

THE GRANTHAM FORMATION IN THE EAST MIDLANDS:
REVISION OF THE MIDDLE JURASSIC, LOWER ESTUARINE BEDS

by

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Summary

The account of the Grantham Formation, including a marine unit, the Stainby Member, is based on sections of the Lower Estuarine Beds formerly exposed in open-cast Northampton Ironstone mines between Grantham, Oakham and Stamford, and on five core borings in the Fenland. The new formal formation name is proposed in substitution for "Deltaic" or "Estuarine" Beds.

The Formation comprises an alternation of very fine-grained sands with marsh clays and a persistent median dark shale (Stainby Member) containing a varied fauna of marine bivalves. The overall thickness varies irregularly from 6 metres at the westerly outcrops to 1.5 metres at outcrop near Grantham, with an increase of the thickness to 5 metres or more at depth in the Fenland. Open marine conditions connecting with the Variable Beds of Northants possibly lay to the west or south-west.

Recent core borings have shown that the characteristic tripartite formation continues eastwards towards Boston, the median Stainby Shale Member retaining its distinct character and marine fossils. The name Grantham Formation is thus applicable across south Lincolnshire, but there is a change, offshore, north-eastwards into a development analogous to, and probably continuous with, the Yorkshire "Deltaic Series."

Introduction

The miles of faces of Inferior Oolite rocks in south-west Lincolnshire, Rutland and Northants, which were open twenty years ago, progressively shrank as the ironstone extraction operation was phased out in 1968-74 in favour of higher grade imported ore. The prospect of losing these highly informative sections led the writer to attempt to record them before they disappeared. The urgent problem was the stratigraphy of the Lower Estuarine Beds, since the Northampton Ironstone has been well documented and the Lincolnshire Limestone will, to some extent, remain available for study.

The interest of the Lower Estuarine Beds was increased by the discovery of a marine phase, originally found by the writer (in student days) around 1935 but subsequently unrecorded by others. This unit is not easy to detect, since fossil preservation is commonly poor and the marine shale disintegrates completely when weathered, or wetted in the unweathered state, but it has been found to be well developed in the area south-west of Grantham and has yielded quite a rich molluscan fauna. A brief listing of this was given in Kent (1971).

The investigation involved measuring nearly 40 outcrop sections, as opportunity permitted, over 5 years. 17 sections are listed in the following pages, extending across south-west

Lincolnshire and north-east Leicestershire into Rutland. In addition, cores of five boreholes became available in the triangle between Lincoln, Grantham and Boston through the courtesy of Dr. J. A. D. Dickson. The abundant molluscan fauna requires detailed study.

Nomenclature

In Lincolnshire the term *Lower Estuarine* has generally been used for all the beds between the Lincolnshire Limestone and Northampton Ironstone, and the boundaries of these formations define the sedimentological unit described here. Further south, the much thicker basal part of the beds (locally white sands) has been included with the Variable Beds of Northamptonshire and with the ironstone itself as "Northampton Sands", a term which has been used quite differently by individual authors (Hollingworth and Taylor, 1951, p.12). The alternative usage applies only to the basal part of the unit, consisting mainly of the ferruginous sands, which were, for example, excluded from the Lower Estuarine at Colsterworth (*op. cit.* p.41). There is, however, no doubt that these beds belong to the same "Estuarine" (so-called) facies group, as is shown below, and the whole interval is here regarded as occupied by a single formation.

Although "Lower Estuarine" is a somewhat more appropriate descriptive name for the Lincolnshire development than "Deltaic", proposed by J. E. Hemingway for the approximate equivalent in Yorkshire, it is still an inadequate description; it is prejudiced by the former usage in different ways in both the Midlands and Yorkshire, and it is inadmissible as a formal name according to the rules of stratigraphical nomenclature devised by the Geological Society of London and International Committees.

The formal name *Grantham Formation* is now proposed for the beds previously known as the Lower Estuarine, specifically in the area between Lincoln, Sleaford and Kettering. It is named after a district particularly notable for workings of the Northampton Ironstone over the last 40 years. At the time of writing the formation is still fully exposed at Harlaxton, in No.6 mine on the Grantham town boundary, and in the last active quarry, No.4 mine, 1½ miles further west. The type section may be taken as that measured in Colsterworth No.2 mine, one mile west south-west of Colsterworth Church (SK 915232), Section No.9 in the following account.

The formal name *Stainby Shale Member* is proposed for the dark shale unit with marine fossils in the upper-middle part of the Grantham Formation; the bed was particularly rich in fossils at Stainby Warren and at Stainby Glebe mine. The latter locality is designated as the type locality (Section No.11).

In the Fenland, the cores of the beds below the Lincolnshire Limestone, the terminal parts of the borings, were only some 10 cm. in diameter, so that the material obtained represents an extremely small sample of this large area. Nevertheless it was sufficient to show that the Lower Estuarine Beds of the Fenland is similar in general facies and is probably continuous with that of the southern outcrops, so that it can be regarded properly as a continuation of the Grantham Formation, including the median dark shale, the Stainby Member equivalent.

It is known that off the north Lincolnshire coast a sharp expansion of the "Lower Estuarine" begins, with a great increase of sands, and, although data are inadequate for accurate definition of facies, the development compares broadly with that of Yorkshire and is better classified in line with the "Deltaic Series" of the north. The north-eastern limit of the named Grantham Formation thus approximates to the present coastline, but the boundary is, of course, transitional and arbitrary.

General Account of Lithology

The typical section can be summarised as follows:

The top member is usually a well-bedded ferruginous fine-grained sand, which may be interbedded with dark shale, as at Harlaxton. Vertical carbonised plant "rootlets" commonly occur except in the uppermost part. There may be no clear-cut boundary between this and the overlying basal Lincolnshire Limestone "Blue Beds" where these are de-calcified. Members of the Institute of Geological Sciences tend to take a boundary a little below the lowest limestone, but the present investigation has failed to find a break or any consistent marker around this part of the sequence. The relationships of the Lincolnshire Limestone and Grantham Formation in the area between Grantham and Stamford bear a marked contrast to those in north Northamptonshire described by Taylor (1946), in that the Lincolnshire Limestone here shows close parallelism with the bedding of the underlying formation with an absence of channelling at the contact. Thickness variation of the upper beds is gentle and relates in part to a general thinning towards the Witham Valley. (Sharp changes in total thickness of the Grantham Formation reflect variation in the development of the ferruginous sandy beds beneath the marine shale horizon).

The ferruginous sand usually passes down by gradation and/or interdigitation into the main median shale body. The transition is fairly rapid and may correspond with a break and re-working of the top part of the shale. Large channel features are extremely rare in the "Estuarine" of this area (a distinction from the Deltaic Facies of Yorkshire). The only case seen, in inspecting miles of quarry faces, is at Harlaxton, where the top sand group is channelled down into the shale member beneath in the easterly workings (SK 892314 to 896310). This channel cuts more deeply north-westwards, but as an isolated case has little significance.

The marine Stainby Member is essentially a lithological mixture. The greater part is dark grey, medium grey, brownish or dark blue-black fine muddy silt interlaminated with streaks of coarser white silt or very fine-grained sand. Laminations are commonly a millimetre or less (with internal grading), in graded-bed units of 3-10 mm. Small scale flaser bedding predominates. Thicker sand streaks (5-10 mm) occur infrequently. The Member is characteristically fissile, separating into large sheets. Vertical carbonised "rootlets" penetrate the bed, particularly from the top, and there are common vertical holes (worm borings?) filled with fine white sand; these have been distorted during compaction of the shaly element in the sequence.

A distinctive dull grey thin sandy mudstone occurs in the lower part of the shale at Harlaxton, Warren Farm and at Stainby Glebe. At the former place this sandy mudstone passes laterally into fissile, slightly bituminous shale, or alternatively into ferruginous sandstone, which is rich enough in iron to develop box-stone structures on weathering. The sandy mudstone bed shows rather thicker sedimentary structures than the adjacent fine silts, being no doubt less compacted, and when fresh tends to be a little pyritic, presumably the original state of the iron. Fossils (particularly small *Aviculopecten*) occur in swarms, and there are several types of borings and "trails".

In addition to the borings, various other trace fossils occur, notably *Diplocraterion* at Colsterworth and Harlaxton and *Chondrites* at Harlaxton, Market Overton and Bicker.

Fossils are rare or absent in the upper part of the bed. The higher fossil streaks in the outcrop sections are made up of swarms of "*Corbula*" covering bedding planes. *Lingula kestevenensis* Muir-Wood occurs at what may be a consistent horizon a little above the base, mainly at or near Colsterworth and in the Fenland at Great Hale, Asgarby and Bicker, as well as at Market Overton near Oakham. At outcrop the main varied fauna is confined to the lowest 15-20 cms., sometimes the lowest 5 cms. Almost invariably shells are dis-articulated; they lie on bedding planes, rarely crossing the bedding even in the case of those which lived in a buried state (e.g. *Pholadomya*), and they consequently tend to be flattened.

The maximum variety of molluscan types was found at Market Overton. In all cases collecting was controlled by the physical conditions of the exposure, in particular by the difficulties provided by vertical unstable rock faces, and, with allowance for this, the next best faunas have been collected from Stainby Glebe, Sproxton and Hungerton. However Saltby, in the same westerly area, has been consistently disappointing, and the variation of preservation of the fauna seems partly fortuitous, as on a modern mud-flat.

Much of the fauna was probably pyritised; pyrite survives in the less weathered material at Harlaxton and at Market Overton. Nacreous preservation may persist in some cases. The predominantly poor preservation is presumably due largely to leaching through the porous matrix; for although the bed quickly breaks down to a sticky clay on open weathering, the predominant lithology is silt, and this material wets and dries easily.

At outcrop the base of the marine shale is almost always sharp, usually with a concentration of larger shells in the lowest 2-5 mm. The lowest 5-10 mm. is often quite sandy and in some places irregular pitted grey "mudstone" nodules occur at this level. A greenish lamina (0.5-1 mm.) may occur at the base. Most commonly the bed beneath approximates to fireclay - a structureless purplish-grey plastic clay with abundant vertical rootlets - presumably a marsh deposit. Elsewhere the marine bed rests directly on illsorted sand.

In the thicker development of the Grantham Formation, as at Saltby, the marsh-clay member is underlain by up to a metre of well sorted very fine-grained white sand, without significant structures other than vertical rootlets penetrating from the top.

The lowest beds of the Grantham Formation are commonly poorly exposed, being obscured by scree or quarry debris, and are much more variable in thickness and lithology than those above. Grey muddy sands seem to predominate; these commonly have a purplish tinge before weathering. At Harlaxton the sands are locally cemented into nodules of 0.3-0.7 metres diameter, with black pitted surfaces. The sands are variably ferruginous and pass into ironstone, which has occasionally been extracted with the main ironstone bed below. Carbonaceous shales may occur at the base, as at Harringworth in Northants and in some Fenland borings, but more commonly the interval lacks shales. At Colsterworth locally a 20 cm. cemented purple sandstone full of vertical plants is cemented on to the top of the Northampton Ironstone.

Upwards from the base of the Stainby Member, there is a progressive loss of the marine fauna and an increase in the "marsh" plant indices; the cycle was thus from marine to "estuarine".

Whether there is a second comparable cycle, lower in the Grantham Formation, is not clear. Although no lower true marine fauna has been found, *Chondrites* occurs in a separate lower shale at the Bicker boring, and the downward passage of the lowest sands at outcrop into a ferruginous facies suggests partial consanguinity with the (marine) Northampton Ironstone beneath; possibly these ferruginous sands were deposited in near-marine waters which became increasingly brackish as marsh conditions spread. The environmental implication of the very well graded white sands within this series is not entirely clear - possibly they are redeposited small sand dunes.

Palaeogeography

In the area south-west of Grantham, the Grantham Formation forms a half lens, with greatest thickness (7-8 mm) in the west and irregular attenuation, 1.7 to 2 m. close to the line of the valley of the River Witham, extending south to Exton and Ketton. The eastward thickness-change affects all the subdivisions of the Formation, the white sands thinning out first, the marsh clay next. The upper sands, the marine shale unit and the ferruginous sands beneath persist eastwards in attenuated form.

Southwards the formation continues across Rutland into north-eastern Northamptonshire, apparently losing the marine element north of the Welland Valley, although the median shale

continues. No marine fossils have been found at either Exton in Rutland or Rushton near Kettering.

A correlation problem develops southwards, as the term "Lower Estuarine" has at times been limited to the upper part of the Lincolnshire Limestone and Northampton Ironstone sequence; the lower part, locally developed as the white sands, being classed with the "Northampton Sands", by Beeby Thompson (1921-28) and Arkell (1933). The sections recently available show that the Stainby Member continues southwards from Grantham to the Welland Valley, with local development of sandy partings, and that a second basal carbonaceous shale member is developed around Harringworth, directly above the ironstone. Thus a direct correlation can be made from Grantham into north Northamptonshire, and the lower sands of the former area are, at least in part, separated by an "Estuarine" (freshwater) plant bearing shale from the marine Northampton Ironstone.

Northwards from Grantham the Formation remains thin, 1.3 m at Belton and 1.5 m at Leadenham, with a major proportion of shale. North of Leadenham, not necessarily to be directly correlated, sands only are recorded at Coleby and Waddington. The Grantham Formation is absent at Lincoln, but at Fillingham (outcrop section) and Welton (borehole) it is again of mixed facies, although no marine fauna is known.

Beneath the Fenland, records of the equivalent "Estuarine" facies are scarce, since few boreholes have penetrated beneath the Lincolnshire Limestone, the main aquifer. They suffice to show, however, that beyond the attenuated Leadenham-Grantham-Colsterworth belt the Formation, still characteristically tripartite, expands again eastwards. The records show that, between Boston and Grantham, dark shale in the middle part is well developed and contains *Lingula*, in addition to marine lamellibranchs as at Colsterworth and Market Overton. Thus this marine belt has considerable east-west extension, perhaps between the edge of the Yorkshire delta and the facing margin of the contemporary shallows and shoreline of the London platform (text-fig.1).

The molluscan fauna, with its abundance of "*Trigonia literata*" (*Myophorella*), suggests a relation to the Variable Beds (Upper Northampton Sands) of Northants., possibly via open marine waters lying west of the present Midlands' outcrops. The records in the Fenland, taken with the knowledge that off the Lincolnshire coast in the North Sea the Grantham Formation appears to be 30 metres thick or more, suggests that the main basin may nevertheless lie to the east. South Lincolnshire may occupy shallows between the main North Sea basin and the partly marine development of a northward Cotswold Basin extension.

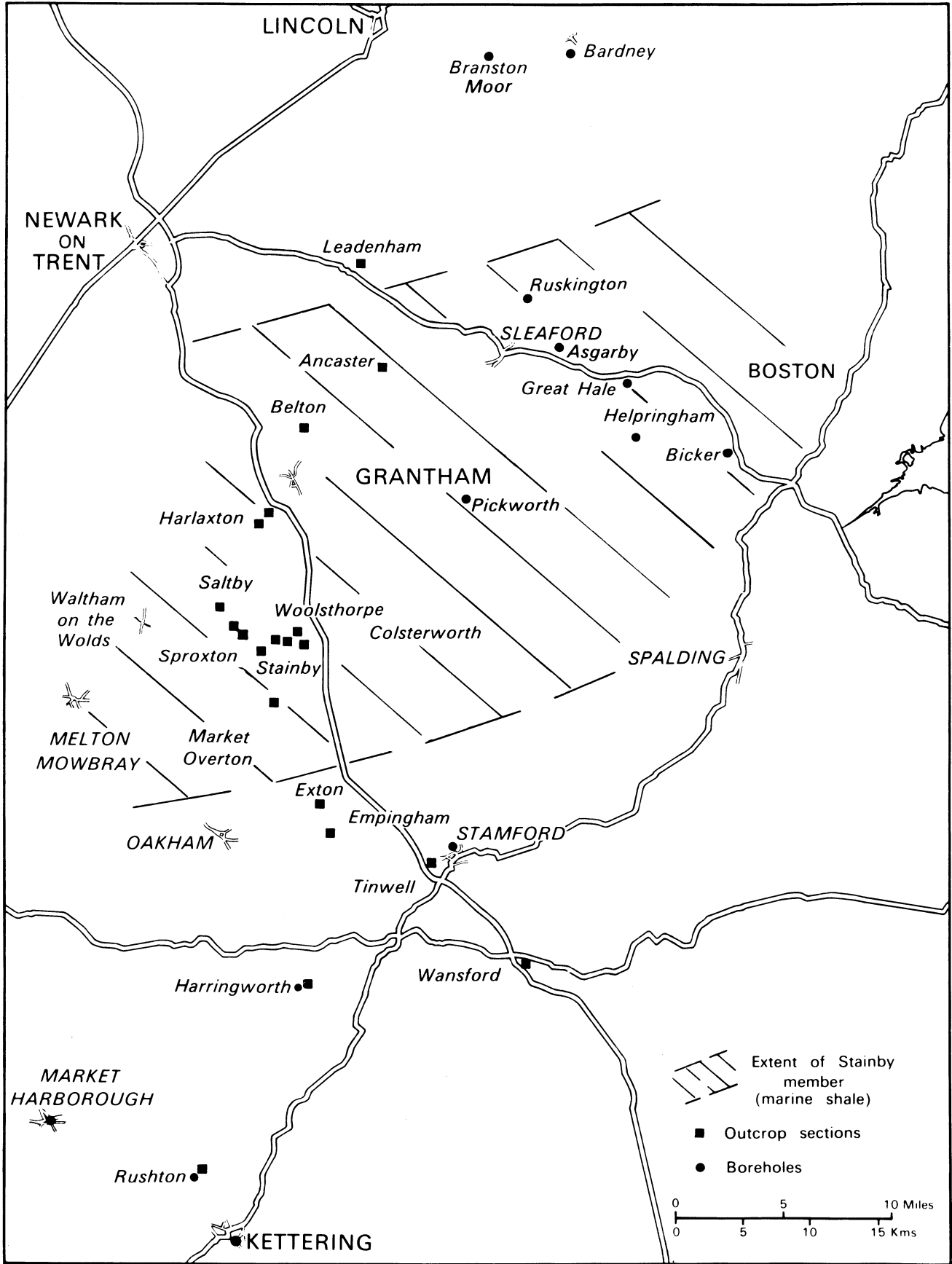
Measured Outcrop Sections

The sections which follow are arranged in geographical order from north-east to south-west and south (text-figs.1 & 2). Records of a further 20 sections in the same area have been deposited with the Institute of Geological Sciences (Leeds Office). Reference to the author's specimen collections are given in the form PEK/505.

1. HARLAXTON - Warren Farm Face (No. 6 Mine)

The section is taken at the eastern end (410 m from the Grantham boundary) SK 904326 and is the north-easternmost modern working of the Northampton Ironstone. It was measured on the 14th April 1972.

		metres
<u>Lincolnshire Limestone</u>	2.76 m.	
<u>Grantham Formation</u>	2.80 m.	
Deeply weathered ferruginous shale with ferruginous sandstone streaks		0.48



Text-fig. 1. Locality map and distribution of the Stainby Member.

	metres
<u>Stainby Member</u>	
Finely flaser bedded blue-grey shale, brittle, disintegrating when wet, with pale silt and very fine-grained sandstone laminae; shale dark blue in the lower part.	0.23
Irregularly lensing fine sandy mudstone, occasionally with oblique bedding, ferruginous and oxidising to ironstone. Passes into papery sandy shale.	0.08
Dark shale with pale sandy streaks as above. Fallen blocks of dark shale with sandy streaks yielded occasional <i>Trigonia</i> , <i>Aviculopecten</i> , <i>Ostraea</i> etc. PEK/505.	0.15
Dull grey to purplish grey fine-grained sandy mudstone with abundant vertical carbonised rootlets, passing down into shaly mudstone.	0.43
Lighter grey silty mudstone	
- irregular junction -	
Light grey, faintly purplish, blotchily yellow-weathered fine sandy clay.	0.41
Rotten ferruginous sandstone, poorly - to un-bedded	0.76

Northampton Ironstone seen to 2.0 m.

The "sandy mudstone" is a distinctive rounded-weathering bed. Fossils are well preserved, tending to be nacreous in the unweathered state; traces of pyrite occur. Rare *Lingula* occurs in its upper part. In stratigraphical position, fossil preservation and lithology, it very closely resembles the "twin sandstone" of Stainby Glebe.

Eastwards (down dip) the sandy mudstone is much more oxidised and passes into brown ferruginous sandstone, with box-ironstone structure which obliterates most of the fossils, except for small *Aviculopecten*; small broad leaves (carbonised) and reed fragments occur.

The shales above have surfaces with swarms of "*Corbula*" at several levels; *Gervillia*, *Trigonia* and *Modiolus* (usually isolated valves) also occur. *Syncyclonema* occurs, showing the internal ribbing. Some (lower?) shale is full of "shell mash" made up of small round *Ostraea* juv. (cf. lower shale at Stainby Glebe). *Diplocraterion* is reported by J. A. D. Dickson.

2. HARLAXTON NORTH (No. 7 Face)

The section measured is in the middle of the face, SK 890311, recorded 26th May 1973.

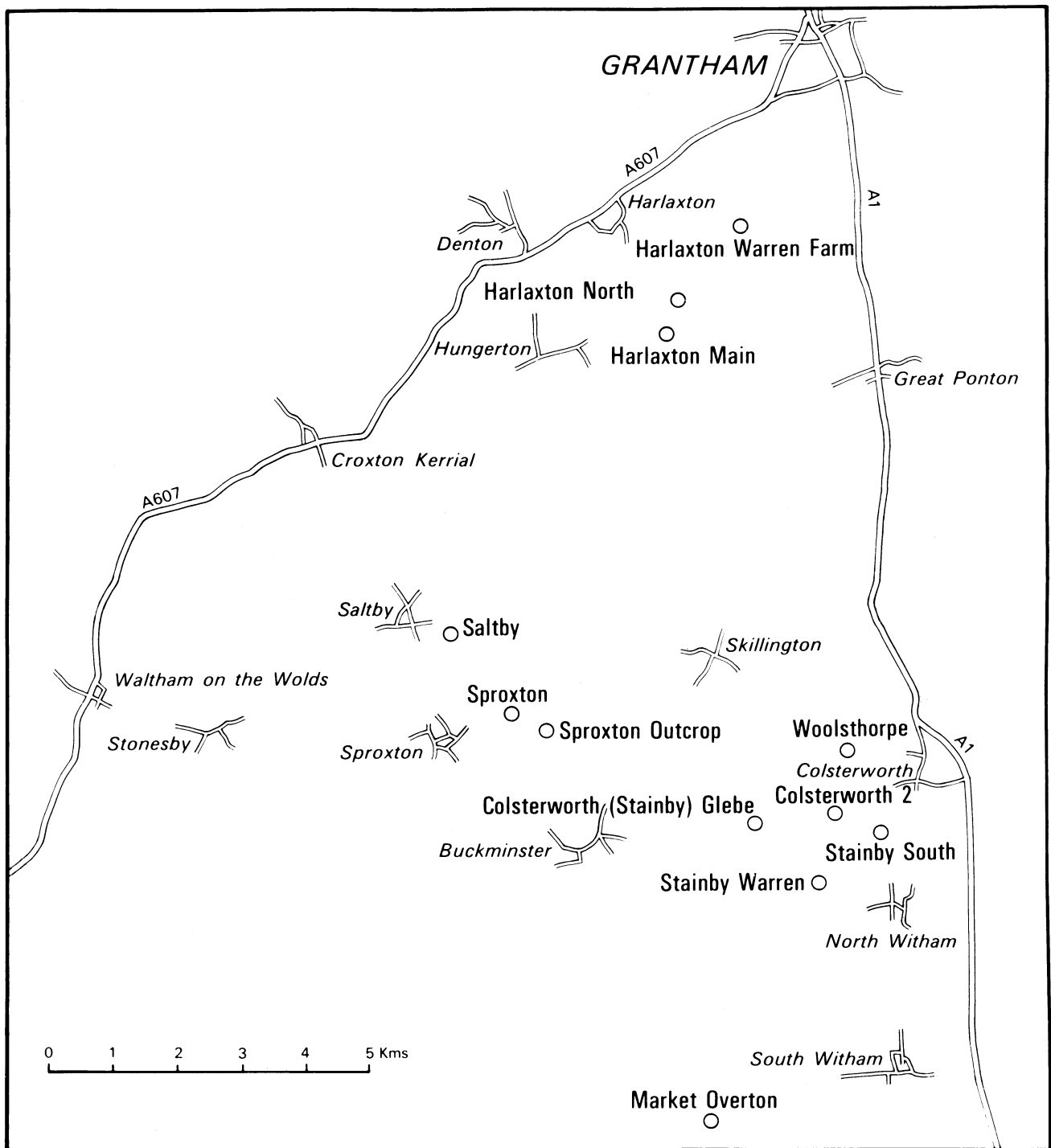
Lincolnshire Limestone 1.5 m.

Grantham Formation 3.29 m.

Yellow-brown sandy marl (poorly exposed).	0.43
Richly ferruginous brown sandy and clayey silts with thin grey shaley partings.	0.41

Stainby Member

Dull grey shales with soft ferruginous sandstone intercalations and ironstone crusts.	0.43
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Text-fig. 2. Ironstone mine localities between Grantham and Oakham.

metres

Dark banded shale. Flaser bedded, fine, light and dark banding commonly showing tone gradation within laminae; sharp junctions at the base of pale silty units, which show micro-channelling into lamina below. Boundary most strongly marked from 75 mm - 175 mm above base. In lower part bedding planes are crowded with small shells. *Protocardium* (pyritised) and fragments of *Pholadomya* 0.66

- Film of sand on gently undulating contact -

Pinkish purple (fresh) to slightly purplish dull lead-grey blocky silty mudstone; abundant rootlets from the top downwards. about 0.61

Pale very fine sand or silt, poorly exposed.

Northampton Ironstone, seen to about 2.1 m.

3. HARLAXTON MAIN FACE (No. 4 Mine)

The main face at Harlaxton is the last operating mine in the Northampton Ironstone Formation, north of the Welland Valley. This face is 1.61 km long and the following column combines details from sections measured from 1969 to 1973 in the eastern part. (SK 895311 approx.).

Lincolnshire Limestone with basal ferruginous "Blue Beds".

Grantham Formation 3.21 m.

Ferruginous sandstone and shale. Regular alternation of fine-grained sandstone, weathering yellow and ferruginous in units of 50 - 120 mm, parted by three beds of blue grey soft shale, streaked with fine sandstone and with sandstone blebs, 30 - 70 mm thick. 0.43

(In the easterly part of the workings, the lower members of this sand group thicken and fill a channel, which cuts 610 mm deep into the underlying shale. This presumably continues a channel in the adjoining face of No. 7 mine. Elsewhere the junction is gradational).

Ferruginous sand, developing boxstone ironstone nodules. 0.05

Stainby Member

Dark grey shale, weathering light blue-grey and buff. Dark filled borings (?) in the upper part, vertical carbonised "rootlets" in the middle part. Minor proportions of light silt partings. Locally a grey cemented mudstone passes into ironstone at the base. 0.56

Closely banded blue-black shale and pale grey silt, with scattered shells, mostly small, except at the base, where the lowest 70 mm yielded *Pholadomya*, *Goniomya* ?, *Nuculana* ?, *Trapezium*, "*Trigonia literata*" (*Myophorella*), rare *Aviculopecten*, *Protocardium*, *Amusium*, rare small gastropods of *Cerithium* type (PEK/443) 0.34

- sharp junction -

metres

Light purple-grey tough clay, weathering to glutinous pug, varying to light chocolate brown. Densely bored in the upper part; locally with contemporary cracks filled with dark shale (overlying bed). Occasional chocolate-brown clay-ironstone nodules, septarian when large, with veins of "kaolinite".

0.5 m to 0.76

- strongly undulating contact -

Northampton Ironstone up to 1.07 m.

Yellow to grey siltstone and fine ferruginous sandstone with irregular nodular masses of chocolate brown ironstone with *Lioceras* cf. *opalinum* and abundant pelecypods in the upper part.

The two lowest members of the 'Lower Estuarine' (the marsh clay and basal sands) thin to about half the thickness given above towards the eastern end of the mine face and remain thin in the No. 6 mine 1.61 km further to the north-east. The main thickness change takes place within 200 metres.

4. SALTBY

Section 90 - 180 metres from the north end of the working face. SK 857262, measured 4th September 1971.

Lincolnshire Limestone 6.00 metres.

Grantham Formation 5.05 metres.

Brown ferruginous sand, locally about 0.23

Grey-brown flaser bedded shale and white silt, level bedded.
(Somewhat disturbed, slickensided.) 0.18

Deep brown very ferruginous quartz sand, locally clean and pale. 0.15

- sharp junction -

Stainby Member

Brown and grey banded shale; silty intercalations are ferruginous and weather brown. Bands 3 - 10 mm, themselves finely banded. Vertical carbonised plants 5 - 25 mm long. (This is the weathered upper section of the main shale group continuing below) Thinning south from 0.6 to 0.33

- passage -

Light grey to dark grey shale "zebra-banded" with pale silt; individual units from a fraction of 1 mm to 3 - 4 mm. show graded tonal banding. Fallen blocks show some layers crowded with *Corbula*, common *Modiolus*, *Protocardium*, scattered *Trigonia* (*hemisphaericus* group). Thickens north to about 1.2 m with cut out of the white sand group below. At the section line - 0.63

	metres
Greenish grey shaly clay, very ferruginous, brown weathering.	0.13
Interbedded light grey clay and brown ferruginous silt.	0.13
- passing down -	
Medium purplish-grey clayey sand with abundant vertical carbonaceous roots, starting at the top of the bed or irregularly within it and into the bed below.	0 - 0.28
Olive brown clay, very silty, with carbonaceous vertical roots penetrating the bed below. The upper part is characteristically but discontinuously pale red-purple (pale magenta) with yellow joints; over 100 m or so of face.	0.12 - 0.25
- Undulating sharp erosional junction, ferruginised -	
White sand - very fine-grained, well graded, grains tending to roundness, white to yellowish mostly pure quartz sand, occasionally micaceous. Unbedded or with trace of level bedding. Cut out in the north as the shale group thickens.	0 - 0.94
Ochreous sand with ironstone layers.	0.13
Lead-grey very fine-grained clayey sand, with irregular brown ironstone crusts increasing to half bulk near the base.	1.60

Northampton Ironstone exposed to about 2.5 m.

5. SPROXTON

South Top Quarry, SK 867248, measured 30th August 1969.

Lincolnshire Limestone 12.8 m.

- gradational junction -

Grantham Formation 3.35 m.

Stainby Member

Finely laminated dark grey (damp) bluish grey clay, with flattened pale muscovitic silty blebs and streaks.	0.20
Alternations of dark shale and pale silts as above - with distinct bituminous smell when hammered - and yellowish grey finely banded mudstone. Vertical rootlets penetrating the whole thickness.	0.26
Finely laminated dark shaly clay and fissile silt as before, with abundant marine shells, including <i>Pteroperma</i> , <i>Trigonia</i> , <i>Pecten</i> , (<i>Amusium</i>), <i>Modiolus</i> , <i>Camptonectes</i> , <i>Pholadomya</i> , <i>Protocardium</i> ? ostracods, plant fragments (PEK/440)	0.42
More clayey shale with silt alternations, passing down into dark grey plastic clay.	0.32
Pale clayey sand, passing down into fine pale purplish sand, poorly exposed.	2.08

metres

Northampton Ironstone about 4.5 m.

6. SPROXTON "Outcrop Face". SK 873348.

On the upper slopes of Buckminster Bottoms valley; open in 1971-73. Measured 25th to 31st March 1972.

Lincolnshire Limestone 4.0 m.

Grantham Formation 2.97 m.

Soft brown clayey sand.	0.15
Flaser bedded brown and purplish ferruginous clayey sand.	0.08
Clear white fine-grained quartz sand, streaked with brown ferruginous sand and sandy shale, passing down into dull grey clayey sand.	0.20
Yellow brown laminated fine-grained sand with vertical dark rootlets, passing down by transition into laminated shale.	0.13

Stainby Member

Blue grey rhythmic banded shale with thin white fine-grained sand streaks; main fining-upwards, graded units 4 - 12 mm, with minor banding of about 0.5 mm. Shelly streaks with <i>Ostraea</i> etc. (small shells) 0.5 m down. White fine-grained sand streaks more numerous in the lower two-thirds; vertical holes filled with clear fine-grained quartz sand or lignite (borings ? or more probably some rootlets.). Abundant shells in iridescent preservation in the lowest 30 cm include <i>Ostraea</i> , rare <i>Lopha</i> , <i>Trigonia</i> (<i>costata</i> and <i>literata</i> " groups), <i>Oxytoma</i> , ribbed sp. (one only), <i>Aviculopecten</i> (common) <i>Amusium</i> , <i>Homomya</i> ?, <i>Pholadomya</i> (rare), <i>Pinna</i> , " <i>Corbula</i> ", <i>Modiolus</i> sp., rare <i>Lingula</i> . (PEK/504).	1.17
Occasional deeply pitted pale mudstone nodules. (PEK/503)	0 - 0.05
Dark grey bedded or poorly laminated tough brown clay or clay-shale, becoming grey and slightly greenish downwards (unfossiliferous). Basally passing down into ochreous clayey ferruginous sand.	0.36
- sharp junction -	
Pale fine-grained clean quartz sand or soft sandstone with abundant vertical rootlets in the upper part. Bedding is indefinite, probably level.	0.61
Fine sand and ferruginous rubbly sandstone passing down into poorly exposed sandy ironstone (not used as ore; presumed part of the Estuarine Beds) about	1.22

Northampton Ironstone seen to about 2.5 m.

In the Stainby Member, there is an occasional surface covered with *Modiolus* and scattered specimens are fairly common. *Ostraea* (mainly small) are locally abundant, associated with small *Pecten* (*Amusium*); the commonest are "*liassica*" shape with an occasional form with broad-attachment ("*irregularis*"). One small oval form has a median radial sulcus extending half the shell length from the hinge. *Trigonia* specimens are fairly common. Some streaks are crowded with "*Corbula*" but this is subordinate. Small *Aviculopecten* are common but not dominant. *Lingula* valves occur separate in a sandy streak, associated with *Pecten* or *Aviculopecten*.

7. COLSTERWORTH: Woolsthorpe Face.

The northern part of the Colsterworth mining area has the Northampton Ironstone nearly flat lying, with the thin Grantham Formation showing remarkable evenness and continuity of individual beds. Bedding is simple and well developed throughout, with apparent perfect parallelism with the Ironstone and overlying Lincolnshire Limestone. The Stainby Member is probably represented by 25 - 50 mm of dark shale, but fossils were not found. Section at the north-east angle of the mine, SK 920242, measured 17th April 1971.

	metres
<u>Lincolnshire Limestone</u> 4.1 m.	
<u>Grantham Formation.</u> 1.83 m.	
Ochreous brown sand with grey layers.	0.10
Alternations of dark grey shale and fine white sand, with a median parting of ochreous sand.	0.15
Brown ferruginous ochreous fine/medium-grain sand.	0.05
<u>Stainby Member</u>	
Dull brownish-grey blotchy clayey sand with flattened clay inclusions and black shale streaks.	0.10
- passage -	
Deep blue-black shaly clay.	0.02
- sharp break -	
Medium grey banded clayey fine sand, layers (graded) 1 mm - 20 mm of light and dark banding. Common vertical rootlets truncated at the top of the bed, ferruginous basally	0.96
Drab grey very lignitic clayey sand.	0.13
Obscure interval.	0.31
<u>Northampton Ironstone</u> seen to 2.5 m.	

8. COLSTERWORTH - Glebe Farm Mine. SK 907245, (approximately) measured 9th January 1971.

Lincolnshire Limestone 8.5 m.

Grantham Formation. 2.25 m.

Ochreous soft sand. 0.31

Stainby Member

Chocolate brown shale (very persistent bed) overlying thin white sand bed towards the south - prominent marker. 0.05 - 0.13

Greenish clayey sand, weathering ochreous. (passing down).

	metres		metres
north		south	
Dark blue-grey carbonaceous shale	0.10	Dark blue shaly clay with fine pale silt bands; vertical plants. More thickly bedded and sandy at the base.	
Dark blue, ferruginous weathering shale with vertical plants.	0.33		1.07
Yellow brown irregular sand.	0.28		
Light grey shaley clay.	0.25		
Ochreous brown fairly hard iron-stone, concretionary.	0.13		
Sand, light grey-green or soft, ferruginous and shaly.			0.51

Northampton Ironstone 2.90 m.

9. COLSTERWORTH No. 2 Mine.

Over the period 1968 - 1973 the most extensive faces were located 1-3 km south-west of Colsterworth village (No. 2 Mine), immediately north of the Buckminster road. Several sections were measured, the following near the western end of the face, SK 914233 (as at June 1970) was most informative.

Lincolnshire Limestone 5.8 m.

Grantham Formation 3.59 m.

Yellowish clayey sand, becoming streaky below.	0.51
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- Gently undulating contact -

Stainby Member

Blue shale, dark, sandy.	0.15
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Blue shale, dark, sandy, rootlet holes filled with white sand.	0.18
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Flaser bedded grey finely pyritic shale; pale silty streaks in medium to light grey shale; dark carbonised rootlets. Scattered shells through the lower 60 cm., <i>Lingula</i> common about 20 cm above the base; at the base irregularly bedded dark carbonaceous silt with nacreous shells including <i>Trigonia</i> ; in part very sandy with sandstone pebbles (PEK/452).	0.91
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Faintly purplish silt or silty clay, with carbonised rootlets.	1.38
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Purple ferruginous cemented sandstone with vertical rootlets (hard bed).	0.46
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Northampton Ironstone 2.7 m.

The *Lingula* bed was particularly well developed at this locality; the species which occurs also in the Upper Estuarine Beds of the district, is identified as *L. kestevenensis* M. Wood. A little further west the shale becomes progressively sandier and, in 1969, the face cut a sand body, some 45 m. across, at the equivalent horizon; this sand yielded good specimens of the U-shaped burrows, *Diplocraterion*.

The ferruginous basal sandstone is notable; this is as hard as the underlying Ironstone but is densely penetrated by vertical rootlet holes which give the appearance of a columnar fracture.

Hollingworth and Taylor (1951, p.12) separated the basal sands in this section as "Northampton Sands", following practice in the Kettering district. The facies is however, clearly "Estuarine" and (as noted above) the whole of the interval between the Lincolnshire Limestone and the Northampton Ironstone is logically regarded as a single lithological unit.

10. COLSTERWORTH: Southern Face.

The mine is situated south of the Colsterworth - Stainby road and shows strong eastward attenuation of the Grantham Formation. The section is a little west of the middle of the face, (SK 920229) and was measured on the 23rd May 1970.

	metres
<u>Lincolnshire Limestone</u> 6.00 metres. Normal development with basal ferruginous limestone.	
<u>Grantham Formation.</u> 1.8 - 3.3 metres.	
Medium or light brown streaky bedded ferruginous sand.	0.10
- sharp junction -	
Lead-grey fine-grained soft sand with sandstone, grading down to buff.	0.38
<u>Stainby Member</u>	0.33
Dull grey and brownish very sandy lignitic clay with vertical rootlets.	0.33
Pale and dark grey finely banded clay, streaked with pale silts, with thin brown fine sand partings. In the middle, a bed contains large shells including <i>Trigonia (Myophorella)</i> ; also <i>Corbula</i> (PEK/451).	0.66
Brownish sand at the top of obscure interval; thickness varies from 0.6 m to	1.82
<u>Northampton Ironstone,</u> 2.00 m. plus.	

The upper beds of this section converge towards the Northampton Ironstone eastwards, as the basal beds thin. 400 m west of the "Old Post Lane" (the North Witham road) (SK 992229) the whole of the Grantham Formation is reduced to 1.35 m with only 5 cm of dark shale remaining in the middle part.

11. COLSTERWORTH: (Stainby) Glebe Mine.

Located 410 m. west of the western end of Colsterworth No.2 mine on the plateau. The section is one fields-length north of Stainby Church, SK 904230 and was measured on the 22nd April 1972.

Lincolnshire Limestone 1.60 m.

Grantham Formation 2.40 m.

Soft ferruginous fine-grained sandstone.	0.05
Weathered blue shale streaked with brown ferruginous sand, developing limonite crusts on deep weathering.	0.23
Soft brown very fine-grained sandstone.	0.05

metres

Stainby Member

Weathered blue and brownish shale, with thin fine sandstone streaks and vertical carbonised plants. 0.41

Dark blue fairly pure shale, only minor streaking with fine-grained sand, sand and silt; some vertical plants. Scattered small shells in the lower part with occasional rich shelly streaks near the base. *Lingula* locally common near the base. (PEK/506). 0.71

- passage -

Twin sandy mudstones - two persistent beds of hard flaser-bedded sandy mudstone, tough, difficult to break or split. Carbonised vertical plants. Many shells, mostly in streaks, *Trigonia* common, large *Pholadomya*, pectinids. Streaks full of "*Corbula*" in the lower part (PEK/507). 0.20

- passage -

Dark grey shale with scattered nodules at the base. Scattered iridescent shells (PEK/508), particularly in sandy laminae close to the base. about 0.10

- irregular junction -

Pale faintly purplish fine-grained sandstone, abundant vertical plants and carbonaceous streaks, patchily stained chocolate-brown. Locally with numerous 15 cm septarian ironstone nodules, the veins being of white chalky material (kaolin ?). 0.61

Northampton Ironstone, up to 2.0 m.

12. STAINBY WARREN

The face is located north-east of Gunby village, and the section was measured at the north-west end of the workings. (SK 163221, 8th November 1969).

Lincolnshire Limestone. 3.5 m.

- irregular junction -

Grantham Formation. 4.14 m.

Dull grey silty shale, 10 cm, passing down into ferruginous shale with ironstone layers and nodules; grey shale bands occur near the base. 0.36

Rich brown ferruginous sand with some ironstone nodules. 0.38

Brownish-grey clayey sand, irregular base. 0.23

Yellow brown sand becoming clayey downwards, with abundant vertical rootlets which penetrate into the bed below. 0.25

Brown-grey clayey sand, greyer when fresh. 0.20

Stainby Member

Laminated brown and grey silty and sandy shale, fining downwards 0.84

- transition -

	metres
Dark grey shale; blue grey with pale silty and sandy streaks, rich shelly layers. In the upper and middle parts, <i>Corbula</i> in great abundance; also <i>Protocardium</i> , <i>Aviculopecten</i> , <i>Modiolus</i> . Close to the base, there is a layer of large single shells, especially <i>Pholadomya</i> and Trigonids; lignitic lenticles occur in the middle part. There are white sand filled rootlet holes.	0.36
- sharp clean junction -	
Grey sand (top only exposed) and obscure interval estimated at	1.52
<u>Northampton Ironstone</u> 3.0 m.	
13. <u>MARKET OVERTON</u> Cottesmore No.6 Mine, SK 896179.	
The section recorded is east of the ramp down to the ironstone level and was measured on the 22nd May 1971.	
<u>Lincolnshire Limestone</u> 3.3 m.	
<u>Grantham Formation.</u> 5.40	
Whitish and light brown streaky slightly ferruginous fine-grained sand.	0.18
Two thin beds of dark sandy shale, ferruginous.	0.02
Rich brown ferruginous fine-medium-grained sand with red-brown irony surfaces.	0.66
Gradation into very ferruginous sandy shale and grey shale.	0.08
<u>Stainby Member</u>	
Dark, pale weathering, very sandy shale and lignitic sandstone alternation, with 100 mm white sand lens near the top, varying from predominantly finely current bedded fine-grain sand with shaly lenses above to dark grey shale banded with white silt below. Bivalves present in the lowest third, particularly abundant in shale/sand alternations of the basal 5 cm. <i>Lingula</i> occurs 10 - 20 cm above the base. Bivalves include <i>Trigonia</i> spp. (abundant), <i>Modiolus</i> , <i>Lopha</i> , (small spp.), <i>Inoceramus</i> (rare) <i>Ostraea</i> , <i>Pholadomya</i> (rare) Pectinids (<i>Chlamys</i> etc.) <i>Protocardium</i> (common). One small coral (<i>Anabacia</i> ?). Pyrite can be found throughout and some of the shells are pyritised. Large pieces of pyritised lignite (5x15 cm) are common near the base. (PEK/460).	0.86
Dull purplish grey silty clay which has acted as a slide plane with 'vertical' plant rootlets now disposed obliquely.	0.13
Dull purplish grey muddy sandstone, fine-grained, with abundant dark vertical rootlets.	0.61
Pale weathering grey sand with vertical rootlets.	0.91
Pale grey sandy mudstone (low weathering).	0.51
Yellow sand, medium-grained, kaolinitic, patchily ferruginous with a 200 mm yellow and reddish oolitic ironstone bed near the middle and irregular box-stone ironstone in the lower half.	1.45
<u>Northampton Ironstone</u> 2.5 m seen.	

14. EXTON, Rutland.

Exton Park Mine, formerly United Steel Co. The section measured is at the western end of the main face, SK 930108 (approx.) recorded on the 24th June 1972. This locality is only 8 km south-south-east of the richly fossiliferous 'Lower Estuarine' of Market Overton, but none of the sections inspected yielded mollusca.

metres

Lincolnshire Limestone, about 6 m.

Grantham Formation. 4.28 m.

Deep yellow-brown very ferruginous soft clayey sand (very fine-grained), with irregular lumpy development of yellow brown ironstone. 0.76

- sharp junction -

Three persistent beds of dull grey shale with partings of light brown fine ferruginous soft sandstone (possible equivalent of the Stainby Shale Member) 0.33

Pale weathering buff fine-grained soft sandstone, penetrated by vertical rootlets from the upper surface. 0.18

Fine-grained soft sandstone, slightly ferruginous, weathering brown in 250 - 350 mm units separated by thin shaly partings. Sandstone units with cross-bedding which dips eastwards at 25-30°. Minor shale wisps on the lower cross-bed surfaces. 0.96

- transitional junction -

Light brown shaley clay, with brown ferruginous sandstone intervals (irregularly lenticular). 0.51

Light grey harder sandy mudstone (mud-supported sand grains, very fine-grained) with wisps of darker shaly clay, lignitic, near the base. 0.53

"Gingerbread-brown" richly ferruginous sandstone, locally developing ironstone box structures, seen to 0.31

Obscure interval about 0.60

Northampton Ironstone, about 2.4 m.

15. HARRINGWORTH, Northants.

Section in the West Quarry, SP 920966, measured on the 19th May 1971.

Lincolnshire Limestone about 15 m.

Grantham Formation. 3.66 m.

Brown ferruginous shaly clay, with 1 cm. brown vertical plant casts which pass down (attenuated) into the bed below. 0.25

Medium blue finely banded silty clay. Laminae 0.5-2.0 mm of pale silt in dark blue clay, lignitic. There are dark vertical rootlets but no trace of marine fauna, either mollusca or problematica. 0.43

Pale grey silt, finely sandy, speckled with lignite; vertical rootlets. 0.23

- sharp line -

	metres
Dark blue plastic clay, highly lignitic at the base.	0.38
Dull yellowish silty clay.	0.28
Silver-grey silt, blocky, slightly sandy.	0.10
Mottled yellow and grey pale clay with vertical plants.	0.46
Light-medium grey blocky silty clay, unbedded.	0.61
Medium grey tough silty clay, very poorly fissile, with fragments of lignite and very abundant plant fragments (nearly all "grass-shaped" leaves and stems), faint lavender purplish tinge. (PEK/461).	0.91
Very lignitic coaly shaly clay, ferruginous, apparently pocketed into the bed beneath.	0.08
 <u>Northampton Ironstone</u> over 2 m.	
16. <u>RUSHTON</u> , near Desborough.	
Section at the western end of the face, SP 85.83, measured 1970.	
<u>Boulder Clay</u> , chalky, 3.0 m.	
<u>Lincolnshire Limestone</u> 6.0 m.	
<u>Grantham Formation</u> . 8.30 m.	
Soft brown ferruginous sand, partly with clayey matrix.	2.44
Pale khaki and ferruginous shale and sand.	0.05
Dark blue grey shale	0.61
- sharp flat junction -	
Dull grey unbedded sandstone, locally pyritic, with shaly intercalations near the top, wispy with white silt below. Black rootlets extending down from the overlying shale.	0.36
Medium dark/black shale and shaly sandstone, tough, hard, pyritic, very lignitic with large pieces of wood; variably sandy, white rootlets.	0.86
Grey well-bedded "zebra rock" - streaked dark shale and white sandstone. Vertical roots.	0.46
Pale lead-grey plastic clay with rootlets.	0.31
Dull purplish sands, ferruginous, clayey.	0.90
Main rootlet bed - white sand and sandstone, holes filled with purplish sands above.	0.46
White sands with horizontal streaks.	1.36
Fairly hard brown ferruginous sandstone.	0.43
 <u>Northampton Ironstone</u> . 1.5 m seen.	

17. TINWELL. Stamford.

The section, measured on the 24th November 1973, is in the lower part of a major water transfer pipe trench, TF 016061

metres

Lincolnshire Limestone 1.7 m.

(with the basal Collyweston Slate development)

- sharply undulating contact developed by concretionary growth. Level stratification across the contact -

Unclassified (probably basal Lincolnshire Limestone equivalent)

Dull brown drab, very fine-grained uniform sand, (about 125 mm) slightly "mealy", with level faintly marked bedding, local sharp fine lamination indicated by carbonaceous films. Ferruginous ochreous layer at the base. 1.20

- Undulating contact, partly stratigraphical, partly due to cambering effect -

Grantham Formation 0.73 m.

Dark grey poorly-bedded carbonaceous clay. 0.05

Pale grey clay-bound fine sand (grade 150 - 200 microns) crowded with plant traces. 0.33

Deep yellow-brown ironstone and ferruginous fine-medium-grained sand. (mixed grade 100 - 250 microns.) 0.20

Pale grey clay, slightly mauve tinged, more usually light bluish, with vertical carbonised plant traces; weathering to a plastic clay. 0.10

White sand, ferruginous, above 0.05

Northampton Ironstone 4.50 m.

Upper Lias seen to 1.0 m.

The Fenland Sections

The five detailed sections which follow are based on cores notified by Dr. J.A.D. Dickson and three of them use his lithological description. They are described in order from north-west to south-east from Branston Moor, near Lincoln, by way of Asgarby and Great Hale near Sleaford, and Pickworth, east of Grantham, to Bicker, south-west of Boston.

Very few other cored borehole sections are available in this area, since most water borings end in the Lincolnshire Limestone, and oil borings were not cored at this level. Three British Petroleum Company/ British Gas borings in the Fenland are, however, relevant. In the Bardney No.2, south-east of Lincoln (TF 1191,6861) the Grantham Formation was 4.0 m thick, recorded as dark grey-green silty mudstone, grey to dark grey, pyritic fine to medium grained sandstone. Ruskington No.1 near Sleaford (TF 0921,4974) was logged as penetrating 7.0 m of dark grey sandy clay, blue grey sandy and white sandstone and medium grey clay. Helpringham No.1 (TF 1753,3884) was more like nearby Bicker (see below) with 7.5 m of grey sandy calcareous shale interbedded with white shaly sandstone. These records have the limitation of being compiled from cuttings only and the chances of any recognisable shells surviving were very small but they tend to show that the core hole sections are characteristic in thickness and lithology for the general area.

18. BRANSTON MOOR borehole.

About 8 km east-south-east of Lincoln. TF 0567,6767. Summary of the section by J. A. D. Dickson.

Lincolnshire Limestone base at 68.0 m. (depth from the surface)

<u>Grantham Formation</u>	2.8 m.	metres
Very hard laminated sandstone (part of the core lost)		0.80
Sandy shales and sideritic mudstone, including dark laminated shale.		0.40
Mudstone with grit horizon; pebbles (including quartz) in the lower part.		0.40
Bioturbated micaceous clayey very fine-grained sandstone with pebbly base.		1.20

Upper Lias at 71.0 m. (top)

This section, in line with those of the northerly outcrops, lacks any distinctive median shale or recognisable marine unit. It is of interest in showing the incoming of the Grantham Formation eastwards from the Lincoln - Nocton area (a deeply buried Palaeozoic high) where the Lincolnshire Limestone rests directly on the Northampton Ironstone.

19. ASGARBY bore-hole.

4.8 km east-north-east of Sleaford, TF 146467. Lithology, summary by J. A. D. Dickson.

Lincolnshire Limestone base at 133.05 m. (depth from the surface.)

Grantham Formation 2.02 m. proved.

Bioturbated sandstone, core fragmented (? soft sand)	0.64
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Stainby Member

Dark grey to black fissile shale, slightly micaceous, with well preserved <i>Lingula</i> at 133.90 m.	0.24
Dark finely laminated shale and sand, with leaf fragments in the upper part, unidentifiable shell fragments and ostracods common below.	0.20
Soft sandstone with rootlets	0.32
Lensing sandy layers with black shale partings; rootlets.	0.62

- lower core lost -

The section provides the northernmost record of the Stainby Member, with marine fossils, although the equivalent may well be represented by weathered shale at Leadenham and Ancaster in which fossils have not yet been found.

20. GREAT HALE bore hole.

9.6 km east-south-east of Sleaford, TF 168433. Lithology described by J. A. D. Dickson.

Lincolnshire Limestone, base 112.54 m. (depth from the surface)

Grantham Formation about 1.5 m proved.

Contorted sands.	0.07
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metres

Stainby Member

Dark shale, with sand-filled desiccation cracks, above laminated, fissile shale and fine silty partings with <i>Lingula</i> sp.	0.23
Hard contorted sand, regularly laminated below.	0.23
Soft micaceous sand.	0.06
Sands and clays, burrowed.	0.13
Laminated siltstones with rootlets	1.65

- core lost, about 1 m. -

21. PICKWORTH bore-hole

12.8 km. east of Grantham, TF 0434,3375.

Lincolnshire Limestone, base 39.9 m, (depth from the surface)

Grantham Formation 0.38 m.

Dull grey sandy clay with clayey sand.	0.38
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Northampton Ironstone ? about 2.0 m.

Sandstone and chamositic clay with red ironstone concretions.	0.17
Green slickensided clay, bright green above, duller below, with rootlets.	0.10
Greenish grey clay with pebbles and concretions of limestone etc.	0.07
Conglomerate of reddish ironstone pebbles (up to 6 cm. diam.) and grey limestone, in clayey matrix.	0.25

Upper Lias (top) 1.5 m. penetrated.

This section is in the area of attenuated Grantham Formation and is close to the easterly limit of the Northampton Ironstone as defined by ore borings. The conglomerate facies of much of it suggests a shoreline development of the Ironstone. Alternatively, the beds might be regarded as essentially a basal conglomerate of transgressive "Estuarine" facies but no conglomeratic base is known elsewhere. The section contrasts with that of the Colsterworth - Leadenham area in lacking the usually persistent Stainby Member.

22. BICKER bore-hole.

9.6 km south-west of Boston, TF 247383. Logged by P. E. K.

Lincolnshire Limestone base at 133.40 m. depth from the surface.

Grantham Formation. 4.40 m.

Fine white sandstone, bioturbated, with carbonaceous streaks, softer below.	0.20
Fine sandstone grading down into silty shale.	0.06

Stainby Member

Fissile laminated interbeds of very fine-grained white sand and dark silty shale. Well preserved small mollusca, including cerithoid gastopods, <i>Pterinopecten</i> juv., <i>Protocardium</i> .	0.10
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	metres
Markedly banded dark shale with thin pale silty bands. Small <i>Nuculana</i> sp. in floods covering bedding planes; rare <i>Lingula</i> sp.	0.10
Very fine-grained sandstone and siltstone, pale grey, and mudstone.	0.20
Moderately well bedded bioturbated dull grey fine sandstone.	0.12
Dark shale with white-sand-filled borings, irregularly slickensided. Passes down into sandy mudstone.	0.21
Highly pyritic irregular mixture of medium-grained white sandstone and grey mudstone. Pyritised <i>Chondrites</i> .	0.03
Dull grey mudstone and waxy clay, greenish, almost fire clay type. Slickensided. Borings as above.	1.20
- core disintegrated in the lower part -	
Harder grey sandstone and mudstone.	0.15
Soft dark mudstone.	0.09
Well banded pale grey siltstone with ironstone concretions.	0.41

Upper Lias (top) penetrated to 0.14 m.

This is the most easterly cored section of the Middle Jurassic in Lincolnshire; in fact, the most easterly cored section south of Spurn Head. It is of particular interest to see that the marine element in the Grantham Formation is maintained if not increased - the replacement of floods of "*Corbula*" by equally abundant *Nuculana* suggests more open sea conditions and the mollusca extend through a somewhat greater thickness than is usual at outcrop. On the other hand, the larger lamellibranchs (Trigoniacea), *Pinna*, *Pholadomya*, *Modiolus*, etc.) are missing. The latter include bottom living species and the difference could be symptomatic of deeper water in the east. The section is also notable for the development of a second marine or near-marine unit (indicated by *Chondrites*) near the base of the "Estuarine".

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