The Lias Succession between Fulbeck and the Vale of Belvoir

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Abstract: The Lower Jurassic beds of the area between Fulbeck and the Vale of Belvoir comprise the Lias Group, traditionally divided into Lower Lias, Middle Lias (including Marlstone Rock Bed), and Upper Lias. Until recently, knowledge of much of this sequence had advanced little since the early part of the century, and only small parts were known in any detail. Recent geological mapping and the drilling of cored boreholes at Fulbeck have enabled the detailed stratigraphy of the Lower and Middle Lias to be unravelled, and a new lithostratigraphic classification has been developed. The succession in the Vale of Belvoir is closely similar to that at Fulbeck, though there is a slight thickness increase. For the higher part of the Lias Group (Marlstone Rock Bed and Upper Lias), the present state of knowledge is briefly reviewed.

This paper arises from the author's lecture to the East Midlands Geological Society (1 July 1989) and a subsequent field excursion (28 October 1990; see Brandon, this issue).

Although the Lias is well exposed on the coast in Yorkshire, Dorset and South Wales, natural exposures are scarce inland. Quarry sections are restricted to specific parts of the sequence of economic interest, and cored boreholes are generally few and far between. For these reasons, in large parts of the country, the sequence is still very poorly known. Until recently, this was the case in the area discussed here (Fig. 1).

Prior to the work described below, virtually the only modern studies of the Lias of the region had been carried out by the late Sir Peter Kent. Between 1936 and 1941 he worked on oil exploration in central and southern England, including the Carboniferous petroleum prospects of Eakring and the Vale of Belvoir. During this period he examined many uncored exploration boreholes which penetrated the Lias. He also examined old quarries and temporary exposures and did some mapping near Foston and Long Bennington [SK 85 42]. Building on previous work by the Geological Survey (Jukes-Browne, 1885;

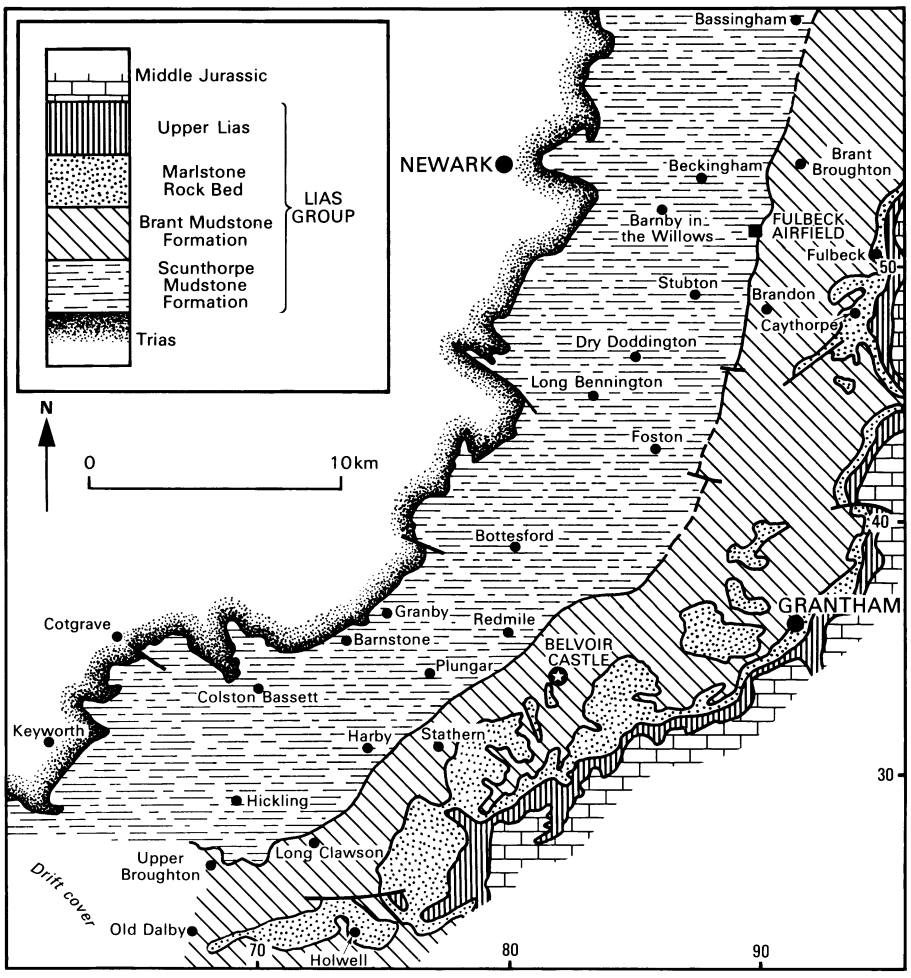

Fig. 1. Location of study area showing localities named in the text. The Vale of Belvoir comprises the area of Lias outcrop lying approximately between Old Dalby and Long Bennington.

Woodward, 1893; Lamplugh *et al.*, 1909) and Trueman (e.g. 1918), he established a lithostratigraphic scheme for the Vale of Belvoir and south Lincolnshire (Swinnerton and Kent 1949, 1976; see Fig. 2), which formed the essential framework for all subsequent work (Hallam, 1968; Cope *et al.*, 1980; Kent, 1980). In addition, he published many short papers on the local geology (1937, 1964, 1973, 1974) and left a considerable volume of manuscript notes, now held by the British Geological Survey (BGS).

Despite the undoubted value of Kent's work, the lack of modern geological maps and cored boreholes in the area meant that details of much of the sequence remained unknown. This situation was remedied in 1986, when UK Nirex Ltd selected the largely disused Fulbeck Airfield [SK 900 510], on the Lower Lias east of Newark, as a possible disposal site for radioactive waste. BGS was commissioned to carry out a geological survey of a large area around the site and a detailed site investigation of the airfield itself was undertaken by Sir Alexander Gibb and Partners. This involved trenching and the drilling of over 70 cored boreholes through the lower part of the Lias. Halved cores and specimens from two of these, F/B1 [SK 8889 5053] and F/B5 [SK 9062 5076], are now stored at BGS, Keyworth.

As a result of the work at Fulbeck, a new lithostratigraphic scheme for the beds between the base of the Lias Group and the base of the Marlstone Rock Bed was developed (Brandon *et al.*, 1990) and is summarised below. Subsequently, survey of the Lias outcrop of BGS 1:50 000 Sheets 126 (Nottingham) and 127 (Grantham) has continued south-westwards from the Fulbeck area into the Vale of Belvoir. Together with information from boreholes, this work has confirmed that the sequence in the Vale is essentially the same as that at Fulbeck, except for a slight overall thickness increase.

Nature and subdivision of the Lias

The Lias Group is a sequence of marine beds which, except for the very basal beds, is of Early Jurassic age. It is underlain by the Triassic Penarth Group (the former Rhaetic) and is overlain by the Middle Jurassic Inferior Oolite Group (Powell, 1984). In the area considered here, most of the Lias sequence comprises dark grey, shaly mudstone containing occasional beds of medium grey, harder, more calcareous mudstone. Limestones make up only a small proportion of the total thickness of the Lias and occur as sporadic nodules or as thin bands which, with the exception of the Marlstone Rock Bed, are seldom more than 0.2 or 0.3m thick. Despite their thinness, many are laterally very persistent, and can be traced for many kilometres. They include both primary limestones and secondary, diagenetic types (Hallam, 1964), the latter often passing laterally into bands of nodules.

Some beds in the Lias are highly fossiliferous. Generally, the fauna is dominated by bivalves, of which *Gryphaea* is conspicuous in the lower part of the sequence. Gastropods, belemnites, crinoids and brachiopods all occur commonly at certain levels, but for the stratigrapher, the most important fossils are ammonites which are the basis of the standard zonation (Fig. 2).

All of the deep boreholes at Fulbeck airfield were geophysically logged. For correlation purposes, the sonic and gamma ray logs proved most useful (Fig. 3). The sonic log measures the speed of travel of seismic waves, which is broadly a measure of rock hardness. In the Lias, this is governed principally by calcium carbonate content. The gamma ray log measures the minute amount of natural radioactivity which is present in all rocks. In sedimentary rocks, higher gamma ray counts tend to be associated with mudstones, and are reduced by an increase of calcium carbonate. Gamma ray logs from some of the British Coal boreholes in the Vale of Belvoir have been used as an aid to correlation; in most cases, individual beds can be recognised, and some can be traced into south Leicestershire, Warwickshire and Northamptonshire.

The Lias Group has traditionally been divided into Lower, Middle and Upper Lias. As originally conceived, these were lithostratigraphic units, but they have tended to become inextricably linked to the chronostratigraphic stages and substages; the Lower Lias with the Hettangian, Sinemurian and Lower Pliensbachian, the Middle Lias with the Upper Pliensbachian, and the Upper Lias with the Toarcian (Fig. 2). To avoid these chronostratigraphic connotations, the old stratal divisions of Lower and Middle Lias have been abandoned. Instead, the sequence below the Marlstone Rock Bed is divided into two new lithostratigraphic formations, the Scunthorpe Mudstone and the Brant Mudstone (Brandon *et al.*, 1990). Together they total about 220m in thickness. A comparable revision for the Marlstone Rock Bed and Upper Lias would be appropriate, but the traditional names are retained pending completion of the necessary detailed study.

Scunthorpe Mudstone Formation

The Scunthorpe Mudstone Formation (Gaunt *et al.*, 1992), forms the lower part of the Lias Group. It is 113m thick at Fulbeck and about 128m in the western part of the Vale of Belvoir, and comprises alternate units of mudstone with thin limestones, and mudstones in which limestones are rare or absent. These units constitute the five component members of the formation.

Barnstone Member (8 to 10m)

The Barnstone Member forms the basal unit of the Lias Group and consists of mudstones alternating with clayey limestones; the latter make up about 30% of the sequence. It forms a prominent feature which can be traced easily through the drift-free ground between Cotgrave [SK 66 35] and Newark [SK 82 54]. Individual limestone beds are typically 0.1 to 0.2m thick. Those in the lowest 2 to 3m are rich in shell debris, suggesting a moderately high energy environment, but most of the others are markedly laminated and form a characteristic flaggy brash in the fields. The intervening mudstones also include a large proportion of finely laminated, bituminous shales ("paper shales"), which are generally quite rare in the Lias. These laminated beds suggest deposition in very quiet anaerobic conditions, perhaps

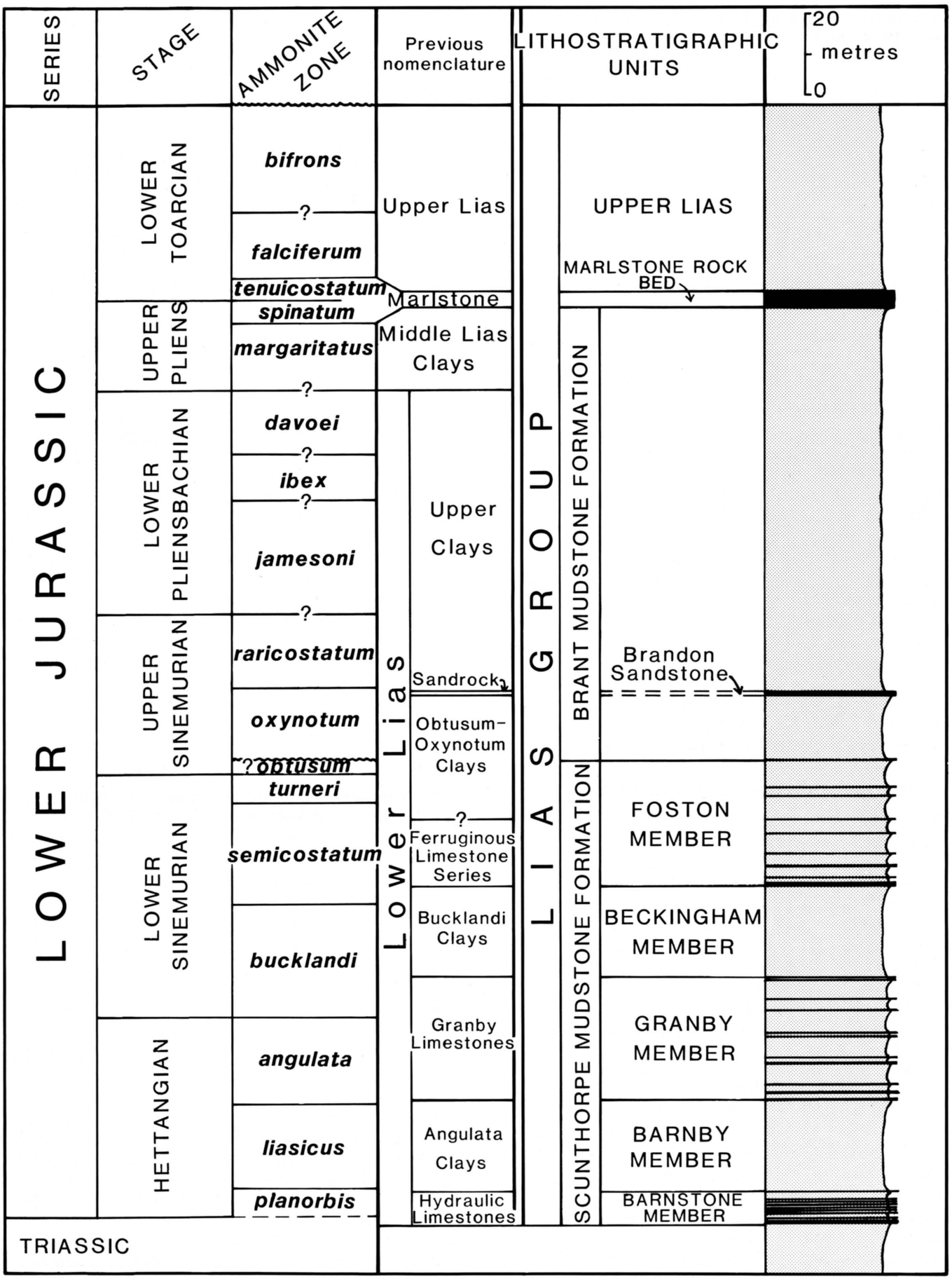

Fig. 2. Stratigraphical classification of the Lias Group in the study area.

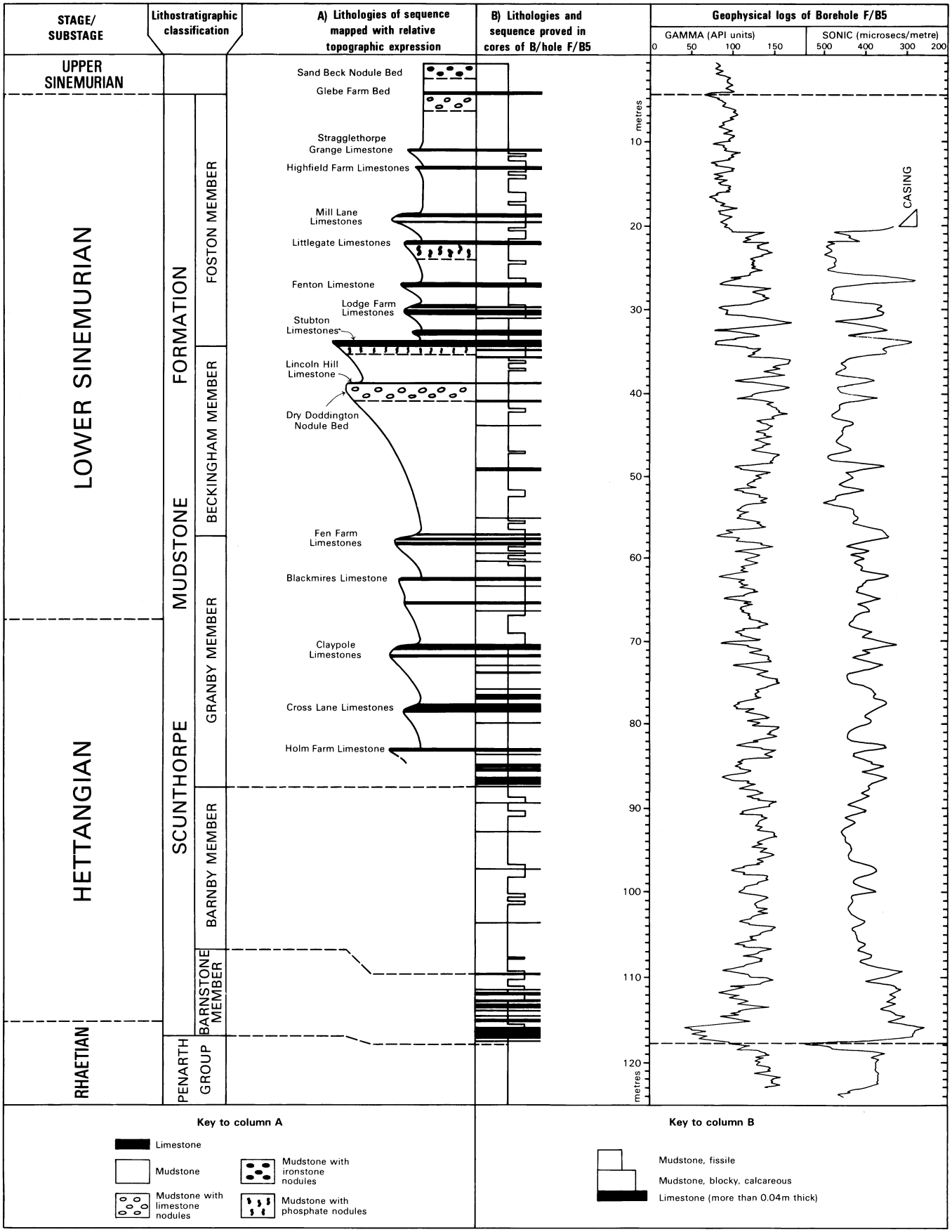

Fig. 3. Lithostratigraphy of the Scunthorpe Mudstone Formation. In columns A and B, the succession determined by mapping is compared with that proved in cores and by geophysical logs of Borehole F/B5. No grain-size variation implied. (Reproduced, with minor modification, from Brandon *et al.*, 1990, by permission of the Yorkshire Geological Society.)

on a wide, shallow shelf with negligible wave and current action. As might be expected, the fauna of the Barnstone Member is generally rather sparse, and the laminated bituminous shales lack bottom-living fauna, but occasionally contain abundant fish and insect debris and remains of marine reptiles such as plesiosaurs and ichthyosaurs.

The Barnstone Member was formerly known as the "Hydraulic Limestones", but because this name has been used elsewhere for beds of different age, the Member has been renamed after the village of Barnstone in the Vale of Belvoir [SK 734 354]. This is one of many sites along the outcrop where the beds were formerly quarried for building stone and cement making. The old name refers to the manufacture of hydraulic cement, i.e. Portland cement (which sets under water) for which the limestones (or "cementstones") had the ideal lime/silica composition. This industry eventually succumbed to competition from more efficient operations elsewhere, and all the quarries are long since disused and most are infilled. However, a few metres of strata are still exposed in a flooded quarry [SK 734 349] opposite the Blue Circle offices at Barnstone. A complete section of the member at this quarry was published by Kent (1937). Geophysical borehole logs indicate that individual beds in the Barnstone Member can be correlated throughout the region. However, correlation of published sections (e.g. Kent, 1937, 1964) is often more difficult; in part, this may be due to the passage of some limestone beds into nodule bands.

The Barnstone Member is largely of early Jurassic *Psiloceras planorbis* Zone age. However, the basal beds, at least 1.6m thick at Barnstone (Sykes *et al.*, 1970) and 2.7m at Fulbeck, have so far yielded no ammonites and are therefore currently classified with the Triassic (Rhaetian) (see Torrens, *in* Cope *et al.*, 1980).

Barnby Member (22 to 24m)

The Barnby Member consists of grey mudstones with a few thin, impersistent clayey limestones and nodule bands. Formerly known as the Angulata Clays, the member is actually almost entirely of *Alsatites liasicus* Zone, not *Schlotheima angulata* Zone, age. For this reason, it was renamed following Kent's (*in* Swinnerton and Kent, 1976) usage of the term "Barnby Clays", which derives from the village of Barnby in the Willows [SK 857 522], where, in 1940, Kent (in manuscript) recorded a section in the large Shire Dyke which extends southwestwards from the village. Fossils are mainly bivalves and, in the upper part of the member, include the earliest *Gryphaea* in the local sequence.

Granby Member (30 to 32m)

Kent (*in* Swinnerton and Kent, 1949) introduced the name Granby Limestones, having examined a section through the member in trenches south of Granby in 1940 (Kent, in manuscript). Although Kent's section, totalling some 20m of strata, cannot be reliably correlated, boreholes show that the sequences at Fulbeck and in the Vale of Belvoir are almost identical. The Granby Member consists of mudstones with many thin limestones, mostly 0.1 to 0.15m thick. The limestones make up less than 15% of the sequence (far less than in the Barnstone Member), and occur in five main groups of several closely-spaced limestones separated by intervals of a few metres of mudstone. Each group of limestone beds produces a minor dip and scarp feature with associated brash, by which it can be mapped. In contrast to the limestones of the Barnstone Member, those in the Granby Member are fairly well sorted, sparry, shell-fragmental limestones, representing periodic episodes of higher energy, possibly the result of storm-generated currents.

The top of the Granby Member is marked by a group of limestones (the Fen Farm Limestones) which forms a readily recognised marker because one, at least, of the beds contains abundant crinoid debris.

Beckingham Member (22 to 27m)

The Beckingham Member was formerly known as the Bucklandi Clays (Swinnerton and Kent, 1949) though it actually extends up from the *Arietites bucklandi* Zone into the *Arnioceras semicostatum* Zone. It is renamed after the village of Beckingham [SK 876 538]. It consists almost entirely of bluish grey shaly mudstones, with a very few thin limestones. Near the top, the Dry Doddington Nodule Bed consists of 2 to 3m of mudstone containing scattered limestone nodules, and is sandwiched between two thin shelly limestone beds. The nodules weather to a characteristic ochreous yellow colour, and are sometimes packed with small *Modiolus*.

The mudstones in the topmost 1m or so of the member contain abundant, small, fawn-weathering phosphatic nodules. These mudstones and a similar phosphatic nodule bed higher in the sequence have been worked in the past. The pits were probably dug to procure mudstone for brick-making, but the phosphatic nodules may possibly have been sought for fertilizer manufacture.

Foston Member (30 to 34m)

The Foston Member, named after the Foston Beck, east of Foston village, [SK 859 429], consists of grey mudstones with thin limestone beds which make up about 10% of the sequence. As in the Granby Member, the limestones are typically 0.1 to 0.2m thick, and occur in groups which form mappable dip and scarp features. The Foston Member is approximately equivalent to the "Ferruginous Limestone Series" of Swinnerton and Kent (1949), although this was never properly defined.

The base of the Foston Member is defined by the Stubton Limestones which include the only markedly ferruginous bed in the sequence; this corresponds with the Lower Ferruginous Limestone or Plungar Ironstone at the base of the "Ferruginous Limestone Series". The top of the "series" was said to be defined by the Upper Ferruginous Limestone, but this bed was never firmly identified. In the Vale of Belvoir, Lamplugh *et al.* (1909) may have considered it to be the Brandon Sandstone (Sandrock) though their quoted fossil evidence suggests a much lower level, within the *Arnioceras semicostatum* Zone (Fig. 2).

The Stubton Limestones form a prominent feature with a well-developed dip-slope. They comprise two to four beds of limestone of varying thickness interbedded with mudstone, together occupying a vertical interval of up to 2.5m. The lower limestones are impersistent, probably secondary, cementstones. However, the upper bed, about 0.6m thick, is persistent and very distinctive. Seen fresh in boreholes, it is a brown and grey mottled, bioclastic sparry limestone with many *Gryphaea*. Characteristically, it contains a scattering of brown, ferruginous (geothite and siderite) ooliths. The whole bed is ferruginous and weathers to an orange-brown colour with irregular, limonitic veins and patches.

Higher limestones in the Foston Member are all shelly and bioclastic limestones, each having individual characteristics by which it can be recognised in the field. One bed (the Highfield Farm Limestone) is distinguished by its high pyrite content.

From the Fenton Limestone upwards (Fig. 3), all the limestones contain a proportion of quartz silt or sand. This increases in abundance north-eastward through the Vale, and at Fulbeck some of the beds are best classified as calcareous sandstones. The sandiness becomes even more pronounced northwards into Lincolnshire, implying a northerly source. These sandy beds are the same age as the Frodingham Ironstone of the Scunthorpe area.

Between the Highfield Farm Limestone (*Caenisites turneri* Zone) and the base of the Brant Mudstone Formation (*Oxynoticeras oxynotum* Zone) no age-diagnostic faunas have been obtained. This gives a maximum of only 8m for the intervening *Asteroceras obtusum* Zone. Although Trueman (1918) recorded this zone from the Old Dalby railway tunnel [SK 684 234], it may actually be absent here (Kent, 1973). The thin development or local absence of the zone may be due to erosion preceding deposition of the Brant Mudstone Formation.

Brant Mudstone Formation

The Brant Mudstone Formation (Fig. 4) comprises the strata between the top of the Scunthorpe Mudstone Formation and the base of the Marlstone Rock Bed. It is named after the River Brant, which flows across its outcrop in the Fulbeck area. The sequence was established entirely from mapping and study of geophysical logs of coal exploration boreholes, as initially no borehole cores were available. Subsequently, the entire formation has been cored by the BGS Copper Hill Borehole at Ancaster [SK 9787 4265]. These cores are currently being examined and details will be published in due course.

From mapping, the formation is estimated to be 110m thick near Fulbeck and is about 150m in the south-western part of the Vale of Belvoir. It is made up of grey mudstones with many levels containing limestone, phosphatic or sideritic (ironstone) nodules, but the persistent limestone beds which characterise the Scunthorpe Mudstone are rare. The base is marked by the Glebe Farm Bed, about 0.4m thick. The lower part of the bed is a bioclastic limestone similar to those in the underlying Foston Member, but the upper (and greater) part is a distinctive brown, highly ferruginous limestone packed with geothite ooliths. The Glebe Farm Bed contains bored limestone and phosphatic pebbles which appear to be reworked nodules, suggesting an erosional relationship with the underlying strata. The bed has the same pebbly character throughout the Midlands and marks a regional non-sequence corresponding with that at the top of the Frodingham Ironstone. The rock contains a few shells, including the robust bivalve *Hippopodium*.

The Sand Beck Nodule Bed, 1 or 2m higher in the sequence has been identified in ditch dredgings across the Vale of Belvoir. It consists of 3 to 5m of grey mudstone with small red and brown-weathering sideritic ironstone nodules, many containing attractive specimens of the ammonite *Gagaticeras* indicating the *Oxynoticeras oxynotum* Zone.

The Brandon Sandstone, some 16m above the base of the formation, was formerly known as the Sandrock, but is renamed after a village [SK 903 483] near Fulbeck airfield. It forms virtually the only mappable feature in the Brant Mudstones, and can be traced from Fulbeck through the Vale of Belvoir as far as Upper Broughton [SK 684 262]. It is probably about 1m thick, perhaps rather less in south-western parts of the Vale, and is a slightly muddy fine-grained calcareous sandstone, which weathers down to a brown loam. Where seen as blocks dredged from the River Brant, it contains common bivalves, often concentrated in lenses, though near the top there are frequent large myids in life position.

The beds immediately below the Brandon Sandstone contain a proportion of fine-grained sand, and may locally include one or more thin impersistent sandstones. They were formerly worked for brick and tile-making at Hougham [SK 893 451] and Brant Broughton [SK 914 531]; this stratum was probably favoured because the sand content prevented undue shrinkage on firing.

The beds above are predominantly mudstones, which at several levels contain large limestone nodules. These occasionally contain ammonites indicating the *Echioceras raricostatum* Zone. About 20m above the Brandon Sandstone, the Loveden Gryphaea Bed comprises about 2m of *Gryphaea*-rich mudstone and associated shelly limestones of *Uptonia jamesoni* Zone age, which can be traced throughout the region. This stratum probably corresponds with the "70" geophysical marker of the south Midlands (Horton and Poole, 1977). The overlying 25m or so of mudstones contain abundant brown and red-weathering sideritic ironstone nodules, often with a concentric structure. The higher part of this interval includes thin shelly ironstones and platy limestones which may correlate with the Pecten Ironstone, a highly condensed bed near the base of the *Tragophylloceras ibex* Zone in north Lincolnshire (Gaunt *et al.*, 1992). Geophysical logs of boreholes suggest correlation of these beds with the "85" geophysical marker of the south Midlands, though the ammonite zonation seems to indicate the latter to be younger.

The highest beds of the formation form the steep scarp slope which forms the southern and eastern boundary of the Vale of Belvoir. These beds include strata of *Prodactylioceras davoei* Zone age, overlain by about 20m of so-called "Middle Lias" (i.e. strata of *Amaltheus margaritatus* Zone age). The latter are included in the Brant Mudstone Formation because, at Fulbeck, their lithology is not sufficiently different from that of underlying beds for a boundary to be mapped. Site investigation boreholes near Leadenham [SK 950 510] indicate that the beds are, however, slightly more silty and micaceous than the bulk of the Brant Mudstone. The sequence in the Copper Hill Borehole 10km to the south-east is significantly more silty, and in more southerly parts of the Midlands, silts and sands are developed at this level.

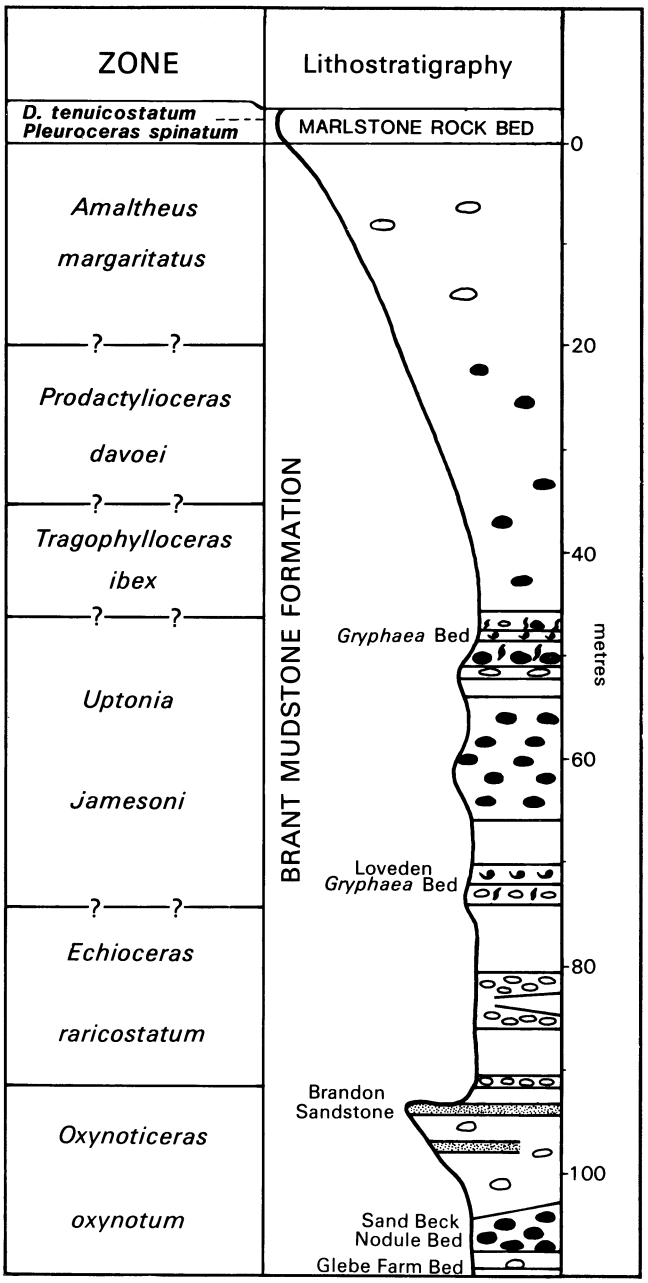

Fig. 4. Lithostratigraphy and biozonation of the Brant Mudstone Formation and Marlstone Rock Bed. Key as Fig. 3: stipple indicates sandy beds.

Marlstone Rock Bed

The Marlstone Rock Bed (actually a unit of formation status) forms a bench capping the major escarpment which rises to about 45m above the clay ground of the Vale of Belvoir, and for this reason is the most prominent unit of the Lias Group in the region. It is up to about 10m thick south of the Vale, 4.7m in the Copper Hill Borehole, and 3m thick at Fulbeck, but at Welbourne [SK 968 547] a few kilometres to the north it thins to zero and does not reappear until well north of Lincoln. Where absent, its horizon is marked by a thin bed with phosphatic pebbles. Ammonite evidence suggests that the thinning is due to condensation though there may be a slight erosive non-sequence at the base of the overlying Upper Lias.

The Marlstone Rock Bed is largely of *Pleuroceras spinatum* Zone age but at some localities the upper part includes strata of earliest Toarcian *Dactylioceras tenuicostatum* Zone age. These latter beds, 1.2m thick at Harston [SK 843 305] near Belvoir Castle, include the so-called "Transition Bed". This is the topmost part of the Marlstone modified by weathering which took place prior to deposition of the overlying beds (Howarth, 1980). The "Transition Bed" is included in the Upper Lias in some accounts (e.g. Hallam, 1968) because of its Toarcian age.

The Marlstone Rock Bed is a sandy, shell-fragmental oolitic limestone, often with a basal sandstone ("sandrock"). It contains a fauna mainly of bivalves and brachiopods, the latter sometimes occurring abundantly in "nests". Lenses of crinoid debris occur at some localities, and belemnites are also common, particularly near the top. When fresh, it is greyish green due to the presence of chamosite, which is the principal component of the ooliths.

Iron is also present throughout the rock as siderite. Weathering and oxidation of the iron produces a warm brown colour, making it an attractive building stone, widely used in the villages of the Vale.

The Marlstone Rock Bed was formerly the basis of a flourishing iron-ore industry. It has been extensively quarried throughout the area, and it is still exposed at many localities, of which the best is probably Brown's Hill Quarry, Holwell [SK 742 233] (Clements, 1989). When fresh, it has a very modest iron content, but in the weathered zone, oxidation and decalcification increases this to 30% or more. For this reason, quarrying normally ceased when the overburden reached 3m or so, and only at Holwell was it mined underground; here the old adits can still be seen in the quarry. Lamplugh *et al.* (1920) and Whitehead *et al.* (1952) described sections and the history of production.

Upper Lias

During mapping at Fulbeck, only a small area of Upper Lias was surveyed and very little new information was obtained. Since then, the Copper Hill Borehole has proved the entire sequence which will be described elsewhere; only brief details are given here.

The Upper Lias forms the slope, capped by the Middle Jurassic beds, which rises above the Marlstone

Rock Bed shelf. It is probably about 35m thick in the Holwell area, but is 45m at Copper Hill and Fulbeck. Northwards, it thins to only 15m at the Humber. This is the result of an unconformity at the base of the overlying Middle Jurassic, which cuts down onto progressively older beds of the Upper Lias: in our area only Lower Toarcian beds are present (Fig. 2).

The Upper Lias consists of blue-grey mudstones with little in the way of lithological variation to permit subdivision. Trueman (1918) gave a generalised section for the Grantham area based on various temporary sections together with that at Rudd's Brickyard [*c.* SK 910 352] west of the railway station, now lost beneath building development. His section amounts to 35m and consists dominantly of grey shales with scattered limestone nodules.

The basal few metres of the Upper Lias are seldom well exposed, but can still be seen in a few places in old Marlstone Rock Bed workings and in some of the associated railway cuttings (e.g. at Holwell [SK 742 233] and Caythorpe [SK 949 469]). These beds, of *Harpoceras falciferum* Zone age, are dominated by finely laminated, fissile bituminous shales. This facies is similar to the paper shales of the Barnstone Member and likewise contains occasional fish and insect remains, and also ammonites and belemnites, but a very restricted benthic fauna.

Conclusions

Geological mapping, first at Fulbeck and subsequently further into the Vale of Belvoir, has shown that the Lias is divisible into a number of units of distinctive lithological and faunal character. The information within this short paper should be sufficient for the reader to be able to identify the formations and members on the ground. Those wishing for more detailed bed descriptions and faunal lists are referred to the account by Brandon *et al.* (1990).

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