains and most depend on an interpretation of their origin.

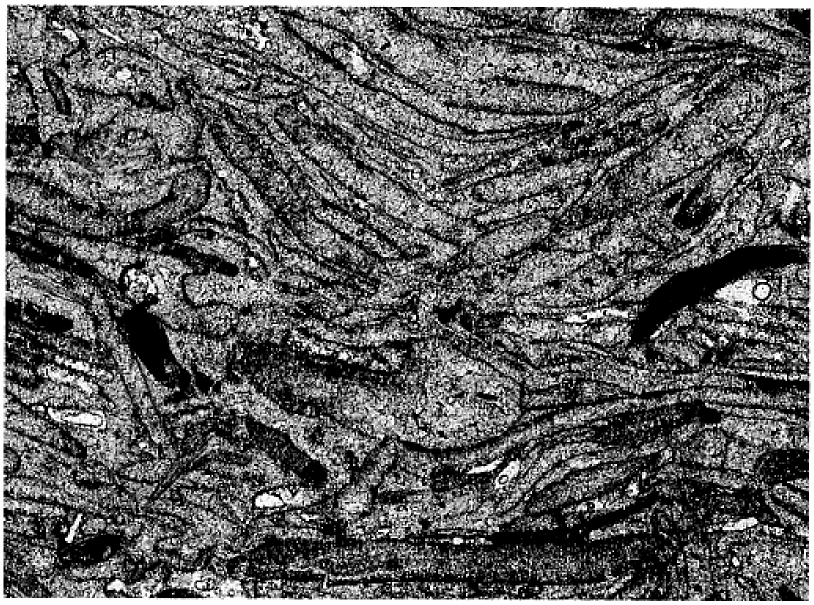
Those grains composed of micrite and lacking any recognizable internal structure are called *peloids*. **75** shows a limestone in which the allochems are mainly peloids, circular to elliptical in cross-section and averaging about 0.1 mm in diameter. Such peloids are generally interpreted as faecal in origin and are called *pellets*. The photograph shows pellets at the lower end of the size range for typical pellets, which extends up to 0.5 mm.

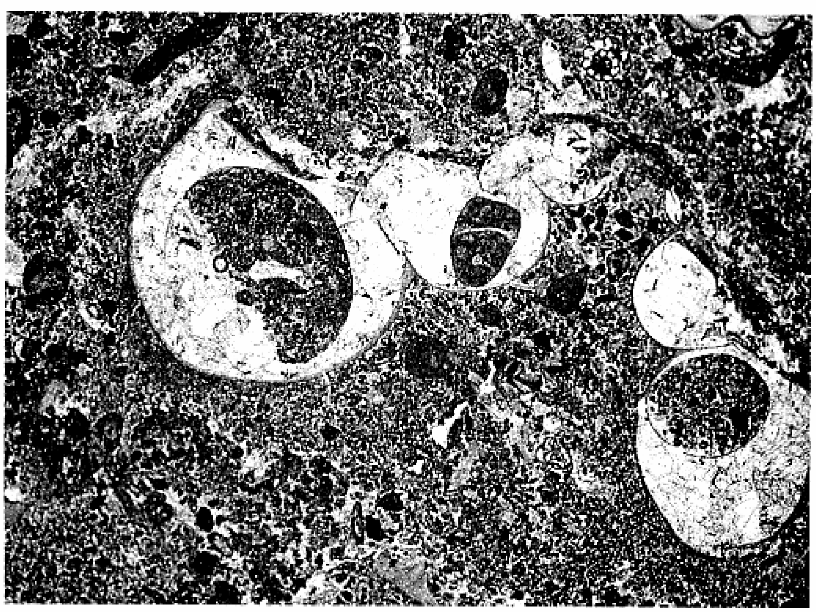
76 shows larger, less regular peloids, some of which have a trace of internal structure although its nature cannot be identified. In the lower part of the photograph are speckled echinoderm plates, and midway up the right hand edge are segments of the dasycladacean alga *Koninckopora* (see **113**). Both echinoderms and algae show signs of replacement by micrite around their margins (micritization, p. 54). It is probable that the peloids were formed by intense micritization of bioclasts, thus accounting for their vague relict structures.

Intraclasts are sediment which was once incorporated on the sea-floor of the basin of deposition and was later reworked to form new sediment grains. **77** shows a large grain which might be described as a 'coated bioclast'. It comprises a nucleus, which is a fragment of a brachiopod shell, surrounded by a coating of microcrystalline calcite. The coating is not laminated, so the grain cannot be called an oncoid (see p. 38); it is external to the shell and has a sharp contact with it so the coating was not formed by micritization (see p. 54). It is therefore likely that it is a fragment of locally-reworked sediment, the brachiopod shell having once been incorporated in a fine-grained sediment which was later eroded to produce intraclasts.

75: Stained thin section, Upper Jurassic, Cap Rhir, Morocco; magnification × 33, PPL.
76: Unstained thin section, Woo Dale Limestone, Lower Carboniferous, Long Dale, Derbyshire, England; magnification × 21, PPL.
77: Stained thin section, Urswick Limestone, Lower Carboniferous, Trowbarrow, Cumbria, England; magnification × 15, PPL.
Peloids are also shown in ***86, 123, 130, 134, 147, 158*** *and* ***162****.*







Bioclasts

Molluscs

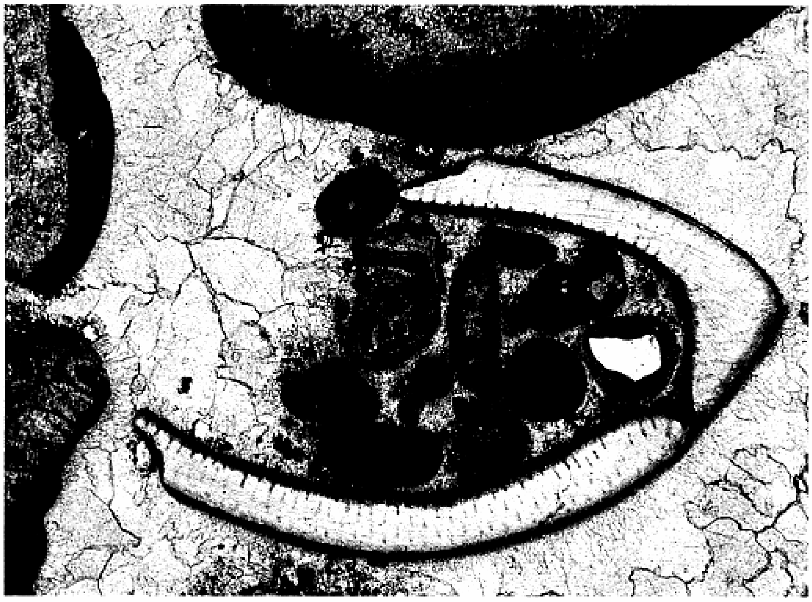
Bivalves and gastropods are common components of limestones. Most were made of aragonite, so although there are a diversity of structures, these are not seen in ancient limestones. Most originally aragonitic molluscs are preserved as *casts* – that is the aragonite dissolved out during diagenesis leaving a mould which later became filled with a sparite cement. There are, however, important molluscan groups which had a calcite shell, especially among the bivalves, and these have well-preserved wall structures.

84 shows a limestone with abundant molluscan casts. In this case shell moulds have been infilled with a few large calcite crystals. Gastropods can be seen, both in long section (lower right) and transverse section (lower left). The long straight shells are bivalve fragments. Careful inspection shows that the long valves in the upper left have a two-layer structure – a thick layer of coarse sparite and a thin layer with a different structure. This latter layer may have been calcite originally, indicating that the organism had a mixed aragonite/calcite skeleton. The rock matrix is micritic sediment.

85 shows a limestone made up almost entirely of rounded bivalve fragments preserved as casts. The shape of the fragments is shown by the thin micrite rims on the margins of the shells. These are *micrite envelopes* and formed by micritization by endolithic algae (p. 54). The cement infilling the bivalves and between the shells is a fine sparite, initially pink-stained non-ferroan calcite, but becoming ferroan towards the centres of pore-spaces as indicated by the bluish staining.

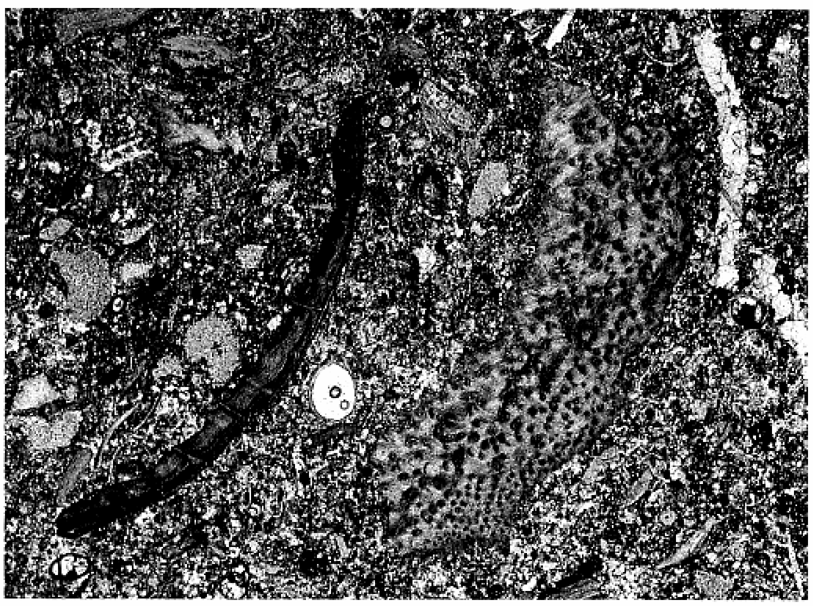
86 illustrates a section through a large thick-shelled gastropod, again preserved as a cast. The outer margin of the shell is picked out by a thin calcite layer, not more than 0.5 mm thick at this magnification, but the inner margin is only clear where sediment has partially filled the internal cavity. The sediment around the shell contains abundant small peloids.

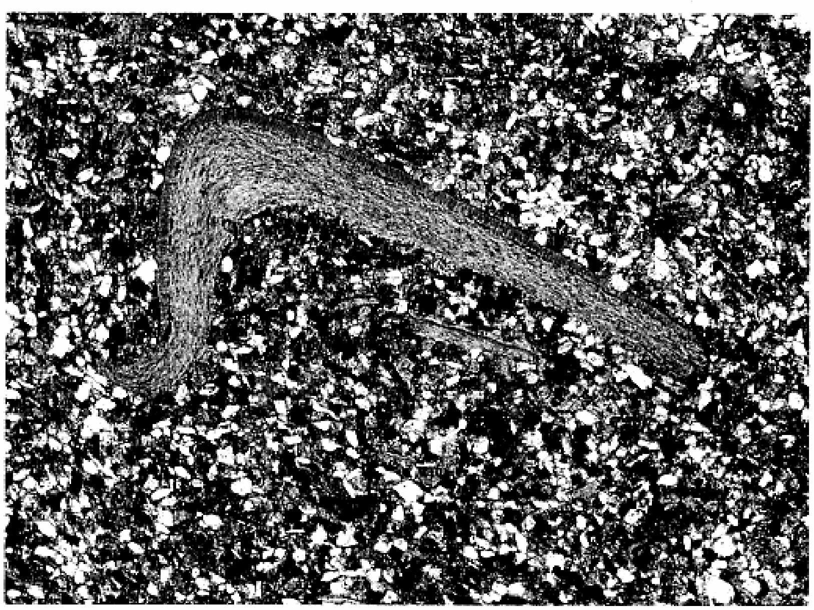
84: Stained thin section, Eyam Limestone, Lower Carboniferous, Ricklow Quarry, Derbyshire, England; magnification × 13, PPL.
85: Stained thin section, Upper Jurassic, Dorset, England; magnification × 14, PPL.
86: Stained acetate peel, Martin Limestone, Lower Carboniferous, Millom, Cumbria, England; magnification × 7, PPL.



Bioclasts

Brachiopods





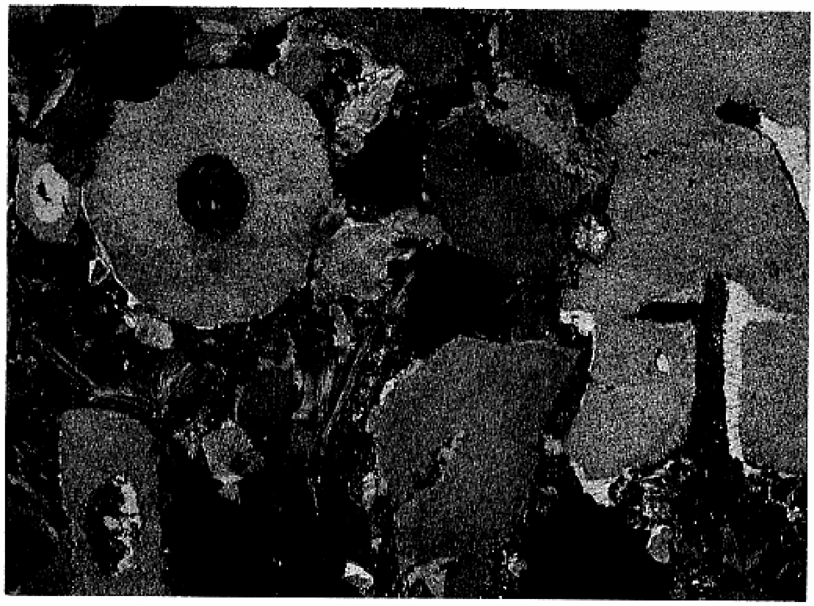
The articulate brachiopods are important constituents of Palaeozoic and Mesozoic limestones. They were originally calcite and so their shell structures are well-preserved. Typically, brachiopods have a thick inner layer of calcite fibres aligned with their length at a low angle to the shell wall. A thin outer prismatic layer may be preserved.

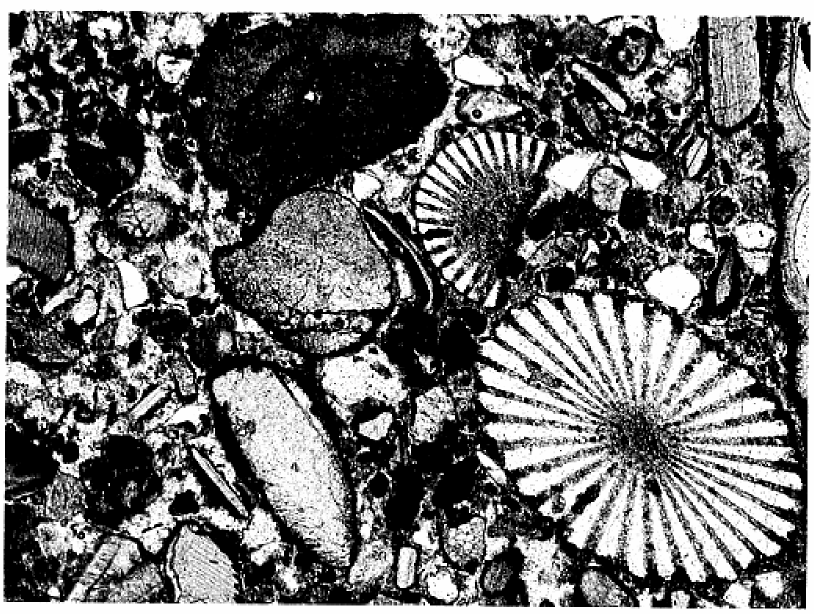
90 shows a broken brachiopod of which parts of both valves are present and surrounded by a micrite envelope (p. 54). The fibrous structure is clearly visible, as are fine tubes at right angles to the shell wall, filled with blue-stained ferroan calcite cement. These are *endopunctae* and they characterize some groups of brachiopods. The sample also shows a good example of coarse, blue-stained ferroan calcite cement.

91 shows two large fragments of *pseudopunctate* brachiopods. In these, the fibrous wall structure is interrupted, not by open tubes but by calcite rods. The left-hand fragment shows the pseudopunctae sectioned parallel to their length. Note the wavy nature of the fibres adjacent to the pseudopunctae. The right-hand fragment is a section of a shell showing the pseudopunctae in cross-section.

92 illustrates a brachiopod fragment with its outer prismatic layer preserved. The foliated nature of the inner part of the wall is also well shown. The shape of the fragment suggests that it is part of a ribbed shell. It is also *impunctate*, lacking either endopunctae or pseudopunctae. These factors in an Upper Jurassic brachiopod indicate that it is part of a rhynchonellid. The fine-grained calcite matrix contains abundant colourless fine sand- and silt-size quartz.

90: Stained thin section, Inferior Oolite, Middle Jurassic, Leckhampton Hill, Gloucestershire, England; magnification × 32, PPL.
91: Stained thin section, Monsal Dale Limestone, Lower Carboniferous, Cressbrook Dale, Derbyshire, England; magnification × 16, PPL.
92: Stained thin section, Upper Jurassic, Jebel Amsitten, Morocco; magnification × 40, PPL.





Bioclasts

Echinoderms

Echinoderms, particularly echinoids and crinoids, are major contributors to the allochemical fraction of marine limestones. They are easy to identify because they break down into plates which, although they may exhibit a wide variety of shapes, are single calcite crystals with uniform extinction. They usually have a speckled or dusty appearance as the result of infilling of the fine pores which permeate the plates.

96 and **97** show a crinoidal limestone in which the sediment is 75% crinoids. Note the speckled appearance of the plates, most of which have uniform interference colours and are thus single crystals, although the ossicle in the upper left comprises two crystals, one showing a greenish colour and one a red colour under crossed polars. The clear spar surrounding some of the crinoid fragments is a cement. The XPL photograph shows that the interference colour of this cement is the same as the adjacent crinoid fragment. Hence it is probable that the cement is in optical continuity with the crinoid. Such cements are common in echinoderm-bearing sediments and are called *syntaxial rim cements* (p. 57). The remainder of the sample comprises micritic sediment and fragments of fenestrate bryozoans (e.g. lower right hand corner).

Echinoid spines are widespread, particularly in Mesozoic and Cenozoic limestones. **98** shows one complete transverse section of a spine (lower right of field), together with a smaller broken fragment. Echinoid spines are circular or elliptical in cross-section and show a variety of radial structures. Like other echinoderm fragments, they are single crystals.

96 and 97: Stained thin section, Eyam Limestone, Lower Carboniferous, Once-a-week Quarry, Derbyshire, England; magnification × 13; 96 PPL, 97 XPL.
98: Stained thin section, Quaternary, Cap Rhir, Morocco; magnification × 31, PPL.
Echinoderm fragments are also shown in **73**, **76**, **78**, **132**, **133**, **139**, **148**, **154**, **178**, **183** *and* **184**.

Bioclasts

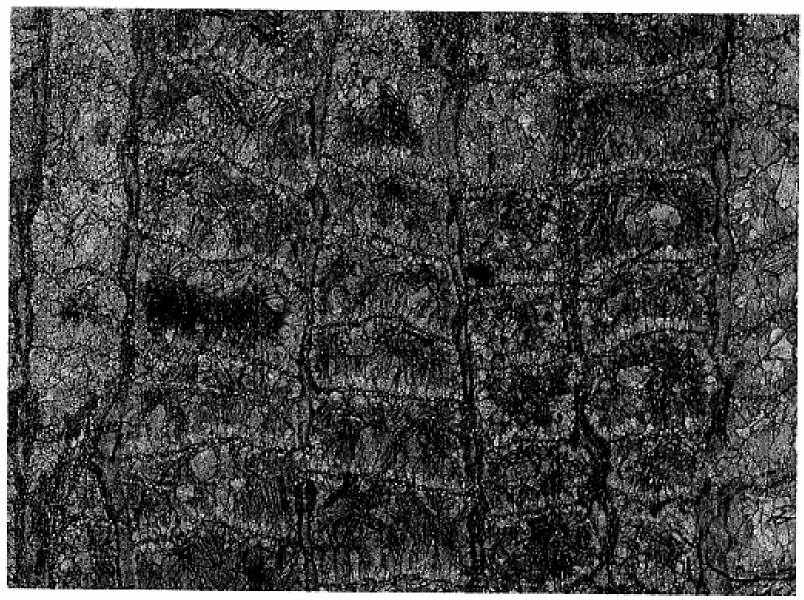
Corals

Corals are best identified by their overall morphology. The rugose and tabulate Palaeozoic corals were calcite, thus their microstructures are well-preserved. The walls are usually fibrous and small fragments which lack evidence of the characteristic coral form can be difficult to identify.

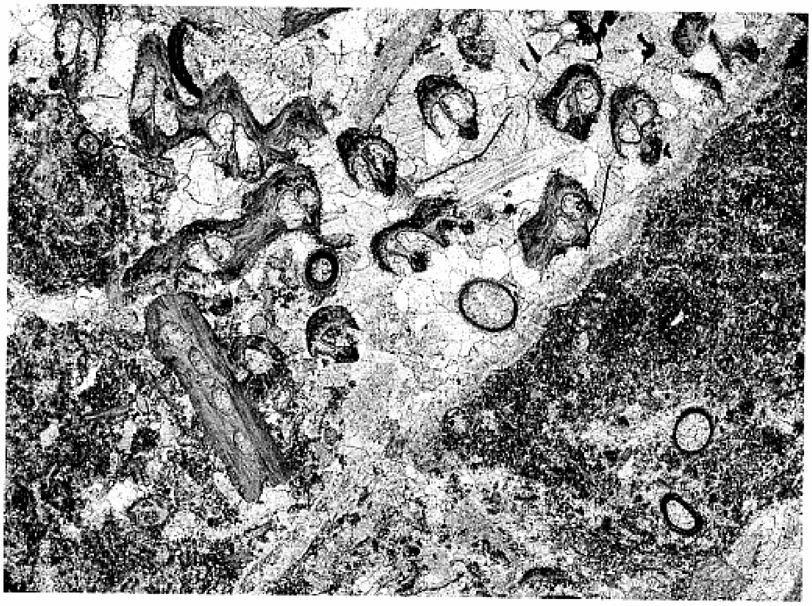
99 shows a transverse section and parts of two longitudinal sections of the colonial rugose coral *Lithostrotion*. Note the thick outer wall and septa seen in the transverse section. The columella and thin tabulae are clearly visible in the longitudinal section. Parts of the coral walls have been silicified (brownish colour). The pore-filling material is mainly sparite cement with some micritic sediment between the corallites.

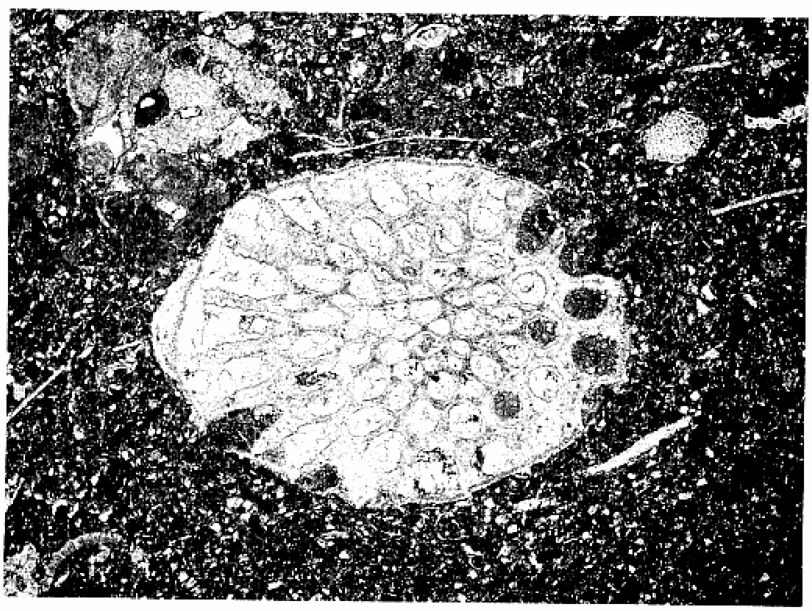
100 shows a section through a tabulate coral. Note the corallite walls and thin tabulae but absence of other internal structures. The infill is sparite cement, initially non-ferroan calcite (pink-stained), but finally ferroan (blue-stained).

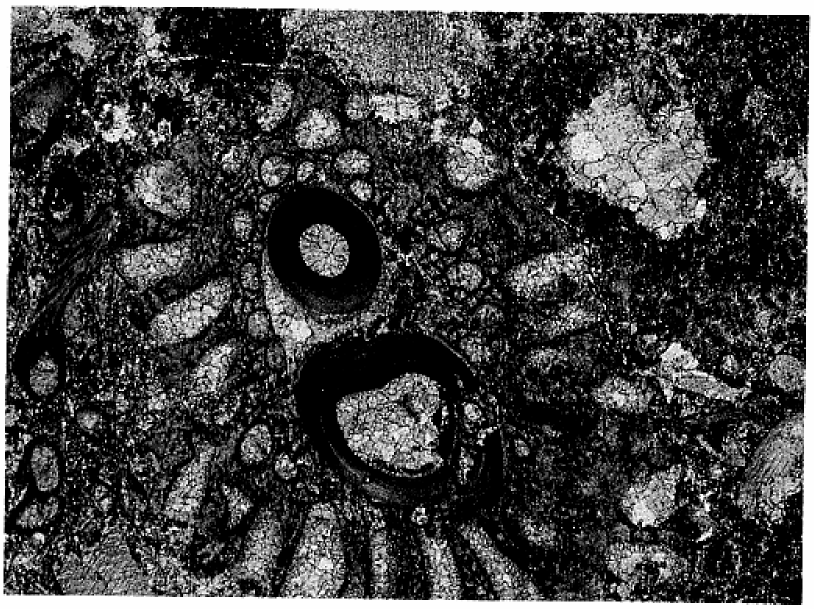
The Mesozoic and Cenozoic scleractinian corals are composed of aragonite and hence their microstructure is not well-preserved in limestones. Scleractinian corals are shown in **126**, **144** and **145**.



99: Stained thin section, Monsal Dale Limestone, Lower Carboniferous, Coombs Dale, Derbyshire, England; magnification × 16, PPL.
100: Stained thin section, Torquay Limestone, Devonian, Brixham, Devon, England; magnification × 16, PPL.







Bioclasts

Bryozoans

Bryozoans are widespread in marine limestones and are particularly common in Palaeozoic reef complexes. Most bryozoans had calcite hard parts and a laminated wall structure is preserved.

Among the most characteristic bryozoans are the frond-like fenestrate types, examples of which are seen in **101**. Note the thick wall of laminated calcite surrounding cement-filled pores (zooecia). Most of the fragments are transverse sections but the large piece to the lower left of centre is a longitudinal section.

102 is a transverse section of a stick-like bryozoan colony, showing the overall rounded shape of the 'stem' and of the zooecia within. Some of these have been infilled with fine sediment (upper right of fragment) but most have a blue-stained, ferroan calcite cement infill.

In **103**, the two circular, concentrically-laminated grains stained red-brown are brachiopod spines. These are encrusted by a bryozoan. Note the thick calcite wall of the bryozoan and the pores of different sizes within the skeleton, filled with pink-stained non-ferroan calcite cement. Some fragments of fenestrate bryozoans can be seen along the left-hand side of the photograph.

101: Stained thin section, Eyam Limestone, Lower Carboniferous, Ricklow Quarry, Derbyshire, England; magnification × 16, PPL.

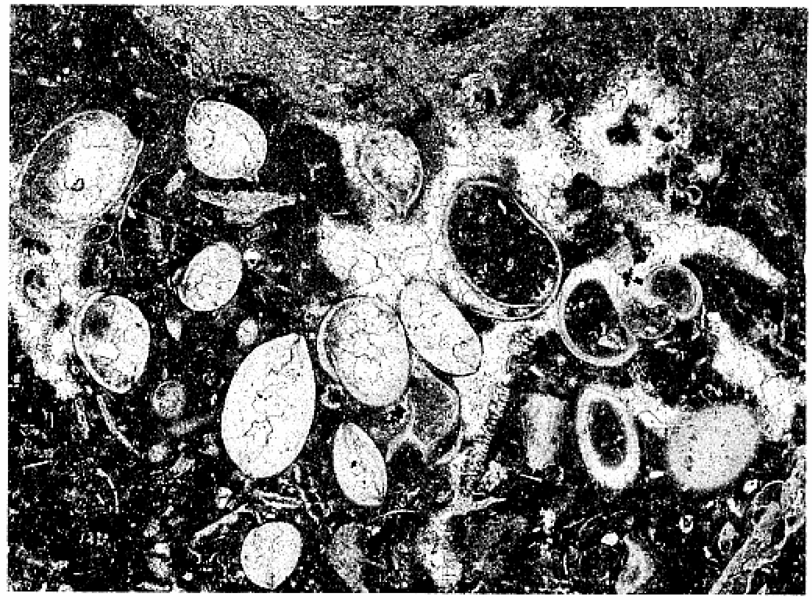
102: Stained thin section, Ouanamane Formation, Middle Jurassic, Western High Atlas, Morocco; magnification × 27, PPL.

103: Stained thin section, Red Hill Oolite, Elliscales Quarry, Dalton-in-Furness, Cumbria, England; magnification × 20, PPL.

Other bryozoans are shown in **96**, **97**, **132**, **133** *and* **178**.

Bioclasts

Arthropods



Ostracods

These photographs show examples of the arthropod microfossils, the ostracods, which are widespread particularly in sediments deposited in brackish or hypersaline conditions. Ostracods have thin valves with a finely prismatic or granular microstructure.

104 shows a group of complete two-valved shells, some filled with sparite cement, some with micritic sediment and some with both. Note the overlap of valves seen in some sections – a characteristic feature of many ostracods.

105 shows disarticulated ostracod valves (thin curved shells) associated with longer straight lengths of shell, which are fragments of a calcitic non-marine bivalve.

104: Stained thin section, Red Hill Oolite, Lower Carboniferous, Elliscales Quarry, Dalton-in-Furness, Cumbria, England; magnification × 40, PPL.
105: Unstained thin section, Upper Carboniferous, Cobridge Brickworks, Hanley, Staffordshire, England; magnification × 16, PPL.
Ostracods are shown also in **117**, **119** *and* **136**.

Trilobites

Trilobite hard parts were originally calcite and a finely granular microstructure is preserved. Each crystal is in a similar but not identical orientation to its neighbours, leading to sweeping extinction when the sample is rotated with the polars crossed (not illustrated here).

106 shows a cross-section of a trilobite (centre) and part of a brachiopod shell (base). Note the hooked shape seen at the left-hand end of the trilobite fragment, produced by incurving of the skeleton at its margin. A vein of blue-stained ferroan calcite follows the edge of the skeleton along part of its length. Note that the trilobite is stained mauve and hence consists of slightly ferroan calcite. This contrasts with the brachiopod fragment which is non-ferroan calcite. In some rocks it is thought that bioclasts originally comprising high magnesium calcite may be replaced by ferroan calcite, whereas those of low magnesium calcite remain unaffected.

106: Stained thin section, Wenlock Limestone, Silurian, England; magnification × 21, PPL.

Bioclasts

Foraminifera

Foraminifera are widespread in marine limestones. Most are calcite but they show a variety of shapes and wall structures. A selection of examples showing some of the variation amongst the foraminifera, is shown here.

The largest and perhaps the best-known foraminifera are the nummulites of the Lower Tertiary, examples of which are shown in **107**. Note the thick walls which have a radial fibrous structure, the fibres being aligned at right angles to the test wall. The matrix is mainly micritic sediment with a little blue-stained ferroan calcite cement.

108 shows discocyclinids, a type of foraminifer with many shall chambers. The matrix is micrite with many fragmented bioclasts.

109 shows a foraminiferal limestone in which the organisms are micrite-walled miliolids. The cement is fine sparite although unfilled pore-spaces remain (e.g. centre of field of view). Partly-filled moulds of bivalves can be seen outlined by thin micrite envelopes. These are the elongate curved grains seen on the right-hand side of the photograph.

107: Stained thin section, Eocene, San Salvador, Majorca; magnification × 15, PPL.
108: Stained thin section, Eocene, Greece; magnification × 16, PPL.
109: Stained thin section, Upper Miocene, Cala Pi, Majorca; magnification × 27, PPL.