OBSERVATIONS ON THE PALAEOECOLOGY AND AMMONITE SEQUENCE OF THE FRODINGHAM IRONSTONE (LOWER JURASSIC)

by A. HALLAM

ABSTRACT. The Frodingham Ironstone is shown from the ammonite evidence to range from the top of the *semicostatum* Zone to the top of the *obtusum* Zone of the Lower Lias. The rich invertebrate fauna, which is considered from a palaeoecological viewpoint, includes traces of sediment-burrowing and shell-boring organisms which are described for the first time. Certain lamellibranchs in a pyrite-bearing bed are shown to be probably dwarfed. Data for such features as shell size, orientation, disarticulation, and wear are given and relationships between the shells and their sedimentary matrix described. The faunal characteristics of the different types of ironstone are discussed and an attempt is made, using both the petrological and palaeontological evidence, to outline the salient features of the environments of deposition. It is concluded that the Frodingham Ironstone was deposited on a marine shoal area isolated from the land and that it records a series of alternating episodes during which the degree of water agitation and the Eh varied considerably.

THE Frodingham Ironstone, of Lower Liassic age, outcrops in north-west Lincolnshire and dips gently eastwards beneath a cover of younger Jurassic rocks. Economically of great importance, its position of outcrop has determined the site of the steel town of Scunthorpe.

Though it has long been known that the ironstone bears a rich and varied marine invertebrate fauna, little palaeontological work has been done since the pioneer investigations of Cross (1875). In this study, an attempt is made to establish the complete sequence of ammonites and so determine the precise zonal position of the ironstone, and to describe the whole macrofauna from a palaeoecological viewpoint. Finally, the palaeoecological data are used in conjunction with the petrological data to further knowledge of the depositional environments.

The rock succession. The distribution and variations in thickness and lithological character of the Frodingham Ironstone have been fully dealt with by Wilson (in Whitehead *et al.* 1952). It is lenticular in form, passing northwards and southwards into shales, and reaches a maximum thickness of 32 feet near Santon, 3 miles east of Scunthorpe. It has proved economically exploitable over an 8-mile belt running north to south through Scunthorpe, and borings have proved an extension at least as far as the River Ancholme, 5 miles to the east.

The author has found it desirable, for the purposes of internal consistency, to measure his own sections along the belt of opencast workings from Coleby in the north to Yarborough in the south.

Coleby Mine (SE 906193)

		ft.	*in.*
6.	Thinly-bedded ironstone, rather shaly in parts, with many fragments of mudstone. *Piarorhynchia* and *Camptonectes* abundant.	2	0
5.	Hard shelly ironstone	1	3
4.	Variable, rather thinly-bedded shaly ironstone with many shale fragments; pisolitic band 1 foot from top	3	8

	ft.	in.
3. Hard, current-bedded ironstone with abundant *Cardinia*. Many lenses, fragments and discontinuous thin bands of mudstone or shale; pisoliths .	9	0
2. Shaly oolite	1	0
1. Shelly ironstone, close to base, as indicated by drainage pump	1	2
	18	1
		seen

The successions at Thealby and Roxby Mines, a little to the south (SE 905177) are generally similar to that at Coleby Mine. The top foot or so contains abundant rhynchonelloids and pectens while the bottom 4 feet, at Thealby Mine, to the base of the quarry and a drainage dyke, consist of varied shaly ironstone, sometimes reddish in colour, sometimes oolitic shale. A thin and fairly persistent, non-oolitic, blue-black shale band, 1½ inches thick, occurs 6½ feet above the base.

Crosby Mine (SE 907133)

	ft.	in.
Dark shales of *simpsoni* Subzone.		
8. Oolitic shale, very rich in belemnites and pelecypods .	0	6
7. Current-bedded reddish to yellow-brown ironstone with fragments of mudstone; *Piarorhynchia* and *Camptonectes* abundant	4	6
6. Shaly oolite with abundant *Gryphaea*.	1	3
5. Shaly oolite with hard shelly bands	2	0
4. Hard, shelly ironstone with two *Cardinia* bands	3	0
3. Current-bedded ironstone with thin shreds of shale	4	6
2. Yellow-brown to reddish shelly ironstone with many shreds and fragments of shale or mudstone and pisoliths; *Cardinia* common	8	0
1. Soft, reddish, decalcified ironstone with *Diplocraterion*.	4	0
	27	9

Grey silty shale (4 inches) passing down into shale.

The section at Conesby Mine (SE 892147) a mile to the north-west, is essentially similar.

Yarborough Mine, north-end (SE 928116)

	ft.	in.
7. Shelly oolitic shale .	0	3½
6. Reddish, partly decalcified shelly ironstone with abundant *Diplocraterion, Pholadomya,* and *Pleuromya*	4	0
5. Blue-grey pyritic ironstone (Snap Band):		
(c) Blue pyritic shaly oolite with abundant *Gryphaea*	1	2
(b) Brown ironstone .	0	9
(a) Blue shaly ironstone, sparsely oolitic	0	5
4. Yellow-brown ironstone with abundant *Cardinia* .	8	6
3. Shaly ironstone with distorted ooliths	0	9
2. Yellow-brown ironstone with *Cardinia*	7	6
1. Soft, reddish decalcified ironstone with shreds of shale and *Diplocraterion*	3	0
	26	4½

Towards the southern end of Yarborough Mine beds 2 and 5c become softer and more shaly and shells become less abundant.

The suggested correlation between the sections, based on both lithology and fauna, is given in text-fig. 1.

Ammonite sequence. Cross (1875) was the first to record ammonites from the ironstone. A number of arietitids were recorded including '*Ammonites*' *semicostatum, scipionanum, compressaries, brooki,* and *conybeari.* These species signified to him a horizon at about the borderline of Lias α and β of the German classification, a very reasonable assignation for its time. Ussher (1890) took this assemblage to represent the *semicostatum* Zone. Specimens of a large '*Coroniceras*', supposedly allied to *C. gmuendense,* were recorded
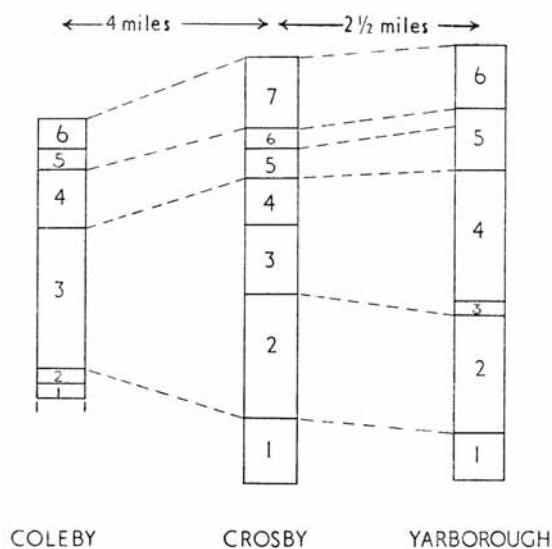
TEXT-FIG 1. Suggested correlation of the main sections of the Frodingham Ironstone. The numbers refer to beds described in the text.

by the Survey from the bottom 5 feet (Lamplugh *et al.* 1920). *Arnioceras semicostatum* was claimed to range from 4 to 5 feet from the base to the top. Arkell (1933) assigned the ironstone to the *bucklandi* (pars) and *semicostatum* Zones. Further collecting in recent years by P. E. Kent and V. Wilson has led to the recognition of *obtusum* Zone ammonites at the top of the succession. On this basis a sequence ranging from basal *semicostatum* Zone to top *obtusum* Zone is now claimed to be present (Swinnerton and Kent 1949; Whitehead *et al.* 1952). This at once raises a problem, for assuming the accuracy of the older identifications there is no published evidence for the presence of the upper *semicostatum, turneri* or lower *obtusum* Zones.

The amplification and revision of the zonal sequence proposed below is the result of re-examination of museum material and further collecting. The Scunthorpe Museum possesses a number of large ammonites with smooth compressed outer whorls of trigonal cross-section, which were obtained from the Frodingham Ironstone late last century. It was presumably these that Cross would have called *Amm. scipionanum* and *compressaries.* Examination of a series of specimens of various sizes collected *in situ* has made it clear

that they belong in fact to the genus *Eparietites* of the upper *obtusum* Zone. Other large specimens in the museum belong to the genus *Asteroceras*, with close affinities with Sowerby's species *A. stellare*. In addition there are one or two large specimens of the highly distinctive *turneri* Zone form *Microderoceras birchi*, hitherto unrecorded from the ironstone. As only the top 10 to 12 feet of the ironstone were worked when all these ammonites were collected (H. E. Dudley, personal communication), a rough lower limit to their occurrence is fixed. A number of small specimens in the museum have been identified by L. F. Spath and include *Asteroceras stellare*, *Aegasteroceras spp.*, *Eparietites tenellus*, and *Epophioceras carinatum*, all *obtusum* Zone forms. This last, highly evolute, species has a close resemblance to *Coroniceras* (*Metophioceras*) *conybeari* of the lower *bucklandi* Zone, and it was presumably this which led to Cross's very pardonable, but highly misleading, misidentification of *Amm. conybeari* from the ironstone assemblage.

The British Museum (Natural History) contains Frodingham Ironstone specimens (C 25133, C 50157) identified by Spath as *Epammonites scunthorpensis* Spath. These specimens have been examined by the author, to whom they seem not readily distinguishable from *Pararnioceras alcinoë*, a species now attributed to the upper *semicostatum* Zone (Dean *et al.* 1961). C 25133 belongs to the Wright collection and was figured by Wright (1878–86. pl. 1, figs. 1–3) as *Arietites bucklandi* and interpreted by Donovan (1954) as *A. scunthorpensis*. Another specimen (C 50156), *Caenisites* cf. *brooki*, a *turneri* Zone form, was collected from near the base of the ironstone at Coleby Mine.

Field collecting has yielded the following information. At Crosby, Conesby, and Yarborough Mines *Arnioceras* aff. *semicostatum* occurs fairly commonly in the bottom 7 or 8 feet and has been found at Coleby close to the top. A band with *Aegasteroceras* and large *Eparietites* occurs at the top of bed 7, Conesby and Crosby, in the top 2 to 3 feet at Thealby and Coleby and at the top of bed 6, Yarborough. Wilson (in Whitehead *et al.* 1952) records *Asteroceras stellare* at 3 feet and 8 to 10 feet below the top of the ironstone at Coleby. Large specimens of *Pararnioceras* aff. *alcinoë* occur in a band 6 feet and 7½ feet above the base at Thealby and Yarborough respectively.

Bed 8, Crosby. contains abundant *Gagaticeras gagateum* together with *Oxynoticeras simpsoni*. Wilson records a specimen of the latter species 3 feet from, and presumably below, the top of the ironstone at Roxby Mine. No other specimen of *Oxynoticeras* has been found below the horizon of bed 8, Crosby.

Text-fig. 2 represents an attempt to give in diagrammatic form a general idea of the ammonite sequence in the Frodingham Ironstone outcrops.

The total assemblage indicates the presence of the upper *semicostatum* Zone (*sauzeanum* Subzone), the *turneri* Zone (*brooki* and *birchi* Subzones), and the *obtusum* Zone (*stellare* and *denotatus* Subzones). Bed 8, Crosby, contains an exclusively *oxynotum* Zone fauna and may be excluded from the ironstone proper. The top of the *obtusum* Zone is best taken above bed 7, that is directly above the band with *Aegasteroceras* and *Eparietites*. The presence of abundant *Arnioceras* in the lower part of the ironstone is misleading as a stratigraphical index since the genus is the longest ranging of the arietitids and different species hard to distinguish. The *bucklandi* and *semicostatum* Zones have been recognized in a limestone-shale facies below the ironstone (Dudley 1942). As noted above, the latter zone ranges up into the ironstone, and the top should be taken above the horizon of *Pararnioceras* but below that of *Caenisites* and *Microderoceras*. The absence of *Promicroceras planicosta* (J. Sowerby) from the Frodingham

Ironstone is interesting, since this species is one of the commonest of the *obtusum* Zone ammonites. As it is particularly characteristic of the lower *obtusum* Zone, for which there is no evidence, it is possible that a minor non-sequence is present. Alternatively the environment was unfavourable for this form.
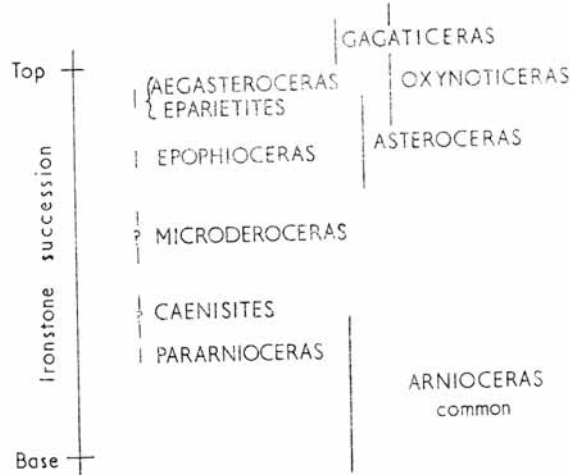
TEXT-FIG. 2. Stratigraphical distribution of ammonites in the Frodingham Ironstone. *Caenisites* and *Microderoceras* have not been collected *in situ* and so their exact location is uncertain. *Arnioceras* is only common in the lower beds, but ranges almost to the top of the succession.

LITHOLOGICAL CHARACTERISTICS

Petrology. The petrology of the Frodingham Ironstone was first described in detail by Hallimond (1925), but most of our present knowledge derives from the work of Davies and Dixie (1951). (See also petrological notes in Whitehead *et al.* 1952.)

The dominant characteristic of the ironstone is the abundance of limonite ooliths with an unusual flattened ellipsoidal shape. A further interesting feature is the presence of several bands of limonitic pisoliths up to 10 mm. in diameter. It has been established that the ooliths were composed originally of chamosite, small quantities of which may still be found. Davies and Dixie distinguished four types of ironstone which are listed here with the standard Survey nomenclature in parentheses.

   Type A (*sideritic limonite-chamosite oolite*). The closely packed ooliths are variably replaced by siderite, small crystals of which occur in the matrix.

   Type B (*sideritic chamosite mudstone*). This non-oolitic rock is the least common type and occurs only as discontinuous thin bands and fragments.

   Type C (*chamositic-sideritic limonite-chamosite oolite*). The ooliths are variably replaced by siderite and occur in a fine-grained matrix of chamosite clay and scattered crystals of siderite. Grains of silt-grade quartz are present locally.

   Type D (*calcitic limonite oolite*). The ooliths are set in a matrix of coarsely crystalline calcite. The rock contains detrital fragments of other ironstone types and is held to signify mechanical disintegration of these ironstones during turbulent conditions.

The upper boundary of the ironstone is sharply defined but the rock passes downwards more gradually into thin limestones and shales, with ooliths diminishing gradually in number and chamosite and siderite being progressively replaced by ordinary clay and calcite. Davies and Dixie gave diagrams illustrating the lateral variation of the different ironstone types. In the south of the ironstone field the bed becomes unworkable owing to the incoming of clay and detrital quartz in several bands. Quartz is also commoner at the northern end of the field.

The following supplementary observations are the result of field and thin section examination by the author.

The ironstone types B and D are very distinct, the latter being characteristically developed as a hard yellow-brown rock often exhibiting false bedding. The softer, reddish-purple to blue-grey types A and C tend to grade into one another. Type C is the more argillaceous, and becomes harder and reddish with increase in the proportion of interstitial siderite. Type D often contains localized patches of mudstone with indeterminate boundaries, in addition to obviously derived fragments. Quartz silt is rare in this type, whereas it is variably common to uncommon in the other ironstones. Broken ooliths (Davies and Dixie 1951) are somewhat commoner than in the other ironstones. The hardness of type B varies with the siderite content; when this is low the rock has the characteristics of a stiff clay. In section this rock is seen to be remarkably free of shells, but, unlike the other ironstones, minute shreds of bituminous matter aligned roughly parallel to the bedding are often present. Typical relationships of B and D ironstone *in situ* are illustrated from Crosby Mine in text-fig. 3. Text-fig. 3*b* shows how a seam of B ironstone may be split into two and both 3*a* and 3*b* illustrate seams which either taper to nothing in a few feet or are sharply broken across and locally displaced.

There are two distinctive bands in the Yarborough section which call for special comment.

Bed 3 in the southern part of the section is a C ironstone containing pale-brown chamosite distorted ooliths or spastoliths (Rastall and Hemingway 1939) elongated parallel to the bedding, in a matrix of green chamosite clay. These ooliths, similar to those figured by Davies and Dixie (fig. vi 4), have characteristics, such as hooked junctions, closely resembling those described by Carozzi (1961), which are attributed to plastic deformation by reciprocal impact due to water agitation. Some have been so shredded out parallel to the bedding that sediment compaction has probably also played a part in the distortion.

Bed 5, known as the 'Snap Band', is rejected as ore because of its high sulphur content, which ranges up to 4·5 per cent. As recognized by Hallimond (1925), this is due to the abundance of scattered quantities of pyrite, which has locally replaced shells in bed 5c, a C ironstone, where it is commonest. Hallimond also observed that at this horizon (5c) the ooliths have been dissolved out leaving *oolicasts* (Pettijohn 1957). Some outer rims still possess a little chamosite, however, whilst minute carbonate crystals may partly fill the interiors. A further feature of bed 5c, hitherto unrecorded, is the presence of abundant light-brown phosphatic nodules with a concentric structure, up to 10 mm. in diameter.

Diagenesis. It is convenient at this stage to outline briefly the main diagenetic changes which have affected the ironstone, with a view to establishing their relevance to the conditions of deposition.

As was recognized by Hallimond, the presence of limonite ooliths in a chamositic matrix implies contemporaneous oxidation on the sea floor, as do those ooliths showing alternations of chamosite and limonite laminae. The siderite is mostly, if not entirely, early diagenetic in origin and was presumably precipitated in slightly reducing alkaline solutions in which an abundance of iron precluded the formation of calcite. In con-

(a)

(b)

I Foot
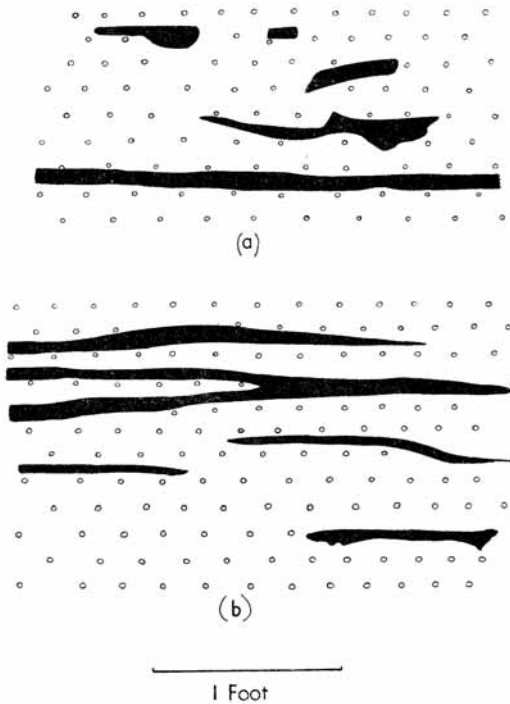
TEXT-FIG. 3. Diagrams illustrating relationships of oolitic ironstone and non-oolitic chamosite mudstone (black) at Crosby Mine.

sequence, its presence has little direct bearing on the conditions of deposition and the distinction between A and C ironstones is not likely to be directly relevant to these conditions.

Pyrite is abundant in certain clayey bands such as the Snap Band. It exhibits replacement of shells and matrix and is therefore diagenetic in origin.

Calcite is essentially confined to shells and to the matrix of D ironstones. In the A and C ironstones thin shells have often been dissolved, as indicated by the presence of moulds. The drusy calcite seems to belong to a comparatively late diagenetic stage, having crystallized in cavities where the iron content of the interstitial waters had

diminished. In some poor ironstones, as at the base of the succession, fine-grained calcite may replace siderite as an early diagenetic mineral.

Shells in A and C ironstones have locally been partly or wholly replaced by chamosite at, presumably, an early stage of diagenesis.

TABLE 1

c — common   o — occurs

AMMONITES		Eulamellibranchia	
Aegasteroceras sagittarium (Blake)	c	*Astarte obsoleta* Dunker	c
Arnioceras aff. *semicostatum* (Young and Bird)	c	*Cardinia concinna*	c
Asteroceras stellare	o	*C. listeri* (J. Sowerby)	o
Caenisites cf. *brooki* (J. Sowerby)	o	*Hippopodium ponderosum* J. Sowerby	o
Eparietites denotatus	c	*Pholadomya ambigua* (J. Sowerby)	c
E. tenellus (Simpson)	o	*Pleuromya* cf. *striatula* (Oppel)	c
Epophioceras aff. *carinatum* Spath	o	*Tutcheria cingulata* (Goldfuss)	o
Oxynoticeras simpsoni (Simpson)	o		
Microderoceras birchi (J. Sowerby)	o	**GASTROPODS**	
Pararnioceras aff. *alcinoë* (Reynès)	c	*Amberleya sp.*	o
Sulciferites sp.	o	*Pleurotomaria anglica* (J. Sowerby)	o
		Small forms seen in thin section	c
NAUTILOIDS			
Nautilus striatus J. Sowerby	o	**BRACHIOPODS**	
		Piarorhynchia juvenis (Quenstedt)	c
		Spiriferina walcotti (J. Sowerby)	o
BELEMNITES		*Zeilleria* cf. *perforata* (Piette)	o
Nannobelus brevis (Blainville)	c		
		CRINOIDS	
LAMELLIBRANCHS		Ossicles seen in thin section	c
Anisomyaria			
Camptonectes lohbergensis (Emerson)	c	**ECHINOIDS**	
Chlamys cf. *textoria* (Schlotheim)	c	Spines seen in section	o
Entolium lunare (Roemer)	c		
Gryphaea aff. *arcuata*	c	**FORAMINIFERA**	
Lima gigantea (J. Sowerby)	c	Seen in thin section	c
L. succincta Schlotheim	o		
? Liostrea sp.	o	**TRACE FOSSILS AND BORINGS**	
Meleagrinella sp.	o	? Sponges	c
Modiolus sp.	o	*Rhizocorallium jenense* Zenker	o
Myoconcha sp.	o	*Diplocraterion parallelum* (Torell)	c
Pinna hartmanni Zieten	o	*Zapfella pattei* Saint–Seine	c
Plicatula sp.	o	Algae	c
Terquemia arietis (Quenstedt)	o		

FAUNA

Composition. The rich invertebrate fauna of the Frodingham Ironstone is dominated by lamellibranchs, as indicated in the faunal list of Table 1, in which the fossils are grouped taxonomically. It is more appropriate in this study, however, to discuss the fauna in terms of its broad ecological subdivisions. The organisms may accordingly be grouped as *endobionts*, more or less permanently occupying, during life, positions within the

sediment, *epibionts*, living on the surface, and *nekton*, swimming in the waters above (Schäfer 1956, Hallam 1960).

The endobionts include two groups of lamellibranchs and soft-bodied forms represented by trace fossils. The myas (*Pholadomya* and *Pleuromya*) occupied permanent burrows, while such unspecialized eulamellibranchs as *Cardinia, Hippopodium, Astarte*, and *Tutcheria* were very probably, by modern analogies, forms which spent most of their time occupying temporary positions just below the surface, but capable of slow movement on or through the sediment if disturbed.
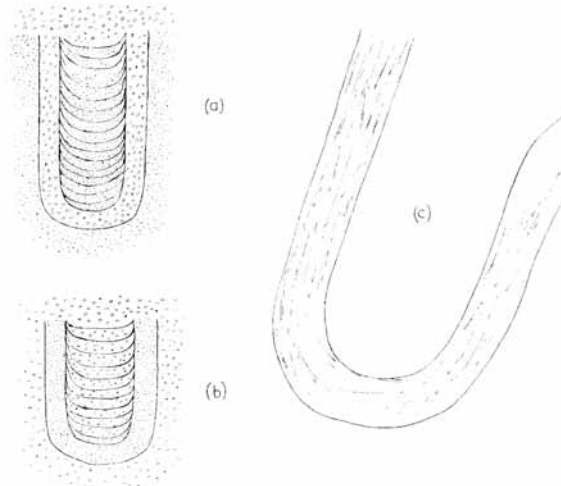
TEXT-FIG. 4. Diagrammatic representation of *Diplocraterion parallelum* (a and b) viewed normal to the bedding and *Rhizocorallium jenense* parallel to the bedding, to illustrate the surface sculpture. ⅔.

The trace fossils include species of the ichnogenera *Diplocraterion* and *Rhizocorallium*. The commoner species, *D. parallelum* (Torell), is represented by small, protrusive, plugged U-tubes with a straight axis and vertical to the bedding, linked by a median laminated zone or *Spreite*. It resembles those recently described from the Blue Lias as *Rhizocorallium* (Hallam 1960). They are most conspicuous where marked out by differences in the sediment. Thus, in the bed directly below the base of the ironstone at Crosby Mine, oolite passes down into shale (text-fig. 4a) while in the overlying ironstone clay-filled U-tubes lie isolated in the midst of oolite (text-fig. 4b). The absence of an overlying band of clay or mudstone implies a certain amount of erosion subsequent to the burrowing. In contrast to these examples, specimens in bed 6, Yarborough Mine, are preserved as oolite within oolite.

Rhizocorallium differs from *Diplocraterion* in its greater size, its orientation more or less parallel to the bedding and in possessing a curved axis. Plugged U-tubes assignable to *R. jenense* Zenker, with an indistinct *Spreite*, occur a few feet from the top of the Yarborough succession. They possess discontinuous longitudinal grooves and bifurcat-

ing thread-like ridges on their surface (text-fig. 4c). This species, not previously recorded in Britain, is much commoner and better preserved in the Cleveland Ironstone near Staithes, Yorkshire. The surface sculpture has been convincingly compared by Weigelt (1929) with the scratch-markings produced by certain burrowing crabs. Seilacher (1952) has interpreted *Diplocraterion* and *Rhizocorallium* as the infilled burrows of sediment eaters.

The epibionts may be classified as vagile and sessile forms. The vagile epibionts include echinoids, known only from scattered spines, and, quite probably, small gastropods and foraminifera, common enough in thin section but virtually impossible to extract because of the hardness of the matrix. An idea of the probable composition of the foraminiferal fauna was obtained by extraction from the shale directly overlying the ironstone at Crosby (bed 8) of species of *Frondicularia*, *Dentalina*, *Lingulina*, *Marginulina*, *Nodosaria*, and *Planularia*.

The much larger group of sessile epibionts includes forms which were attached during life to the surface by means of byssi or pedicles (anisomyarian lamellibranchs and brachiopods) or rooted (crinoids). A small number of lamellibranchs (oysters, *Plicatula*) cemented themselves to *Gryphaea* shells lying on the sediment surface. *Gryphaea* itself was sessile but free lying, while the unattached pectens and limas probably had limited powers of swimming. (The Frodingham Ironstone *Gryphaea* resemble *G. arcuata* of the older Sinemurian but differ in being on the whole less tightly coiled and having a greater ratio of breadth to length.) Finally there are traces of a number of shell-boring organisms. Many *Gryphaea* in bed 6, Crosby, contain small cavities with structures indistinguishable from borings of the cirripede *Zapfella*, as described by Saint-Seine (1954). The cavities as exposed on the shell surface are elongate and sometimes slightly arcuate, rounded at one end and tapering to a point (text-fig. 5a), with dimensions averaging 1.5×0.5 mm. Where the outer layers of the shells have been worn away the cavities are seen to expand downwards into larger, sac-like structures, ranging up to 5×1 mm., which may be filled with sediment. Some at least of the cirripedes seem to have bored into the shells after death of the host, since they occur on the median part of the left valve, which during life must have lain adjacent to if not actually embedded in sediment.

A second type of boring is common in many *Gryphaea* shells (text-fig. 5a). This consists of minute, superficial perforations ranging up to 0.5 mm. in diameter, variably normal or oblique to the shell surface. In size and shape these perforations bear some resemblance to those produced by clionid sponges (Topsent 1887), but this assignation is tentative.

Yet a third type is represented by borings that closely resemble those of certain algae (Duncan 1876), very common in and seemingly confined to shells in type D ironstones. These constitute a ramifying network of fine tubes averaging 5μ in diameter and infilled by finely crystalline siderite (text-fig. 5b). The straight or slightly sinuous borings are aligned mostly normal to the shell margin and are occasionally seen to branch. There is no apparent relationship to the structure of the shells, even when they have been recrystallized. They are apparently confined to lamellibranch shells (cf. Cayeux 1914). Algal borings have been recorded by Cayeux from French Liassic ironstones, and it was presumably such structures as these that Hallimond (1925) referred to in passing as 'algues perforantes'.

The last group, the nekton, consists of varied cephalopods which probably had but transient contact with the sea bottom during life.

Distribution. Many of the beds in the ironstone contain abundant fossils, with *Gryphaea* and *Cardinia* the most conspicuous. Individual species, however, vary considerably in abundance as the succession is ascended, first one and then another coming into prominence. Certain thin bands especially rich in certain species may indeed be useful
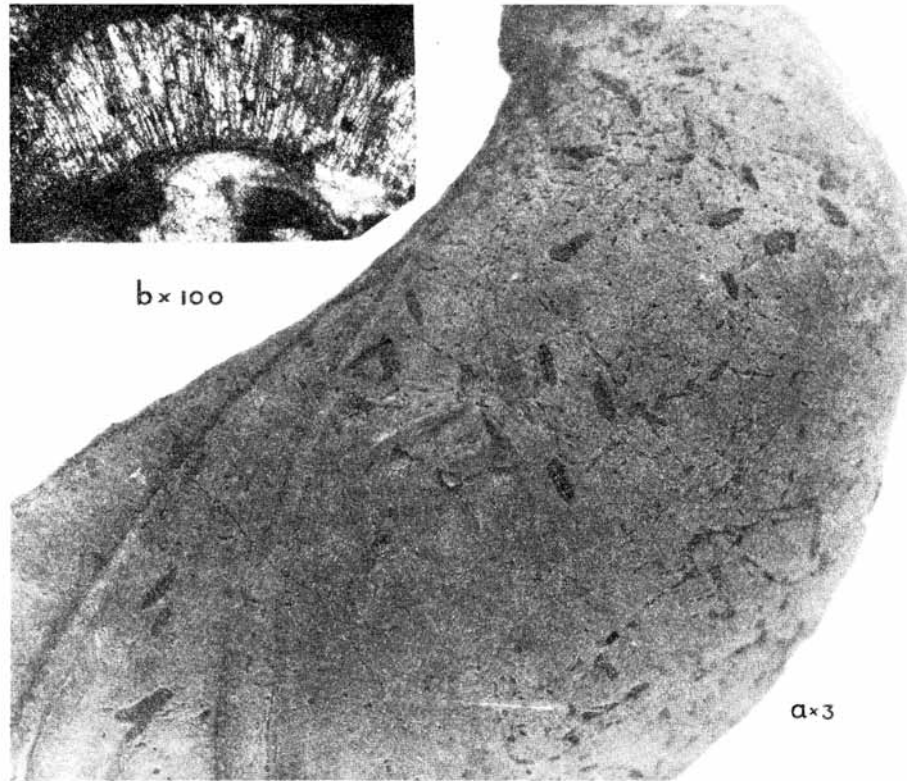

TEXT-FIG. 5. *a*, Cirripede and ?sponge borings in a *Gryphaea* shell from bed 6, Crosby. × 3. *b*, Algal borings in a lamellibranch shell, Crosby. × 100.

for local correlation. For example, *Gryphaea* is very common in bed 6, Crosby, and bed 5c, Yarborough. *Cardinia* is especially common in bed 3, Coleby, and beds 2 and 4. Yarborough and Crosby. *Piarorhynchia* is abundant in the top 4 feet of all sections but uncommon below this level. *Camptonectes* is very abundant also in the top 2 feet of all sections. Certain ammonites such as *Pararnioceras*, *Eparietites*, and *Aegasteroceras* are largely confined to thin bands, whose position in the succession has already been noted.

Laterally, over a small distance, shells tend to be uniformly distributed, the only (rather dubious) suggestion of clustering being with *Piarorhynchia* in bed 7, Crosby.

Size. A conspicuous feature of the ironstone is the large size of many of the ammonites and pelecypods, the largest being ammonites of maximum diameter 620 mm. (*Eparietites*) and 300 mm. (*Asteroceras*).

What appears to be a genuine case of dwarfing occurs in bed 5*c*, Yarborough, the upper part of the Snap Band, which is crowded with lamellibranchs in the northern part of the section. The most amenable fossils for analysis are specimens of *Cardinia concinna*
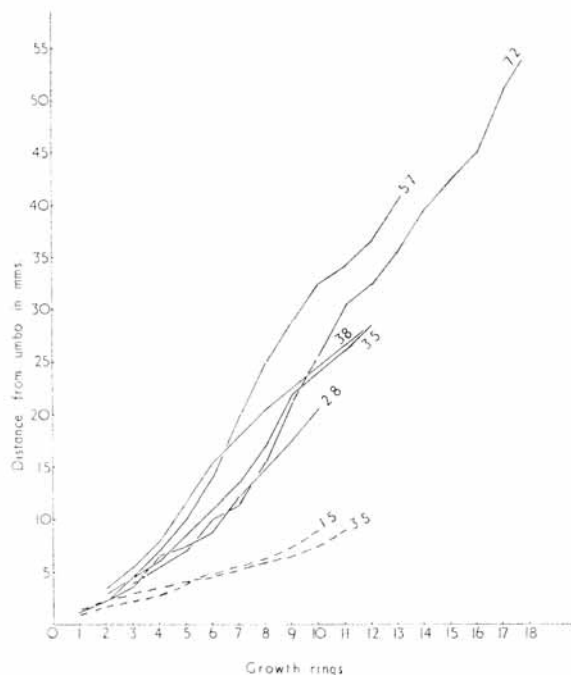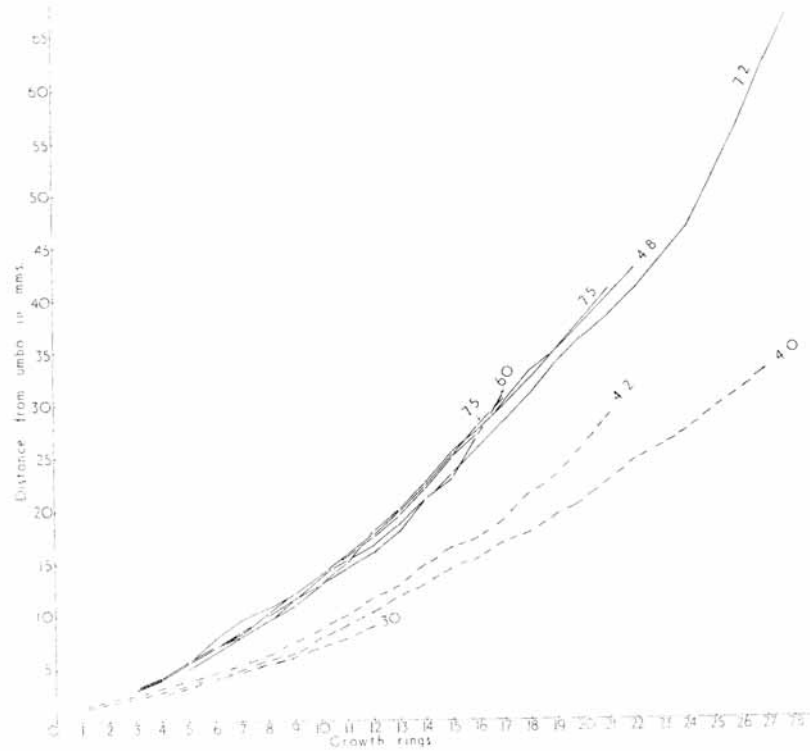

TEXT-FIG. 6. Graphical analysis of the spacing of growth-rings in shells of *Cardinia concinna*. The broken lines represent specimens from the Snap Band. Length of each specimen given in mm.

and *Pholadomya ambigua*. The *Cardinia* shells have distinct growth striae, which are numerous, fine and closely spaced, and growth-rings marked by acute depressions on the shell surface, which are much fewer in number, regularly spaced, and far more prominent. The maximum size of four specimens of *Cardinia* collected from the bed in question is 35 mm., as opposed to 125 mm. for normal representatives of the species elsewhere in the ironstone. Full measurement of growth-rings was possible on two of these specimens and a graph was plotted (text-fig. 6) to compare the spacing of these rings with those of a sample of normal *Cardinia* collected near the base of the ironstone. It is seen that the shells fall on different curves, with those from the Snap Band having much more closely spaced growth rings, indicating that they are not merely juveniles. A

similar result was obtained for internal moulds of *Pholadomya*, comprising small forms
from the Snap Band and large forms from bed 6, Yarborough (text-fig. 7). Although the
numbers of specimens from the Snap Band are small, this does not affect the validity
of the interpretation, as a correlation of size and growth rate has been demonstrated.

A further possible case of dwarfing is suggested by collection from bed 5c of three

TEXT-FIG. 7. Graphical analysis of the spacing of growth-rings in specimens of *Pholadomya ambigua*.
Conventions as in text-fig. 4.

small specimens of *Lima gigantea* (maximum length 16 mm.), a species which elsewhere
in the ironstone attains ten times this size. It is very unusual to find specimens as small as
16 mm. outside the Snap Band. Unfortunately, proof of dwarfing is not possible in the
absence of pronounced growth-rings. There are a number of other small shells including
Astarte obsoleta, Camptonectes lohbergensis, Pseudolimea pectinoides, and *Amberleya sp.,*
but as these are naturally small species there is no reason to presume dwarfing. By far
the commonest fossil is *Gryphaea* aff. *arcuata*. Though the shells are mostly small, the
length of the right valve ranges up to 45 mm., which is not appreciably smaller than the

maximum of 65 mm. for the ironstone as a whole. Growth-rings are too irregular for reliable measurement but from the size distribution and comparisons of tightness of coiling it seems likely that at least the bulk of these oysters are juveniles.

Shell orientation and disarticulation. Large *ammonites* always lie parallel to the bedding but small specimens have a more irregular orientation. This situation compares with that in the Blue Lias of Dorset and is explicable as a purely mechanical phenomenon

	⌢	⌣	(	○	◐
BED 3, COLEBY					
Cardinia	313	34	37	6	1
BED 6, CROSBY					
Gryphaea (left valve where disarticulated)	58	82	50	10	5
BED 7, CROSBY					
Camptonectes	173	61			
Chlamys	12	8			
Gryphaea (left valve)	12	15			
Pseudolimea	17	13			
BED 8, CROSBY					
Camptonectes	7	7			
Cardinia	1	4		3	
Chlamys	23	24	14		
Gryphaea (left valve)	34	75	42		
,, (right valve)	44	41	25		
,, (articulated)				3	
Pholadomya					10
Pseudolimea	2	5	3		

TEXT-FIG. 8. Quantitative estimate of disarticulation and orientation of lamellibranch shells from several ironstone beds. The three columns on the left represent disarticulated valves in various orientations, the two on the right articulated shells.

(Hallam 1960). *Belemnites* lie mostly parallel or slightly oblique to the bedding. Their orientation in the planes of bedding was not determinable.

An attempt has been made in text-fig. 8 to give some quantitative expression to the orientation and degree of disarticulation of the commoner *lamellibranch* shells in typical samples of the various ironstones. Orientation of the shells and disarticulated valves is indicated diagrammatically.

In ironstones of type D, where *Cardinia* is very common, it is readily apparent from general observation that there is a high degree of disarticulation and a high predominance of valves convex upwards. Bed 3, Coleby, is a typical example, studied in vertical section.

Bed 7, Crosby, is a variable A–D ironstone. There is again a preponderance of valves convex upwards, though less pronounced than in bed 3, Coleby. Disarticulation is complete. Bed 6, Crosby, is a rather clayey type C ironstone containing abundant large gryphaeas. There is a high degree of disarticulation, with a predominance of incurved left valves convex downwards. As Zeuner (1933b) observed, this orientation is an exception to the general rule among lamellibranchs and is a consequence of the unusual shape of the left valve and its reaction to bottom currents. If such a valve lies on its side,

a regular water current moving across it will cause a shallow pit to be excavated in the sediment around its upstream side so that the valve will eventually come to be embedded in a horizontal position, predominantly convex downwards (Zeuner 1933a). Though this orientation is similar to the probable life position there is every indication that the shells have been disturbed after death. The degree of disarticulation is high and occasionally left valves are found locked in each other. In one case the valve of an oyster was found cemented on the underside of a left valve convex downwards, implying disturbance subsequent to the growth of the incrusting oyster.

Bed 8, Crosby, a shale with limonite ooliths, contains *Pholadomya* in growth position together with numerous disarticulated epibiont lamellibranchs. Neither the small pectens nor the right valves of *Gryphaea* show any preferred orientation in the horizontal position, a natural consequence of the almost planar shape. In contrast the left valves of *Gryphaea* have a pronounced tendency to lie convex downwards.

The results for these two argillaceous beds compare well with those obtained by Zeuner (1933b) for left valves of *Gryphaea* in clayey sediment. Comparison is made here in terms of percentages.

	Convex down	Convex up	oblique
Bed 6, Crosby	43	31	26
Bed 8, „	50	22	28
Zeuner, 1933b	43	23	34

Zeuner found that in fine sandstone there is a much larger proportion (72 per cent.) of valves convex downwards, a result attributed to the stronger action of currents embedding shells in the substratum.

In contrast to the highly disarticulated epibiont and 'conditionally vagile' endobionts (*bedingt vagile Endobionten* of Schäfer, 1956), such as *Cardinia*, the deep-burrowing myas are invariably found undisturbed in growth positions with the anterior ends pointing obliquely downwards at a high angle to the bedding.

Disarticulation of *crinoids* (into small ossicles) seems complete, whereas in the *brachiopods* it is negligible.

Shell wear and fragmentation. *Gryphaea* exhibiting considerable signs of wear are present in bed 5c, Yarborough, and bed 8, Crosby. Many of the smaller shells are worn smooth, with a total loss of growth ridges. Sharp edges are truncated and, in extreme cases, left valves resemble subrounded pebbles. A few belemnites in bed 8, Crosby, collected within shale, have been broken near the apex and the jagged edges worn smooth. Generally speaking, evidence of wear among other shells in the ironstone is not conspicuous.

Only a rough qualitative estimate is possible of the degree of shell fragmentation. Broadly, fragmentation of large, thick shells is slight, in contrast to small, thin shells. Fragmentation, highest in the D ironstones, is never extreme and no shelly layers composed entirely of finely comminuted debris have been seen.

Shell diagenesis. Original lamellar structure is preserved in brachiopods and in certain lamellibranchs such as *Lima gigantea* and many *Gryphaea*. The thick prismatic layer of *Pinna hartmanni* is unaltered. All this suggests original calcitic shells. Extensive recrystallization of $CaCO_3$ has taken place in some *Cardinia* and *Gryphaea*, while the

aragonite of ammonite shells has recrystallised to calcite. In many clayey ironstones, a lot of solution of thin ammonite and lamellibranch shells has been effected; myas are invariably represented by moulds. It is possible that the myas possessed aragonitic shells at least in part, but it is not necessary to assume this in accounting for their invariable absence, since Hecht (1933) has demonstrated that thin, large shells, such as were possessed by the myas, are readily dissolved within a muddy sediment in the presence of decaying organic matter. Chamosite has replaced shells quite extensively in

Calcite shell   Mudstone
Drusy calcite   Oolite
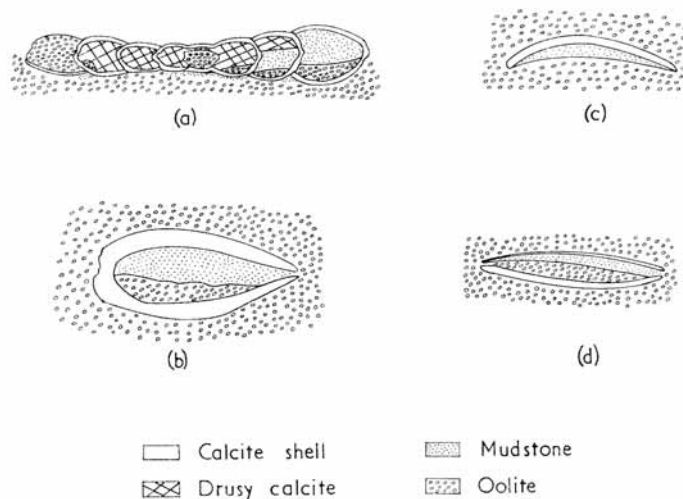
TEXT-FIG. 9. Shell–matrix relationships in the Frodingham Ironstone, as drawn from actual specimens.

some A and C ironstones and chamositized shells are to be found not uncommonly in D ironstones. Local replacement by siderite and pyrite is recognizable.

Shell-matrix relationships. Ammonites have been examined by means of polished sagittal and transverse surfaces. The body chambers contain sediment similar to the external matrix. The sediment of the inner chambers of *Aegasteroceras* in type A ironstone at Yarborough Mine tends to be rather less oolitic than the external matrix. The inner chambers in some D ironstones are filled with variable amounts of oolite, mudstone, sometimes containing scattered ooliths, and drusy calcite, which may only partly fill the cavities. In some large specimens a few inner chambers may be markedly oolitic compared with their neighbours, suggesting that local fracture of the shell wall has allowed the influx of coarse material from the enveloping sediment. A particularly interesting matrix structure is exhibited by a specimen of *Epophioceras* from Thealby (text-fig. 9a). Considering the sectioned chambers on the right, the lowest parts are filled with oolite, which is overlain in two of them by mudstone. The upper part of the chambers is filled by drusy calcite. Small quantities of mudstone lie directly beneath the shell.

Some interesting relationships are shown by cardinias in the D ironstones. Articulated shells variably contain oolite, sideritic chamosite mudstone with scattered ooliths, and drusy calcite. Where both mudstone and oolite are present the latter may occupy the lower part of the shell interior (text-fig. 9b, cf. text-fig. 9a). In the same type of ironstone small pockets of mudstone frequently occupy positions beneath the 'canopies' represented by *Cardinia* and *Gryphaea* valves convex upwards (text-fig. 9c, cf. text-fig. 9a). Sometimes the canopy is directly underlain by drusy calcite. Text-fig. 9d illustrates a sectioned specimen of an *Entolium* valve resting on a *Cardinia* valve, with mudstone beneath the former resting on oolite. No pockets of mudstone are found, however, in association with valves convex downwards.

Many small gastropods and other microfossils are seen in thin sections of oolites to have interiors filled with mudstone or drusy calcite.

RELATIONSHIP BETWEEN LITHOLOGY AND FAUNA

The sideritic mudstones of type B are clearly distinct in that there is virtually no trace of organic life.

In contrast the clayey oolites (types A and C), which are not readily distinguishable from a faunal point of view, abound in fossils. Endobionts including myas in growth positions and sediment eaters (*Diplocraterion*, *Rhizocorallium*) are an important element of the fauna which is frequently dominated, however, by varied epibionts and nekton. The high degree of lamellibranch and crinoid disarticulation and the evidence of orientation, fragmentation, &c., implies a fair amount of disturbance of shells after death, but there is no reason to suppose that the organisms in question did not live in the environment reflected in the sediment.

The faunal peculiarities of bed 5c, Yarborough, can be correlated with two distinctive sedimentary features, the high sulphur content and the presence of phosphatic nodules. Analyses of two samples of shelly rock containing the dwarfed lamellibranchs gave sulphur contents of 0·84 and 0·93 per cent. These analyses are well below the bulk sulphur content of the Snap Band as a whole (Whitehead *et al.* 1952), due most probably to the absence of large clots of pyrite from the samples. They are nevertheless appreciably higher than most values for the ironstone.

The D ironstones contain most of the fossils present in the clayey ironstones with the notable exception of myas, *Diplocraterion* and *Rhizocorallium*. On the other hand, *Entolium* is commoner, and traces of boring algae are abundant. Text-fig. 8 shows that the degree of disarticulation is no higher than in the A and C ironstones whereas the percentage of *Cardinia* valves oriented convex upwards is conspicuously higher than in pelecypods from these latter types. It is apparent from the experimental work of Johnson (1957) that valves lying in the more stable position convex upwards (excepting *Gryphaea*) are more readily buried by the action of bottom currents on the sediment. Such a pronounced preferred orientation in the D ironstones could be a consequence, either of the action of strong currents, or of prolonged exposure to moderate currents.

In view of the evidence of erosion in the D ironstones, noted by Davies and Dixie and in this paper, the important question arises to what extent the fauna has been derived from the clayey ironstones. Most of the organisms represented as fossils evidently flourished in muddy conditions, as they abound in many Lower Liassic shales, and it is

very doubtful whether they could have tolerated the turbulent conditions implied by oolite in which mud is largely absent. Certainly the scattered chamositized shells would seem to be exotic to this environment.

It is here that a consideration of the shell-matrix relationships becomes critical to an understanding of the depositional environment. The presence of pockets of mud adjacent to the inner side of valves convex upwards (text-fig. 9c) could be held to indicate removal by currents of a mud-filled shell from its original environment, and subsequent disarticulation and loss of most of the mud filling. This interpretation would fail, however, to explain the absence of mud on the inner side of valves concave upwards, nor could it account for the presence in some specimens (text-fig. 9a, b) of mud overlying type D oolite, which must have entered the empty shell first, or of the pockets of mud underlying the outer side of the ammonite of text-fig 9a. The one feature these mud pockets have in common is that they lie in positions which would have been protected by shells on, or just below, the sediment surface from the agitation of bottom waters. The mud seems, in fact, to have been deposited *in situ* and protected from subsequent winnowing. No macro-fossils have been discovered with interiors of ordinary A or C ironstone.

It follows from these facts that deposition of the D ironstones may have been accomplished in several phases, periods of strong water agitation, during which mud was removed, alternating with quieter periods when fine particles were enabled to settle once more. Rather than the ooliths having been transported far, therefore, much of the D ironstone could be residual in origin, having been derived from unconsolidated sediment. While many of the fossils doubtless are exotic to the turbulent environment in this sense, others could perhaps have lived during the quieter phases. The presence of scattered ironstone pebbles does signify, nevertheless, some erosion of consolidated rock.

ENVIRONMENTS OF DEPOSITION

The absence of fossils and the presence of shreds of bituminous matter aligned parallel to the bedding suggest that during deposition of the sideritic mudstone (type B) the bottom waters were anaerobic and therefore unfavourable for bottom life. If this were not so, burrowers would have destroyed all trace of lamination and the bituminous matter would have been lost through oxidation. It is possible, therefore, that the siderite was precipitated syngenetically.

The clayey oolites, however, contain a rich bottom fauna, lack bituminous matter and any trace of microlamination, and bear evidence of moderate water agitation, all signifying well-oxygenated bottom waters. Bottom disturbance was sufficient to move the shells of epibionts and 'conditionally vagile' lamellibranch endobionts, but too weak to winnow away mud or erode deep-burrowing myas.

Faunal evidence could well have a bearing on the controversy about whether chamosite ooliths were formed *in situ* within the sediment (Pulfrey 1933; Caillère and Kraut 1954) or by the rolling action of gentle currents on the sea floor (Whitehead *et al.* 1952; Dunham 1960); the latter implies that chamosite would remain stable in an oxidizing environment. Those ooliths with alternating laminae of chamosite and limonite signify either a regular shuttling to and fro on the sediment surface between regions of differing

oxidation-reduction potential or periodic exposure and reburial. The author finds the latter alternative more plausible, but conclusive evidence is lacking as yet.

In regard to bed 5c, Yarborough, though the presence of diagenetic pyrite does not necessarily signify anaerobic conditions in the bottom waters during deposition, a high pyrite content very probably implies the existence of fair quantities of H_2S in the original sediment. As deficiency of oxygen is known to be a potent factor inhibiting growth the dwarfing of the endobionts *Cardinia* and *Pholadomya* may reasonably be attributed to this factor. The abundance of shells and of highly worn specimens of *Gryphaea* and the presence of phosphatic nodules suggests that, in addition, this part of the Snap Band represents an episode of very slow sedimentation.

The calcitic limonite oolite (type D) signifies a comparatively turbulent environment and was largely produced by erosion of the other ironstones. While erosion of consolidated rock played a role, as evidenced by the presence of pebbles, it is here suggested that the most significant process might have been the winnowing away of unconsolidated mud from the clayey oolites by strong water agitation, not necessarily accompanied by much transport of ooliths. The only organisms which were certainly well adapted to these conditions were boring algae and the epibiont *Entolium*. Much of the remaining fauna was, in all likelihood, derived from the A and C ironstones though some species may have been able to tolerate periods of quieter water when mud was enabled to settle.

The ironstone succession, as a whole, signifies a series of alternating phases of quiet and disturbed water and of reducing and oxidizing bottom conditions. In regard to the likely depth of formation of the D ironstone, Nadson (1927) observed that boring algae in the Black Sea are most abundant from sea-level down to 20 to 25 m. and he found no trace below 40 m. This seems plausible enough bearing in mind the light requirements of algae, but boring algae have been claimed also in deep sea corals (Duncan 1876). This apparently anomalous result seems to warrant further investigation.

There is no evidence to indicate the immediate proximity of a shoreline, and the ironstone may have passed in all directions into marine shales, as it certainly does to the north and south. The comparative rarity of detrital quartz, except at the margins of the ironstone field, may signify the presence of an adjacent 'clastic trap' in slightly deeper water, as first suggested by Cayeux (Whitehead *et al.* 1952). We may accept with a fair degree of confidence that the ironstone formed on a shoal isolated from the land. Sedimentation rates seem generally to have been rather low, since the ironstone is markedly condensed compared with shales of the same age elsewhere. Periodically, shells exposed on the sediment surface were subjected to prolonged episodes of wave or current disturbance, boring, incrustation, and wear.

Although, according to orthodox theory, the bottom waters must have been enriched in iron compared with the present day, the fauna gives little indication of having been affected. It is typical, with few exceptions, of that which flourished in Lower Sinemurian muds elsewhere. Compared with the nearest well-exposed shale succession of the same age, at Robin Hood's Bay on the Yorkshire coast (which the author has examined in detail), *Cardinia* and *Entolium* are relatively more abundant and the normally ubiquitous *Oxytoma inaequivalve* apparently rare or absent. Brachiopods have not been found in Yorkshire. These slight differences, and the large size to which many of the species grew, could be attributable, partly to higher temperatures and better oxygenation on the shoal, and partly to lower rates of sedimentation than on the surrounding sea floor.

In the relative abundance of ammonites and endobionts and the rarity of brachiopods, except at one horizon, the Frodingham Ironstone differs considerably from the Marlstone Rock-bed ironstone of the Middle Lias. It is similar in these respects, however, to the Cleveland Ironstone of Yorkshire, excepting that brachiopods are somewhat commoner in the latter, though never dominant as in the Marlstone. These differences probably relate to the presence of muddy sediment in the original depositional environments of the Frodingham and Cleveland Ironstones, suggesting that the controlling factor might have been the degree of water agitation.

REFERENCES

ARKELL, W. J. 1933. *The Jurassic System in Great Britain*. Oxford.

CAILLERE, S., and KRAUT, F., 1954. Les gisements de fer du bassin Lorrain. *Mem. Mus. Hist. Nat. Paris*, (C), **4**, 1-175.

CAROZZI, A. V. 1961. Distorted oolites and pseudo-oolites. *J. Sed. Petrol.* **31**, 262-74.

CAYEUX, L. 1914. Existence de nombreuses traces d'Algues perforantes dans les minerais de fer oolithique de France. *C.R. Acad. Sci.* **158**, 1539-41.

CROSS, J. E. 1875. The geology of north-west Lincolnshire; with an appendix by R. Etheridge. *Quart. J. geol. Soc. Lond.* **31**, 115-29.

DAVIES, W., and DIXIE, R. J. M. 1951. Recent work on the Frodingham Ironstone. *Proc. Yorks. geol. Soc.* **28**, 85-96.

DEAN, W. T., DONOVAN, D. T., and HOWARTH, M. K., 1961. The Liassic ammonite zones and subzones of the north-west European province. *Bull. British Mus. (Nat. Hist.): Geology*, **4**, 437-505.

DONOVAN, D. T., 1954. Synoptic supplement to T. Wright's monograph on the Lias ammonites of the British Islands (1878-86). *Pal. Soc. Lond.*

DUDLEY, H. E. 1942. The Lower Lias beds in the Frodingham Railway Cutting, north-west Lincolnshire. *Proc. Geol. Ass. Lond.* **53**, 152-5.

DUNCAN, P. M. 1876. On some thallophytes parasitic within recent Madreporaria. *Proc. Roy. Soc. Lond.* **25**, 238-57.

DUNHAM, K. C. 1960. Syngenetic and diagenetic mineralisation in Yorkshire. *Proc. Yorks. geol. Soc.* **32**, 229-84.

HALLAM, A. 1960. A sedimentary and faunal study of the Blue Lias of Dorset and Glamorgan. *Phil. Trans. Roy. Soc.* (B), **243**, 1-44.

HALLIMOND, A. F. 1925. Special reports on the mineral resources of Great Britain, XXIX. Iron Ores: Bedded ores of England and Wales. Petrography and Chemistry. *Mem. Geol. Surv.*

HECHT, F. 1933. Der Verbleib der organischen Substanz der Tiere bei meerischer Einbettung. *Senckenbergiana*, **15**, 165-249.

JOHNSON, R. G. 1957. Experiments on the burial of shells. *J. Geol.* **65**, 527-35.

LAMPLUGH, G. W., *et al.* 1920. Special reports on the mineral resources of Great Britain, XX. Bedded ores of the Lias, Oolites and later formations in England. *Mem. Geol. Surv.*

MONAGHAN, P. H., and LYTLE, M. A. 1956. The origin of calcareous ooliths. *J. Sed. Petrol.* **26**, 111-18.

NADSON, G. 1927. Les Algues perforantes de la mer Noire. *C.R. Acad. Sci.* **184**, 896-8.

PETTIJOHN, F. J. 1957. *Sedimentary Rocks*. New York. 2nd ed.

PULFREY, W. 1933. The iron-ore oolites and pisolites of North Wales. *Quart J. geol. Soc. Lond.* **89**, 401-30.

RASTALL, R. H., and HEMINGWAY, J. E., 1939. Black oolites in the Dogger of north-east Yorkshire. *Geol. Mag.* **76**, 225–33.

SAINT-SEINE, R. DE. 1954. Existence de Cirripedes acrothoraciques des le Lias: *Zapfella pattei* nov-gen., nov-sp. *Bull. Soc. géol. Fr.* **6**, (4), 447–51.

SCHÄFER, W. 1956. Wirkungen der Benthos-Organismen auf den jungen Schichtverband. *Senckenbergiana Leth.* **37**, 183–263.

SEILACHER, A. 1952. Zur Einteilung und Deutung fossiler Lebensspuren. *Univ. Tübingen dissertation.*

SWINNERTON, H. H., and KENT, P. E. 1949. The geology of Lincolnshire. *Lincs. N. H. Brochure*, **1** (*Lincs. Nat. Union*).

TOPSENT, E. 1887. Contribution à l'étude des Clionides. *Arch. Zool. exp. gén., sér.* **2**, suppl. no. 4, 1–165.

USSHER, W. A. E. 1890. Geology of parts of north Lincolnshire and south Yorkshire. *Mem. Geol. Surv.*

WEIGELT, J. 1929. Fossile Grabschächte brachyurer Decapoden als Lokalgeschiebe in Pommern und das *Rhizocorallium*-Problem. *Zeitschr. für Geschiebeforsch.* **5**, 1–42.

WHITEHEAD, T. H. *et al.* 1952. The Liassic Ironstones. *Mem. Geol. Surv.*

WRIGHT, T. 1878–86. Monograph on the Lias ammonites of the British Islands. *Pal. Soc. Lond.*

ZEUNER, F. E. 1933a. Die Lebensweise der Gryphäen. *Palaeobiologica*, **5**, 307–20.

—— 1933b. Die Lage der *Gryphaea arcuata* im Sediment. *Zbl. Miner. Geol. Paläont.* B, 568–74.

A. HALLAM
Grant Institute of Geology,
University of Edinburgh,
Edinburgh, 9

Manuscript received 15 June 1962