Conesby Quarry, North Lincolnshire

[SE 899 143]

K.N. Page

Introduction

The Conesby and Yorkshire East quarries complex (Figure 5.6) has provided the richest documented faunas of the Frodingham Ironstone Member of the Scunthorpe Mudstone Formation, of Sinemurian age, a deposit historically of great economic importance. Bivalves dominate the fossil assemblages, accompanied by ammonites, belemnites and rare intact echinoderms. Ammonite faunas from this site indicate the presence here of several biohorizons that, although rarely developed elswhere in Britain, are of key significance for Upper Sinemurian correlation across Europe. Sedimentologically and palaeoecologically this site is important for understanding the development of Lower Jurassic ironstone facies in Great Britain. Stratigraphically and taxonomically it is a key site for the study of mid-Sinemurian ammonite faunas.

The Frodingham Ironstone Member has been mined around Scunthorpe for more than 130 years and was the basis for the town's former prosperity in steel-making. These links are so strong that the town's coat of arms incorporates three *Gryphaea,* one of the most conspicuous fossils in the surrounding quarries. The ironstone is no longer worked as an ore and, with the dosing of the workings, most of the former exposures have been, or are in the process of being, lost to landfill or are flooded (Knell, 1990). The Lower Jurassic succession is overstepped by an early Cretaceous unconformity as the Market Weighton High is approached (Cope *et al.,* 1980a) and hence the Frodingham Ironstone Member does not extend far north of the River Humber. To the south it can be traced for some 17 km before passing into mudstones and less ferruginous limestones. Scunthorpe itself lies on the present outcrop of the Frodingham Ironstone Member, with its maximum preserved updip extent lying less than 5 km to the west. To the east it reaches a maximum thickness of about 10 m (32 ft according to Hallam, 1963) at Santon, about 5 km east of Scunthorpe, but has been traced at depth at least as far as Immingham, some 30 km east of Scunthorpe, and may well extend beyond the coast (Knell, 1990). The upper boundary of the Frodingham Ironstone Member is quite sharply defined, with an abrupt change from ironstone to mudstone. However, the lower boundary is more ill-defined and typically shows a progressive upward increase in the proportion of ironstone facies to mudstone (Hallam, 1963).

There is relatively little early work on the ironstone, the first account of the orefield being in Cross (1875), which , with the addition of a brief account in Ussher (1890), formed the basis of all subsequent reports up to the publication of Wilson (1948). Later work on the ironstone included that of Hallimond (1925), Davies and Dixie (1951), and Whitehead *et al.* (1952). The stratigraphical distribution of the ironstone has been discussed since some of the earliest publications, with more recent accounts including Hallam (1963), Cope *et al.,* (1980a), Gaunt *et al.* (1992) and Page (1992). Specifically palaeoenvironmental analyses are represented only by the work of Hallam (1963) and Young *et al.* (1990b). In the late 1980s and early 1990s intense activity associated with a landfill scheme at the Conesby Quarry site, north-east of Scunthorpe, yielded a considerable fauna from the ironstone (Knell, 1988), though few specimens were associated with precise stratigraphical information. This is particularly significant for the ammonite faunas, making precise comparison with other sites difficult. Sole (2001) and Thompson (2001) have given accounts of the rescue-collecting operations at Conesby Quarry.

Yorkshire East Quarry is adjacent to the Conesby Quarry site and formerly was part of the same quarry complex, though excluded from the landfill schemes; the construction of a railway embankment partitioned the once continuous quarry face (Figure 5.6). Mechanical excavations at Yorkshire East Quarry, organized by British Steel in 1995, facilitated the first detailed stratigraphical recording of a section in the Frodingham Ironstone Member, which has now, in part, compensated for the lack of detailed information from the Conesby Quarry site. The new section showed the basal Charmouth Mudstone Formation, overlying the upper, fossil-rich, portion of the Frodingham Ironstone Member and was recorded and sampled in detail (Page, 1995).

Description

The section at Conesby Quarry has never been documented in detail but is closely similar to other sites nearby that have. Hallam (1963) stated that the section through the Frodingham Ironstone Member at Conesby was 'essentially similar' to that which he gave for the Crosby Mine [SE 907 133], only 1 km to the south-east. At the latter site he recorded a section through 8.54 m (27 ft 9 in.) of the Frodingham Ironstone Member, dividing it into eight distinct beds capped by dark shales. The section reproduced below (Figure 5.7) is based largely on that exposed at Yorkshire East Quarry, where excavations exposed more than 7 m of the Frodingham Ironstone Member (beds 0–23) and the lowest 3.5 m or so of the Charmouth Mudstone Formation (beds 24a–c) (Figure 5.8). At least 10 m of the mudstones were formerly seen in the adjacent Conesby Quarry site but have not been logged in any detail either for here or for the Yorkshire East Quarry, though records from Conesby Quarry have been incorporated into the section described below for Yorkshire East Quarry Sellwood (1972) logged 34 m of the predominantly argillaceous Charmouth Mudstone Formation in the Raricostatum and Jamesoni zones above the ironstone at Roxby Mine [SE 910 170], about 3 km to the north-east. Lithostratigraphical correlation between the section recorded here and those recorded by Hallam (1963) at Crosby Mine and Sellwood (1972) has proven difficult or impossible.

	Thickness (m)
PLEISTOCENE	
Sands, unconsolidated, pale.	
UPPER SINEMURIAN–LOWER PLIENSBACHIAN SUBSTAGES	
Charmouth Mudstone Formation	
24c: (Conesby Quarry). Mudstone, grey, with alternating paler, ?silty bands. Occasional bands of small pale-coloured phosphatic nodules present. Bivalves and ammonites frequent, usually crushed in the mudstones, but occasionally partly preserved uncrushed in phosphatic nodules. Stratigraphically important faunas include: *Apoderoceras* sp. (gr. *nodogigas/aculeatum* Bio-horizon, Taylori Subzone), *Paltechioceras* ex grp. *aplanatum* (*aplanatum* Biohorizon, Aplanatum Subzone), *Leptechioceras cf. macdonelli* (*macdonnelli* Biohorizon, Macdonnelli Subzone), *Leptechioceras* cf. *planum* (*subplicatum* Biohorizon, Macdonnelli Subzone), *Echioceras* sp. (Raricostatum Subzone) (Page, 1992).	> 6.0
24a–b: (Yorkshire East Quarry). Marl, pale greenish-grey weathering, with scattered small micritic nodules and a pale-grey, burrowed (*Chondrites*) soft calcareous lenticle at c. 1.45–1.60 m above base (= Bed 24b). Nodules yield small bivalves, including Oxytoma, and Gagaticeras sp.. Gagaticeras also occurs crushed in marl from around 0.55 m above the base of Bed 24a. Oxynoticeras cf. simpsoni is present at approximately this level in the former Conesby Quarry site, indicating the Simpsoni Subzone.	c. 3.5
Scunthorpe Mudstone Formation	
Frodingham Ironstone Member	
23: Chamositic band, rusty-weathering, typically soft and sandy, with small (*c.* 3–4 cm) black, hollow-centred concretions in lower part. Rare dark olive-green unweathered patches.	0.01

22: Sandstone, silty, chamositic, soft, shelly; dark olive-green with small white-shelled bivalves when unweathered. Occasional *Gryphaea* present. Hardened dark, purplish-grey mudstone clast near top. Similar hard mudstone forms an impersistent band locally at base of bed. Calcareous shelly lenticles present locally. *Eparietites denotatus* present. Corresponds to the *denotatus* Biohorizon, Denotatus Subzone.	0.14
21: Sandstone, chamositic, greenish-grey, with small white shells (when unweathered). Flaggy bedded, typically splitting into 3 bands (beds 21a–c). Ammonite fauna includes *Eparietites fowleri* in upper 0.1 m (= 21c); corresponds to the *fowleri* Biohorizon, Denotatus Subzone. This is probably the level that has yielded very rare *Xipheroceras trimodum* and *Angulaticeras* sp. in Conesby Quarry. *Aegasteroceras* is also likely to be present.	0.28
20: Sandstone, chamositic, with white calcareous shelly lenticles up to 1.5 cm thick full of small bivalves and occasional ammonites. The latter commonly with green chamosite-impregnated shells. Traces of cross-bedding present locally. Some hard mudstone clasts present. Ammonite fauna includes: *?Eparietites* sp. (*c.* 0.05 m below top of bed; Denotatus Subzone); *Asteroceras* ex grp. *smithi* (transitional to *Aegasteroceras*)*; ?Xipheroceras* sp. (in upper *c.* 0.12 m); *Asteroceras* ex grp. *smithi sensu stricto* (*c.* 0.15–0.3 m below top of bed; corresponds to the aff. *arnouldi–blakei s.s.* biohorizons, Stellare Subzone); *Asteroceras* ex grp. *stellare, Xceras* sp. (*c.* 0.4–0.77 m below top of bed)	*c.* 0.5–0.8
19: Sandstone, chamositic, silty, fine, sandstone, some shells (bivalves) present.	0.05–0.2
18: Sandstone, calcareous with some shelly lenticles. Impersistent hard marl (up to 0.06 m thick) seen in upper part.	0.1–0.72
17: Sandstone, ferruginous, soft, red-brown weathering, with some harder bands. Scattered *Gryphaea* present.	0.45
16: Sandstone, chamosite oolite, hard, ferruginous, weathering a dark-brown colour. Shelly band with abundant *Gryphaea* in lower part.	0.45
15: Sandstone, ferruginous, brown, soft.	0.45 m
14: Sandstone, calcareous, shell rich, with abundant large bivalves (*Gryphaea* and *Cucullaea*)*.*	0.3–0.35
13: Seam, soft silty, fine, sandy.	0.1
12: Sandstone, shelly oolitic, with *Cucullaea,* etc.	0.45
11: Pebble bed, intraclastic, full of small ferruginous clasts generally < 1 cm in diameter.	0.10
10: Sandstone, calcareous and ferruginous, shelly, flaggy weathering in upper part, with large shells (*Gryphaea, Cucullaea*)*.*	0.16

9: Sandstone, calcareous, ferruginous, shelly. In two blocks separated by a parting. Upper block (9b) with common large shells (*Gryphaea, Cucullaea*). Lower block (9a) with fewer shells, but concentrated near top. Some small intraclastic pebbles present in lower part of 9a.	0.6
8: Soft sandy parting.	0.05
7: Sandstone, shelly, calcareous, ferruginous, with abundant *Cucullaea,* etc., and some pectinids.	0.28
6: Soft sandy parting.	0.05
5: Sandstone, calcareous, ferruginous, with large shells (*Cucullaea,* etc.) concentrated near top.	0.2
4: Soft sandy parting.	0.05
3: Sandstone, very shelly, calcareous, full of large shells, especially *Cucullaea,* with some *Gryphaea.*	
2: Soft sandy parting.	0.220.05
1: Sandstone, massive, ferruginous, flaggy weathering near top, with some *Gryphaea.* Around 0.4 m present above water level on north side of access ramp to conservation exposure, below massive-bedded ferruginous sandstone seen (largely inaccessible on south side of ramp). Lower part in southern area of site more flaggy bedded.	*c.* 2.5
0: Soft silty band seen just above water level on south side of site.	*c.* 0.15 (seen)
(Loose blocks of soft silty sandstone beside the flooded excavation in the southern area of the Yorkshire East Quarry site yielded abundant *Gryphaea* and common *Euagassiceras* ex grp. *resupinatum* with *?Arnioceras* sp.. The lithology and location suggest an origin within or close to the base of Bed 2, Sauzeanum Subzone)	

Within the ironstone itself, four basic lithologies have typically been recognized in the district (Davies and Dixie, 1951; Whitehead *et al.,* 1952; *Hallam,* 1963; Gaunt *et al.,* 1992), with a fifth described in Young *et al.* (1990b). Their basic characteristics, based largely on Young *et al.* (1990b) and Hallam (1963), are as follows:

Type A: Bioclastic ooidal grain-ironstone — calcitic bioclasts and goethite/berthierine ooids, more-or-less replaced by siderite, all covered with a thin berthierine grain coating and siderite cement. In hand specimen a spongy mass of berthierine-bearing shiny ooids. Hallam (1963) noted that types A and C often tend to grade into one another.

Type B: Sideritic mud-ironstone — small rhombs of siderite among parallel-orientated berthierine flakes. Ooids and bioclasts virtually absent. In hand specimen a tough indurated blue-grey mudstone. Hallam (1963) noted that this type is remarkably free of shells but, unlike the other types, it often contains minute shreds of organic matter parallel to bedding.

Type C: Goethite ooidal wacke-ironstone — goethite/berthierine ooids, more-or-less replaced by siderite, within a fine-grained berthierine/siderite matrix. The ooliths and pisoliths occur in a berthierine-rich mudstone with siderite crystals and quartz grains. Hallam (1963) noted that this is more argillaceous than Type A.

Type D: Ferruginous bioclastic limestone — goethite/berthierine ooids and calcareous bioclasts, more-or-less replaced by siderite, in a coarse sparry calcite cement (subdivided into D1, dominantly bioclastic, and D2, dominantly ooidal). Hallam (1963) noted that this often contains localized patches of mudstone with indeterminate boundaries, as well as obvious mudstone lithodasts. Quartz silt is rarer in this type, while broken ooliths are somewhat commoner, than in the other types of ironstone. This type often exhibits cross-bedding.

Type E: Berthierine-bearing silty ooidal mudstone — siderite absent and clastic material prominent.

All five types of ironstone appear to be present in the Conesby district and lithologies are often relatively fresh and in part unweathered, particularly at the centre of large blocks. Types B and D are particularly distinct, with Type B often forming discontinuous or bifurcating seams within the more dominant Type D. The preservation of this material is ideally suited for further work on the formation, especially into the mineralogy and diagenesis, and as no contemporary published study exists, beyond the observations of Gaunt *et al.* (1992, pp. 35–6).

Fossils are frequently abundant in the ironstone, particularly in the topmost 1–2 m. Hallam (1963) listed more than 40 species whereas Young *et al.* (1990b) cited a figure of 42 species of bivalve alone, and provided data on the facies distribution and life habits of 35 of these. Individual shell bands typically are dominated by only one or two bivalve species, often *Cardinia* or *Gryphaea.* Shelly lenticles in the upper part of the ironstone may be rich in pectinids, including *Camptonectes, Entolium* and other bivalves, while the brachiopod *Piarorhynchia* (probably *Cuneirhynchia oxynoti,* although there is no mention of the Frodingham Ironstone Member in Ager's (1956–1967) monograph) was said by Hallam (1963) to be abundant in the top 1.25 m (4 ft) of all sections through the Frodingham Ironstone Member, though uncommon below this level. Cross (1875) also recorded *Spiriferina walcotti* from the ironstone. Hallam (1963) noted that moulds of thin-shelled bivalves occur in the types A and C ironstones and that other shells are at least partly replaced by chamosite. Calcitic preservation is found in Type D ironstones, where the bivalves are predominantly disarticulated, with valves convex-up and showing a higher degree of fragmentation than in other ironstone types and an abundance of algal borings. Deeper-burrowing bivalve species often are preserved in life position in types A and C but are absent from Type D.

Echinoderm debris is a common component of the more bioclastic units and intact echinoderm material has also been recovered. Knell (1988) figured large intact specimens of the asteroids *Solaster* and *Archastropecten,* while a specimen of *Isocrinus tuberculatus* (misidentified as *Isocrinus robustus*) was figured on the front cover of the July/August 1990 (vol. 6, no. 4) issue of *Geology Today.* These intact echinoderms invariably are associated with thin day lenses within the ironstone.

Hallam (1963) observed numerous foraminifera in thin-sections of the ironstone facies and was able to extract representatives of six genera from the mudstone immediately overlying the Frodingham Ironstone Member at Crosby Quarry. He also described several types of ichno-fossil from the member. Within the sediment itself he observed large, sub-horizontal, *Rhizocorallium* burrows and smaller, vertical U-tubes of *Diplocraterion.* Although many were filled with the same material as the surrounding sediment, some were seen to be filled with mudstone despite their position in exclusively ironstone parts of the succession. He also described and figured three types of microscopic or submicroscopic boring from the shells of *Gryphaea* and other bivalves at Crosby Mine. He attributed these to cirripedes, clionid sponges and algae, and noted that the algal borings were confined to shells in Type D ironstones.

Only Sellwood (1972) has investigated the palaeoecology of the overlying Charmouth Mudstone Formation, though at Roxby Mine some 3 km to the north-east rather than at this site. Above a winnowed shell bed at the top of the Frodingham Ironstone Member he identified seven minor cycles (Sellwood, 1970) up to the base of the Aplanatum Subzone, with each cycle coarsening upwards from dark mudstones to paler bioturbated siltstones before being abruptly succeeded by the mudstones at the base of the next cycle. The Aplanatum Subzone and Jameson' Zone was developed in non-cyclic mudstones with a prominent shell bed, containing broken and encrusted material, at the Raricostatum–Jamesoni zonal boundary.

Interpretation

In the first geological account of the Frodingham Ironstone Member, Cross (1875) recorded a number of ammonite species that would now be assigned to the genera *Arnioceras, Agassiceras, Caenisites* and *Metophioceras,* together indicative of the Bucklandi, Semicostatum and Turner' zones. Ussher (1890) interpreted this assemblage as representing the Semicostatum Zone while Arkell (1933) assigned the ironstone to the Semicostatum and part of the Bucklandi zones. Hallam (1963) re-examined material in Scunthorpe Museum and collected new material, concluding that the Frodingham Ironstone Member spanned the interval from the Sauzeanum Subzone, near the top of the Semicostatum Zone, to the Denotatus Subzone, at the top of the Obtusum Zone. Earlier biostratigraphical mis-interpretations he attributed to the misidentification of *Eparietites* and *Epophioceras* as *Agassiceras* and *Metophioceras* respectively.

More recent collecting (K.N. Page, unpublished observations) has refined the biostratigraphy still further, with the recognition of several discrete biohorizons (Page, 1992) in the upper part of the Frodingham Ironstone Member and the Charmouth Mudstone Formation of the Conesby Quarry area. Evidence for the presence of further biohorizons in the district is indicated by museum material, especially in the collections of Scunthorpe Museum that form the main repository of specimens from the ironstone. The biohorizons recognized in the upper part of the Frodingham Ironstone Member are particularly important. The lowest of these, the *blakei* (X) Biohorizon, is one of the most widespread in Europe, being recorded from North Yorkshire, Gloucestershire, possibly Somerset, Burgundy, the French Jura and Switzerland (Dommergues *et al.,* 1994; Blau and Meister, 2000). This fauna at Conesby Quarry is the best preserved in Britain and hence of primary importance for international correlation. Above the *blakei* Biohorizon fauna, the upper *c.* 0.12 m of Bed 20 in Yorkshire East Quarry yields coarsely ribbed *Asteroceras* ex grp. *smitbi,* transitional to *Aegasteroceras* spp.. A similar fauna occurs with *Arnioceras* aff. *arnouldi* in Burgundy, suggesting a correlation with the aff. *arnouldi* (XI) Bio-horizon of the Stellare Subzone. *Aegasteroceras* ex grp. *sagittarium* was formerly abundant in Conesby Quarry (Figure 5.9), indicating the succeeding *sagittarium* (XII) Biohorizon, while *Eparietites undaries,* representing the cf. *undaries* (XIII) Biohorizon, has also been found near the top of the Frodingham Ironstone Member (Joss, 1980). However, both biohorizons remain unproven at Yorkshire East Quarry, with the next fauna recovered from that site being typical *Eparietites fowleri* in the upper *c.* 0.1 m of Bed 21. The *fowleri* (XIV) Biohorizon is well documented in Britain only in the Conesby district, but has been recognized in Burgundy and in south-east France (Page, 1992; Blau and Meister, 2000). This fauna includes the rare eoderoceratid, *Xipheroceras trimodum* and an unusual species of extremely oxyconic *Angulaticeras,* apparently unlike anything recorded elsewhere in north-west Europe. Bed 22 yields well-preserved *Eparietites denotatus* indicating the *denotatus* (XV) Biohorizon. Records of *Oxynoticeras simpsoni* in the topmost Frodingham Ironstone Member (e.g. in Gaunt *et al.,* 1992) could, therefore, be late Denotatus Subzone *Eparietites,* including *E. denotatus* itself thathas a body-chamber indistinguishable from true *O. simpsoni.*

The lower part of the Frodingham Ironstone Member has been less intensively collected in recent years, but Hallam (1963) cited examples of *Arnioceras* aff. *semicostatum, Pararnioceras* aff. *alcinoe, Caenisites* cf. *brooki* and *Microderoceras birchi* in addition to various Obtusum Zone taxa. Specimens of *Euagassiceras* from near the base of the section recorded here, together with Hallam's (1963) records, indicate the presence of the Sauzeanum, Broold, Birchi, Stellare and Denotatus subzones within the Frodingham Ironstone Member. No conclusive evidence has been found for the presence of the Obtusum Subzone, an observation that was commented on by Hallam (1963).

In the overlying Charmouth Mudstone Formation Sellwood (1972) recognized a complete sequence of subzones through the Raricostatum and Jamesoni zones at Roxby Mine, but assigned the top of the Frodingham Ironstone Member and less than 1 m of the overlying mudstone to the Oxynotum Zone. However, specimens of *Eparietites* aff. *glaber* in Scunthorpe Museum indicate that the base of the Charmouth Mudstone Formation lies in the uppermost Denotatus Subzone. Furthermore, the lowest part of the formation in the Scunthorpe district has yielded a form, transitional between *Eparietites* and *Oxynoticeras,* referable to *Eparietites collenotii* (Dommergues *et al.,* 1994). This represents the aff: *glaber* Biohorizon previously recorded only from France and unknown elsewhere in Britain. Later faunas of Raricostatum Zone and basal Jamesoni Zone were recorded from the Conesby Quarry sites, though cut out at Yorkshire East Quarry by Quaternary deposits, but the Oxynotum and Densinodulum subzones were unproven.

The absence of any evidence for the Obtusum Subzone suggests a region-wide non-sequence at this level but the local absence of other biostratigraphically defined faunas probably indicates no more than the sporadic occurrence of fossil-rich lenses within the Frodingham Ironstone Member. Similarly, the apparent absence of the Oxynotum and Densinodulum subzones at Conesby, despite their supposed presence at Roxby (Sellwood, 1972), probably reflects collection failure. Nonetheless, it is clear that sedimentation during deposition of the Frodingham Ironstone Member was discontinuous. Hallam's (1963) observation of mudstone-filled *Diplocraterion* burrows within an entirely ironstone part of the succession implies modest periods of erosion during deposition. Similarly the presence of intensively bio-eroded *Gryphaea* shells suggests that shell material was exhumed or remained exposed on the sea floor for significant periods of time. Sellwood's (1972) comment, that subzonal boundaries within the Raricostatum Zone correlate with the tops of minor sedimentary cycles, also implies that there may have been significant pauses during deposition of this part of the Charmouth Mudstone Formation.

The palaeoecology of the ironstone has been discussed by Hallam (1963) and typical fossils illustrated in a booklet by Knell (1990). Young *et al.* (1990b) provided a contemporary review and suggested that grading, bioturbation, sedimentary structure and shell-rich coquinoid biofabrics indicated alternating storm and fair-weather conditions. These features are displayed in tripartite pseudo-cycles, comprising a storm couplet overlain by background sediments, although they have been modified to varying degrees by subsequent lower-energy events. Young *et al.* (1990b) suggested that the major storm events represented in the Frodingham Ironstone Member might occur as infrequently as once in 150 000 years yet they noted that the depth of scouring was of similar magnitude to the bed thickness. From this they inferred that sediment remained in the mobile superficial layer for a similar length of time, perhaps accounting for the apparent mixing of some of the ammonite faunas.

These storm events, infrequent though they might have been, inevitably had a significant effect on the taphonomy of the ironstone faunas, with shells being reworked, transported, and in some cases destroyed, although storm-produced units contain essentially the same species as inter-stratified fair-weather deposits. As discussed by Young *et al.* (1990b), Type C ironstones represent background fair-weather deposits with fossil-rich fabrics showing an interplay between physical and biological depositional processes, including intense bioturbation. In contrast the types D1 and D2 ironstones represent tempestites, with sorting (both size and taxonomic), fragmentation and convex-up orientatation of bivalve shells. Coquinas of *Cardinia* and pectinids characterize the base of many of these tempestite pseudo-cycles. Hallam (1963) concluded that the organic material and lack of bioturbation in the Type B ironstones suggested deposition in anoxic bottom waters.

There is evidence within the Frodingham Ironstone Member of both high-energy shoal conditions and lower-energy periods with deposition of more muddy suspended sediment, which was then intensely bioturbated (Gaunt *et al.,* 1992). This environmental instability, with rapid deposition following storms, was a major factor in the obrution mechanism that caused preservation of articulated asteroids and crinoids beneath thin mudstone lenses. The prevalence of tempestite facies within the member indicates that the sea floor was well above storm wave-base whereas the presence of abundant endolithic algal borings in bivalves in Type D ironstones indicates a position well within the photic zone, with deposition perhaps occurring in no more than 20–25 m of water (Hallam, 1963).

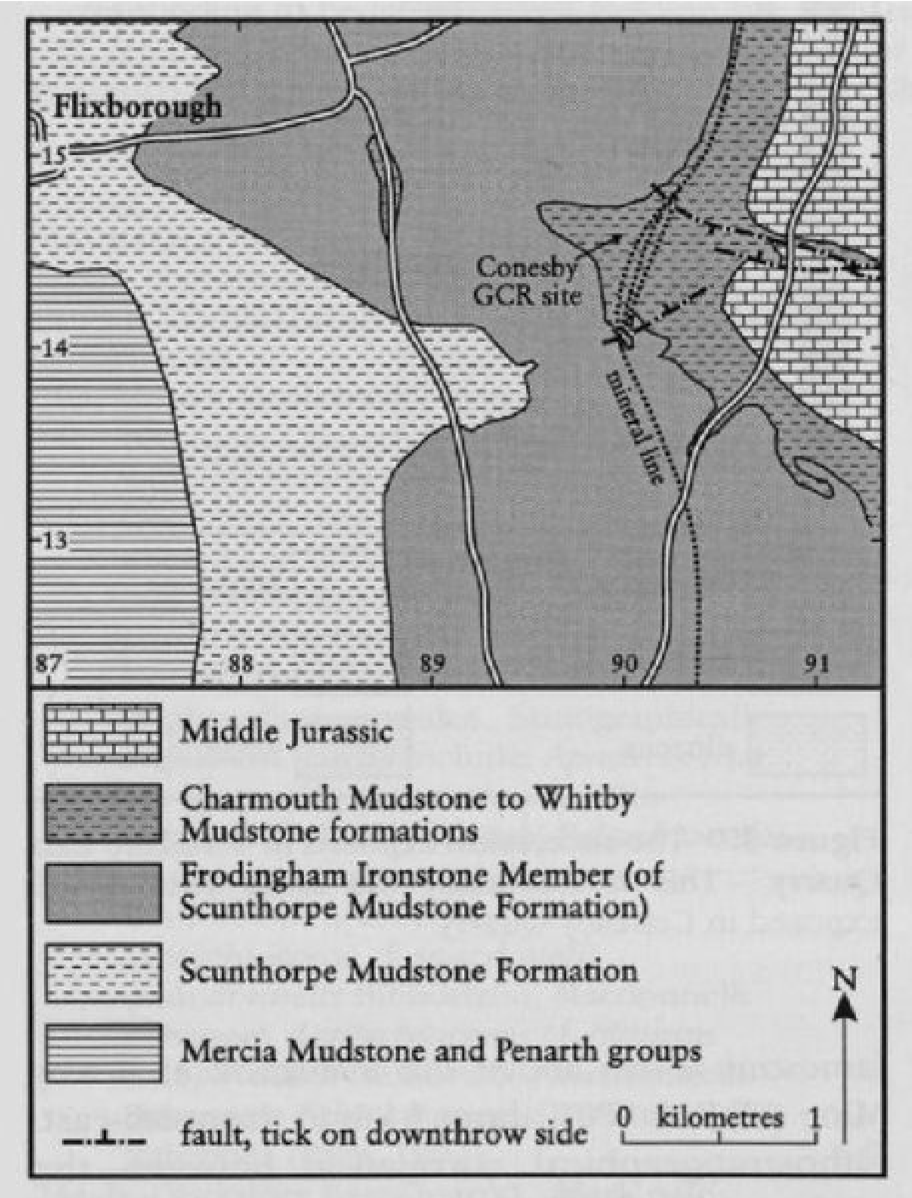
As with so many sedimentary ironstones, the precise reasons for the geographical and stratigraphical location of the Frodingham Ironstone Member remain uncertain. However, it is perhaps significant that the Pecten Ironstone Member within the Charmouth Mudstone Formation, of upper Jamesoni to lower Ibex zone age, is confined to the same geographical area as the older Frodingham Ironstone Member, suggesting a common underlying control. The somewhat condensed nature of the Frodingham Ironstone Member, with barely 10 m of ironstone correlating with almost three times this thickness of clastic sediments in Robin Hood's Bay, to the north, and five times this thickness on the Dorset coast, suggests slow rates of deposition. The often low proportion of clastic material in these ironstones also indicates deposition in an area of sediment starvation, perhaps on a local high. In this respect the proximity of the Frodingham Ironstone Member to the southern margin of the Market Weighton High may be significant (Figure 5.10), with periodic movement on this structure perhaps exerting a major influence on facies development in the Lower Jurassic Series of the area. The absence of similar ironstones at this level in adjacent basins, and their development instead at other levels, suggests that eustatic changes exerted only a minimal influence, if any at all, on the development of these facies.

Young *et al.* (1990b) considered that the primary iron mineral in the ironstone was berthierine. The formation of this mineral requires low-oxygen, low-salinity conditions, which conflicts with the apparent palaeoecological evidence for well-oxygenated conditions. It has been suggested that the berthierine was formed elsewhere, perhaps in brackish-water lagoons protected from the sea by some form of barrier, perhaps shell banks, and received dissolved and particulate iron from an adjacent low-lying and well-vegetated landmass with lateritic soil formation (Gaunt *et al.,* 1992). Subsequently these berthierine-rich muds were washed into a fully marine, shallow-water environment, perhaps during storms. Nonetheless, the frequent low-diversity but high-abundance characteristics of the benthic fauna does tend to suggest some form of restricted conditions at times, though this may have taken the form more of physical factors associated with these facies rather than any chemical properties of the seawater at this time.

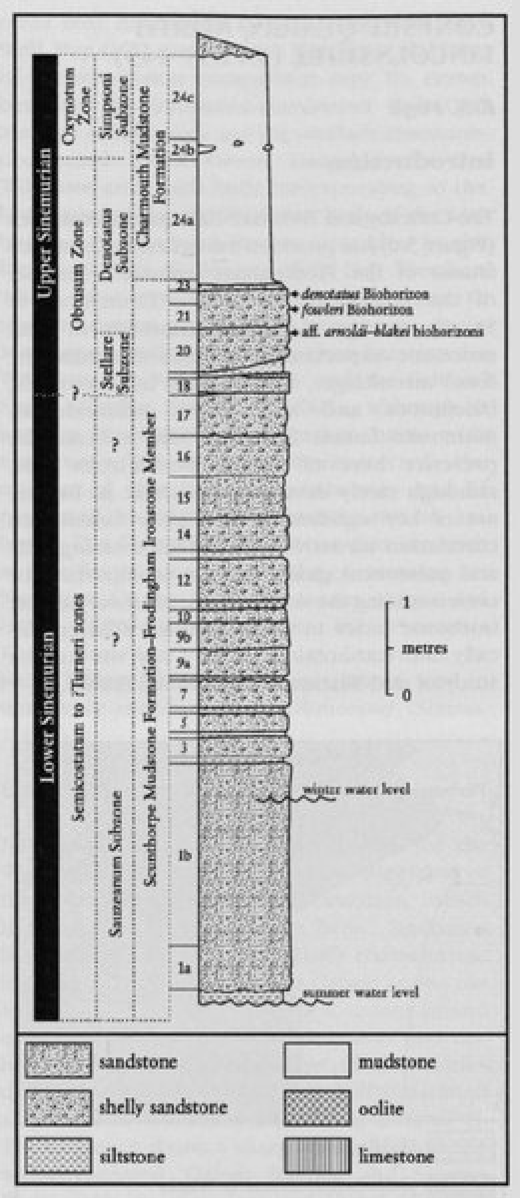
Conclusions

Yorkshire East Quarry is one of the last remaining exposures of the Frodingham Ironstone Member, adjacent to the former Conesby Quarry, which has yielded the richest-known faunas from this unit. The well-preserved ammonite faunas indicate the presence of several biohorizons within the Obtusum Zone, including the *blakei* Biohorizon, a key reference level for correlating Upper Sinemurian sequences across Europe, and the aff. *glaber* Biohorizon, otherwise unknown in Britain. Other elements of the fauna include intact specimens of several species of asteroid, an extreme rarity in the British Lower Jurassic Series, and of *Isocrinus tuberculatus.*

References

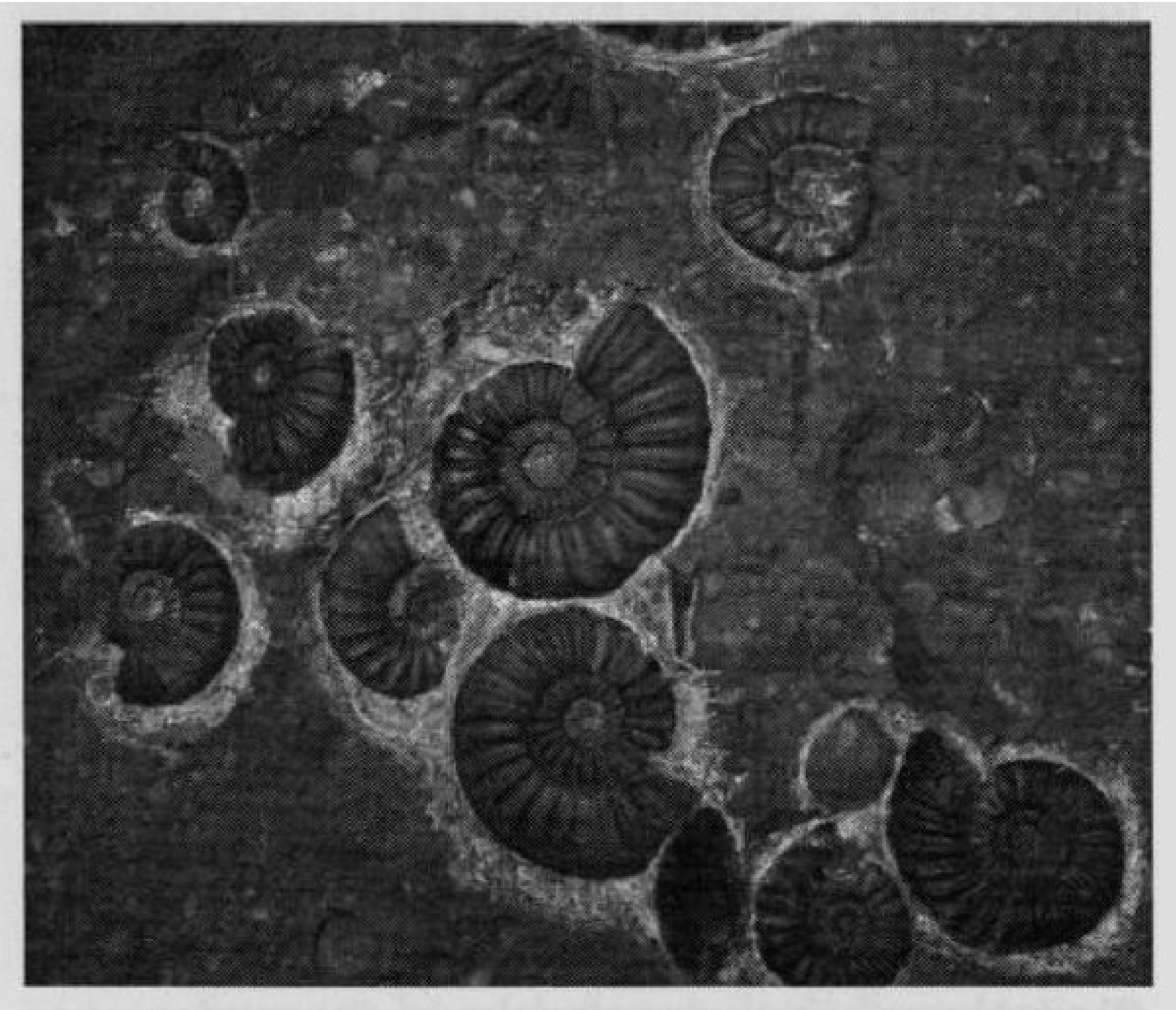


(Figure 5.6) Geology and location map for the Conesby Quarry GCR site and Yorkshire East Quarry.

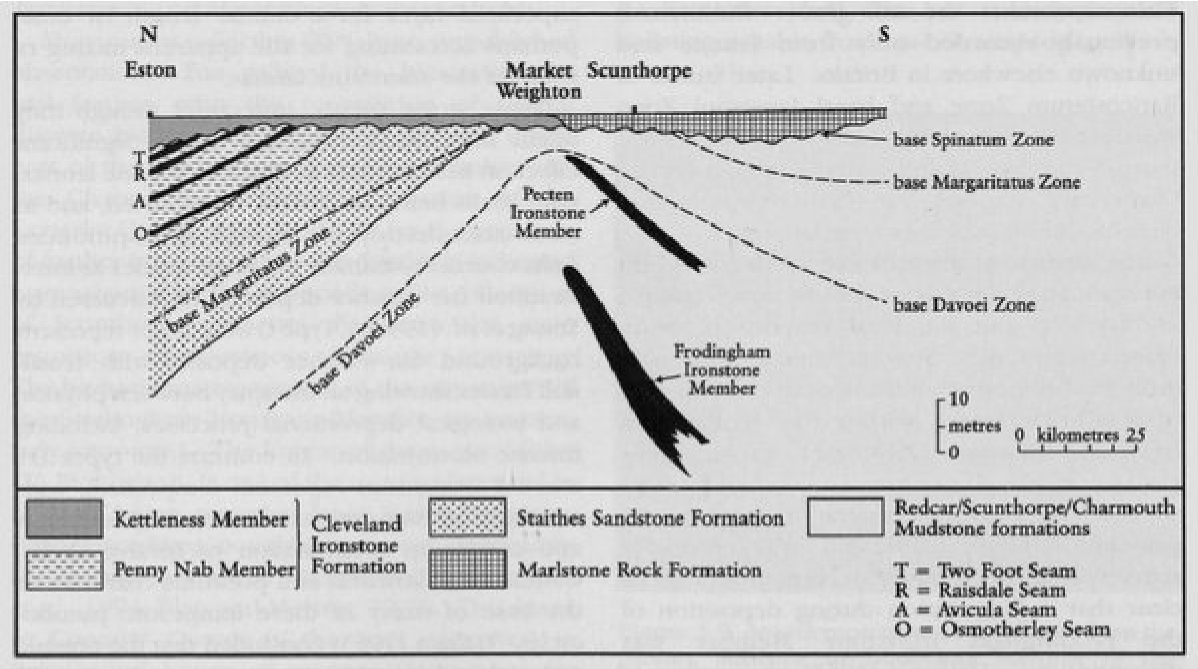


(Figure 5.7) The succession exposed in Yorkshire East Quarry. This is essentially the same as that still exposed in Conesby Quarry.

(Figure 5.8) Yorkshire East Quarry, Conesby; trial excavation in mid-1995, prior to SSSI notification. The lower face shows around 7 m of bedded Frodingham Ironstone Member above water level, with the top 1 m corresponding to beds 20–23 and yielding late Stellare to Denotatus subzone faunas. Above, and in the rear cliff, around 3.5 m of Charmouth Mudstone Formation can be seen, of Simpsoni Subzone age. The succession is capped by Quaternary 'Cover Sands'. (Photo: K.N. Page.)



(Figure 5.9) Aegasteroceras and other fossils from the Stellare Subzone or Denotatus Subzone of the Frodingham Ironstone Member at Conesby Quarry. Specimen in the collections of the National Museum of Wales. (Photo: M.J. Simms.)



(Figure 5.10) Schematic section across the Cleveland Basin, Market Weighton High and northern end of the East Midlands Shelf showing the relationship of the Liassic ironstones to the underlying structure. After Howard (1985).