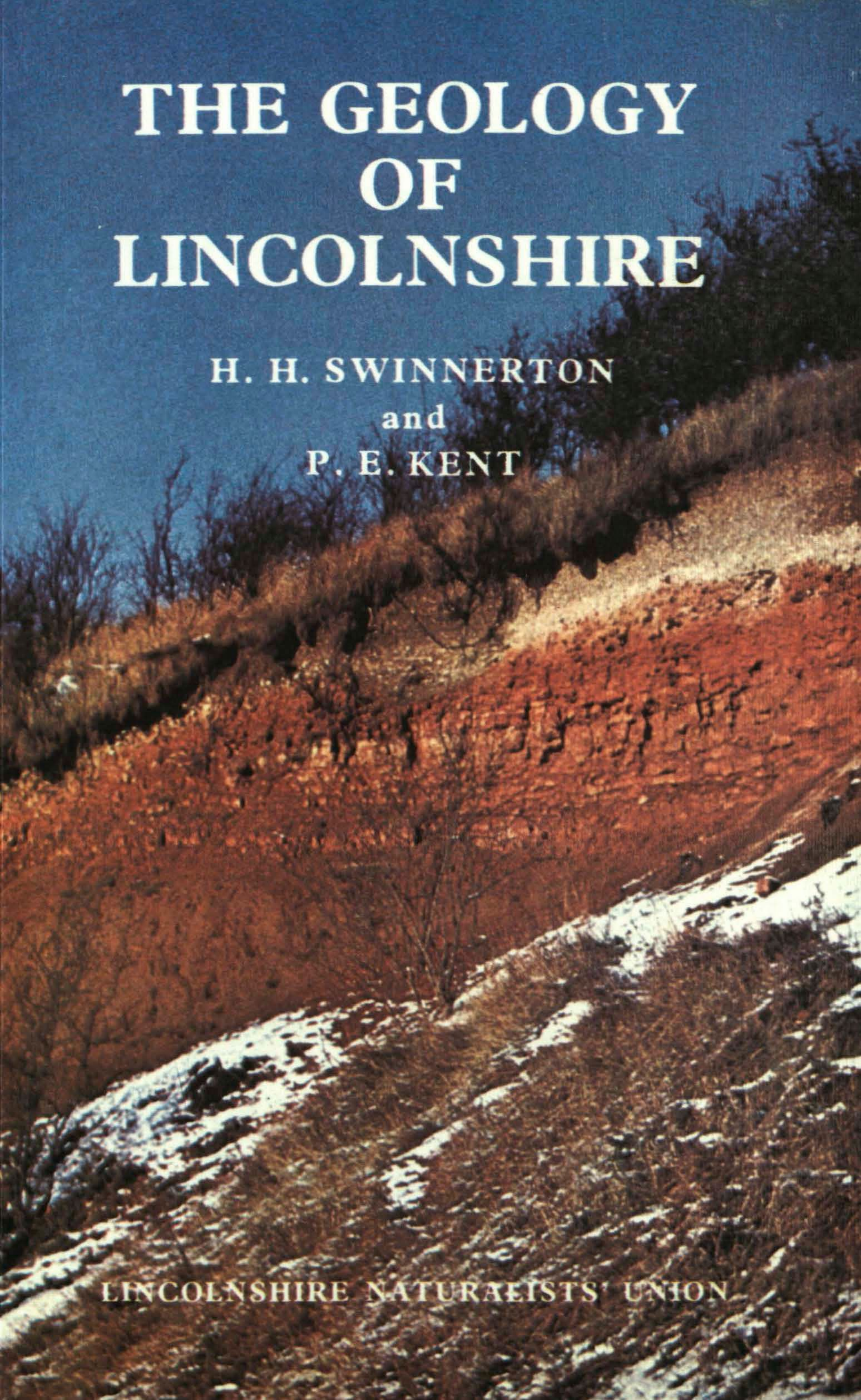
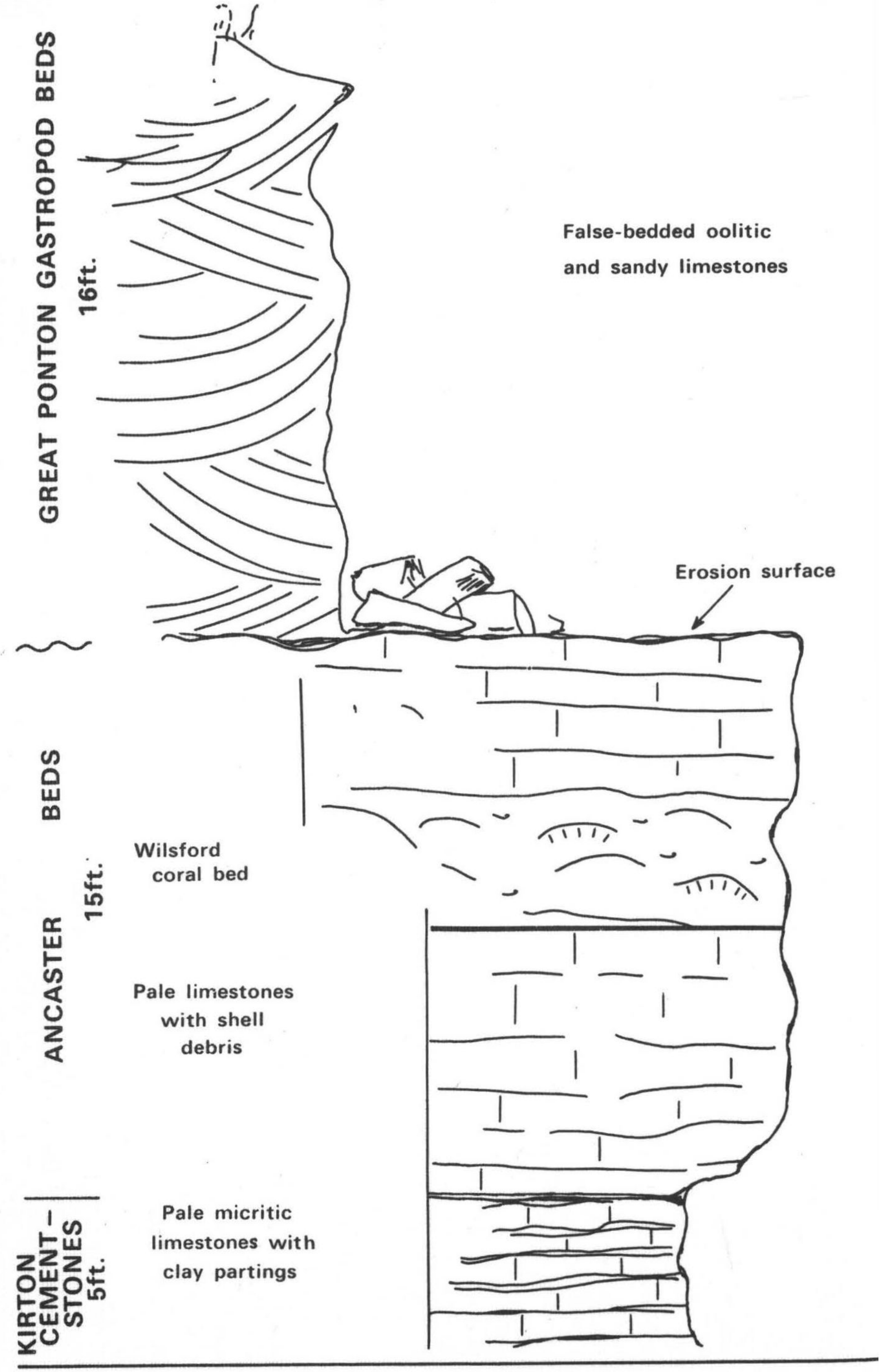
THE GEOLOGY OF LINCOLNSHIRE

H. H. SWINNERTON
and
P. E. KENT



LINCOLNSHIRE NATURALISTS' UNION



Section at Castle Quarry, Ancaster

THE GEOLOGY OF LINCOLNSHIRE

SECOND EDITION

LINCOLNSHIRE
NATURAL HISTORY BROCHURE
No. 7

THE GEOLOGY OF LINCOLNSHIRE

From the Humber to the Wash

by

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by
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The Red Hill, Goulceby, showing Red Chalk and Carstone
by D. N. Robinson, M.SC.

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Between pages 50 *and* 51

The second edition of this book is dedicated to the memory of Henry Hurd Swinnerton, who not only contributed extensively to the geology and prehistoric archaeology in Lincolnshire but also assisted many others to develop their interests and knowledge in science and scientific methods.

Although outstanding as a natural scientist, continuing with original research into his ninetieth year, his dominant concern was for the welfare and education of the younger generation, to which he devoted a large part of his life. It is appropriate that this dedication should appear on one of the works he planned to introduce science to a wider readership.

PREFACE TO FIRST EDITION, 1949

THE coming into being of this booklet is due to the initiative of the Lincolnshire Naturalists' Union who, in addition to originating the idea, were prepared to sponsor it. At their request I as senior author undertook to produce it; and, with their consent, enlisted the help of the junior author because of his unique knowledge of certain aspects of the subject. My thanks are due to him for consenting to accept the sole responsibility for Chapters 4, 5, 7-9, 13 and for the major part of the work involved in Chapter 17 and in the Bibliography.

The Chapters on the Pre-Cretaceous rocks and on the structure of Lincolnshire, incorporate the results of investigations carried out by Dr. Kent in the course of his duties with the D'Arcy Exploration Company. Our thanks are therefore due to the Chairman and Directors of the Anglo-Iranian Oil Company, Ltd. for permission to include this material and for the assistance given by the Company's staff in the preparation of the figures.

In presenting the Structural Contour Map of the Mesozoic rocks, we wish to acknowledge the careful work of Mr. C. H. Dinham of the Geological Survey and of Mr. C. F. B. Shillito of Brocklesby who collected, over a period of many years, well records which most usefully supplement earlier published sources.

Our thanks are also due to the Council of the Geological Society of London for permission to reproduce figures 5 and 6 from their Journal. Among others to whom we are indebted for help, reference may be made to the Librarian of the Gainsborough Public Library for information about Mr. F. M. Burton, and to Mr. W. G. Summers, formerly of the Grantham Public Library for similar details about Mr. H. Preston. In conclusion we are particularly grateful to Mr. F. T. Baker, Secretary of the Lincolnshire Naturalists' Union for ever ready help and advice on many occasions.

H.H.S.

PREFACE TO SECOND EDITION

THE first edition of this book in 1949 summarised many decades of work by the Geological Survey, by academic workers and by amateurs, in what was a relatively static landscape. Changes were slow and exposures were infrequent. The railway cuttings made in the last century were mostly overgrown and the village clay pits which had operated in the years before easy communication were already lost to sight. Since that time, however, the development of the countryside has accelerated to a remarkable degree. There is no overall increase in availability of permanent exposures – in fact the progressive loss has continued – but many constructional activities have provided temporary sections in hitherto unknown parts of the rock succession. Most notable are the deep cuts provided by pipelines for gas and for water transfer; in addition new road cuttings have exposed the rocks, more rivers have been deepened and the foundations of new electricity pylons have provided cross-country spot sampling opportunities. The process will doubtless continue, and it is important that those with opportunities to record data should extract the maximum of information from the temporary sections, which in some cases may only be open for a few days or even hours. Most of the many additions to the information in the following pages have come from such sources.

The first edition also made frequent reference to the sections found in deep boreholes down dip from outcrops. This had its value in producing a regional account of the geology, which proved particularly relevant at a time when there was special interest in the succession of eastern England as North Sea exploration began. Regional concepts have now broadened much further, to include the North Sea and relations with continental Europe, and are consequently beyond the range of a county geology. In recasting the book the emphasis has been brought back towards the local successions, adding more details of the less well known parts of the stratigraphic column and of their local variants for better understanding of the processes responsible for the rocks of Lincolnshire.

The greater part of the text for which Professor Swinnerton was originally responsible however remains relevant and is retained without change.

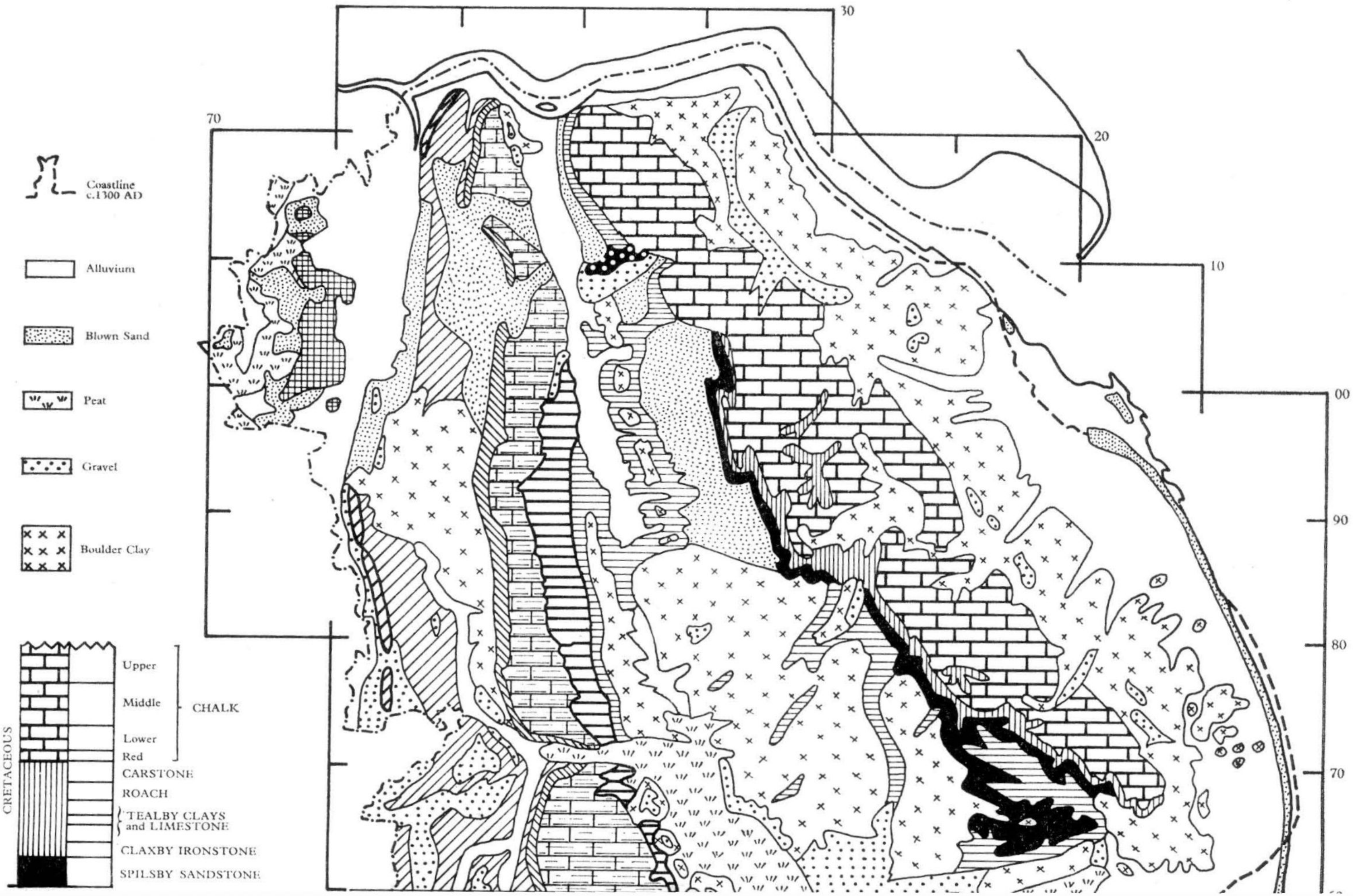
The present writer is responsible for most of the new information on the Lias and Oolites, but Dr. P. F. Rawson of Queen Mary College provided new data on the Upper Jurassic and Lower Cretaceous, and warm thanks are due to him for his assistance. Similarly, Professor A. Straw has assisted with the revision of the Pleistocene chapters.

Grateful thanks are due to Miss L. O. Scott for much help with proof reading and bibliographical work, and also to Mr. D. N. Robinson for a great deal of assistance with the post-glacial history, for compiling the geological map and supplying photographs.

Readers will notice the introduction of new names, which may seem inconvenient, carrying with them the prospect of abandonment of old ones. It is clearly easier to use the familiar "Rhaetic", "Lower Estuarine" etc., than to adopt new forms, but these and other older names lack precision and are to a greater or lesser extent misleading. In this new edition, therefore, some old names are used together with the corresponding new formal ones which are now required by international rules. The original names remain on the old maps and in the former descriptions of the geology; they will still be required for reference, and both formal and informal systems must exist together for a long transitional period.

P. E. Kent

West Bridgford,
Nottingham, 1975.


Coastline c.1300 AD
Alluvium
Blown Sand
Peat
Gravel
Boulder Clay
Upper
Middle
Lower
Red
CHALK
CARSTONE
ROACH
TEALBY CLAYS and LIMESTONE
CLAXBY IRONSTONE
SPILSBY SANDSTONE
CRETACEOUS
30
70
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90
80
70

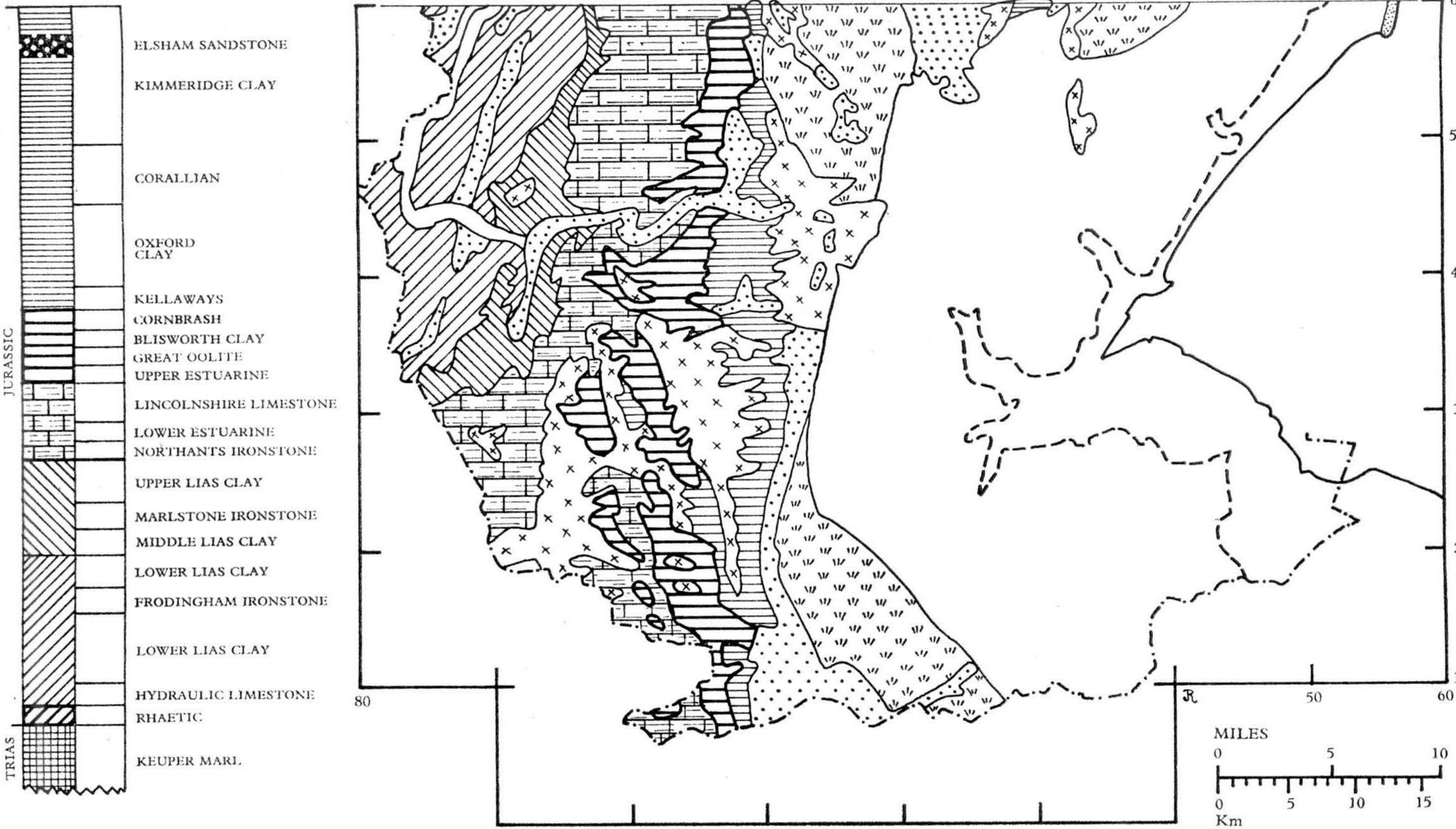
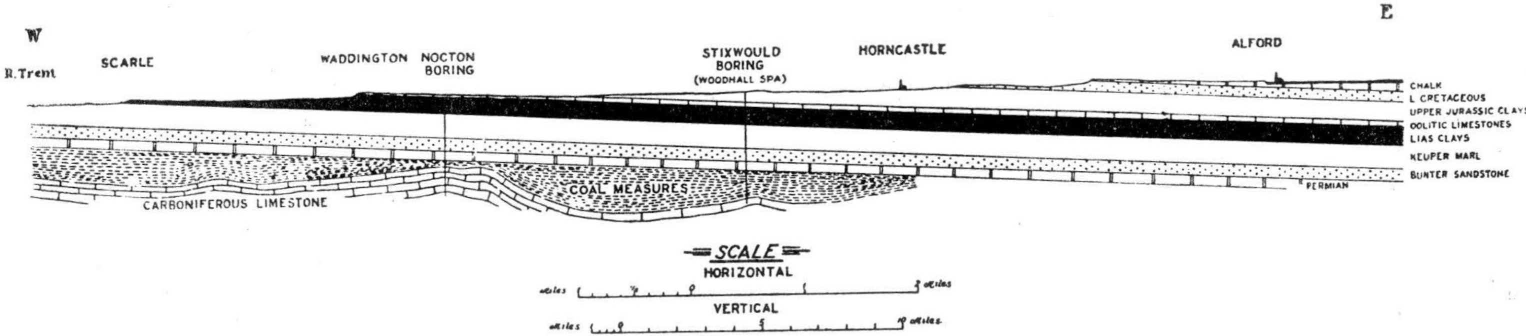


Fig. 1. The Geology of Lincolnshire.

(compiled by D. N. Robinson)

WEST–EAST SECTION THROUGH LINCOLNSHIRE



The vertical scale is exaggerated four times for clarity, so that dips shown are abnormally high.

Fig. 2

CHAPTER 1

INTRODUCTION

GEOLOGY is primarily concerned with the rocks which form the foundations of the countryside. These may be considered from three distinct standpoints — origin, arrangement and age. The rocks which make up the Lincolnshire countryside originated as sediments which settled down, or were deposited, on land or in water. For that reason they are described as sedimentary rocks, to distinguish them from igneous rocks, which solidified from a hot liquid state, and from metamorphic rocks, which have been subjected to such varied and intense experiences that they have been completely changed from their original sedimentary or igneous state.

Sedimentary rocks are generally arranged in layers or strata and are accordingly often referred to as stratified rocks. The greatest portion of each layer is hidden underground beneath other layers; only a narrow selvage, known as the outcrop, shows at the surface. Such layers of rock may be flat or folded into upfolds or anticlines and downfolds or synclines.

In any given area the rock layers may be horizontal or tilted. In the latter case the direction of maximum tilt is the direction of DIP. The direction which is at right angles to this is called the STRIKE.

Where several layers are seen lying one above another it is evident that (unless they have been turned upside down) the bottom layers were formed first and the top layers last. The former therefore represent an earlier and the latter a later point of time. Quite often when a layer was deposited the shells or skeletons of the animals that lived and died at the time became buried in sediment and have become what are now described as fossils. Thus each layer provides a record of the conditions under which the rock was formed whether of land or water and of the animals and plants which lived at that part of the earth's surface at that time. These conditions, however, vary greatly from shallow to deep water; from positions where the sweep of currents allows only coarse sediments to accumulate to others where the water drifts quietly along bringing only the finest silt and mud. The types of deposit thus produced are spoken of as *facies deposits*. Similarly also the characteristic associated assemblages of fossils are referred to as *facies faunas*. The geologist, by studying the nature of each layer and of the fossils it contains is able to reconstruct much of the past history of that part of the earth's surface, and catch glimpses of events which took place millions of years ago.

The fact that some of the rocks which now make up the land were formed in the sea reminds us that the crust of the earth is not stable but rises and sinks so that such an area as that of Lincolnshire has in the past been frequently covered by the sea and just as frequently it has been dry land. Directly rocks are lifted from the sea floor to form land they become subjected to the shattering action of frost and other factors of the weather. The waste products are carried by running water to the sea. Thus the outcrops of the rocks are gradually worn away and denuded. Naturally some rocks yield more quickly than others to these processes. Thus hills and valleys are formed and the surface of the land becomes diversified. The study of these processes and their results is called Physical Geology.

Sooner or later the land sinks once more below sea level. As it passes slowly below the surface of the sea the waves beat against its margins and wear away its features to an almost flat surface, which passes down to become the floor of the sea and in due time is buried under a new succession of deposits. The layers of rock ultimately formed from this succession all have the same amount of dip and are said to succeed one another conformably. The rocks below them, upon whose bevelled edges they rest are likewise conformable to one another but they dip at a different angle. The upper set of rocks rest upon the outcrops of the lower and are therefore said to rest unconformably upon them. Between the time represented by the youngest of the lower set and the oldest of the upper there was a long stretch of time during which land conditions prevailed, rocks were worn and finally carried down below the sea. An unconformity thus presents us with a break in the sequence of the rocks and a gap in the historic record.

For the purposes of examining its rocks in exposures Lincolnshire suffers from the absence of sea cliffs and from the almost unbroken covering of good soil. In some parts of the county quarries in limestone and chalk are relatively numerous; elsewhere the underlying rocks may be seen occasionally during road widening operations, in trenches and similar temporary exposures. Much information about the more deeply seated rocks has been gained from boreholes that have been made in the search for water, oil and coal.

CHAPTER 2

SURFACE FEATURES

As compared with Derbyshire and the Lake District, Lincolnshire is characterised by low relief. Three-quarters of its area is less than 100 feet high and much of this lies close to the sea-level. The remaining quarter nowhere rises to 600 feet. The nature and the distribution of the surface features are primarily controlled by the character and arrangement of the underlying rocks (Fig. 2). Apart from a certain degree of minor folding, which will be dealt with later, the strata are flat and dip gently eastwards across the county. Thus it comes about that in traversing the county from west to east the outcrops are passed over in order from the oldest to the youngest. The former belong to the Keuper and Lias formations which, apart from several thin belts of limestone and ironstone, consist of clay which offers little resistance to the action of weathering agencies, and have consequently been worn down to form the low ground which skirts the western margin of the county and, at its northern end, merges into the still more low lying Carrlands.

The Oolite Limestones, which come next in age, being more resistant have not been worn down so quickly; and thus produce high ground which runs southwards from the Humber as a narrow strip known as the 'Heath' or the 'Cliff'. This has a steep face or scarp slope facing westwards, and an opposite slope, the dip slope, which inclines gently eastwards. The striking scarpland feature is crossed by two valleys known as the Lincoln and the Ancaster gaps. As this strip approaches and passes Grantham it broadens out rapidly mainly because the dip of the rock becomes more gentle. It rises westwards to form a plateau having an altitude of about 400 feet. At the same time a resistant belt of ironstone appears in the upper part of the Lias and contributes its quota of high ground to the north-western margin of the plateau. This portion of the limestone outcrop is dissected by a number of valleys having a general north-south trend.

The remainder of the county, bounded as it is by these limestone uplands on the west, the sea on the east, the Humber on the north, and the Wash with the Fenland on the south was for many centuries in a state of semi-isolation from the rest of the country. In its northern half, this part of the county is made up of three north-south strips; Upper Jurassic clay lowland on the west, the chalk Wolds in the centre and the Marshland in the east. The Wolds form a compact area of high ground extending from the Humber in a S.S.E. direction to the vicinity of Spilsby. Many of its boundaries rise steeply and provide from their crests expansive views over the adjoining lowlands, the Central Clay Plain on the west, the Marshland on the east, and the Fenlands on the south.

The dominant river in the county is the Witham which, with its tributaries, drains most of the Lias and Upper Jurassic clay plains, and the northern part of the Fenland. Two other large rivers, the Trent and the Welland cross the N.W. and the S.E. corners of the county respectively. The river Ancholme drains the northern part of the Upper Jurassic clay lowland and discharges into the Humber. A number of streams rise in and about the margin of the Wolds and flow directly to the sea across the Marshland. A large stream, the Steeping river, flows south-eastwards along the southern end of the Wolds and the adjoining Fenland into the Wash. In addition to the natural drainage much artificial drainage has been established in the Carrlands and the Fen country.

In the northern half of the county a thin layer of Boulder Clay covers portions of the lowlands. Its surface has a gently rolling character, and, along the fringes of the Wolds, it blankets the lower parts of the steeper slopes which accordingly rise less abruptly than they otherwise would.

In the southern half of the county the Boulder Clay together with the underlying oolite and later rocks passes down to and below sea-level and is covered by clays of estuarine origin. These produce extensive areas of flat ground, portions of which lie below the high spring tide level but are protected from inundation by artificial embankments.

CHAPTER 3

THE AGE AND ARRANGEMENT OF THE ROCKS

It has been already observed that many of the events which happened on the face of the earth in past ages have left their records in the rocks. The most important of these events has been the passage of time. The extent of this may be inferred from a consideration of the layers of sedimentary or stratified rocks which may be examined in cliffs, quarries and other exposures. The sediments which make up any one layer must have taken time to accumulate, and consequently each layer represents a limited spell of time. Under normal conditions it may be assumed that in any vertical succession of layers the lower ones were formed before the upper or later layers were laid down. They are therefore referred to as older and younger rocks respectively.

If a trench, several thousands of feet deep, were made from west to east across Lincolnshire, the rocks which make up both the surface and the foundations of the county would be exposed in its sides. Figure 2 is a diagrammatic representation of such an exposure which shows the types of rocks, their order and arrangement. Such a diagram is known as a geological section and is based on evidence collected from quarries and cliffs, outcrops and borings.

In the upper part of this section the layers of rocks are seen to dip eastwards under one another so that the surface is made up of younger rocks in the east and older ones in the west. A similar section across Wales and England shows that over this much larger area the rocks are similarly arranged and include some younger and many older rocks than those shown in Figure 2. All these together have a total thickness of about twenty miles and, having regard to their slow rate of accumulation, they must represent a vast stretch of time. The oldest rocks shown have been in existence so long that they have been subjected to many changing degrees of pressure and temperature, with the result that their original character has been lost and the fossil remains they may have contained have been utterly destroyed. While some of the rocks have been thus completely metamorphosed, others, which are slightly younger, have been only partially changed. It is not surprising therefore that the deepest known foundations of the countryside consist of rocks which have been much metamorphosed.

The rocks just referred to are frequently interpenetrated by igneous rocks which were injected into them in a liquid state, during one or other of those various periods of igneous activity which occurred from time to time. The granites, which are the commonest of these rocks, have been formed at wide intervals of time and the relative age of any one type of granite can usually be discovered by considering its relationships to the rocks it has, or has not, penetrated.

The contemplation of this great succession of rocks and the changes which some of them have undergone, creates a sense of the vastness of the time which they represent. This is, however, too vague to satisfy the scientific mind and consequently a variety of efforts have been made to arrive at some estimate of its length in terms of years. The most reliable of these is based upon a careful investigation of the degree of change undergone by radioactive minerals in igneous rocks of various ages, and of the degree of change produced in adjoining minerals by radioactive emanations. From these investigations it seems reasonably certain that the oldest rocks which have been seen at the surface of the earth were formed 4000 million years ago. The probable date of formation of various later rocks is shown in the accompanying table which gives the names of the more important divisions of geological time.

TABLE I

The Divisions of Geological Time

ERAS	PERIODS	AGE (In millions of years)
Cainozoic	Quaternary	1
	Tertiary	60
Mesozoic	Cretaceous	120
	Jurassic	145
	Triassic	170
Younger Palaeozoic	Permian	
	Carboniferous	
	Devonian	325
Older Palaeozoic	Silurian	
	Ordovician	
	Cambrian	500
Precambrian		4000

NOTE — The names which are underlined relate to rocks found in Lincolnshire. Their average rate of deposition may be estimated at about one foot in 250 years.

So far the sedimentary rocks have been thought of as consisting of flat layers either lying horizontally or dipping gently as seen in the upper part of Figure 2. In the lower part, however, they are seen to be folded. This fact directs attention to another series of events of outstanding importance usually referred to as mountain building and decay. These took place along certain belts of the earth's surface where the rocks were subjected to intense lateral pressure with the result that they underwent various degrees of folding or even crumpling. The movements were by no means catastrophic for they took place slowly over periods of several millions of years. Uusually the belt was raised gradually above sea level and became exposed to the destructive action first, for a short time, of the sea; and then, for a very much longer time, of atmospheric agents. For a while the belt was occupied by hill ranges and mountain systems, but ultimately these were worn down to low lying plains. In due time these were submerged and then buried under a new series of sediments. The layers of rock which were then piled one upon another formed a continuous or conformable succession. The bottom-most layers, however, rested upon the upturned and truncated edges of the rocks which had been folded and eroded. A simple example of such an unconformity is seen in Figure 2 where the Permian rests upon the Coal Measures.

Reverting to the table given above it may be noted that the rocks laid down during any one period of time are spoken of collectively as a formation. The formations found in Lincolnshire are shown over. Still further detail is given in later chapters.

TABLE II

The Geological Formations of Lincolnshire

(1) FORMATIONS FOUND AT THE SURFACE

ERAS	PERIODS	
Cainozoic	Quaternary	Post Glacial
		Glacial or Pleistocene
Mesozoic	Cretaceous	Upper
		Lower
	Jurassic	Upper:
		Kimmeridge Clay
		Oxford Clay
		Kellaways Beds
		Middle:
		Great Oolite
		Inferior Oolite
		Lower:
		Lias
	Triassic	Rhaetic
		Keuper

(2) FORMATIONS FOUND IN BORINGS

Mesozoic	Triassic	Bunter
Younger Palaeozoic	Permian	
	Carboniferous	Coal Measures
		Millstone Grit
		Carboniferous Limestone
Older Palaeozoic	Quartzites and conglomerates	
Precambrian	Metamorphic rocks	

CHAPTER 4

PRE-JURASSIC ROCKS AT DEPTH

Although this book is mainly concerned with the outcropping rocks, these represent only the later part of a long history. The concealed rocks have their importance in understanding the later cover; they have importance also for economic deposits of oil and gas, possibly in due course for coal although this is at present too deep for working.

Directly beneath the Jurassic is the Permo-Triassic series, the 'New Red Sandstone' of older authors. The highest thin member is the marine Rhaetic, described with the Jurassic in Chapter VI. Beneath this are the continental deposits of the Keuper and Bunter, deposited in hot deserts.

The KEUPER (Mercia Mudstone formation), of which the top is seen along the Trent valley, was the product of long lasting dust-desert conditions. The great bulk is red 'marl' — calcareous silt and clay. At intervals particularly strong sheet floods spread fine sand across the basin, forming thinly bedded sandstone members known locally as 'skerries'. The water was salty, so that large salt crystals were formed as it dried out; the next flush of water dissolved this salt, filled the cavities with salt and this left behind salt casts, 'pseudomorphs', as evidence. Fossil suncracks and rain prints were preserved in the same way. Fish lived at times in the transient pools; shoals of them were stranded near Nottingham and buried in drying mud. Scattered teeth and scales have been found in the highest beds, in the 'Tea Green Marls' which directly underly the Rhaetic.

Calcium sulphate — gypsum — was widely deposited in the later Keuper in quantity sufficient for exploitation. It has been extensively quarried in east Nottinghamshire and is known to extend into Lincolnshire, but it is rather deeper and has not yet been worked here.

Boreholes show that the thousand feet of Keuper overlies BUNTER SANDSTONE (Sherwood Sandstone formation), a continental formation of a different kind. Water-borne torrential gravels and coarse sands were carried into the edges of the desert basin — in the Midlands and in south Lincolnshire. Finer sands and salts were swept from the flanking hills further into the basin, so that the Bunter beneath Lincolnshire and east Yorkshire is mostly rather different from that of the outcrops.

Probing more deeply still we penetrate the PERMIAN — dolomites and marls deposited in the marginal parts of a salty sea which extended across northern Europe. Across Lincolnshire various members die out southwards towards the edge of the original basin. The old shoreline, now deeply buried, can be traced across southern Lincolnshire.

Down to the Permian the rocks of Lincolnshire form a conformable series — the beds follow one another regularly, and although deposition varied enormously with climatic variation there were no episodes of folding, no major uplifts, to interrupt the steady process of subsidence as sediments accumulated. The base of the Permian however marks a major change — the formation rests on a surface bevelled across folded, faulted and eroded Carboniferous rocks. This surface is remakably flat and even, dipping north-eastwards a little more steeply than the surface rocks.

The CARBONIFEROUS rocks most frequently encountered beneath are Coal Measures, which extend across the centre and north of the country and contain coal seams of workable thickness (but at great depth). South of Sleaford Coal Measures were eroded so that the older Millstone Grit and Carboniferous Limestone are bevelled by the Permo-Trias, and older rocks still — ancient metamorphic rocks comparable to those of Charnwood, and granitic igneous rocks — come to the old eroded surface in the southerly Fenland and probably beneath the Wash.

There is now extensive knowledge of these deep seated rocks; this shows that Lincolnshire has been part of a rigid shelf extending from the south Midlands into Yorkshire, and it is this rigidity — historically extending from the older Palaeozoic to the present day — which controls the simple belted outcrop pattern of the much later surface rocks.

CHAPTER 5

THE NATURAL HISTORY OF THE MESOZOIC

At the opening of the Mesozoic Era the Lincolnshire area along with the rest of Britain, was situated far inland away from the sea. This phase is represented in the rocks of the county by the Keuper Marl during the formation of which desert conditions prevailed. These were antagonistic to all forms of life and consequently fossil records of both animals and plants are almost unknown.

During the remainder of the era this area became partially occupied by sea for brief spells of time. Though remains of land animals and plants have been found elsewhere they are rarely represented among the fossils found here. Nevertheless these do show that where land did appear for a while it became occupied by both plants and animals.

In Jurassic times the living landscape presented a strange scene, for as yet neither green grasses nor the flowers of the field had evolved. Plant forms were for the most part comparable in size with bushes and small trees. These included ferns and tree ferns some of which produced large primitive types of flowers. In addition such archaic conifers as the Monkey Puzzle *(Araucaria)* also existed. In the Cretaceous period more familiar types of trees appeared upon the scene such as Maple, Willow, Oak and Alder.

In this county the Lincolnshire Limestone has yielded *Araucarites*. Fragments of plants have also been found in the Estuarine beds of the Jurassic and the Roach iron ore of the Lower Cretaceous. Careful search for and investigation of such fossils would throw more interesting light upon those ancient vegetations.

A rich fauna of land animals also existed during these times in other parts of the world. Unfortunately the remains of such are relatively scanty in Britain. Those that have been found, however, do prove that small primitive mammals about the size of a rat had already evolved, but that reptiles of all sizes and habits dominated the land. Some of these with bat-like wings had invaded the air, which was already occupied by large flying insects. Others again sought a livelihood in the sea and became adapted in varying degrees for life in the water. Since Lincolnshire was submerged most of this time it is not surprising that remains of the latter have been found. These include *Teleosaurus* from the Kimmeridge Clay. Though this primitive crocodile spent much of its time in the water its limbs were only slightly modified so that it could, without difficulty, walk and run on land. *Plesiosaurus*, however, spent most of its time swimming about in the open sea. Its limbs had, in consequence, become modified into short stout oar-like paddles. Like the seal it no doubt sometimes shuffled out of the water up on to the beach. In *Ichthyosaurus* the reptilian type of body became perfectly adapted for a life spent wholly in the water. It was shaped like a fish and propelled itself by means of its tail, while its short flipper-like limbs could be used only as lateral rudders.

Fossil remains of fishes are more common. They are, unfortunately, often in a fragmentary state, for as with the reptiles, their skeletons were made up of a multitude of bones which, when the flesh decayed, often fell apart and became scattered about. Teeth, which are the most durable parts of the skeleton, are quite commonly found. They belonged mainly to either sharks or skates. Those of the former were sharp and pointed e.g., *Lamna* from the chalk. Those of the latter are stout with broad crushing surfaces, e.g. *Strophodus*, from the Great Oolite, and *Ptychodus*, from the Chalk.

Other lowly occupants of the sea were much more numerous and varied. As their hard parts consisted of compact single shells their fossil remains are abundant and more frequently complete. Of these three-quarters belong to the Mollusca, which are divided into three orders: Cephalopods, Pelecypods (Lamellibranchs) and Gastropods.

The Cephalopods are represented in existing seas by the Pearly Nautilus of the Pacific and the Cuttlefishes. Fossil Nautilus occurs occasionally, as for example in the Lias; but the remains of the closely allied but extinct Ammonites are more abundant. The Ammonites were a rapidly evolving group and have consequently proved to be invaluable to the geologist in dating the rocks. As with Nautilus, the shell consists of a narrow cone or conch which is coiled upon itself like a watch spring. The coils are referred to as 'whorls'. The cavity of the shell is divided into a series of chambers by thin shelly partitions or septa. The edge where each septum joins on to the inside of the conch is known as the septal suture. In the Nautilus this appears in the solid fossil as a simple curving line, but in the Ammonite it is frilled.

As the Ammonites evolved, the shape of the cross section of the whorl, the degree of coiling, the type of ornamentation and the complexity of the frilling of the suture-line underwent perpetual change. Because of this the fashion of the Ammonites, at successive intervals of time, differed markedly, and consequently their fossil remains have proved to be most useful indicators of the time when the rocks in which they were found, were formed as deposits on the floor of the sea.

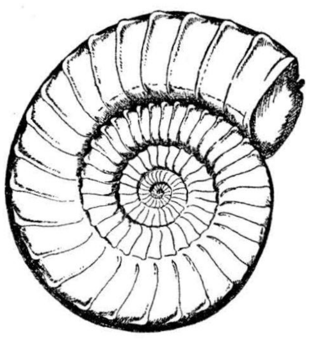
This changing fashion and its use may be illustrated by a brief description of four ammonites which characterise the lower, middle, and upper portions of the Lower Lias respectively (Fig. 3).

Psiloceras planorbis occurs in the lowest layers. In cross section its whorls are laterally compressed into a tall oval. Its surface is almost devoid of ornamentation. The degree of coiling is slight so that all the coils from the centre outwards are visible.

Schlotheimia angulatum is found in the next higher layers. In cross section its whorls are similar in shape to those of *planorbis* but they are stouter. The outer coils enclose the inner to a slightly greater extent. The surface is ornamented with stout curving ribs and those of the opposite sides join one another at a sharp angle along the outer or ventral surface of the coils.

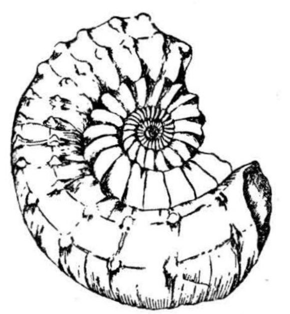
Coroniceras bucklandi occurs in the beds a little higher up. Its whorls are moderately stout and in cross section are almost square in shape. The surface is well ornamented with stout, gently curving ribs which extend from the inner to the outer margin of the sides. The outside or ventral surface is decorated with two grooves separated by a keel.

SOME ZONAL AMMONITES OF THE LOWER LIAS



Coroniceras Bucklandi

Scamnoceras angulatum



Androgynoceras showing capricorn ribbing on the inner coils

Fig. 3

Androgynoceras henleyi is a representative of a very variable family of ammonites which is characteristic of the highest layers of the Lower Lias. The whorls are approximately round in cross section. In the inner coils the calibre of the conch increases slowly. Followed outwards it increases more and more rapidly until in the outer coil it is greatly swollen. The inner coils are ornamented with stout ribs which run into one another across the ventral surface. Specimens consisting only of these inner whorls are quite common and are known as 'capricorn' ammonites. On the outer coils this simple coarse ornamentation gives place to one having a finer and more complex pattern.

The characteristic types of ammonites which occur in the Upper Lias are the genera *Dactylioceras* and *Harpoceras*. In the former the cross section is round or slightly oval and the sides are ornamented with ribs which bifurcate as they pass on to and across the venter. In the latter the cross section is compressed and high. The venter is ornamented with a sharp keel and the sides with numerous sickle-shaped ribs.

In *Macrocephalites* from the Cornbrash of the Middle Jurassic the cross section is wide and depressed. As the outer coils closely envelope the inner, the shell as a whole tends to be almost spherical.

In the Upper Jurassic Clays many of the ammonites are 'perisphinctoid'. That is to say that in general appearance they resemble *Dactylioceras* from which, however, they are distinguished by details in the ornamentation and in the pattern of the suture line.

Two types of ammonites represented by the genera *Phylloceras* and *Lytoceras* are of peculiar interest because they range with comparatively little change throughout the Jurassic and Cretaceous. A very interesting feature about certain sections of the Upper Cretaceous ammonites is that they assume strange forms. Thus in *Turrilites* the coiling, unlike that of other ammonites, is on the 'corkscrew' pattern; and consequently the fossil may often be mistaken for a Gastropod. The presence of suture lines, however, definitely settles its ammonite affinity.

Belemnites belong to that section of the Cephalopods which is represented to-day by the Cuttlefishes. They produced small conical straight shells divided into chambers as in *Nautilus*. In the latter as in the ammonites the animal's body was enclosed in the last and largest chamber. In the Belemnites the shell was completely enclosed within the body and became a centre around which an excessive secretion of lime was deposited. This resulted in the formation of a strong and beautifully shaped solid structure known as the 'guard'. This is commonly all that is preserved in the fossil state. Belemnites are relatively common in clay deposits. Those found in the Lower Cretaceous are sufficiently distinctive to be of value as time indicators (Fig. 11).

The Mollusca which occur most abundantly as fossils are the Lamellibranchs. They exhibit an amazing variety of form and ornamentation, but on the whole they have a simpler type of structure than the ammonites and consequently are not so useful as time indicators. Notwithstanding their relative simplicity a careful study of individual types based upon collections of numerous specimens from successive horizons usually reveals a sequence of progressive changes which throws much light on evolutionary principles as well as providing some basis for their use as time indicators.

VARIETIES OF *OSTREA IRREGULARIS*

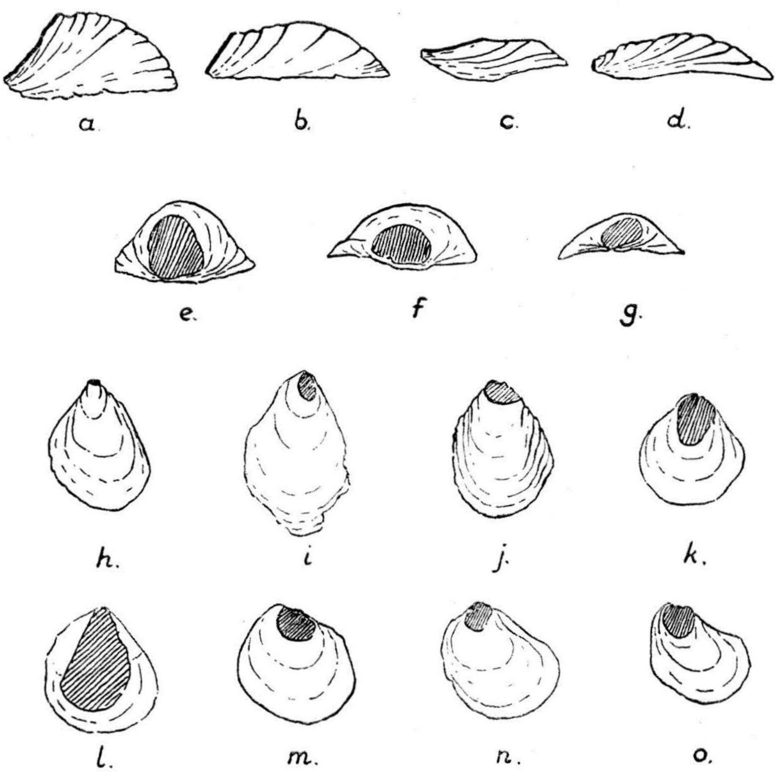


Fig. 4

One of the simplest forms of shell is that of the oyster *Ostrea*. The earliest Jurassic species is that of *O. liassica* which occurs in the bottom beds of the Lias. It is a form which, in common with other oysters, varies greatly in shape. During the early growth stages the shell became cemented to some object such as a stone or a shell. The area by which it was attached is easily recognisable and varies in size. In this species the shell is flat but in the slightly later one, *O. irregularis*, as its name implies, the shell is very variable in many respects: in shape of outline, in the size of the area of attachment (Fig. 4). Some individuals are flat, others are concavo-convex in varying degrees. In successively higher levels the same extraordinary variability is maintained but is accompanied by an increasing tendency for the left valve to thicken and curl. In consequence of this a shell is produced which is so different from that of *Ostrea* that it merits not merely a new specific but a new generic name, viz: *Gryphaea* (Fig. 5). At least two new species of this genus arose out of *O. irregularis*. The one *G. incurva* (c) attained its fullest expression in the Bucklandi zone. The other, *G. cymbium* (e) reached its acme later and some of its stages in evolution are abundantly represented among the fossils found in the ironstone workings at Scunthorpe and Frodingham.

The tendency to increasing curvature described above is known as the 'gryphaeoid trend'. It seems to have affected oyster stocks on several later occasions, but the history of those stocks still remains to be worked out. Typical *Ostrea* species occur at various levels throughout the Jurassic: *O. hebridica, subrugulosa, undosa,* and *Lopha marshii* in the Middle Jurassic Oolites: *O. delta* in the Upper Jurassic Clays. Out of these there arose quite separately such gryphaeoid species as *G. bilobata* of the Kellaways Rock and *G. dilatata* of the Oxford Clay. A nearly smooth, flat oyster, *Ostrea delta,* is characteristic of the highest Ampthill Clay and the basal Kimmeridge.

One important group of zonal fossils much used in the study of the Upper Cretaceous succession belongs to that division of the animal kingdom known as the Echinodermata, which includes the starfish and sea urchins. The latter are of two kinds. Those with round outline and radial symmetry, and those with more or less heart shaped outline and bilateral symmetry. The two heart urchins *Holaster* and *Micraster* are the ones which have proved to be most useful. The shell or test is made up of a mosaic of pentagonal plates arranged in rows which rise from the mouth on the ventral surface to the apex. In some rows the plates are pierced by minute pores and are so arranged as to produce a star-like pattern on the upper surface. This feature is alluded to in the syllables 'aster' at the ends of the names given above. With the passage of time this and other parts of the test underwent a series of minute but striking changes. The various degrees of these have proved invaluable in dating the layers of the chalk.

From this rapid and scanty survey of the changes undergone by various kinds of animals, it will be realised that though there is some satisfaction in knowing the names of a fossil, it is an eye for the detailed features they exhibit and for the changes these undergo that is of most value to the study of Geology in the field and to that of evolution in the home.

REPRESENTATIVE INDIVIDUALS BELONGING TO THE *OSTREA - GRYPHAEA* PLEXUS

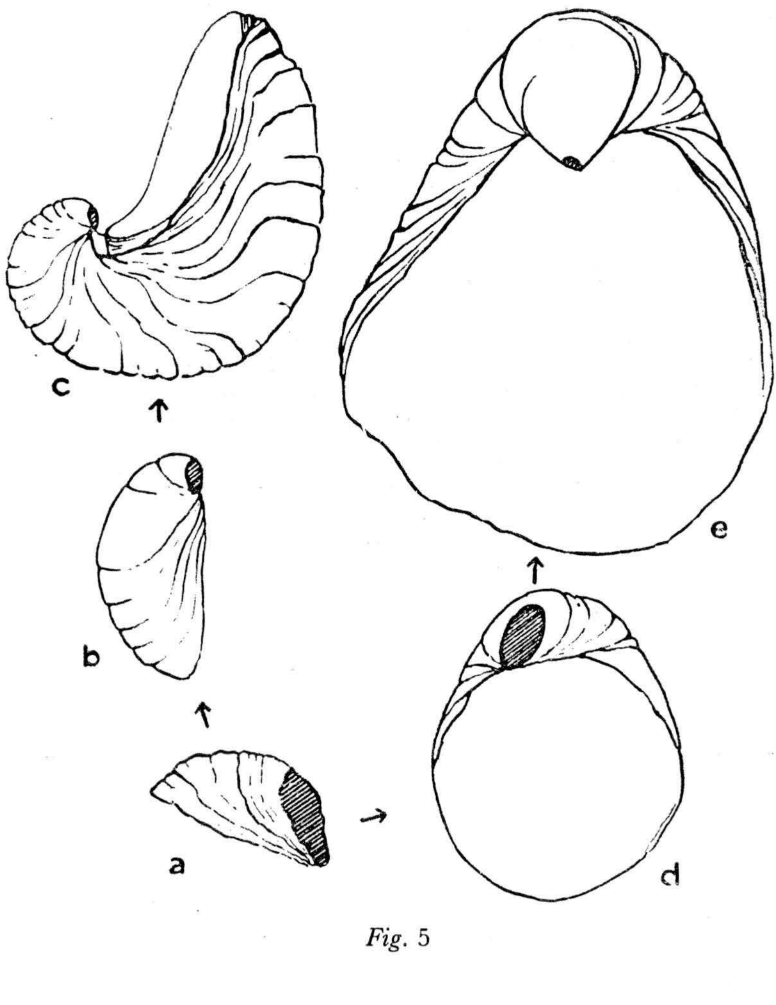


Fig. 5

CHAPTER 6

THE RHAETIC (PENARTH) BEDS

The Trias ended with a marine incursion which flooded the desert basins of northwest Europe with sea water, ending the regime of mainly red clays and sandstones and inaugurated the deposition of the mainly grey clay and limestones which continued through much of the Jurassic.

The rocks deposited at this time of change are of particular interest, those of Lincolnshire showing features unique in Britain. They form the group traditionally called Rhaetic, after the type of locality in southern Europe, but for which in England the formal name Penarth Beds has now been adopted. They have at different times been grouped as the end of the Trias or as the beginning of the Jurassic, but the former is now accepted world-wide, although it is less convenient in England.

	JURASSIC (LIAS with Hydraulic limestones) above	
PENARTH BEDS	LANGPORT BEDS	Nodules with marine fossils
	COTHAM BEDS	Greenish grey, brown and red clays with limestone nodules
	WESTBURY BEDS	Black shales with minor sandstones and a thin limestone
		Nonsequence
	TRIASSIC Tea Green and Red Marls below	

Surface exposures show only limited parts of the formation, and although they may be of great value — as for example the temporary Kettlethorpe section of the Upper Rhaetic described below — the bulk of information in Lincolnshire comes from shallow borings.

In England in general the marine incursion initially led to the deposition of dark grey or black finely laminated shales, Westbury Beds, often crowded with molluscs. Thin sandstones, with bones and fish scales (as described below) also occur. This was a limited marine development, lacking the open water fauna — such as ammonites — which are found in the equivalent beds in the Alps. Marine conditions were interrupted by a lacustrine phase, the greenish shales and silts of the Cotham Beds, which normally contain only ostracods able to live in fresh or brackish water conditions. Marine waters spread in again before the end of the period in southern England and the Midlands, but it is only recently that a marine element has been found in Lincolnshire, at the top of the Cotham Beds.

In Lincolnshire the Rhaetic outcrops as a belt less than a quarter of a mile wide from Collingham northwards past Gainsborough and Scunthorpe to the Humber. It occupies the face of a gentle rise — known as the Rhaetic Scarp (produced by its softness in contrast to that of the overlying Lias Limestones) and dips eastwards beneath overlying later beds. The softness has another result — rarity of exposures — for the clays and shales quickly weather down in temporary exposures and form no reefs or waterfalls in the beds of the few streams which cut the scarp. Knowledge of the sequence is consequently based mainly on well and borehole sections; surface exposures usually show only a limited part of it.

GENERALISED SECTION AT PILHAM AND SCOTTER

UPPER RHAETIC (COTHAM BEDS), up to 27 feet thick	
Pale bluish grey shaly clay	5 – 8 feet
Light reddish brown and grey shaly clay	10 – 12 feet
Dull grey, pale grey and deep reddish brown clay with nodules of pale limestone containing *Estheria*; in some places sandstone beds with fish teeth are present in the lower part	12 feet
LOWER RHAETIC (WESTBURY BEDS, OR BLACK SHALES) up to 36 feet thick	
Dark grey shaly clay	5 – 8 feet
Dull black shale, with dark grey impure limestones	5 – 10 feet
Dark grey or black pyritic shale with abundant shells, especially *Pteria contorta*, and three or more beds of richly micaceous pale grey sandstone containing fish fragments and shell casts ..	15 feet
Dark grey finely laminated shale containing few fossils, with a thin sandstone bed near the base ..	5 – 8 feet

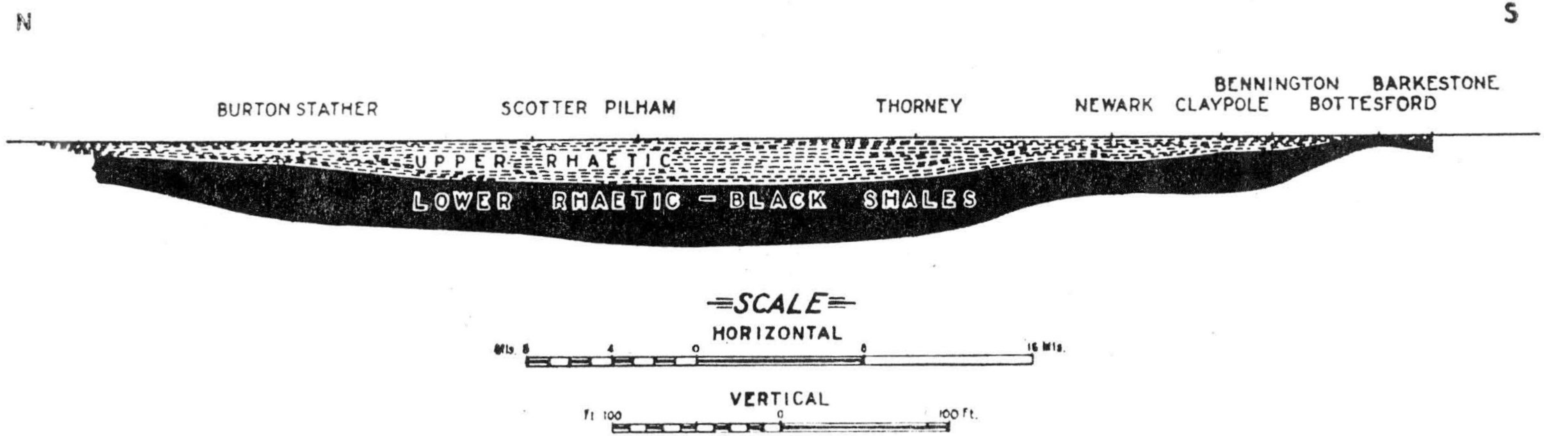
The special features of the Lincolnshire Rhaetic are its thickness (much greater than that in the Midlands, and equal to the maximum so far known in this country) and the character of the upper beds. The formation shows two contrasting subdivisions, the uppermost mainly of pale clay and soft shale (weathering to marl at outcrop), the lowermost mainly hard black shale (Fig. 6). The thickest development is found near Gainsborough. A generalised section based mainly on shallow borings at Pilham and Scotter is shown on page 19.

Detailed sections of the early Upper Rhaetic at Scotter and of the greater part of the Lower Rhaetic at Lea Cutting have been published elsewhere ([22, 13]).

The Westbury Beds, black shales, were the earliest deposits of the marine incursion. The greater part of north-western Europe had previously been a level stretch of dust-desert with extensive brackish lakes; over this area the Rhaetic sea spread swiftly to the margins of the basin. The water was unoxygenated and probably brackish; iron sulphide accumulated on the bottom to blacken the accumulating muds, and the mollusca which abounded were small stunted species. At intervals transient stronger currents spread thin layers of quartz sand across the basin; layers which entombed the teeth, scales and bones of countless fish. It was originally suggested that these bone-beds are due to wholesale killing of countless individuals by a sudden change of conditions, but it is alternatively assumed that they represent slowly accumulated condensed deposits — richly fossiliferous because of lack of sediment. The association of numerous bone-beds with thicker developments, particularly notable in Lincolnshire, is however, difficult to reconcile with lack of sediment, and there is perhaps still something to be said for a catastrophic theory of origin — the thin sandstones being possibly due, for example, to a flush of fresh water from nearby land which killed large numbers of fish by lowering salinity.

Apart from the unusual thickness, the most interesting feature of the Lincolnshire section is the development of reddish beds in the Upper Rhaetic. In the Boultham boring the whole thickness of this (eight feet?) is recorded as liver-coloured clay; in the sections which have lately become available up to half of the subdivision is brownish shale and clay (as may be seen at outcrop in landslip exposures between Alkborough and Burton Stather), parts of which are bright brick red. The normal greenish clay of the Cotham Beds in the Midlands is difficult to distinguish from the Tea Green Marl of the upper Keuper, and is to be regarded as a temporary reversion to Keuper climatic and depositional conditions. The reddish brown development of north-west Lincolnshire provides additional and still more striking evidence of the temporary return of the Keuper facies.

DIAGRAMMATIC SECTION ALONG THE RHAETIC OUTCROP IN LINCOLNSHIRE



Development of the sub-divisions in the Lincolnshire basin.

Fig. 6

There are incomplete exposures of Upper Rhaetic at Scotter ([22]) and of the Upper and Lower Rhaetic in the slipped Trent cliff between Burton Stather and Alkborough. Nearly a century ago the partial section in Lea Cutting, Gainsborough, was carefully recorded by Burton ([13]), and the beds have also been seen — but not measured — in Torksey railway cutting. Information of the same kind may again become available in temporary sections, and it is of importance in supplying far more detail of the beds than can be obtained from wells and boreholes.

A quarry worked for a short time at Kettlethorpe, in Kesteven, which exposed the Lias-Rhaetic junction, showed a marine development near the top of Cotham Beds (Kent 1970). There the greenish marls contained a layer of limestone nodules two to four feet across and six to nine inches thick; these were locally crowded with shells (including *Modiolus langportensis* and *Dimyopsis intusstriatus*), which in the south of England characterises the Langport Beds (White Lias), a widespread limestone group at the top of the Rhaetic. This limestone is absent north of Warwickshire and Kettlethorpe is the only locality where a marine equivalent is known; further records would be valuable.

The thickness variation of the beds across the county is, however, known from numerous shallow and deep boreholes. These have shown that the Lincolnshire Rhaetic forms a thick lens, separated from that of east Yorkshire by the thin development of Market Weighton, and from that of the Midlands by the similarly attenuated development of the Foston – Grantham area. It is quite unusual in its thickness and shows more evidence of the temporary return of the Keuper facies than has been recorded elsewhere in the country.

CHAPTER 7

LOWER JURASSIC – THE LIAS

Jurassic rocks form the floor of about three-quarters of Lincolnshire, and although a veneer of drift too often hides them from sight they comprise a wonderful storehouse of fossils, and their variation throws much light on conditions of sedimentation and the past history of the East Midland area. In Lincolnshire the sequence is not quite complete; the two highest members of the south of England (Portland and Purbeck Beds) have only recently been recognised and were partly eroded during the Cretaceous.

The Lias

The Lias extends as a broad strip west of the Lincoln cliff from the Humber to the county boundary west of Grantham. The greater part of the formation is made up of clays — so that the outcrop is marked by low ground of gentle relief — but there are important ironstones at two horizons; the Lower Lias Frodingham Ironstone of North Lincolnshire, and the Middle Lias Marlstone Ironstone which was worked from Caythorpe southwards into Leicestershire

Liassic deposition was dominated by clays, laid down in muddy seas. Animal life abounded at times, but many beds are nearly barren, as though the conditions — especially for bottom living animals — were too unattractive for proliferation. Fortunately these conditions never lasted long, and the Lias is one of the richest sources of fossils in the stratigraphic column. The most varied life coincides with the times when the sea cleared, during deposition of the limestone groups of the Lower Lias, of the ironstones (Frodingham Ironstone, Pecten Ironstone and Marlstone Ironstone), but rich ammonite beds are found for example in the Upper Lias shales also.

The formation has three main subdivisions — the Upper, Middle and Lower Lias, and these are again divided, palaeontologically into zones, and alternatively according to local rock types. The zones can be traced over the whole country irrespective of lithological changes, while the rock types have a more restricted significance, but are useful for recognition in the field and for mapping. In Lincolnshire there is a slow lithological change in the Lower Lias from the south to the neighbourhood of Kirton, and then a more rapid change to the different development of the Scunthorpe district. The Middle Lias is more variable, its upper division being locally reduced to a mere remnant in the Lincoln district, and the lower part showing a particularly marked northward attenuation, while the Upper Lias shows across the county an interesting progressive southward movement of the belt of maximum sedimentation. Each subdivision, and indeed most of the Jurassic beds, shows a progressive northerly thinning towards the stable Market Weighton block of south Yorkshire, which acted as a hinge on the edge of the subsiding Lincolnshire basin.

THE LOWER LIAS

The Vale of Belvoir, where Lincolnshire, Nottinghamshire and Leicestershire meet, is the largest drift-free outcrop of Lower Lias in the region, and it consequently supplies the standard succession for the East Midlands. Description will start with this area for each group of beds. The relation between the different subdivisions and the time zones is shown in the accompanying table and in Figure 7.

Stages	Zones	N. Lincolnshire	S.W. Lincolnshire
Pliensbachian	*Prodactylioceras davoei*	Pecten Ironstone	
	Tragophylloceras ibex	Upper Clays	
	Uptonia jamesoni	Upper Clays	
Sinemurian	*Echioceras raricostatum*	Upper Clays	Sandrock
	Oxynoticeras oxynotum	Upper Clays	Obtusum – Oxynotum Clays
	Asteroceras obtusum	Frodingham Ironstone	Obtusum – Oxynotum Clays
	Arnioceras semicostatum	Frodingham Ironstone	Ferruginous Limestone Series
	Coroniceras bucklandi	Granby Limestones	Bucklandi Clays
		Granby Limestones	Granby Limestones
Hettangian	*Schlotheimia angulata*	Angulata Clays	
	Psiloceras planorbis	Hydraulic Limestones	

DEVELOPMENT OF THE LOWER AND MIDDLE LIAS IN LINCOLNSHIRE

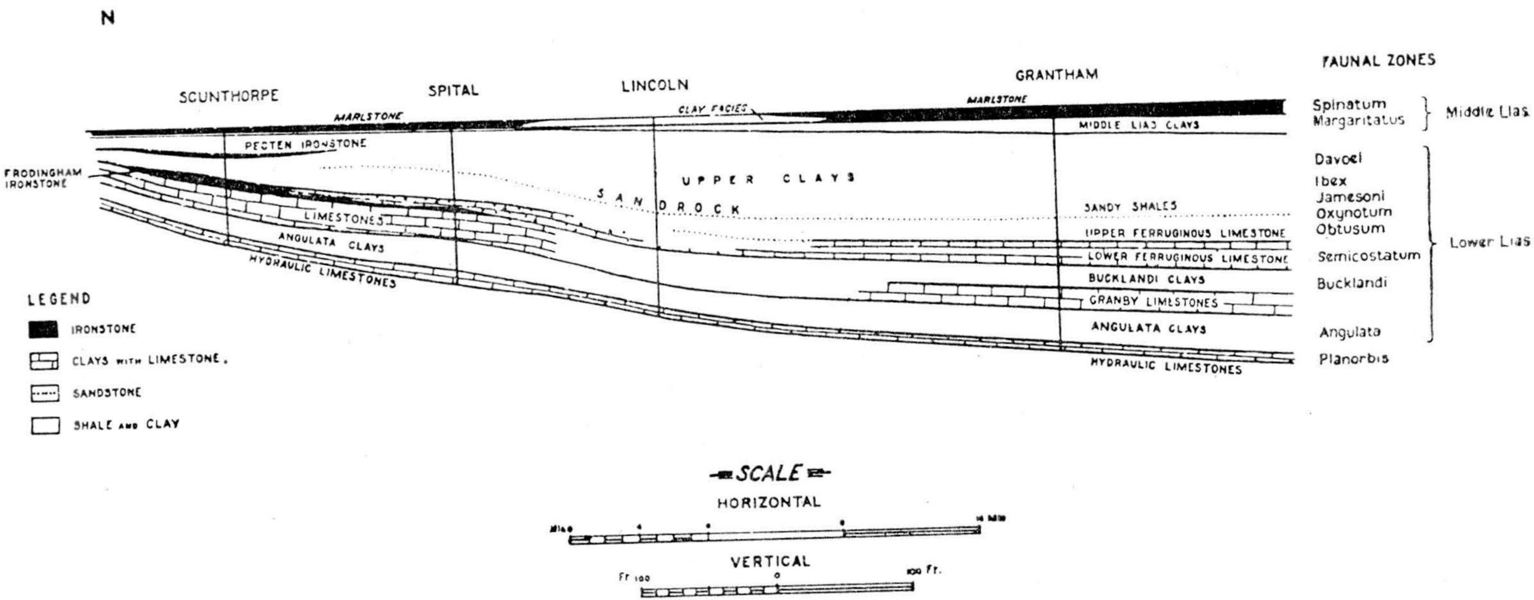


Fig. 7

The Lower Lias of Lincolnshire is distinctly more varied than that of the rest of England, with its two ironstones, the ferruginous limestone development and thin sands and silty intervals at two or three levels. These features (with the associated typical faunas) show that the water was often fairly shallow, and that although we cannot trace shoreline conditions the western edge of the sea may have been only a few tens of miles away. Part of the control of deposition was provided by the hinge effect of the Market Weighton block in south-east Yorkshire, towards which most of the subdivisions thin because of the restricted rate of subsidence of the sea floor. This dominant feature affected not only thickness but also the lithological facies, as is shown in Figure 8.

The lowest subdivision is the HYDRAULIC LIMESTONES, consisting of 20 – 30 feet of alternating shales and argillaceous limestone beds. Some of the earlier limestones are shelly and were deposited in shallow water. Later beds show evidence that they were partly segregations by separation of calcium carbonate from a limy mud after deposition. These beds have been exploited for lime and cement at many points along the outcrop, but the only quarry now working is just beyond the Lincolnshire boundary at Barnstone in Nottinghamshire. These beds mark the beginning of normal marine conditions; they contain representatives of most of the fauna which extends through the lower zones of the Lias. The characteristic nearly smooth ammonite — *Psiloceras planorbis* and allied forms — occurs abundantly, and gives its name to the zone. The upper beds contain a related ribbed form, *Caloceras*. The basal part of the beds, directly following the special Upper Rhaetic facies, has a fauna rich in lamellibranchs (*Modiolus minimus, Pleuromya tatei, Ostrea liassica*) but lacking ammonites; it is consequently termed the 'Pre-Planorbis Beds'. The rather hard shelly limestones of this group are often seen in shallow exposures, for example north-west of Bottesford, and on drift-free areas in north-west Lincolnshire. Overlying the Hydraulic Limestones is a deeper-water dark shale and clay group, the *Angulata* or Barnby Clays. (The proper name is suggested after a type section in the Shire Dyke at Barnby-in-the-Willows.) Hard beds are infrequent; *Cardinia* is sometimes abundant, the zonal ammonite *Schotheimia angulata* occurs in the higher part, although it is more frequent in the overlying beds. In south-west Lincolnshire these clays measure about 70 feet, and are diversified by only a few very thin shelly limestones containing *Ostrea* and crinoid columnals.

Above these clays is the second limestone group of the Lower Lias, locally named the GRANBY LIMESTONES, deposited in shallower water which sometimes cleared. These consist of numerous beds of soft-weathering impure limestones, with thick partings of shale which weather to clay at outcrop. The Limestones span the upper

Angulatum Zone and the lower Bucklandi Zone, reaching an overall thickness of 70 – 80 feet in south-west Lincolnshire. The lower beds usually contain abundant large *S. angulatum* together with *Lima* (*Plagiostoma*) *gigantea*; the middle beds contain the button coral *Montivaltia haimei*, and the small brachiopod *Calcirhynchia calcaria*. The uppermost bed is often shelly, with very common *Pentacrinus*, demonstrating a short phase of clear water. Near Swinethorpe this limestone contains abundant small *Schlotheimia* together with the keeled ammonite *Metophioceras* belonging to the next zone and it must there be precisely on the zonal boundary. Elsewhere the top bed may contain ill preserved ammonites of the Bucklandi Zone only.

The Granby Limestones were cut through at Long Bennington in 1967 in constructing the by-pass and are commonly exposed in ditch exposures thereabouts. Pieces of large *Schlotheimia* are common, even on ploughed land. Conical shelly limestone nodules known as *Kulindrichnus* can also be found in the fields, together with innumerable *Gryphaea*. The northward continuation of the limestones from Norton Disney past Eagle to Harby was mapped with the help of pipeline trenches in 1968 and is shown on the new edition of the I.G.S. map Lincoln (Sheet 114). The limestone group makes low rises on which several villages are situated, and was probably a source of household water in former centuries. *Gryphaea* beds are of course the dominant feature; *Kulindrichnus* nodules are common in the middle beds; very large *Lima* (*Plagiostoma*) *gigantea* are common, and the little coral *Montivaltia haimei* occurs.

Down the dip to the east the Granby Limestones are well developed at Foston and Grantham, and the fauna of the lower part can be recognised in a less calcareous development at Boultham, Blankney and Stixwould. At Spital the group measures a hundred feet in thickness, extending nearly up to the level of the Frodingham Ironstone, and 70 feet of beds has been measured in railway cuttings at Scunthorpe and Flixborough, extending up to the base of the ironstone. A detailed section of the upper part has been given by H. E. Dudley ([16]). Further exposures are available in the slipped ground of the Cliff near Alkborough, but no description of the succession is available.

An interesting development in the north of the county is the occurrence of shiny brown limonite oolite grains in several of the limestone beds – precursor of the iron – precipitating conditions of the Frodingham Ironstone. This feature continues into south Yorkshire and may be related to shallower water conditions on the flank of the Market Weighton block; it is a tendency which began in the *angulata* zone.

In south and central parts of the Lias outcrop the Granby

Limestones are succeeded by more clays which thin northwards in north Lincolnshire by passage into clays-with-limestones. In the south the thickness is about 80 feet; there is a progressive reduction to 60 feet at Foston and Bassingham and, as noted above, continuous clays are not developed in the north. Fossils are generally rare and uninformative; those which have been found show that the group belongs to the upper part of the Bucklandi Zone, and the subdivision is conveniently named the BUCKLANDI CLAYS.

Next comes the most interesting and important group of the Lower Lias: the FERRUGINOUS LIMESTONE SERIES, which passes in north Lincolnshire into the Frodingham Ironstone, described separately below. In south-west Lincolnshire this group is predominantly clayey, with thin ferruginous limestone bands. It is 90 feet in thickness, from the Lower Ferruginous Limestone* of Plungar, Allington and Foston at the base to the Upper Ferruginous Limestone which outcrops about a mile further east. The first of these horizons is represented in the south by about five feet of light brown ferruginous limestone crowded with limonite-oolite grains. *Gryphaea, Cardinia* and the ammonite *Arnioceras* occur abundantly. Traced northwards the bed retains its ferruginous character through Fenton and past Beckingham, but is represented by impure limestone near Norton Disney. In the drifty ground west of Lincoln it has not been found, but it recurs as an 'ironshot limestone' a mile east of Stow and probably continues from there to the Frodingham Ironstone area.

Various impure limestones occur interbedded with clays in the middle part of the group — occasionally crowded with small ammonites — but they have not been found to be persistent, and the next mappable bed is at the top of the group: the Upper Ferruginous Limestone. In the south-west, near Muston, this is a blocky bed distinguished by the rarity of limonite ooliths, the virtual absence of *Cardinia*, the occurrence of rare but widespread *Spiriferina* and the presence of round-whorled wide-ribbed ammonites of the genus *Euagassiceras*. When traced northwards the bed is seen to be distinctly silty near Foston (one mile east of the village); at Doddington Littlegate it is finely sandy; one-and-a-half miles west of Brant Broughton it is a dark grey sandy rock, and on the same line of strike a little further north it is found to pass into the Calcareous Sandstone of Bassingham, Aubourn Mill and Thorpe-on-the-Hill†.

* The "Plungar Ironstone" of Judd.

† The Geological Survey in 1885 correctly traced the Lower Ferruginous Limestone from Harby (Leicestershire) via Allington to Dry Doddington, but beyond a faulted belt at the latter place followed the Upper Ferruginous Limestone, and then the Calcareous Sandstone, incorrectly implying that these were on the same level as the bed of Allington.

At Aubourn Mill this yields the typical fauna of the Upper Ferruginous Limestone.

Down dip to the east the Lower Ferruginous Limestone passes into shale and clay with thin limestone bands, and it is likely that the irony facies is a shallow water development lying west of deeper water clays. The Upper Ferruginous Limestone is developed in the normal facies down dip from the Muston outcrop but is probably represented by ten feet of silts at Blankney, and by three feet of sandstone at Stixwould. In this case the facies lines appear to run nearly east-west.

The northward transition from this predominantly clayey series with thin limestones or sandstones into the thick Frodingham Ironstone has not yet been traced in detail. In the intermediate area, at Spital and Kirton (Cleatham) the clay element is known to be greatly reduced, but there is much more sandstone present than in the normal Frodingham development. The evidence of fossils shows, however, that the Lower Ferruginous Limestone is almost exactly equivalent to the lowest bed of the Frodingham Ironstone, and that the Upper Ferruginous Limestone is possibly represented by one of the middle beds.

The FRODINGHAM IRONSTONE of the Scunthorpe district is the most important economic mineral in Lincolnshire, providing the basis for the great iron and steel industry which has grown up on its outcrop. The ore is worked over a distance of about ten miles. In this stretch it varies from 18 – 32 feet in thickness, a body of rock consisting almost entirely of calcareous oolitic ironstone with only unimportant and local developments of limestone and clay. The lowest part of the ironstone yields *Arnioceras* and *Coroniceras alcinoe* and is ascribed to the upper part of the Semicostatum Zone. From the middle part have been collected rare ammonites of *obtusum* and *turneri* dates and in beds above this have found ammonite faunas ascribed to the *planicosta, sagittarium* and *denotatus* subzones of the higher part of the Obtusum Zone. The last mentioned fauna is found in a purplish brown ironstone which forms the highest 1 – 4 feet in the middle part of the outcrop; it is locally fairly rich in ammonites, including discoidal *Eparietites* as much as 14 inches across; it also includes representatives of the genus *Oxynoticeras* belonging to the next highest zone. (The latest review has been carried out by Dr. M. K. Howarth of the British Museum.) These faunas show that the ironstone is not only equivalent to the Ferruginous Limestone Series of south Lincolnshire, but that it also includes the Obtusum beds above, and part of the Oxynotum Zone, which are still clays as far north as Sturton. The rock is thus a highly condensed deposit, the lateral equivalent of 150 feet or more of deeper water beds further south.

Other fossils are variably abundant in the rock. The oyster *Gryphaea* occurs in countless numbers throughout, showing different varieties in different beds. *Cardinia*, often large, is very common in the middle parts and the nearly smooth *Lima* (*Plagiostoma*) *gigantea* is also common and of large size. Belemnites and gastropods occur frequently in particular beds, and brachiopods are present sporadically.

With exposed faces of the rock extending for more than ten miles the Frodingham Ironstone provides a wonderful collecting ground, and one where much stratigraphical and palaeontological work remains to be done.

Overlying the Ferruginous Limestone Series and Frodingham Ironstone is a relatively uniform group of clays with nodules, named the OBTUSUM-OXYNOTUM CLAYS from the zones present. The group measures 70 feet in the Vale of Belvoir, where it is infrequently exposed but has yielded the ammonite *Caenisites turneri* in a pylon foundation near Barrowby. This zonal index, common in the south of England, was previously unrecorded in Lincolnshire but it is now known also from a pylon foundation at Saxilby, as well as at Scunthorpe. The clay group apparently thickens northwards to 100 – 120 feet near Sturton-by-Stow, where deepening of the river Till in 1939-40 showed that the beds have a rich fauna. Six ammonite horizons were found extending through the two zones of the series; the most interesting being one or two white limestone beds, crowded with small ammonites, in the lower part. The genera found included *Gagaticeras*, *Hemimicroceras* and *Parechioceras* (Oxynotum Zone); *Asteroceras*, *Epophioceras*, *Promicroceras* and *Xipheroceras* (Obtusum Zone). The richness of the fauna is a reminder of the amount of information still to be collected from casual exposures in the Lias.

Another distinctive hard bed, the SAND ROCK, overlies this clay group and marks the junction between the Oxynotum and Raricostatum Zones. It is well developed in north Leicestershire, passes for a few miles into sandy shales towards Grantham, and then forms a continuous low ridge from Hougham to Brant Broughton. There A. E. Trueman ([34]) found an *oxynotum* fauna in associated sandy clays, and deepening of the river Brant (1973) showed a 2 – 4 feet sandstone with large bivalves (*Modiolus*, *Pholadomya*, etc.), the zonal ammonite *Oxynoticeras* and (at the top) an echioceratid. Sandy clays at about the same level have recently yielded *Oxynoticeras* and *Gagaticeras* near Coates-by-Stow.

Sandy beds were formerly exposed in a brickyard a mile east of Bassingham (now obscured) and they have recently been seen in the river Till at Broxholme. At the latter place the main hard bed is a one foot thick brown calcareous sandstone, with the ammonite *Bifericeras*, overlying pale sandy clays. The sandy beds persist in strength as far north as Cleatham (Kirton Lindsey), and they are represented by only a few inches of finely sandy clays in a thinner development at Scunthorpe.

The Sand Rock is the last of the feature-forming hard beds in the Lower Lias south of Lincoln; it is followed by the UPPER CLAYS spanning the Raricostatum, Jamesoni, Ibex and Davoei Zones. Very fine sand and silt was still being carried into the basin during the early part of this interval, so that intercalations of pale sandy clays and silts, rich in the white mica muscovite, continue through the Raricostatum Zone.

The lower part of these beds has lately (1973) been exposed in deepening the river Brant. There are few hard beds, some pale silty clays, large spiny ammonites (probably *Crucilobiceras*) as well as the smooth *Leptechioceras*, together with large *Gryphaea mccullochii* and abundant belemnites. Richly fossiliferous beds with *Leptechioceras* were also found when the new Grantham sewage works was built at Marston, associated with silty beds. The last mentioned genus is present at Scunthorpe, in the clays about 15 feet above the Frodingham Ironstone — demonstrating a considerable thinning of the middle part of the Lower Lias towards the north.

There is a further sandstone bed (not known to form a feature) some 60 feet above the base of the Upper Clays; this was exposed in 1964 in a pylon foundation near South Hykeham and is known also in some of the deep borings. It yielded at outcrop a range of bivalves and the ammonite *Platypleuroceras*.

Older publications show that the corresponding zones of the Upper Clays are well developed in south-west Lincolnshire where the beds contain a rich fauna of ammonites, gastropods and lamellibranchs. The occurrence of small gastropods in samples from about this position in the deep borings at Spital and Blankney suggest that the fauna is well developed further north. Unfortunately the railway cuttings near Grantham and the old Woolsthorpe brickyard from which Jukes Browne collected have been overgrown for many years. The beds should, however, be sought if temporary exposures occur, for they comprise one of the richest parts of the local Jurassic sequence.

Approximately in the middle of the Upper Clays in north Lincolnshire is the richly fossiliferous ironstone crowded with large ribbed pectens, which is appropriately named the PECTEN IRONSTONE to distinguish it from the Frodingham Ironstone below and the Middle Lias Ironstone above. This bed usually measures 4 – 5 feet thick; it is not worked as an ore. The fauna recorded from the bed indicated that it belongs to the Ibex Zone or at latest to the early part of the Davoei Zone (the uppermost subdivision of the Lower Lias), not to the Middle Lias as the old memoirs state. Further south beds with ironstone nodules occur at about this level, for example at Woolsthorpe, and two sandy ferruginous limestone beds recorded in the Grantham boring may possibly be at the same horizon. More information is, however, needed to determine the southerly equivalents of the Pecten Ironstone.

The uppermost part of the Upper Clays, the Davoei (formerly Capricornus) Zone, has been exposed in several brick pits near Lincoln and in temporary exposures as far south as Grantham. The zonal ammonite (*Prodactylioceras davoei*) is occasionally found, single specimens having been collected at Lincoln, Waddington and Hougham Station, but the beds contain large numbers of beautifully preserved wide ribbed 'capricorn' ammonites, together with the large inflated forms representing the older growth stages of these (Fig. 3). *Oistoceras* is the commonest form. In the lower part of the zone, at Bracebridge, where A. E. Trueman ([34]) described the succession, fragments of the large ammonite *Lytoceras fimbriatum* are also common, together with earlier capricorns of the genus *Androgynoceras*.

Bracebridge and Waddington were the last Lincolnshire localities south of Scunthorpe where the Lias clays were exploited, and the most extensive exposures available are thus at this level.

THE MIDDLE LIAS

Paltopleuroceras spinatum	Marlstone Ironstone
Amaltheus margaritatus	Middle Lias Clays

The Middle Lias of the Midlands is generally divisible into two parts, distinctive lithologically and faunally. The uppermost is the Marlstone or Marlstone Ironstone, which consists of sandy and calcareous ironstones, widely worked as an ore; the lower part is the Middle Lias Clays which are in many places markedly sandy, and thus contrast with the Lower Lias Clays beneath.

In Lincolnshire the arrangement is less simple. Already on the south-western boundary of the county the MIDDLE LIAS CLAYS have lost almost the whole of their sandiness, and have become indistinguishable from Lower Lias except where open sections provide fossils. They are known to thin northwards from about 100 feet in Leicestershire to 56 feet at Grantham and 30 feet at Lincoln. They are reduced to 18 feet at Kirton Lindsey, but still contain the characteristic fauna (Howarth and Rawson 1965). This is the last known occurrence until northeast Yorkshire is reached.

The MARLSTONE IRONSTONE extends as a northwardly thinning bed past Grantham and Caythorpe (where it has been worked in extensive quarries) to Navenby, but there it disappears and is not seen again as a mappable unit until it appears near Ingham, 17 miles to the north. A. E. Trueman (1918) concluded that this absence was due to passage into clays, but Howarth (1958) from further collecting and work on the ammonites has shown that the whole of the Middle Lias Clay sequence near Lincoln belongs to the Margaritatus Zone. The Spinatum Zone and hence the Marlstone equivalent, is present only as a line of ironstone nodules. This is an example of condensed deposition. The circumstance that the Marlstone is also absent in borings at Blankney, but is present again further east at Stixwould, Woodhall Spa and Ruskington, suggests that this is due to interrupted deposition related to the deepseated Nocton uplift, which has had a long history of positive movement extending intermittently from the Carboniferous into post-Jurassic times.

Fossils are usually common in the Middle Lias. The Margaritatus Zone Clays yield the large discoidal zonal ammonite with its corded keel fairly commonly, together with the handsome *Modiola scalprum*, *Goniomya hybrida* and other lamellibranchs, beautifully preserved when they come from unweathered clay as at Bracebridge. Overlap of Lower and Middle Lias faunas recorded by A. E. Trueman has not been confirmed by later work.

Where the Spinatum Zone is developed as Marlstone Ironstone it contains brachiopods often in great abundance — mainly *Rhynchonella tetrahedra* and *Terebratula punctata* and their allies. Pectens, belemnites and crinoids also occur commonly, but ammonites are usually rare except in the north, where strongly ribbed square-whorled ammonites of the genus *Paltopleuroceras* occur. In the south the rock bed includes an Upper Lias element, with species of the genus *Dactylioceras* at Navenby and Harston.

At the top of the Middle Lias at Bracebridge is three feet of greenish and grey shale with the fauna of the 'Transition Bed' (Acutum Zone) of the Midlands. This contains *Protocardium*, *Goniomya* and other lamellibranchs common in the Middle Lias together with fine ribbed ammonites of the genus *Dactylioceras*, which reaches its acme in the overlying Upper Lias, and the characteristic small discoid ammonite *Tiltoniceras acutum*, named after Tilton in Leicestershire. This thin bed has a very restricted occurrence in England, being known mainly in synclinal areas where it escaped removal during a minor phase of erosion. In Lincolnshire it is known at Bracebridge, at Kirton Lindsey and in the Grantham district, and a greenish shale occurs in the corresponding position in the Blankney boreholes.

THE UPPER LIAS

The Upper Lias of Lincolnshire consists almost entirely of undiversified dark blue-grey clays, whose lateral variations can only be studied by means of the contained fossils.

Except for small inliers in valleys of the Inferior Oolite plateau, the Upper Lias is restricted to the steep face of 'The Cliff,' forming the fall between the level ground of the Lincolnshire Limestone above and the Marlstone Ironstone beneath. The outcrop is therefore usually covered by slipped material from above, and it is only very occasional deep artificial exposures and cored water borings that have provided evidence of the succession.

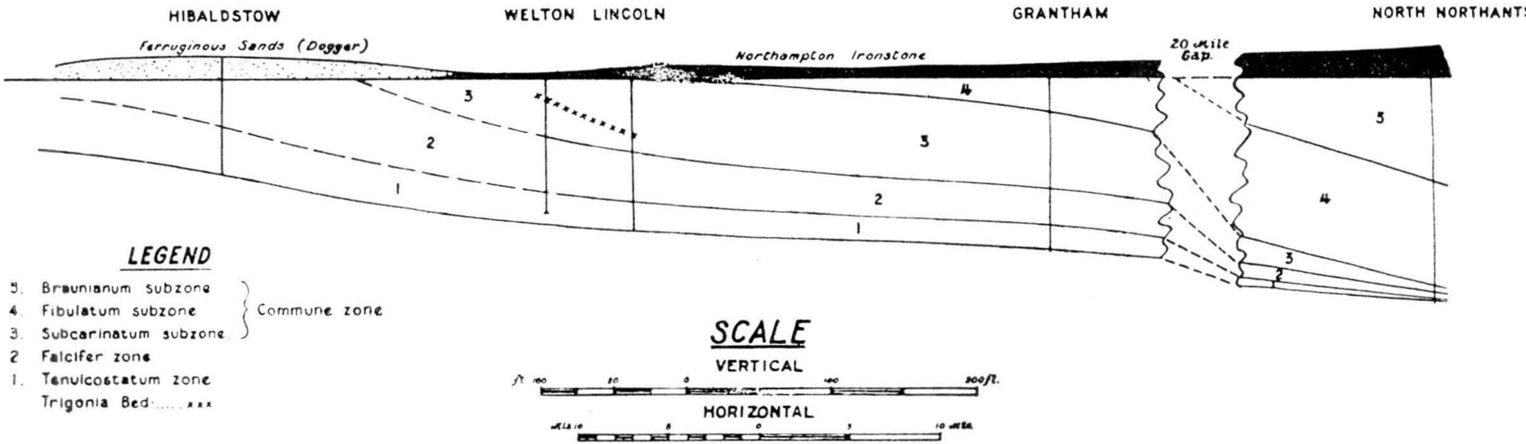
In Lincolnshire, as in England generally, there was a progressive southward movement of the belt of maximum deposition during the Upper Lias. The lower zones are therefore found to be best developed in the north but thin southwards (e.g. the 'Paper Shales', hard, thinly bedded shales of the lowest zone, measure 35 feet near Hibaldstow, 15 feet at Lincoln and near Grantham, one foot in Northamptonshire); the lowest part of the Commune Zone is best developed from Lincoln to Grantham, and the highest beds are found in the southernmost part of the county only (Fig. 8).

The fauna of the Upper Lias is less varied than that of other Jurassic formations. Ammonites tend to be common throughout — either discoid involute forms with sickle-shaped ornament belonging to *Harpoceras* and *Hildoceras*, or round-whorled evolute closely ribbed species belonging to the genus *Dactylioceras*. Apart from these, belemnites and one or two species of lamellibranchs usually complete the fauna. Forty feet below the top in the Lincoln district, however, is a shell bed with abundant *Trigonia pulchella* and other lamellibranchs; this extends northwards, occurring within 20 feet of the top at Welton. In the Grantham district a thin oolite bed has been observed 30 feet above the base of the clays, but such breaks in the uniform clay sequence are unusual ([25]).

The broad zonal sequence is well known from A. E. Trueman's work on the brickyards at Grantham and Lincoln ([34]), but little has been seen of variation between these places. There is, in particular, a marked thickening of the formation near Caythorpe([26]) and near Woodhall Spa known from boreholes; how this is related to the regional variation of zones has yet to be discovered.

An important section at Kirton Lindsey has been recorded by Howarth and Rawson (1965) in a clay pit at Mount Pleasant which is still partly accessible. This shows 38 feet of shale, the lower part laminated 'paper shale', belonging to the lowest zones of the Upper Lias. In the upper part (Exaratum subzone of the Falcifer Zone) is a row of limestone nodules with abundant ammonites (mostly *Harpoceras* spp.) and small gastropods (a pelagic genus,

RELATIONSHIP OF THE INFERIOR OOLITE AND UPPER LIAS



The northerly overstep of the Lias zones by the Ironstones and sands, and the variation in thickness of the Upper Lias zones, due to southward migration of the belt of maximum deposition (partly after A. E. Truman). Actual thicknesses reveal more local variation than is shown here.

Fig. 8

Coelodiscus), together with a primitive brachiopod, *Discinisca*, which is a rarity in the Jurassic. (An identical bed occurs at Harston, near Grantham, and has been recorded at Grantham itself; it should be sought in the intervening country). Beneath, the shales contain *Harpoceras* cf. *exaratum*, and the lower beds yield allied species together with allies of the zonal ammonite *Dactylioceras tenuicostatum*, which occurs at the base in a hard pebbly mudstone cemented onto the Middle Lias Marlstone.

Towards the end of the Upper Lias there was a slight uplift which led to general cessation of deposition and to erosion of the upper beds in the north (Fig. 8). The base of the Northampton Ironstone (in the south) or Dogger (in the north) contains rolled and eroded fossils and nodules washed out of the clays during this period.

CHAPTER 8

THE MIDDLE JURASSIC ROCKS

Inferior and Great Oolite

The Inferior and Great Oolite received their names in the Bath district, where oolitic limestones characterise the whole series. Inferior Oolite was the name given to the lower part, and Great Oolite was the name adopted for the upper beds with thick and important building stones. In other parts of England the oolitic character is less prominent, and in Lincolnshire it is restricted to parts of the Inferior Oolite (Lincolnshire Limestone) which is here much more impressive and economically important — both for building stones and for ironstone — than the relatively attenuated Great Oolite Series above.

The Middle Jurassic was a period of shallow seas across England and western Europe. In contrast to the underlying Lias and the overlying Upper Jurassic clays, when the dominant deposits were clays laid down in muddy seas, the Inferior and Great Oolite and Cornbrash are characterised by limestones rich in the denizens of clear waters, abundant shallow water mollusca and — at some levels — corals in quantity enough to make little reefs. During breaks in limestone deposition the two thin sand and clay units, the so-called 'Lower Estuarine' and the Blisworth Clay were laid down in conditions transitional between fully marine and brackish water. There is a lateral transition in Lincolnshire from the more nearly continuous limestone deposition in the Cotswolds towards the deltaic facies of the equivalent beds in Yorkshire, and in consequence each of the limestone units deteriorates northwards — the Inferior Oolite developing a cementstone facies in its lower part, the Great Oolite muddier with oyster beds, and even the notably persistent Cornbrash limestone giving way to a shaly development locally in the north of the county.

	NORTH LINCOLNSHIRE	MID LINCOLNSHIRE	SOUTH LINCOLNSHIRE
LINCOLNSHIRE		Great Ponton Beds	
	Hibaldstow Beds	Ancaster Beds	Clipsham Stone
	'Crossi' Bed		
LIMESTONE	Kirton Beds: Kirton Shale, Kirton Cementstones	Cementstones	Oolites
	Kirton Beds: Raventhorpe Beds	Oolites	
	Hydraulic Lst. Blue Beds	Blue Beds	Blue Beds – Collyweston Slate
NORTHAMPTON BEDS	Lower Estuarine = Grantham Fm.		
	Dogger	Northampton Ironstone	

The subdivisions of the Inferior Oolite shown in the table have been worked out over many years. Judd in 1875 proposed the major division into Lincolnshire Limestone above and Northampton Sand below, but later authors have caused confusion by restricting the latter term to the Northampton Ironstone only, and by replacing it by 'Basement Beds' which have been differently defined in different districts. Names for the subdivisions of the Lincolnshire Limestone are partly long established; others have been added as a result of recent work ([18, 29, 30, 31]).

THE NORTHAMPTON IRONSTONE AND DOGGER

The Northampton Ironstone rests with a sharp, often eroded, junction upon the Upper Lias Clays. It is a ferruginous and sandy shallow water formation contrasting strongly with the beds beneath, and was evidently deposited under very different conditions. The eroded surface of the clays, and the occurrence of rolled fossils and nodules derived from them show that there had been a phase of uplift, exposing the muddy bed of the Liassic sea to erosion so that the upper beds were removed. When subsidence was resumed and deposition again took place the shallow seas of the area were swept by sand laden currents, in which the ferruginous sands and siliceous ironstone were accumulated.

The typical Northampton Ironstone shows two different aspects. As usually seen, in the weathered form at outcrop, it is a rich brown sandy rock with prismatic 'boxes' of hard brown and black ferric oxide, which may form concentric shells with softer material inside and out. When encountered at depth it is a compact, uniform greenish rock, in which the iron is combined as carbonates or silicates. Richly ferruginous rock of both types has been extensively worked in south Lincolnshire, northern Leicestershire, Rutland and Northamptonshire. The last quarries in operation were at Colsterworth and Harlaxton, but the ironstone has been worked in the past also at Leadenham and Greetwell. North of Lincoln the rock becomes less ferruginous, and it is replaced by ferruginous sands of no value as iron ore. This facies is continuous with the 'Dogger' of Yorkshire, and is usually given that name.

In the south of the county the Northampton Ironstone measures about 20 feet; it thins northwards to about 8 feet at Leadenham and Lincoln. For a few miles north of Lincoln the bed appears to be a very thin ironstone, but with the incoming of the more sandy facies there is again an expansion, the beds locally measuring as much as 36 feet at Spital and 24 feet near Broughton. Down dip to the east both ironstone and sandstone thin out rapidly. The ironstone for example is absent beneath the south Fenland, and measures only 1 – 4 feet in inliers in the Nocton district. The Dogger ferruginous sands are similarly absent down dip to the east, or are represented by only a few inches of conglomeratic sandstone — as near Brigg.

Fossils are nearly always rare or absent in the bed; the workings at Colsterworth providing the most striking exception to this within the county. They are consequently all the more important when they do occur. In northern Oxfordshire the apparently equivalent beds yield the fauna of the basal Inferior Oolite (*scissum* zone) and the whole of the bed has been presumed to be of this date. In Northamptonshire, however, Beeby Thompson referred the rock to the *opalinum* zone of the uppermost Upper Lias and rare ammonites show that this is the date of the upper part of the Ironstone at Harlaxton. Specimens from the base of the bed in a boring west of Colsterworth have been dated as from the *dumortieria* zone of the Upper Lias (Richardson 1931). Although the last might be derived, part of the Northampton Ironstone evidently belongs to the Lower Aalenian stage, (Upper Lias). As the Yorkshire Dogger yields fossils of the *murchisoni* zone (Inferior Oolite) it is possible that there is a change in date of the bed across country such as is found in the Upper Lias/Inferior Oolite sand of south-western England, deposition having started earlier and finished earlier in the south than in the north. This concept is supported by the occurrence of a Yorkshire type of fauna in the corresponding beds ('Dogger') near Brigg, but more information about zonal indices is needed.

THE LOWER ESTUARINE BEDS (GRANTHAM FORMATION)

The marine Northampton Ironstone is succeeded by the first of the non-marine intercalations of the Middle Jurassic; the group traditionally known as LOWER ESTUARINE. These beds, up to 20 feet of white and buff partly ferruginous sands with faintly purplish marsh clays and dark marine shale, are the southerly partial equivalent of the Middle Jurassic deltaic beds of Yorkshire. They differ from normal deltaic beds in that they are thin, the individual members are persistent over many miles, channelling is rare and marsh deposits (with abundant vertical plant rootlets) are dominant.

It appears that across Lincolnshire the Yorkshire delta was built out towards a facing shoreline (for Northampton Ironstone, Lower Estuarine and Lincolnshire Limestone all thin out south-eastwards in the southern Fenland) and our 'Lower Estuarine' is a lagoonal series, with slow and interrupted deposition in a wide coastal zone of mud flats and sands. Open sea existed towards the south-west, in the direction of the Cotswolds.

The characteristic sequence, from above downwards, shows a few feet of ferruginous bedded sands grading down into a dark grey sandy clay and shale member, three to six feet thick, resting on marsh clays and white sands. The latter are locally so ferruginous as to rank as low grade ironstone, occasionally even taken with the Northampton Ironstone beneath. Vertical plant traces are found in most of these beds (least in the uppermost part) and marsh conditions evidently spread over the area at intervals throughout the period of the Grantham Formation.

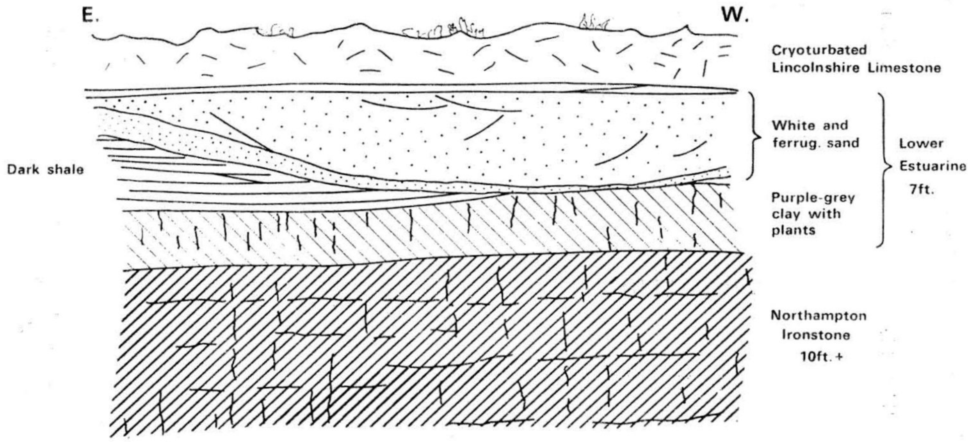
The dark grey shaly member is named the Stainby Shale. It is streaked with fine sand and is occasionally replaced by continuous sand (a local sand bank). In mid and north Lincolnshire it appears to be non-marine and is loaded with coaly material (lignite), but across south Lincolnshire from Great Hale (where it has been found in a boring) and Grantham south into Rutland it began with a flush of sea water, which truncated the pale purplish marsh clays and carried in abundant marine mollusca. Unfortunately the preservation is poor, and the shales disintegrate completely on weathering, but the basal few centimetres have yielded abundant *Trigonia*, less common *Pholadomya*, *Modiolus*, *Protocardium*, *Aviculopecten* and floods of the bivalve '*Corbula*' which persist into the higher beds, slowly dying out, perhaps more tolerant of brackish conditions than the other forms. The primitive brachiopod *Lingula* occurs a little above the base in the Colsterworth area and at Great Hale. Trace fossils including the U-shaped borings of *Diplocraterion* show that conditions included those of inter-tidal flats (Kent 1975).

With the rest of the Lower Estuarine the marine unit dies out east of the Witham; it is at its thickest in the westerly outcrops.

We thus have an indication that a seaway existed, at least temporarily, in that area, but we do not know how far to the west the Estuarine gave place to fully marine conditions.

The formation has been superbly exposed in the miles of ironstone mine workings in the south of the county, but it is a soft member and is soon obscured after abandonment (Fig. 8a). We know too little of the development northwards and good sections are worth recording.

CHANNEL IN LOWER ESTUARINE (GRANTHAM FORMATION) HARLAXTON No. 6 MINE



Channel cuts into the dark shale which contains marine fossils. Strong glacial disturbance is seen in the Lincolnshire Limestone above.

Fig. 8*a*

THE LINCOLNSHIRE LIMESTONE

The Lincolnshire Limestone is the most characteristic part of the Oolites of the county. It is a hundred feet thick lens of limestone, thinning out a few miles beyond the Yorkshire and Northamptonshire boundaries, and extending eastwards into the North Sea.

The lower half, the Lower Lincolnshire Limestone or the Kirton Beds, is characterised by a nearly constant thickness but variable lithology; the upper half, the Upper Lincolnshire Limestone comprising the Hibaldstow, Ancaster and Great Ponton Beds, show less lithological but much more thickness variation, as shown on the accompanying section (Fig. 9).

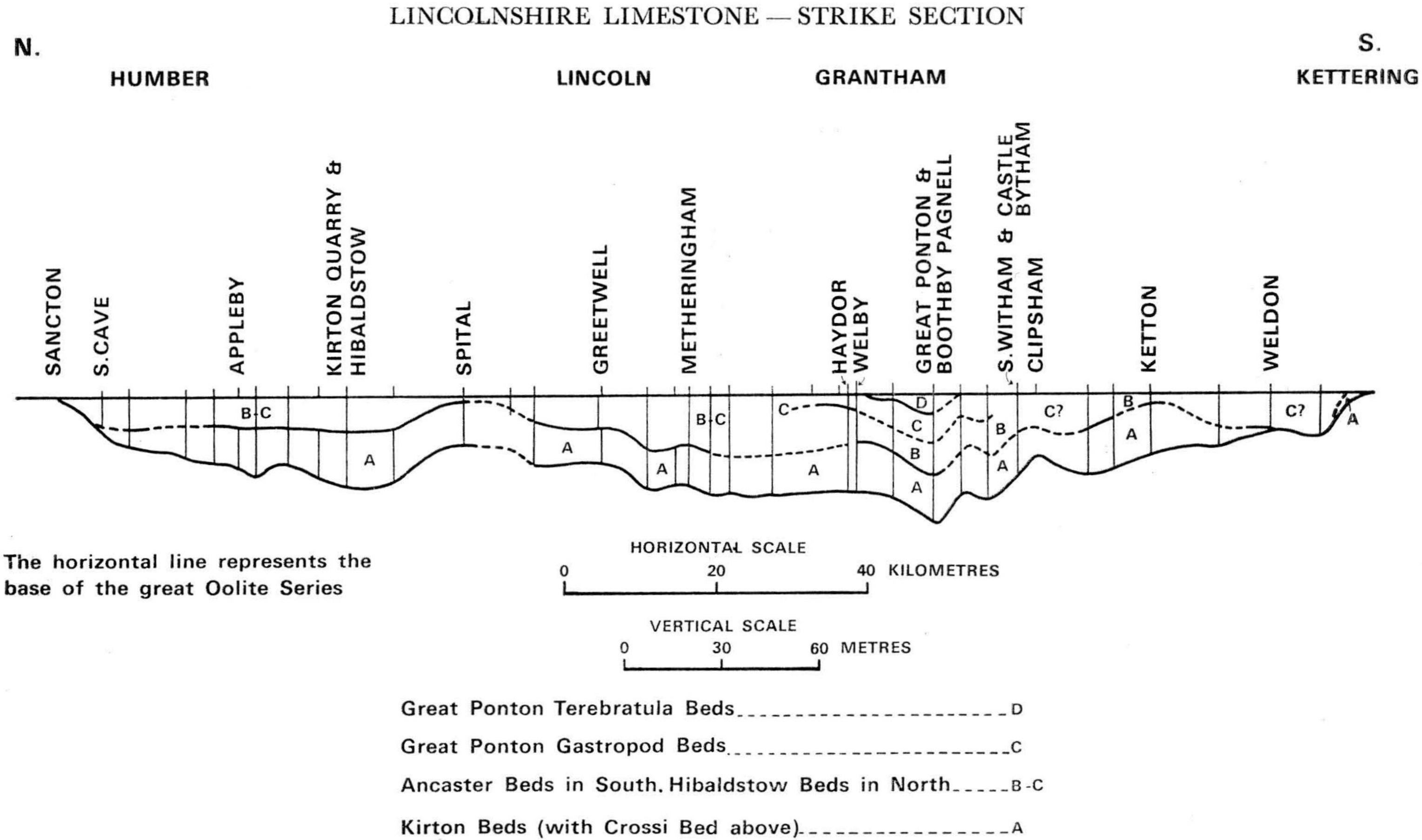


Fig. 9—Showing the limitation of the later subdivisions to pre-Great Oolite synclinal areas. Well and surface sections are indicated by vertical lines.

Deposition of much of the formation was in clear, agitated shallow sea water, in which the lime was often deposited as concentric ooliths and pisoliths; in which shallow water molluscs and lime-secreting algae flourished, corals were common and occasionally became massive enough to be ranked as reefs.

In the south the sea remained clear throughout the limestone period; further north there was a muddy influx at first (giving rise to the shale-and-argillaceous-limestone Kirton Beds, and the rather more extensive but thinner Cementstones further south) but this died away and in the Upper Lincolnshire Limestone the whole area was occupied by clear water.

There is a long history of differing opinions about the correlation of the limestone with the standard successions of the south of England. The lamellibranchs and gastropoda are abundant but most are uncertain indices of date and others are special to Lincolnshire. Brachiopods are sometimes abundant but most of these also are limited to Lincolnshire. One, the tiny *Acanthothiris crossi* mentioned below, is nevertheless an excellent marker through the county.

Accurate correlation with the standard succession depends here (as elsewhere) on discovery of ammonites. The first major step forward was the identification by L. F. Spath of a series of *Hyperlioceras* and other ammonites from the Lower Lincolnshire Limestone (Kent and Baker 1937), which showed that the beds from a little above the base up to the Cementstones belong to the *discites* zone. More recently the same genus has been found in the Lower Lincolnshire Limestone at Clipsham and Greetham in Rutland, and also across the Humber at South Cave (Senior and Earland-Bennett 1973). The basal part of the Upper Lincolnshire Limestone proves to be somewhat later, as shown by discovery of *Sonninia* at Castle Bytham by L. Richardson, and (very recently) at Ropsley by J. A. D. Dickson. Except for a few feet of the lowest beds it seems likely that the greater part of the formation is of early Middle Inferior Oolite date, but it is still possible that the highest part (Great Ponton Beds) is later.*

The part of the limestone suspected of being Lower Inferior Oolite is the basal 2 – 6 feet, which yields the large stout gastropod *Natica leckhamptonensis, Pecten* (*Amusium*) *personatus* and other forms known in the Oolite Marl of the Cotswolds. No ammonites have yet been found in this member.

* The Cementstones have more recently yielded *Fissilobiceras* referable to the *laeviuscula* zone, and higher beds are believed to be of *ovalis* date. (M. Ashton, personal communication).

The earliest part of the Limestone is represented by the COLLYWESTON SLATE of Rutland and southernmost Lincolnshire. This is a thin group of siliceous limestones, weathering into thin, regular slabs, which form a particularly beautiful roofing material. The fissility is entirely due to thinness of bedding, the beds are not true slates (metamorphic rocks with induced cleavage) in the geological sense. The workable slate is not known to extend into Lincolnshire, but characteristic elements of the fauna occur in the basal beds at Buckminster (Leics.) and Ancaster, and the basal Blue Beds, next described, may be a partial equivalent.

Normally the lowest member of the Limestone is the BLUE BEDS which are 3 – 5 feet of hard ferruginous sandy limestones, dark blue when fresh, but weathering brown, with only rare ooliths. The fauna is mainly restricted to small Pectens and *Gervillia.* These beds are persistent through the central part of the county, and are overlain in the north by the sandy or micritic limestone misnamed the Hydraulic Limestone, formerly grouped with the underlying Lower Estuarine Beds, which continues into east Yorkshire.

The basal sandy limestones are followed by marly or pure oolites, thickly bedded, totalling 15 – 20 feet in thickness. These oolites, the 'Silver Beds' of the Lincoln district, the lower part of the Little Ponton Beds of the south, are often richly fossiliferous; in particular the pencil-like gastropod *Nerinea* (*Ptygmatis*) occurs in large numbers in some beds. They contain also a varied assemblage of lamellibranchs; belemnites occur occasionally and groups of echinoids have been found. Corals occur, but they are less important than in the beds above. The large quarries at Leadenham and Greetwell provide the best permanent exposures of these beds in mid-Lincolnshire, but there are smaller sections at Cammeringham, Boothby Graffoe, Ancaster Station, in the abandoned ironstone workings around Harlaxton and Colsterworth, at Little Ponton and at Little Bytham. Through the south and central parts of Lincolnshire they show only minor changes, but in the north the equivalent beds become variable, shaly and sandy (the Raventhorpe type of development of the old memoirs),and have at times been confused with the Lower Estuarine Beds. This feature is related to a northerly trend towards an 'estuarine' facies, although the strata are apparently still marine up to the limits of the county.

The third subdivision of the Kirton Beds is the CEMENTSTONES — chalky or hard limestones containing only scattered ooliths, interbedded with shales. These beds appear by transition from normal oolites near Colsterworth, and persist northwards. In the north a harder, thick bedded development has been worked for cement in the quarries at Kirton. At the top of these beds around Nocton is a thicker shale with large compound corals, sometimes several feet across. Towards the north this shale bed becomes more important and forms the 15 feet thick Kirton Shale overlying the Cementstones, which now constitute raw material for the cement works. The limestone-and-shale below is not very fossiliferous, but the Kirton Shale includes large reef-like masses of corals, oysters and small brachiopods which provide a rich collecting ground.

At the top of the Cementstones is the most important marker bed of the Lincolnshire Limestone for correlation across country. This is the CROSSI BED, characterised by the small spinose Rhynchonellid *Acanthothyris crossi*. In extraction the spines of the key fossil are usually broken off to scars or short stumps, but occasionally specimens may be found weathered out of softer limestone with long spines tapering to hair-like thinness. This bed is found in south Lincolnshire at the base of the Ancaster Beds and above the Cementstones or their equivalent, and it can be traced northwards almost continuously through the county by way of Nocton, Welton and Spital to the Brigg district. In the south the bed is usually 3 – 6 feet thick, but in north Lincolnshire the index fossil occurs through some 20 feet of beds from the top of the Kirton Cementstone into the base of the Hibaldstow oolites. Despite this variation, the Crossi Bed forms a constant marker at the boundary of the Upper and Lower Lincolnshire Limestone. It is absent occasionally in mid-Lincolnshire, as at Ancaster, where the Upper Lincolnshire Limestone cuts down into lower beds, and (more frequently) south-west of Stamford where deep channels were cut into the Lower Lincolnshire Limestone and filled with the raggy and coarsely oolitic Upper division.

Depositional conditions at this level became much more uniform, and the ANCASTER BEDS (in the south) or HIBALDSTOW BEDS (in the north) are evenbedded pure oolites which extend without important changes across the county. They vary from oolites set in a clear calcite matrix (oospartite), through oolite cemented with micrite, to coarsely aggregated oolite and algal pellety limestone and shelly calcarenite, often with the small shells enveloped in concentric carbonate coating. Large fossils are rare, and the homogeneity of the rock in all respects makes it a valuable building stone. The pure oolites of this horizon are responsible for the attractive stone buildings of 'Cotteswold' type along the Cliff, and have provided material for many beautiful Lincolnshire churches. The Ancaster freestone quarries provide the besι exposures of these beds in the county.

The Ancaster Beds as seen in the Wilsford quarries consist of coarse grained detrital limestone (shelly oolite), the Ancaster Rag, resting with a slight unconformity on even grained oolite, the Ancaster Freestone. Fossils are small and include gastropoda and lamellibranchs. Other alternations of Rag and Freestone occur below, as is known from boreholes, and it is believed to be a different Rag bed which is exposed immediately above the Lower Lincolnshire Limestone in the quarries close to Ancaster. The Rag there rests on Cementstones with a minor unconformity; the Crossi Bed having been eroded away before its deposition. Numerous minute Terebratulae, of a type characterising the Upper Lincolnshire Limestone in the south (Weldon Beds), can be found in the hollows of the eroded surface of the Cementstones.

The uppermost part of the Limestone, the GREAT PONTON BEDS, is at present known only in the more southerly parts of the county. At Great Ponton it consists of a lower raggy series of very shelly false bedded oolitic limestones crowded with brachiopods (above), gastropods and lamellibranchs (below), which have yielded a very large fauna in the past and still provide unlimited opportunities for collecting. A cutting immediately south of Great Ponton station is now the best exposure from this point of view. Away from Ponton the beds become less fossiliferous and apparently pass partially into coarsely pisolitic limestone (rock containing calcareous nodules made up like the smaller ooliths with which they are surrounded, of concentric layers of calcite), but raggy beds overlying the Ancaster stone which continue northwards at least as far as Metheringham provide a more typical development of the horizon.

Discovery of ammonites at new localities and new horizons is the most important need for establishing the date of the subdivisions of the limestone, and anyone may happen on most important information if this is borne in mind.

POST INFERIOR OOLITE MOVEMENT AND EROSION

The restriction of the highest beds of the Lincolnshire Limestone to a synclinal area near Ponton and Grantham suggests a phase of earth movement before the Great Oolite was deposited, and even more striking evidence is provided in north Lincolnshire, where the normally very persistent Hibaldstow Beds are absent over the crests of small folds at Spital and Broughton.

It seems that deposition ceased in the Upper Inferior Oolite, that gentle folding took place and that the surface was subsequently planed off by erosion. When deposition was resumed with the Upper Estuarine Series, the sands and clays were laid down on an even surface cut across the folded limestones, so that the higher beds are present in the downfolds but absent on the upfolds.

THE GREAT OOLITE SERIES AND CORNBRASH

Cornbrash	
Great Oolite Series	Blisworth Clay (Great Oolite Clay) Great Oolite Limestone Upper Estuarine Series

After the Inferior Oolite Limestones were gently folded by the phase of earth movement, the area was again reduced to an even plane before it sank below sea level and deposition was resumed. The Great Oolite Series which accumulated in the subsequent period shows an alternation of brackish (estuarine or deltaic) and truly marine sediments. Deposition of this series and of the Cornbrash and Kellaways Beds above was not interrupted by significant earth movements, so that although the beds are characterised by rapid variation in a vertical direction there is unusual lateral persistence of individual members. Thus in the alternation of beds of contrasting lithological types the series is linked with the Inferior Oolite, but it differs from it in that each bed shows little change in the seventy mile long outcrop through the county, or down dip to the east.

In Lincolnshire the series has three subdivisions, as shown above; clays with subordinate sands above and below, and limestones in the middle part.

UPPER ESTUARINE BEDS

The clear water in which the oolites of the Lincolnshire Limestone was deposited was invaded by the sands and muds of the lithologically varied Upper Estuarine Beds. In the north of the county the lowest beds are pale silty sands, 5 – 10 feet thick, representing part of the 'White Sands' of Northamptonshire. In the intervening area these sands are usually absent, but may be replaced laterally by silty clays, perhaps a deeper water facies towards the centre of the basin.

Above the basal sandy beds the formation is made up of 15 –20 feet of clays with minor limestone beds, recognised by Aslin (1968) as deposited in a series of rhythmic units, each one beginning with a layer of marine shells in greenish clays; upwards the shells die out as the marine influence lessens in favour of brackish or fresh water conditions; plant remains increase and the series darkens to purple. Limestones are irregularly developed, most frequently at the marine level. This arrangement is well developed in north

Northamptonshire; it persists in Lincolnshire as far north as Ancaster but sections have elsewhere not been good enough for comparison in detail. The lowest rhythm in Lincolnshire contains *Lingula kestevenensis* with the oyster *Liostrea hebridica* (formerly named *Ostrea sowerbyi*) in abundance. *Modiolus imbricatus* and *Placunopsis socialis* occur in most of the rhythms.

Water wells in the Fenland usually show one Estuarine Limestone three to five feet thick, but there is no certainty that these relate to a single horizon and two beds occur locally.

The section at Ancaster has been described in detail by Aslin. It shows six rhythmic units, four or five of them with a marine element, and a silty clay passage sequence at the top with abundant crushed specimens of the brachiopod *Kallirhynchia* sp. Inadequate sections elsewhere suggest that the marine element diminishes northwards, and no Estuarine Limestone was seen in sections north of Spital, but silty beds with *Kallirhynchia* still occur at the top of the sequence.

Like other Jurassic clay formations, the Upper Estuarine is rarely exposed, but it may be seen above the Inferior Oolite freestone in the quarries at Clipsham (Rutland) and Ancaster, and it is still visible in the partly overgrown railway cutting at Heighington.

GREAT OOLITE LIMESTONE

The Great Oolite Limestone is rarely well seen in surface exposures. In the south it is developed as buff limestone beds of moderate hardness, rubbly when weathered, separated by thin marly partings. It contrasts with the Inferior Oolite in not being oolitic — despite its name. In the centre and north of the county the limestones become harder and fissile and oyster beds are commonly developed. Near Spital the lower part was much sandier than in the south. North of Brigg the subdivision ceases to be mappable, and borehole records show that although it is present as far north as Clapgate, rock beds have become subordinate to shale and the thickness is variable. The final disappearance north of the Appleby-Thornholme syncline is apparently sharp, and is likely to be due to overlap by the Blisworth Clay. According to borehole records the thickness in the county is usually about 12 feet, but there is an apparent rather irregular variation which may often be due to the personal factor in deciding formation boundaries in a gradational series.

Much the commonest fossils are small *Ostrea*. *Liostrea hebridica* (formerly *sowerbyi*) is abundant throughout, and the ribbed *L. subrugulosa* occurs commonly in the uppermost beds. In the southernmost part of the county, as in Northamptonshire, the formation has a good fauna containing a number of lamellibranch species, echinoids and fish remains. Further north it becomes increasingly impoverished, demonstrating a steady lateral change towards the purely estuarine conditions found in Yorkshire. Brachiopods occur however in some variety as far north as Lincoln (11) where they include a French species not known elsewhere in Britain, and *Kallirhynchia* occurs at Spital and probably locally elsewhere in the north. Small exposures of the formation can be found in the upper part of the Ancaster quarries.

BLISWORTH CLAY

After the interval of limestone deposition represented by the Great Oolite Limestone there was a reversion to clay deposition. The Blisworth Clay consists of bluish and green clays in the lower part, and dark blue clays or shales above. The fauna is uniformly poor in species although it may be rich in numbers, consisting mainly of beds of oysters — *Liostrea subrugulosa* being locally abundant in the uppermost part. Dark shales crowded with this oyster were for example exposed beneath the Cornbrash in the old Sudbrooke Park stone pits. The formation thus represents an estuarine or deltaic interval between the truly marine limestones above and below.

From the north of the county to Folkingham the Blisworth Clay measures about 20 – 25 feet in thickness, and this measurement is maintained to the eastwards into Norfolk. In the south of the county abnormally great thicknesses are found in the Dunsby syncline, while beyond in the Isle of Ely the clays became much reduced.

THE CORNBRASH

Although the Cornbrash is a thin bed — often less than six feet thick in Lincolnshire — it is one of the most persistent units of the Jurassic Rocks, extending almost continuously from the south coast to east Yorkshire (15). In relation to its thinness, it is remarkable in containing two largely different faunas; the Lower Cornbrash is linked by its fossils to the Middle Jurassic beneath, while the Upper Cornbrash contains genera which range up into the overlying Upper Jurassic (Kellaways Beds, etc.).

In Lincolnshire the LOWER CORNBRASH is usually a grey shelly limestone, hard when fresh, sometimes weathering soft. The disc-like zonal ammonite, *Clydoniceras* has been found occasionally; the characteristic brachiopods *Ornithella obovata* and *Cererithyris intermedia* are usually present to date the bed. '*Avicula*' (now *Meleagrinella*) *echinata* is a characteristic small spinose lamellibranch sometimes very abundant in the bed. Lower Cornbrash is only known at intervals in the county, localities including Skillington, Newton, Dembleby, Osbournby, Potter Hanworth, Sudbrooke (near Lincoln) and Appleby (near Scunthorpe). No trace of the bed was found in complete sections at Walcot, Aslackby and Sleaford ([19]).

A pipetrench section at Bishop Norton showed a soft limestone with a rich Lower Cornbrash fauna with characteristic lamellibranchs and brachiopods (Kent 1972); there and also in some boreholes drilled by the Institute of Geological Sciences on the Humber shore there is no hard rock bed in the Cornbrash.

The UPPER CORNBRASH apparently extends continuously through the county. In the Bourne – Sleaford section of the outcrop it consists of two hard limestone beds separated by one or two feet of yellow ferruginous marl. The upper limestone yields typical brachiopods (*Microthyris sublagenalis*, etc.) and occasional specimens of the globose zonal ammonite *Macrocephalites*. The yellow marl contains two very large oysters (smooth *O. undosa* and ribbed *Lopha marshii*) and various rare brachiopods, beautifully preserved. North of Sleaford, at Sudbrooke and near Appleby, the subdivision is mainly of limestone, with the same zonal fossils.

The small stone pits in which Cornbrash was formerly worked at Sudbrooke, Quarrington, Hacconby and Hanthorpe are now unfortunately obliterated. The fauna can be collected from ploughed fields when the soil is thin — from the stony 'brash' which gave the formation its name — but as the formation is so thin quite shallow temporary sections can provide diagnostic information. *Macrocephalites* has for example been found in field rubble at Roxholm near Sleaford. Small mapping exposures can be found in ditches and drains which cross the outcrop, and there is always a chance of finding the zonal ammonites.

Plate 1. Lias Limestone, Swinethorpe: ammonite bearing crinoidal limestone with abundant small *Schlotheimia* and larger keeled *Metophioceras* from Granby Limestone. (SK 880694) *(Photo by B.P.)*

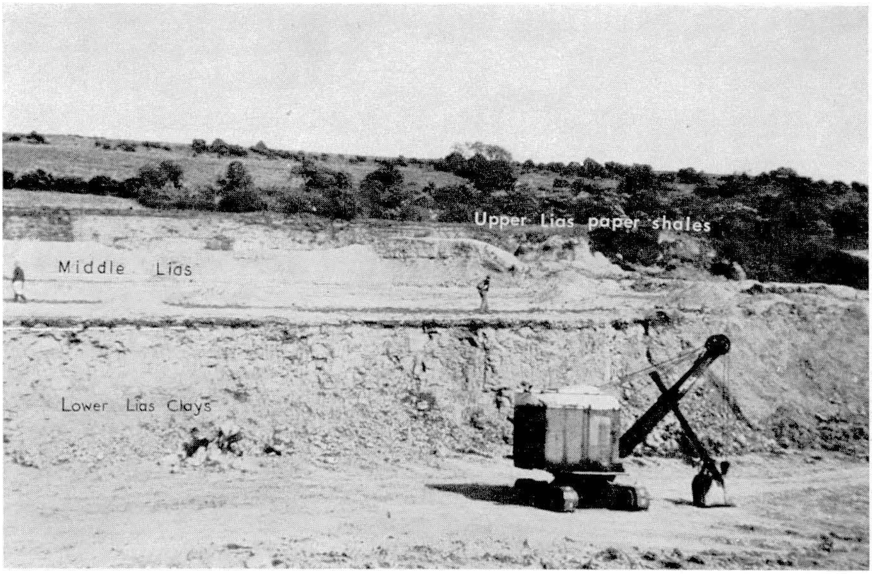


Plate 2. Bracebridge brick pit in Lias Clays with Lincolnshire Limestone scarp behind. (SK 972763). *(Photo by D. N. Robinson)*

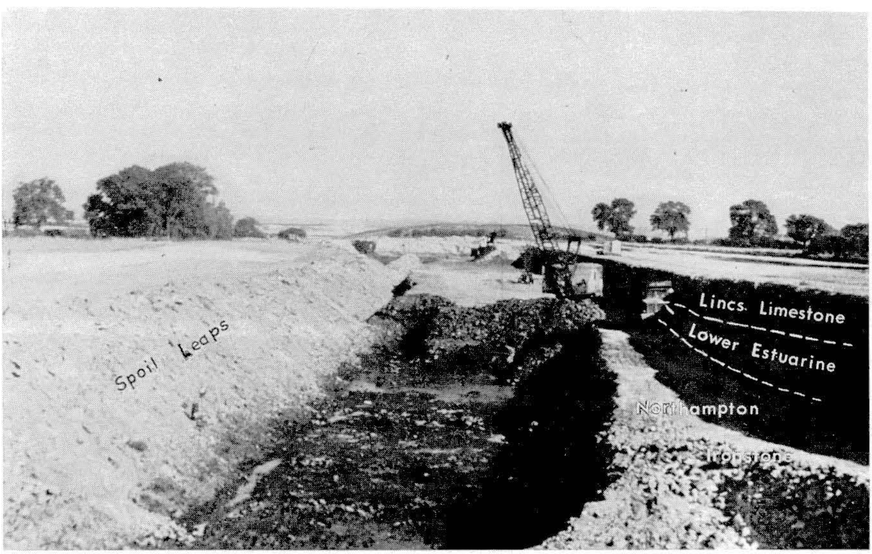


Plate 3. Stainby Glebe quarry: Northampton Ironstone overlain by Lower Estuarine and Lincolnshire Limestone. (SK 917235). *(Photo by D. N. Robinson)*

Plate 4. Former quarry in Frodingham Ironstone; site restored and now occupied by Anchor steelworks. (SE 925085). *(Photo by D. N. Robinson)*

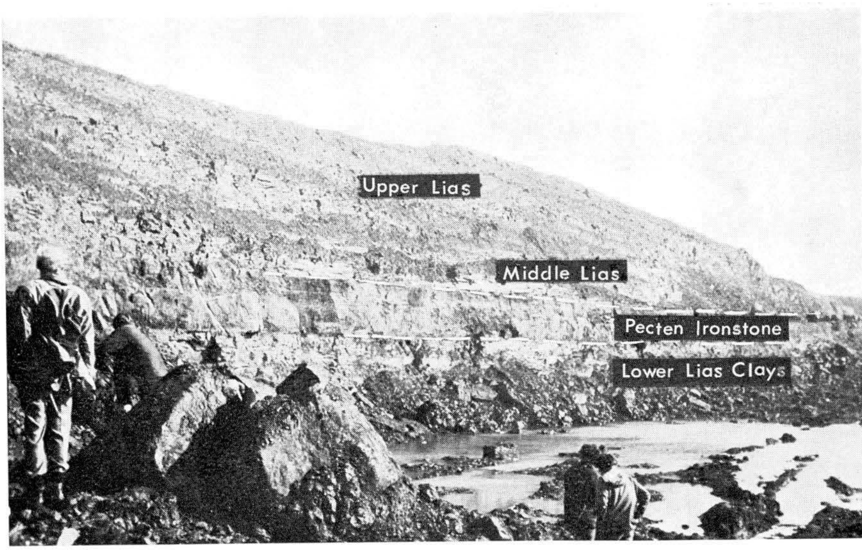


Plate 5. Crosby Warren quarry with Pecten Ironstone and Upper Clays of Lower Lias. (SE 912312). *(Photo by P. E. Kent)*

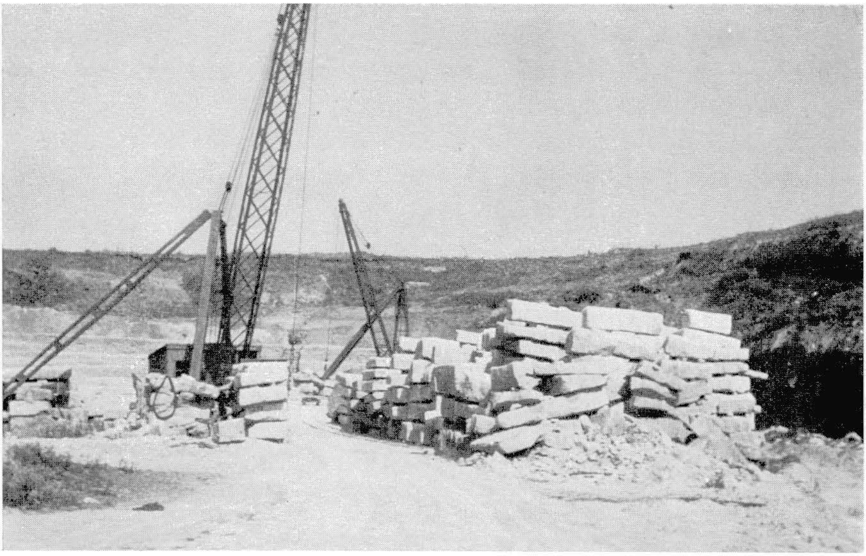


Plate 6. Gregory's quarry, Wilsford: Lincolnshire Limestone (Ancaster Beds) and Upper Estuarine. (SK 991409)

(Photo by P. E. Kent)

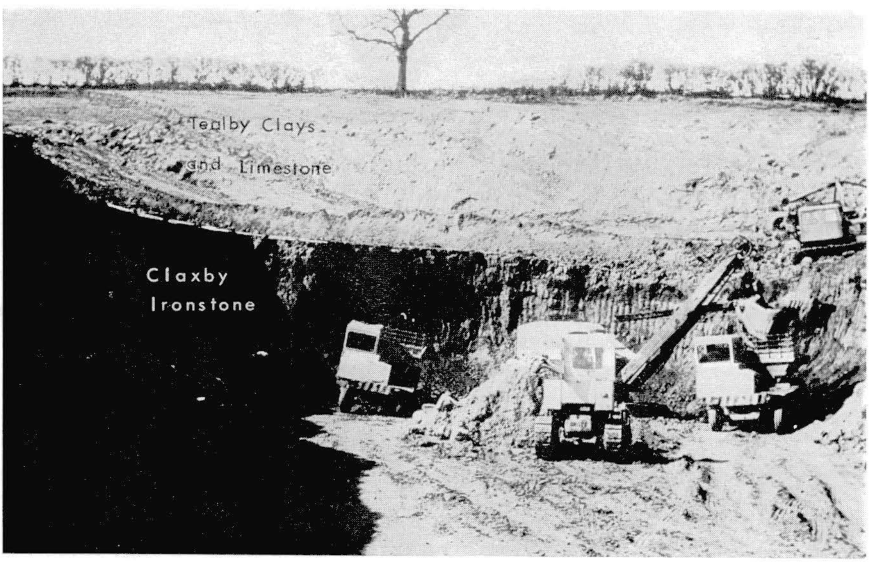


Plate 7. Former opencast working for Claxby Ironstone (overlain by Tealby Clays and Limestone) at Nettleton. (TF 120978)

(Photo by D. N. Robinson)

Plate 8. Tetford Hill Chalk quarry with Pink Band (dark line across centre) and solution pipe (?) at surface. (TF 329760)
(Photo by D. N. Robinson)

Plate 9. Castle Gravel quarry, Tattershall: organic lens in delta gravels of pro-glacial lake. (TF 215568) *(Photo by D. N. Robinson)*

Plate 10. Lincolnshire's largest flint in Ashby Hill Chalk quarry. (TA 241006) *(Photo by D. N. Robinson)*

Plate 11. Gas pipeline at crest of Wold scarp: Carstone, Red Chalk and White Chalk. (TF 302772) *(Photo by D. N. Robinson)*

Plate 12. Wold scarp south from Searby. (TA 070063)
(Photo by D. N. Robinson)

Plate 13. Lower Cretaceous ridge (left) and Wold scarp north from Belchford Hill. (TF 308762) *(Photo by D. N. Robinson)*

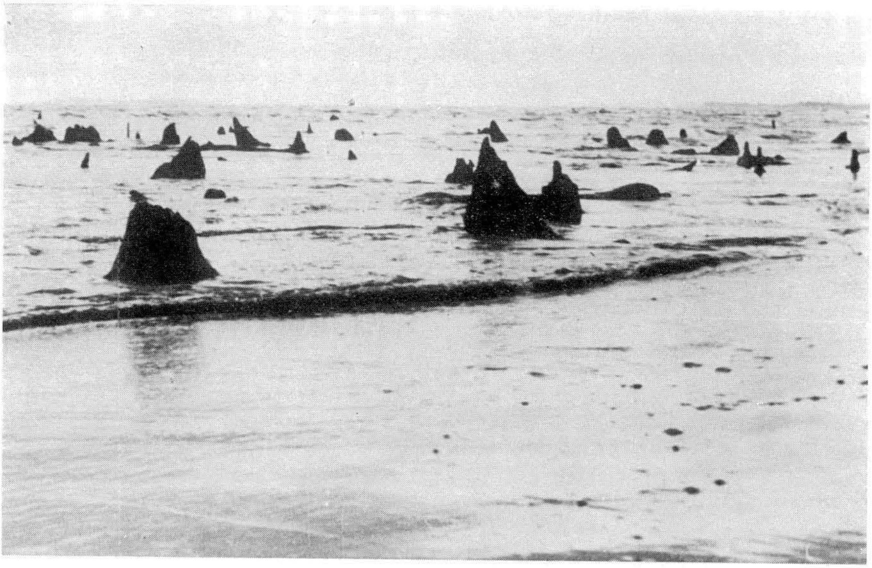


Plate 14. Submerged Forest at Trusthorpe exposed by a low spring tide in September 1952. *(Photo by G. F. Morton)*

Plate 15. Boulder Clay (Upper Marsh Till), Peat and fragments of Submerged Forest at Huttoft Bank. (TF 545785)
(Photo by D. N. Robinson)

CHAPTER 9

THE UPPER JURASSIC CLAYS

The Upper Jurassic forms the great clay belt which lies east of the Lincoln Cliff and extends to the Wolds; it extends from the Humber southwards through the Fenland to Cambridgeshire. Over this stretch the solid clays are rarely seen, for the mantle of drift, to which they themselves contributed extensively, is almost continuous. Consequently these beds, although nearly a thousand feet in thickness, remain among the least known of the Lincolnshire formations, and provide one of the greatest potential fields for new discoveries.

For many years the clays were divided into two — the Oxford and Kimmeridge Clays — and they are shown thus on current geological maps. Roberts ([32]), however, found that the Corallian, in the Ampthill Clay facies which was already known in Bedfordshire, was developed between the two, and a tripartite division has to be adopted.

Stages	Lithological Divisions		Maximum Thickness
Kimmeridgian	Kimmeridge Clay		300 feet
Upper Oxfordian	Ampthill Clay		200 feet
Lower Oxfordian	Oxford Clay		300 feet
Callovian	Kellaways Beds:	Kellaways Sand Kellaways Clay	25 feet 15 feet

Mapping of the three clay subdivisions in the drift-obscured outcrops of North Lincolnshire must depend on temporary exposures, and recording these (with collection of ammonites) is an important field where the amateur can help.

The Upper Jurassic was initiated by the deposition of the shallow water Kellaways Beds, when a flood of sand was spread over the whole depositional basin. The supply of coarse material then ceased — most probably because of rising sea level, extension of the sea area, caused the shore lines to move further beyond Lincolnshire. Sands continued to be deposited nearer the basin edge in Yorkshire and Scotland, but in our area and further south in England the deposits were all essentially shales and clays, even though the water depth fluctuated from time to time (deeper during Oxford Clay and Kimmeridge Clay deposition, a shallower phase during deposition of the Ampthill Clay).

THE KELLAWAYS BEDS

The Kellaways Beds are linked to the Oolites by lithology, but to the Oxford Clay by fauna. Over the greater part of Lincolnshire they form a uniform series rarely less than 25 or more than 35 feet in thickness. The upper three-quarters of this thickness is normally sandstone, the lowest part clay. North of Sleaford a variable thickness at the top of the sandstone is cemented to form the 'Kellaways Rock'.

The Kellaways Beds are often covered by Fen deposits in south Lincolnshire, and they are consequently best known from borings. They occur, however, frequently at surface from Caenby northwards, and show up to 20 feet of sand with cemented sandstone at the top. When they are exposed they yield numerous fossils — mainly *Gryphaea bilobata* and the large belemnite *Cylindroteuthis oweni*, with other lamellibranchs and occasional ammonites. At outcrop the sandstone tends to be leached as a result of its high porosity, and the calcareous fossils are often represented by hollow casts, but where this has not taken place the formation is a rich fossil bed.

Exposures can be found in ditches and temporary exposures on the drift-free parts of the outcrop. Fossils are best preserved in the cemented sandstones, but belemnites survive also in the loose sands.

No regular trend in thickness changes has been found. The series measures 38 feet as far north as Hibaldstow, is reduced to 20 – 25 feet between Brigg and Appleby, but appears to maintain this thickness beyond, and in south Yorkshire the sands thicken at South Cave. Towards the east, down dip, the bed varies from 21 feet (Stixwould) to 34 feet (Faldingworth), and south-eastwards the deeply buried bed maintains its thickness beyond the Wash (North Creake). The Kellaways Beds are thus among the most regularly developed members of the Jurassic series, showing that depositional conditions were unusually uniform.

OXFORD CLAY

The Oxford Clay has an outcrop four miles or more wide running the length of Lincolnshire immediately east of the rising ground formed by the Oolites, but it is now rarely seen, as the old brickyards which formerly exposed it beneath the veneer of Fen Deposits are now all abandoned and overgrown.

At the base, overlying the Kellaways Beds, is a persistent bed of shale which is noticeably bituminous in the unweathered state. Above this the remainder of the formation is of virtually uniform blue grey shaly clays with pyritised fossils, pyrites concretions and occasional layers of cementstones. The fauna is well known in the Peterborough district, where the zonal sequence is largely complete ([24]). Old records of ammonites (together with the ubiquitous *Gryphaea dilatata*) from abandoned brickyards at Timberland, Bardney, Langworth Bridge and more recent records of *Cosmoceras, Quenstedtoceras* and *Creniceras* from a borehole near Brigg indicate that the lower and middle zones persist across the county.

During excavations for a reservoir at Cadney, near Brigg, in 1973, about 15 feet of Upper Oxford Clay were exposed. Hundreds of small, beautifully preserved, pyritised ammonites belonging to *Quenstedtoceras, Cardioceras* and *Peltoceras* have been collected by Dr. P. F. Rawson, together with bivalves, belemnites and some saurian vertebrae. Exposures like this are rare, but all the more important when they can be found. The earlier parts of the formation are excellently seen around Peterborough, but there are no permanent openings within the county. Much more information is needed on the details of the succession.

Measurements of total thickness in boreholes show that the Oxford Clay thickens from Norfolk (about 150 feet) to central Lincolnshire (249 feet at Stixwould, more than 239 feet at Miningsby) and then thins northwards to the Brigg district (probably less than 200 feet) and south Yorkshire.

AMPTHILL CLAY (UPPER OXFORDIAN)

The presence in the Fenland of a clay representative of the Corallian Limestones of other parts of England was first recognised when Thomas Roberts showed that the lowland belt between the Oolites and the Wolds should be divided into three, not two, belts of nearly equal width — the middle one being the Ampthill Clay equivalent to the varied series of Corallian Clays and sandstones of southern England and Yorkshire.

Roberts observed that the Ampthill Clay could be easily distinguished at outcrop by its nearly black colour, and by the common occurrence of selenite. Pyrites nodules and pyritised fossils, common in the Oxford and Kimmeridge Clays above and below, are absent.

Palaeontologically it may be recognised by the presence of two large oysters, for *Gryphaea dilatata* ranges into these beds from the Oxford Clay, and *Ostrea delta* extends from the Ampthill Clay into the Kimmeridge beds above. A number of ammonites were recorded in past years but their nomenclature needs revision; *Amoeboceras serratum* has however been found to be abundant and well preserved in the upper beds.

The highest beds contain the ammonite *Ringsteadia* (as in Dorset), with abundant *Ostrea delta* and masses of the colonial sea worm *Serpula tetragona*. These beds have been seen in sections at Elsham, and the *Serpula tetragona* beds are intermittently exposed on the Humber shore at South Ferriby, close to the overlapping Cretaceous.

The Ampthill Clay measures only about 80 feet wide over the north-western boundary of Norfolk, but it expands greatly to mid-Lincolnshire where, (on mainly lithological evidence of borehole records) it is estimated at 200 feet at Stixwould and 209 feet at Miningsby. In the north the precise thickness is not known, but the formation is likely to be only half as thick.

Temporary sections made for foundations, pipelines etc. are well worth investigating and recording in this little known formation. Collection of ammonites is particularly necessary; beautifully preserved *Amoeboceras serratum* in the Boulder Clay of the Midlands must have come from here, but their precise source is still unknown. The nearest permanent exposure is at Melton, north of the Humber.

KIMMERIDGE CLAY

A century ago there were many brickyards working the Kimmeridge Clay, but almost all of them became abandoned and overgrown before modern palaeontological methods could be applied to their zoning. At the present time there are only small exposures of the upper beds on the edges of the Wolds.

Immediately above the base are clays with abundant specimens of the large round-whorled ammonite *Pictonia* in the lower part. A little higher are beautifully preserved ammonites of the genus *Rasenia*, named after Market Rasen where brickyards provided hundreds of museum specimens in the last century. About 25 feet of clays with small *Rasenia* and *Amoeboceras* of the Cymodoce zone now exposed beneath the Lower Cretaceous unconformity in the South Ferriby chalk pit have been investigated by Arkell and Callomon.

At this level the regime of clay deposition (which had been continuous since the Kellaways) was interrupted in north Lincolnshire by a flush of fast-flowing water which brought clear quartz sand as far east as the Wolds. This is the Elsham Sandstone, about 20 feet thick, exposed around Elsham village; it contains lime-cemented masses which are locally rich in fossils including the perisphinctid ammonite *Xenostephanus*. This bed was thought to be a northerly relic of the Spilsby Sandstone before the discovery of fossils proved it to be early Kimmeridgian. (Kent & Casey 1963)

The clays formerly exposed at Stickney brickyard, near Tattershall, belong to the slightly higher beds of the Pararasenia mutabilis Zone. Well preserved but fragmentary specimens of this ammonite occur in association with large septarian nodules, and they have been found also at Revesby three miles to the north. An exposure of the immediately succeeding *eudoxus* zone near Hemingby showed bituminous shales with *Amoeboceras*, the lower oil shale level of southern England. The Aulacostephanus Zones are thicker than these basal beds, for in the Benniworth borehole beds from about 300 – 350 feet below the top of the Kimmeridge clays yield ammonites referred to this horizon. The next zones, characterised by species of *Gravesia*, are similarly at present only known from boring records, for this genus occurred in the boring at Donington-on-Bain ([27]) but has not yet been found at outcrop. Beds of poor quality oil shale occur in these beds — the middle part of the local Kimmeridge — and they increase in number and quality towards the top of the formation. Richly fossiliferous bituminous shale with the horny brachiopod *Orbiculoidea*, ammonites and fish remains was exposed in an old brick pit at Fulletby, and other beds may be seen occasionally in natural exposures on the steep hillsides of the Wolds escarpment.

The latest beds of the Kimmeridge Clay recognised in Lincolnshire belong to the Pectinatites pectinatus Zone, which is known at Nettleton, at Acre House near Claxby, and at Langton. Small exposures close beneath the Lower Cretaceous indicate broad parallelism between the Kimmeridge and the base of the Spilsby Sandstone — thus ammonites of the genera *Pectinatites* and *Virgatosphinctoides* have been found a short distance beneath the Sand at Old Bolingbroke, Fulletby, Salmonby and at Nettleton Top. There are apparently irregularities in the contact (as near Spilsby) which may be due to channelling when strong currents washed the Spilsby Sandstone into the basin, but these appear to be local.

Coarsely ribbed round-whorled ammonite fragments occur in the base of the transgressive Cretaceous Carstone; these could be either a Lower Kimmeridge *Rasenia*, from clays being eroded in north Lincolnshire, or a relic of the later Kimmeridge *Pavlovia* zones now eroded (as was formerly thought). More material of this kind would be welcome.

Overstep by unconformable Cretaceous is rapid north of Caistor. South of Elsham village only a thin remnant of the main Kimmeridge Clay body is present above the Elsham Sandstone; north of the village (by the Barton road) the Red Chalk (with possible

Carstone) rests directly on the sandstone, and at the Humber this bed and some 50 feet of lower clay is also cut out, the Red Chalk resting on clays with *Serpula tetragona* colonies and *Ostrea delta* near the Ampthill/Kimmeridge boundary (Fig. 12). Locally there seems to have been channelling of the clay surface, as recorded near Spilsby, but this never reached the middle or lower beds, and there is no steady northerly accentuation of the diastema in the section of the Wolds south of Caistor where the Lower Cretaceous beds are present.

It would be a satisfactorily tidy arrangement if this break in deposition marked the Jurassic–Cretaceous boundary, but the dating is not so simple. It is now known that the transgressive lower Spilsby Sandstone is still Jurassic, equivalent to the Portlandian beds of Dorset. These beds are described in the next chapter.

At a later period — after the deposition of the Lower Cretaceous — an additional phase of uplift and erosion was associated with southward tilting, so that the later Carstone and Red Chalk were laid down on a surface which not only truncated the Lower Cretaceous towards the north but which cut down to the Ampthill Clay at Ferriby and even reached the Lias near Market Weighton in Yorkshire.

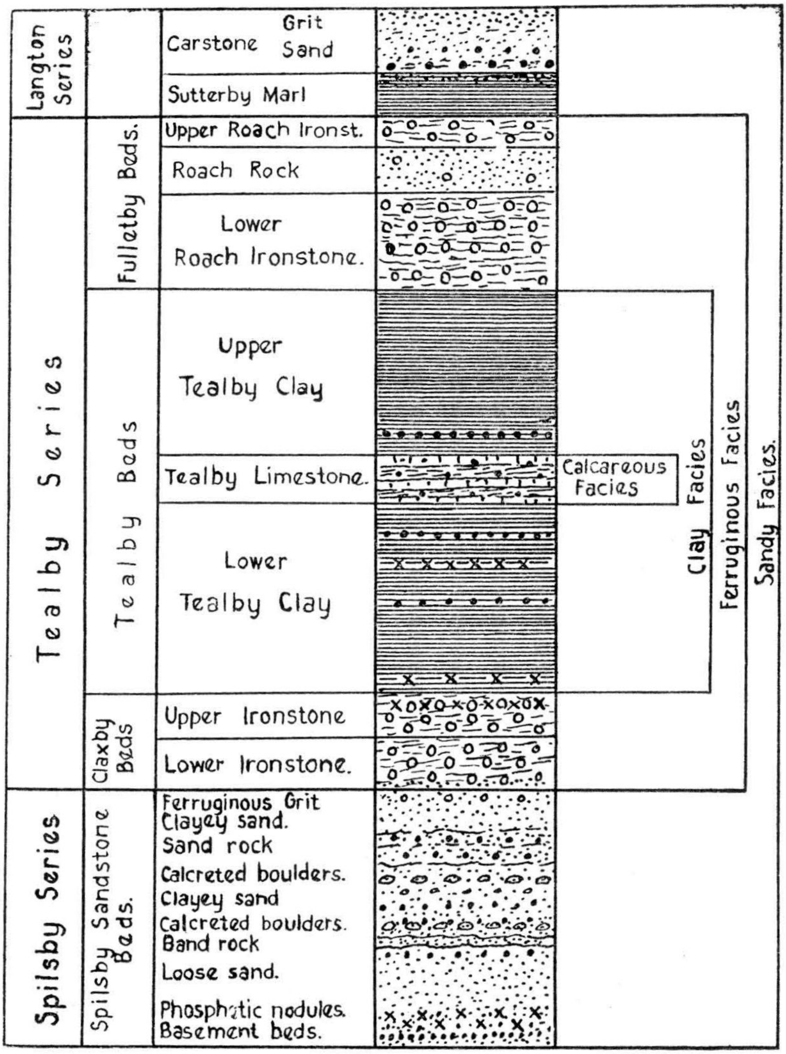
CHAPTER 10

FOUNDATION ROCKS OF THE WOLDS

The Lincolnshire Wolds are capped by the gently dipping partly dissected layer of the Chalk, and below this, forming the face of the western scarp and the bottoms of deeper valleys, is a mixed series of sands, clays and ironstones. When the first edition of this book was written they were all firmly ascribed to the Lower Cretaceous and mainly regarded as the marine equivalent of the fresh-water Wealden deposits of southern England, the basal member, the Spilsby Sandstone, resting with a major break on the middle part of the Kimmeridge Clays, so that supposedly the Portland and Purbeck Beds of the south were missing. It was consequently thought that they were deposited in an arm of a northern early Cretaceous sea extending southwards into Lincolnshire and ending at a barrier across the Midlands.

Further work on the ammonites by Dr. R. Casey of the I.G.S. has produced the unexpected conclusion that the Lower Spilsby Sandstone is directly equivalent of the Portland Beds and earliest Purbeck Beds of Buckinghamshire and Dorset and is hence Jurassic. There must have been an open seaway from Lincolnshire to the south coast at the time (Casey 1973). The upper part of the Spilsby Sandstone proves to be the equivalent to the upper part of the south of England Purbeck Beds, which are lacustrine limestones, muds and gypsum. A solitary incursion of the sea in the southern lake left a sheet of oyster shells known (from its appearance) as the Purbeck 'Cinder Bed'; this flush of marine water is however now believed to have come through Norfolk. This incident is taken to be the beginning of the Cretaceous from the evidence of international correlation, and it marked the beginning of the northerly sea connection as it was previously envisaged. From that time onwards the Lincolnshire Lower Cretaceous was in fact deposited in a basin open to the north, showing close links with Speeton in Yorkshire and, faunally, with Russia.

A SECTION OF THE LOWER CRETACEOUS AND SPILSBY BEDS IN THE CENTRAL WOLDS



o Oolitic Iron x Phosphatic nodule ● Glauconite

The junction between the Jurassic and Cretaceous lies within the Spilsby Sandstone, at a phosphatic nodule bed in the middle part.

Fig. 10

Thus we have to adjust the traditional views and recognise that the Lower Spilsby Sandstone is Jurassic, overlain by a Neocomian series, which is the equivalent of the essentially fresh water late Purbeck and Wealden of southern England. Only a minor representative of the Aptian stage is present in Lincolnshire, in contrast to the very thick lower Greensand of the south.

For the purposes of describing the rocks in the Wolds it will be convenient to divide this area into three parts: the south Wolds roughly defined on the north by a line running through Louth and Donington-on-Bain; the central Wolds lying north of this line and extending to the Barnetby – Kirmington valley; and the north Wolds, lying between this and the Humber.

The most complete development of the Lower Cretaceous is preserved in the south Wolds. Cores of borings put down in the search for water, more especially at Alford and Fordington, have yielded a relatively complete picture of the sequence and have provided a key to the understanding of the few small and isolated exposures which occur at the surface ([45, 47]). An inspection of the accompanying section (Fig. 10), will give an idea of the general character and order of occurrence of the rock types. In the rich variety of these this area presents a striking contrast to the Lower Cretaceous as seen at Speeton, in Yorkshire, where they consist almost entirely of clay.

The SPILSBY SANDSTONE rests unconformably upon the Kimmeridge Clay which has suffered some erosion of its upper zones. This clay formed the floor of this late Jurassic sea for a brief time during which marine worms made their burrows in it. These became filled subsequently with dark sand from the base of the Spilsby Sandstone.

The bottom three feet of the sandstone present several features of especial interest. The sand is dark and rich in glauconite, a green silicate of iron, and in phosphatic nodules. The latter include fragments of ammonites derived from the erosion of the Kimmeridge Clay and are frequently penetrated by pear-shaped cavities made by the boring bivalve *Martesia*, specimens of which may often be extracted from the stony casts of the borings. These features all indicate that the sands accumulated at a very slow rate upon the sea floor. Other fossils occur which will be discussed later.

The Spilsby Sandstone as a whole varies considerably in thickness. It attains a maximum of about 70 feet along a north – south line running through Fordington and Tetney Lock, and thins eastwards to as little as 20 feet under Skegness. It is mainly an arenaceous deposit made up of various grades ranging from fine gravel through coarse and fine sand to silt. Glauconite is present throughout. Much of it is loose and friable but irregular lumps, hardened by a calcareous cement and varying greatly in size, occur at some levels.

Near the base whole layers are similarly cemented and have provided building stone locally.

In the top five feet glauconite gives place to oolitic grains of iron ore. This change marks the passage to the Claxby Ironstone which normally has a brown clay matrix but in its lower portions contains much grit like that found in the sandstone. Oolitic iron ore is abundant but irregularly distributed. Worm burrows sometimes filled with these grains, sometimes with clay, are common. In the middle levels moderately phosphatised material having a creamy or pinkish colour occurs either as part of the matrix or in the form of nodules. Non-ferruginous clays occur interbedded with the ironstone. These tend to thicken southwards and attain a thickness of as much as 18 feet. In an old brickyard at Hundleby they may be seen covered and underlain by the ironstone. Shallow excavations in the ironstone, which forms the floor of the yard, yield many fossils, especially belemnites.

The passage of the CLAXBY IRONSTONE upwards into the Lower Tealby Clay is marked by the disappearance of oolitic iron ore grains and the appearance of glauconite and of black phosphatic nodules. The former occur abundantly at several higher levels. The latter occur occasionally in lines associated with fossils eroded by the solvent action of water.

The TEALBY LIMESTONE may include grey shales consisting of shelly and fine quartzose sand with some glauconite and occasional grains of oolitic iron ore. Some layers are hardened by the presence of calcareous cement. These were formerly used for building stone especially in the vicinity of Donington-on-Bain.

The UPPER TEALBY CLAY differs from the lower in the general absence of glauconite which, however, does occur in some abundance at one level. It is also more varied in colour ranging from dark grey to buff. Its upper portions are silty.

In the FULLETBY BEDS oolitic iron ore reappears often in sufficiently large quantities to produce the Roach Ironstone. The clay matrix resembles the Upper Tealby Clay in variety of coloration. Just above the middle the matrix becomes sandy and the grains of iron ore diminish and the level hardens to form the Roach stone. In its uppermost portions the iron ore grains reappear in force and the clay matrix becomes dark grey and black. With the disappearance of the ore the Fulletby Beds pass into the Sutterby Marl.

The SUTTERBY MARL is about 10 feet thick, the top portion of which loses its black colour and becomes a light creamy grey. Above this the CARSTONE facies gradually sets in. At first it is a fine dark sand marl with much glauconite. This changes upwards into a loose sand of fine and then medium texture. In its upper portions it becomes a coarse grit with small pebbles, which merges into the overlying Red Chalk. Though the maximum thickness of the Carstone is little more than 30 feet it represents a considerable period extending from Lower into Upper Cretaceous times. The boundary between these must lie somewhere in the Carstone, probably about the base of the grit, but much more careful examination of this rock in the field is required before the precise position can be fixed.

From the above account and the table in Figure 10 it will be seen that the Lincolnshire succession exhibits an interesting sequence of rock types made up of sandstone, ironstone, clay and limestone in that order in its lower part, but in the reverse order in its upper part. The precise conditions under which each type was formed is unknown but it is probable that at the time of formation of the Spilsby Sandstone the shore line was not far away. Gradually as the shore shifted further afield sedimentary facies favourable to the formation first of ferruginous, then clay and finally calcareous deposits moved across the south Wolds area. The presence of glauconite and of phosphatic nodules at various levels indicate a temporary slowing down of the rate of deposition.

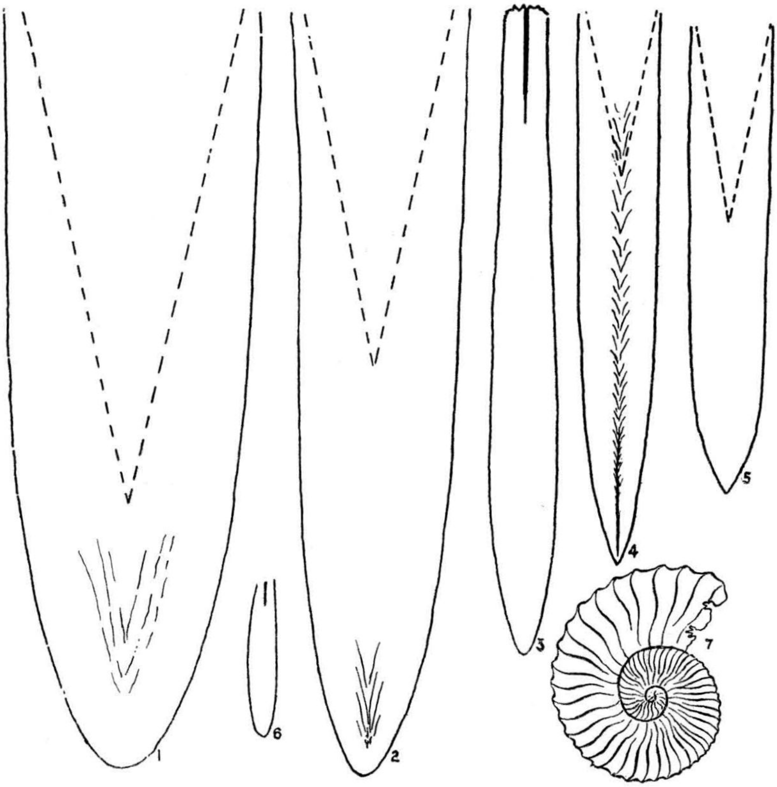
This sequence of conditions now returned over the area in the reverse order. The shore line drew near once more. Whether it, too, also passed across and left it for a while as dry land subject to erosion is a problem which awaits solution by a closer study of the Carstone.

The Lower Cretaceous rocks of this area thus present us with an excellent example of a progressional followed by a regressional series of deposits.

Fossils are widely distributed throughout the Lower Cretaceous series. Ammonites are usually fragmentary but occasionally well preserved specimens are found and are of great value in the precise correlation of levels with one another in Lincolnshire and Yorkshire. Belemnites are much more common and are therefore more broadly useful in such correlation (Fig. 11). Recent critical studies on both groups of organisms have lead to a fuller knowledge of the relationships to one another of the deposits of the two regions ([46]).

Some of the fossils have Russian affinities. Thus the belemnites of the basal Spilsby Sandstone include *Acroteuthis partneyi* and the only British representatives of the *Acroteuthis* subgenus *Microbelus*; the latter is well-known from the Russian Platform and Siberia (Pinckney & Rawson 1974). A direct connection with faunas from the Soviet Union is also indicated by some of the ammonites from various horizons within the Spilsby Sandstone, such as *Paracraspedites* and *Subcraspedites* of various species. Equally notable in relation to British correlation is the occurrence of the genera *Kerberites* and *Crendonites*, characteristic of the Portland Beds of southern England, together with derived Kimmeridge forms (*Pavlovia* etc.).

OUTLINES OF BELEMNITES



1. *Acroteuthis lateralis* 2. *A. subquadratus*
3. *Hibolites jaculoides* 4. *Aulacoteuthis absolutiformis*
5. *Oxyteuthis brunsvicensis* 6. *Neohibolites minimus*
7. A Lower Cretaceous ammonite *Deshayesites*

Acroteuthis lateralis characterises the Jurassic part of the Spilsby Sandstone; the other forms are Cretaceous.

Fig. 11

Passing to higher zones it may be noted that earlier workers confused *A. quadratus* with *A. lateralis* and consequently gave the latter a more extended range than it actually possessed. It is, however, limited to the Spilsby Sandstone. *A. subquadratus* appears in the ferruginous grit, which caps this sandstone and continues to the top of the Claxby Ironstone in the middle of which a very varied assemblage of belemnites occurs together with the ammonites *Lyticoceras*, *Polyptychites* and *Tollia*.

An even greater confusion has existed over *Hibolites jaculum*. The specific name of many specimens, which were formerly called by this name, has been altered to *jaculoides* and the correct name for the zone is now the Jaculoides Zone, which includes the upper part of the Claxby Ironstone and the Lower Tealby Clays. The Brunsvicensis Zone extends from the base of the Tealby Limestone to the top of the Fulletby Beds. Most of the belemnites in this zone belong to or are related to *Oxyteuthis brunsvicensis*. Several species of the genus *Aulacoteuthis* also occur in the Upper Tealby Clay and are characterised by the presence of a groove along the mid ventral line. The ammonites *Crioceras* (an uncoiled genus) and *Simbirskites* occur in the Tealby beds.

The Sutterby Marl has proved to be especially interesting. The presence in it of the belemnite *Neohibolites ewaldi*, associated with the ammonite *Deshayesites* (*Parahoplitoides*), links this bed up with the Ewaldi marl and the black clay which underlies it at Speeton. This ammonite fauna provides a corresponding link with the base of the Carstone in Norfolk and with the Atherfield clay in the Wealden basin. From this it follows that the beds below the Sutterby marl are the marine equivalent of much if not the whole of the Wealden Beds.

In the absence of fossils from the Carstone its exact correlatives elsewhere are unknown, although Albian brachiopods and foraminifera are recorded from the finer-grained Carstone sands just north of the Humber at Melton (Owen, Rawson & Whitham 1968). An insignificant exposure of the dark sandy marl in its lower portion did yield fragments of an ammonite which was unidentifiable and suggests that more extensive excavation would yield better specimens and throw valuable light upon this problem.

Belemnites and ammonites have always received the lion's share of attention on account of their stratigraphical value. Nevertheless other groups of organisms are represented among the fossils, and every opportunity for collecting them should be used. Brachiopods are common at some horizons, especially in the highest part of the Claxby Ironstone of the northern Wolds. A number of new species have recently been described (Owen 1965, 1970; Owen & Thurrell 1968). Foraminifera are abundant and limestone, clay and even ironstone will repay the labour involved in extricating them.

Lamellibranchs are common but gastropods are less frequent. The shells unfortunately are usually very friable. The matrix containing them should therefore be brought home and allowed to dry slowly. By impregnating the shell with melted wax or some other cementing material while the matrix is being dissected away very perfect specimens can be obtained. Crustacea occur occasionally in nodules and in the Tealby Limestone. Echinoids are rare. Worm burrows are common, especially in the ironstones.

In the central and northern portions of the Wolds the members of the Lower Cretaceous undergo only slight lateral change (Fig. 12). The Tealby Limestone becomes more pure and massive towards the north and it yielded fine ammonites (*Simbirskites*) at the time it was worked near Tealby and Normanby. In the neighbourhood of Walesby, the Roach ironstone facies comes in just above the Tealby Limestone probably as the result of a lateral change in the Upper Tealby Clay. In these areas the whole of the Lower Cretaceous has been uplifted and eroded. In the central Wolds erosion is less complete and portions of the series remain, but in the northern they have gone completely, together with portions of the underlying Jurassic beds. Of the Carstone only the lower portion (which may be earlier than Upper Cretaceous) appears to have been similarly affected. The upper, coarser section, on the contrary, extends northwards and comes to rest upon the eroded edges of successive members of the underlying series until it eventually lies directly upon early Kimmeridge Clay. This unconformity below the upper part of the Carstone in the north and central Wolds, and possibly also within the southern portion, marks the lower limit of the Upper Cretaceous in Lincolnshire. Before passing on to the consideration of the beds which lie above it reference should be made to the beach exposure at South Ferriby where a clay adjoining the Red Chalk is reported to have yielded specimens of belemnites belonging to the Brunsvicensis Zone; this material might be glacially transported Speeton Clay from East Yorkshire.

In the central and northern parts of the Wolds the dominant feature is the northerly overstep of the Upper Cretaceous, which cut out progressively earlier beds until the whole of the Lower Cretaceous was eroded north of Caistor (Fig. 12). Between the editions of this book the whole series has been excellently exposed in workings for the Claxby Ironstone at Nettleton Top, workings which exposed the Spilsby Sandstone, ammonite bearing, at the base, the ironstone itself and the overlying Tealby beds. Associated quarries in the chalk (still open) showed the Carstone above. Dr. F. Rawson has supplied the following account of the Lower Cretaceous.

"There is a sharp junction between the ammonite-bearing Lower Spilsby Sandstone (Upper Jurassic) and the Claxby Ironstone, and

DIAGRAMMATIC SECTION SHOWING RELATIONSHIPS OF THE SUBDIVISIONS OF THE LOWER CRETACEOUS ROCKS

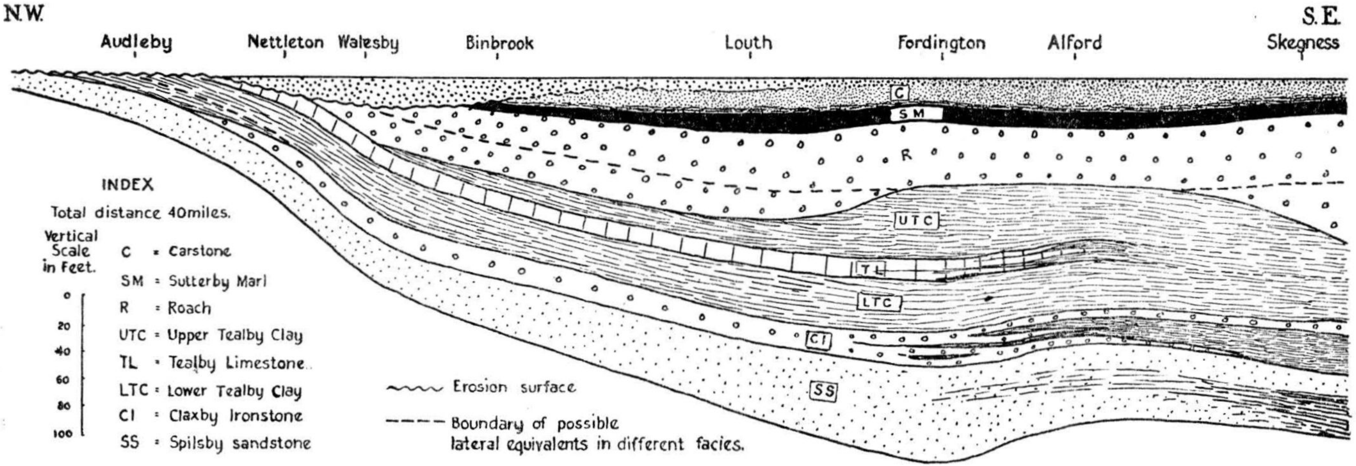


Fig. 12

derived Spilsby fossils occur in the base of the latter bed. The Ironstone reaches its maximum thickness (about 20 feet) in Nettleton Valley and is highly fossiliferous. The most prolific horizon is at the top, where a cream and pink coloured calcareous ore, resembling that in the middle levels further south, has yielded numerous ammonites, belemnites, bivalves, brachiopods and small corals. The overlying Lower Tealby Clay (30-50 feet) is like its counterpart further south, and is the only bed in Lincolnshire that at all closely resembles the Speeton Clay of Yorkshire. Fossils are common but usually poorly preserved; they include mud-borrowing lamellibranchs (e.g. *Panopea*), the belemnite *Hibolites jaculoides* and rare ammonites (*Aegocrioceras, Simbirskites*). There is a rapid upward passage into the Tealby Limestone, which consists of courses of impure limestone interbedded with thin clays and oolitic ironstone. Some bedding planes are crowded with the scallop *Entolium orbiculare*, while flat, sandy nodules in the lower part of the Limestone always enclose the "lobster" *Meyeria rapax*.

The oolitic ironstone facies of the Upper Tealby Clay is well developed at the southern end of Nettleton Valley where it is still visible in old workings that considerably pre-date the description of the area by Geological Survey officers published in 1890. It thins rapidly northwards and disappears completely towards Nettleton Top."

CHAPTER 11

THE UPPER CRETACEOUS

Following the brief uplift at the end of the Lower Cretaceous a prolonged sinking took place accompanied by extensive transgression of the sea over all, except the loftier portions, of the British Isles. The period during which this took place is called the Upper Cretaceous. An early event was the union of the two basins of deposition across the Midland area. While this was taking place the Gault and Upper Greensand (Albian) of the south were deposited and passed laterally into the Upper Carstone and Red Chalk of the northern region. The further extension of the sea over the land in all directions was accompanied by the accumulation of the white chalk to a depth of 1000 feet or more.

As already shown the upper part of the Carstone is intimately linked with the overlying Red Chalk. It must therefore be taken along with this as belonging to the Upper Cretaceous for it marks the return of the sea after a phase of movement, and the beginning of the prolonged and profound submergence which persisted through Upper Cretaceous times. In the south it consists of coarse grit which becomes coarser northwards where it encloses phosphatised and eroded fragments of fossils derived from the beds below.

The RED CHALK is perhaps the most striking rock in the Wolds in that its outcrop provides remarkable splashes of red which stand out so prominently in this landscape of colourful soils. Its junction with the Carstone is marked by the intermixture of yellow, drab and pink marls with the topmost layers of the latter and of grit with the bottom portions of the Red Chalk. In the south it is 11 to 12 feet thick, but it diminishes northwards to six feet at Otby and less beyond. At the bottom it is marly but above it is hard and nodular. It varies in colour, being dark red below, becoming lighter and merging into pink and yellowish pink at the top. At Searby it becomes white ([42]). Small exposures occur occasionally from which collections of fossils may be made. The small belemnite *Neohibolites minimus* is abundant in the marl but is less so in the harder layers which yield *Terebratula biplicata.* The ammonite *Hoplites interruptus* has been recorded. The comment made by a writer in 1859 is still largely true. Referring to the Red Chalk of Lincolnshire he says, "There is a great geological darkness in that land".

Many quarries, sometimes very extensive, provide abundant opportunities for examining the WHITE CHALK ([41]). On the whole this rock is harder than it is further south where the occurrence of several hard beds provided early workers with the initial datum levels to work from. Nevertheless the Totternhoe Stone and the Melbourn Rock can be recognised here also.

In Norfolk and elsewhere, the White Chalk when present in its fullest development is as much as 1000 feet or more thick and has been divided into 11 zones named after characteristic fossils. In Lincolnshire the greatest thickness of the White Chalk which has been found at its outcrop is slightly less than 300 feet in the neighbourhood of Louth (Fig. 13). As the highest zone hitherto recognised is that of *Holaster planus*, it would appear that this small thickness is due to the removal of the higher zones by denudation. This is confirmed by a boring at Kilnsea, just beyond the extreme north-east of the county, in south Yorkshire, where, under a cover of Boulder Clay, 1000 feet of chalk have been passed through without reaching the base. Flint casts of fossils from higher zones have been found in gravels and have been taken as evidence of the former presence of these zones in Lincolnshire.

The LOWER CHALK (CENOMANIAN) has a thickness in the Wolds of about 75 feet ([38]). There appears, however, to be a tendency for it to thin slightly towards the south-east for in a boring at Maltby in the Marsh it was only 60 feet thick and thus seems to approach the still smaller thickness seen in Norfolk.

Later workers on the Cenomanian find that the usual scheme of zoning does not hold for Lincolnshire. While *Holaster subglobosus* is common in the lower layers it is rare or absent in the upper. On the other hand *H. trecensis* is frequent above. It is therefore suggested that the zone of *Holaster subglobosus*, with the subzone of *Terebratulina ornata* at its top, should embrace the lower part of the Cenomanian, and the zone of *H. trecensis* the upper.

The Cenomanian exhibits a variety of lithological divisions. Its base is marked by the 'Sponge' bed which rests upon the Red Chalk and consists of pinkish and yellowish pink chalk. Though only two to four inches thick it is remarkably persistent throughout the Wolds. The *Inoceramus* bed, which is five to six feet thick, has a layer of green coated nodules at the base. The remainder consists of hard whitish grey chalk. Above this come 30 feet of hard bluish grey chalk with thin bands of greenish grey marl. It is capped by the Totternhoe Stone which is a massive hard bed of dark grey fossili-

SECTION OF UPPER CRETACEOUS
(Modified after Bower, Farmery and Carter)

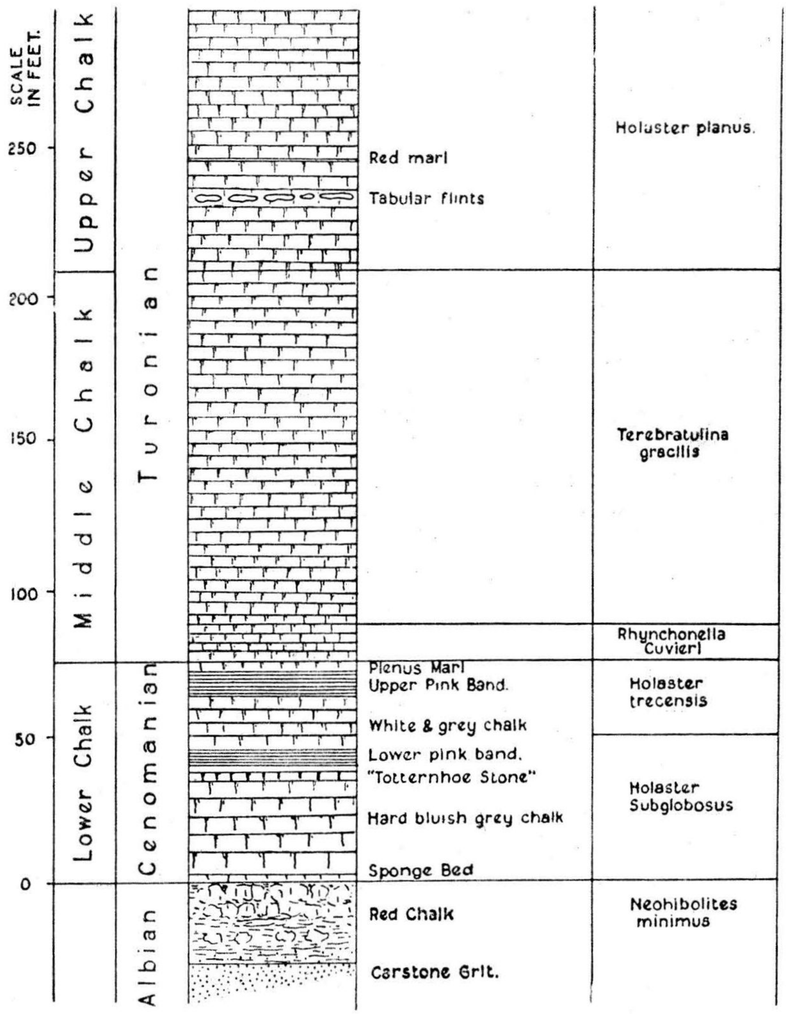


Fig. 13

ferous chalk three feet thick. This is succeeded by 10 – 12 feet of whitish grey chalk which in the region between South Thoresby and Louth is varied by the presence of two bands of pink chalk, near the base and top respectively. The upper boundary of the *H. subglobosus* zone is a little above the lower pink band. Resting on the top of the upper pink band and marking the summit of the Lower Chalk is a layer of dark grey laminated clay. This is about one foot thick and is characterised by the presence of *Actinocamax plenus* and is referred to as the Belemnite or Plenus Marl.

The Plenus Marl, a notably brief interval of clay deposition in the clear chalk sea, is widespread in Britain and the North Sea and is now ascribed on mineralogical evidence to ash fall from a volcanic eruption (Hallam & Selwood 1968). It hence provides a particularly exact time datum across country.

The entry into the MIDDLE CHALK is marked by the zone of *Rhynchonella cuvieri* which is made up of 12 – 15 feet of hard grey and yellowish grey chalk ([39]). The chalk at about this level is the source of specimens of the very large ammonite *Pachydiscus* (two to three feet across) which have been found for example in the quarries at Nettleton.

The overlying zone of *Terebratulina gracilis* is estimated to be 120 feet thick and consists on the whole of pure creamy white chalk. It is compact, evenly bedded with lines of flint nodules.

The next zone, that of *Holaster planus*, together with the two zones just described, make up the Turonian. In English usage, however, it is taken as the bottom division of the Upper Chalk and has been found to be at least 88½ feet thick. Its lower portion consists of hard chalk which becomes softer above and includes partings of grey marl. Flint occurs in large flat lenticular masses or in continuous layers several inches thick. Large hollow conical flints known as Paramoudras or Potstones are sometimes found. The largest recorded was seven feet six inches high and three feet four inches diameter at the top.

Relatively few fossils occur in the zone of *Rhynchonella cuvieri* but the number increases up to a maximum in the *Planus* Zone where nearly 200 different species have been found.

CHAPTER 12

THE TERTIARY SCENE

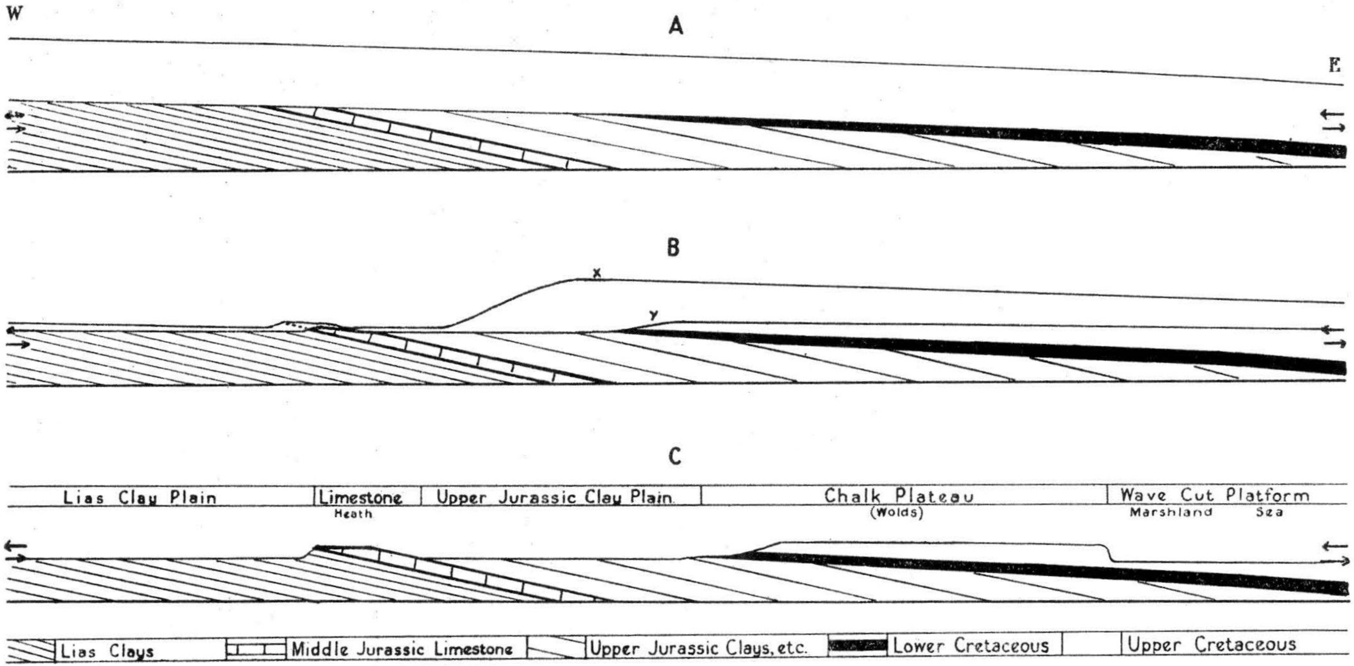
The evidence for the events which took place during the Cainozoic or Tertiary Era does not lie recorded in the rocks, but in the features of the landscape. The presence in the south of England and in East Anglia of extensive sheets of Tertiary marine deposits shows that on several occasions portions of those areas were submerged under the sea. Up to the present no traces of such deposits have been found in Lincolnshire, though it is not inconceivable that traces, like the Lenham Beds, may yet be found on the Wolds.

The fact that Cretaceous and Jurassic rocks of this county are above sea level and in some places stand at an altitude of several hundred feet shows that the long downward movement of the earth's crust which resulted in the submergence of eastern Britain with the North Sea and in the formation of these rocks eventually ceased and uplift set in. Since all these rocks are tilted eastwards it is evident that the uplift was not uniform, but was greater in the west. It was in that direction that the rocks emerged first and became exposed to the destructive action for a short time of the sea and then for a much longer period to that of the rain and rivers, frost and wind.

As the floor of the sea emerged to form that vast chalky downland, rivers and streams came into being and, flowing eastwards, did the great work of transporting the rock waste away from the land. They thus played a vitally important part in the shaping of the new landscape.

Stage by stage the western margin of each formation was removed, thus exposing the rocks below to a like destruction (Fig. 14). All this must have gone on for a very long time, probably the larger part of the Tertiary Era ([62]). Thus the countryside, which at first was occupied entirely by chalk downs gradually acquired its present belted arrangement of the outcrops referred to in an earlier chapter. Naturally the softer clays yielded more quickly and were worn down to a lower level than the more resistant limestones and chalk.

GEOLOGICAL AND GEOMORPHOLOGICAL SECTIONS ACROSS NORTH LINCOLNSHIRE



A. At the opening of the Tertiary Era.
B. In Early Tertiary (x = early surface profile y = later surface profile, ← = Base level)
C. In Late Tertiary (→ = Base level)

Fig. 14

Thus low lying clay plains came into being separated by ranges of hills with steep scarps facing west and gently dipping surfaces sloping eastwards.

Meanwhile the rivers continued their courses along the bottoms of the valleys which they had initiated. These were excavated also across the hard belts of limestone and chalk and produced gaps in the ranges ([63]). Some rivers more advantageously placed than others captured the tributaries and headwaters of these. Thus the drainage systems of the Yorkshire Ouse, the Trent-Witham, and the Wash rivers of the Welland, the Nene and the Great Ouse came into being (Fig. 15).

Certain peculiarities about the shapes of those hill ranges known as the 'Heath' or 'Cliff' and the Wolds throw light upon the late Tertiary history of Lincolnshire. One important factor in the gradual removal of a layer of hard rock overlying a clay is the process of land-slipping. When the clay belt is worn below the level of the outcropping lower surface of the harder rock then the weight of the latter tends to squeeze out the clay which is supporting its edge. This consequently tends to break and slip down the slope. In the hill feature thus produced the full thickness of the rock forms the dominant part if not the whole of the face of the scarp. The crest of the hill then marks the dividing line between the scarp face and the dip slope. An inspection of the scarp face of the 'Heath' and the Wolds reveals the fact that only a small fraction of the total thickness of the limestone or of the chalk crops out on the scarp slope and that the crest between the dip and the scarp has been bevelled down to an almost flat surface which may be nearly horizontal. This bevelling could only have taken place during a prolonged 'still stand' or period of stationary base level. During such a time the surfaces of the clay belts would soon be worn down to base level and denudation would cease. Meanwhile the harder rock belts were worn down more slowly and for the time being stood up as hill ranges. In due time they also were reduced almost to the same level as the clay plains. The whole of the Lincolnshire countryside was in the late Pliocene an extensive low-lying plain or peneplain. Evidence for this exists in the concordant summit surfaces at 450-550 ft in the central Wolds, followed by part of the ancient trackways of the High Street and Bluestone Heath Road. Succeeding stages of the late Pliocene and early Pleistocene saw a gradual recession of the sea marked by probably four periods of 'stillstand', that is periods when sea level was constant. These resulted in the formation of marine platforms at lower levels on the hillsides. These can be seen as gently inclined facets on ridges and spurs in the Wolds at 380-420 ft, 280-350 ft, 190-240 ft and 80-150 ft, and as bevels on the Heath. No marine deposits are found in conjunction with them because of later erosion particularly by ice. (Straw 1961).

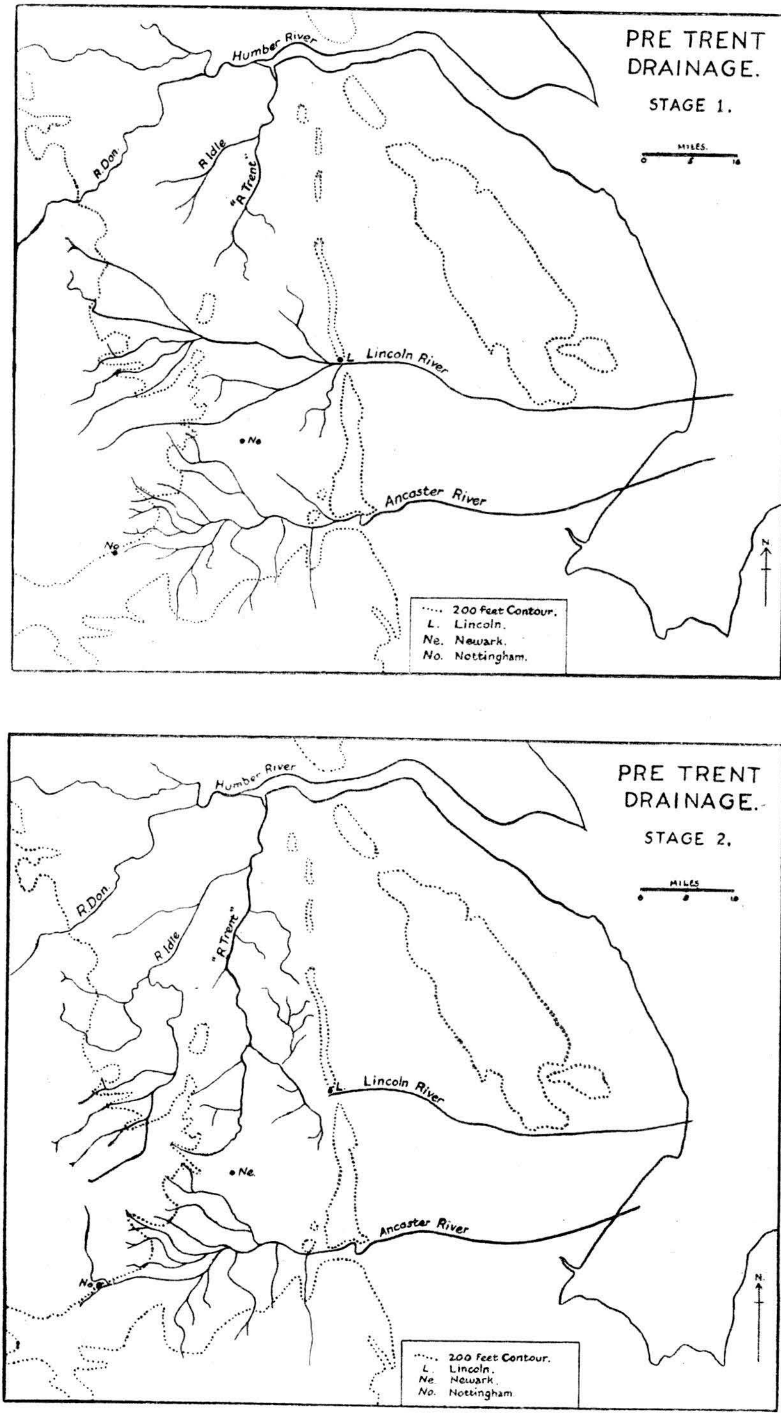

PRE TRENT DRAINAGE.
STAGE 1.
MILES.
0
5
10
Humber River
R. Don
R. Idle
"R. Trent"
L
Lincoln River
Ne
No
Ancaster River
N
200 feet Contour.
L. Lincoln.
Ne. Newark.
No. Nottingham.
PRE TRENT DRAINAGE.
STAGE 2.
MILES
0
5
10
Humber River
R. Don
R. Idle
"R. Trent"
L.
Lincoln River
Ne.
No.
Ancaster River
N.
200 feet Contour.
L. Lincoln.
Ne. Newark.
No. Nottingham.

Fig. 15

The fact that these fragments of an ancient peneplain now lie several hundred feet above sea level indicates the renewal of uplifting earth movements accompanied by a revived activity of denuding agencies and of the rivers mentioned above. Once more the clay belts were worn down towards the new base level while the erosion of the hard belts lagged behind and formed hill ranges once more. At the same time the rivers kept pace with the lowering of the clay belts by deepening their gaps across the ranges. The Yorkshire Ouse thus initiated the formation of the Humber gap while the other Lincolnshire rivers played a similar part in the establishment of the much wider Wash gap. The streams which flowed eastwards down the gently sloping surface of the harder belts were also rejuvenated and initiated all those processes which resulted in the formation of those valleys which are such a striking feature in the scenery of the Wolds, especially in their southern portion.

While the surface of the Limestone belt consisting on the west of peneplain, on the east of dip slope, to-day rises gradually from the adjoining plain of the Upper Jurassic clays, that of the Wolds passes abruptly at its eastern margin into a steep slope which cuts across the valleys and truncates the intervening hilly spurs. As revealed by numerous borings in the Marshland this slope descends to a depth of about 80 feet below the present surface and passes rapidly into a level platform which, at about the same depth, forms the foundation for the whole of that area. This feature therefore points to another prolonged period of still stand during which the level of the sea relative to that of the land was about 70 feet lower than it is now. At the opening of that period the surface of the Wolds, sloping gently eastwards, passed under the sea. Gradually the waves cut their way into the land, removing the lower reaches of the valleys and truncating the spurs until the shore line came to lie in the position of the western margin of the Marshland. At that time the east Lincolnshire coast presented a striking contrast to its present condition and resembled much more closely that of the existing Sussex coast. In those far off days, holiday makers, had there been such, could have walked along footpaths following the tops of chalk cliffs that looked out towards the North Sea.

CHAPTER 13

THE STRUCTURE OF LINCOLNSHIRE

In the foregoing pages the story of the various episodes of earth movement has been outlined in its relation to the accumulation of sediments. This may be recapitulated briefly.

In the Pre-Cambrian times, before life appeared on the planet, volcanic sediments accumulated over the Midlands and Lincolnshire, and these were sheared and twisted into highly metamorphic rocks. At a later period older Palaeozoic sediments were laid down, but no great thickness of these has yet been found and they may have been largely removed before the accumulation of the thick Carboniferous series. Lincolnshire was on the south-eastern edge of this Carboniferous basin, and suffered progressive tilting towards the north-west during the period. Late in Carboniferous times the Variscan movements developed, and in the associated adjustments the floor of newly accumulated Carboniferous sediments was crossed by great wrinkles — many miles in length and thousands of feet in height. These divided the Lincolnshire part of the original basin into largely separate synclines, and the structural downfolds and upfolds remain as evidence of the mountain building movements, even though the topographic irregularity was completely planed off by erosion before the Permian rocks were laid down.

This phase of orogenic movements — the last which affected Lincolnshire — coincided with the ending of north-westerly tilting which had characterised the Carboniferous period, and the beginning of easterly tilting which, broadly speaking, was continuous through Permian and Mesozoic times.

At first (during the Permian and earlier Trias) the area of greatest subsidence lay north of Lincolnshire, in east Yorkshire. At the beginning of the Jurassic period the Market Weighton block in south Yorkshire became a stable, non-subsiding area, and in Lincolnshire rocks of this and the Lower Cretaceous periods were laid down in a basin limited by this block in the north and by the complementary stable Mesozoic London platform in the south.

The even subsidence of the basin was interrupted occasionally by short-lived minor periods of folding — as in later Inferior Oolite and mid-Cretaceous times (Fig. 16) — and was ended by a general uplift beginning at the end of the Cretaceous. Probably gently eastward tilting took place through much of the Tertiary, as subsidence of the North Sea basin progressed. Some renewal of movements took place along ancient lines of faulting and folding — adjustments which are very small in comparison with their older congeners, but which nevertheless have their importance in relation to mineral exploitation and water supply. Latterly, easterly tilting has again resulted in accumulation of sediments — the recent clays and silts still being laid down in the Fenland and the Wash.

In the following pages the surface structural features of the county are described area by area, and the general features are shown on the structural contour map, drawn on the two main water bearing horizons of the county (Fig. 16). The post-Cretaceous flexures mostly arose on or near older lines of folding, and the history of each area is now briefly traced.

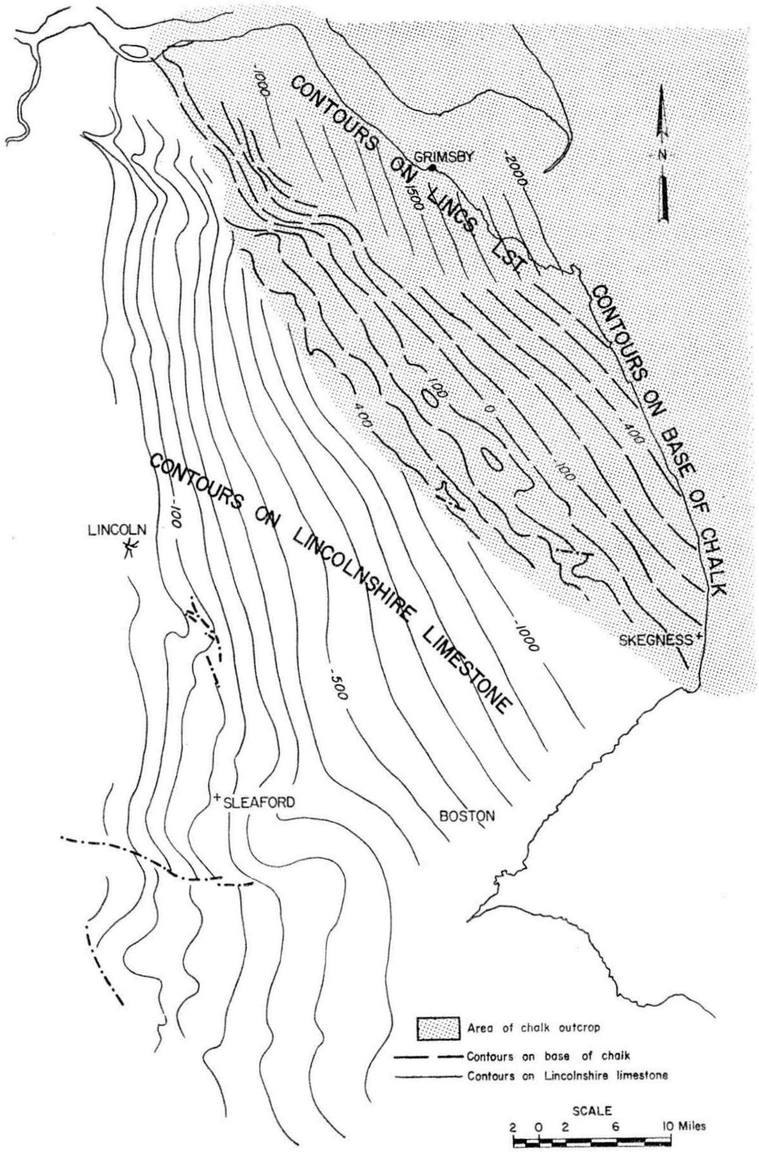
NORTH LINCOLNSHIRE

In the northernmost part of the county are two lines of movement which affect both the Jurassic and Cretaceous rocks — one coincident with the Humber, the other running from Scunthorpe E.S.E.-wards past Brigg and Caistor.

At the Humber, the Lias and Oolite outcrops turn sharply eastwards, and the Kimmeridge Clay and Red Chalk outcrop well to the east of their normal line of outcrop north-east of South Ferriby. Each of these rocks returns to the normal line of strike north of the estuary, and the structure has consequently been interpreted as an east-west anticline. Steep and variable dips suggest that faulting occurs and H. C. Versey ([53]) has regarded faulting as the most important factor involved. In either case the structure is complex, but most of the evidence is hidden beneath the Humber.

The Scunthorpe – Brigg – Caistor structural line is more accessible, and better known. It is responsible for two notable deflections of the normally straight north-south scarps — the Inferior Oolite at Scunthorpe, the Cretaceous at Grasby — and for a less obvious deflection of the Lower Lias at Flixborough. In the west the structure is a combination of folding and faulting, producing a 'trough' about 70 feet deep across the Frodingham Ironstone out-

STRUCTURAL CONTOURS ON LINCOLNSHIRE LIMESTONE (TOP) AND CHALK (BASE)



The Lincolnshire Limestone contours are also shown – from borehole records – north of the Wolds where the formation is overlain by Chalk, to illustrate the structural divergence due to pre-Upper Cretaceous tilting and erosion of the Jurassic beds.

Fig. 16

crop, and a faulted syncline between Santon, Appleby and Thornholme. Over the Inferior Oolite outcrop the southern flank of the structure increases in importance while the other dies out, so that the syncline is replaced eastwards by a faulted monocline of northerly downthrow, which trends south-eastwards towards Brigg. This in turn can be traced past Wrawby almost to the larger east – west structure at Grasby, which has a northerly downward displacement of 300 feet, mainly due to folding.

The main part of these movements is evidently post-Cretaceous, as the chalk is involved in the folding. The tracing of Inferior Oolite thickness changes however shows that the Hibaldstow Beds reach a local maximum in the syncline associated with the fold just east of Broughton, and are thin or locally absent on the top of the steep flank close to Broughton village. This indicates that a slight preliminary subsidence took place along the line of folding at the time of the early Great Oolite movements, so that in the erosional phase which followed, the Hibaldstow Beds were removed on the high standing sections but preserved in the syncline.

Elsewhere in north Lincolnshire one other fold of the system is known. There is a small deflection in the Inferior Oolite scarp at Harpswell due again to a small W.N.W. – E.S.E. fold, with northerly downward displacement. Here there is evidence of a longer history, for the surface wrinkle is known to be parallel to and immediately south of the Spital anticline, in the deep-seated Carboniferous rocks which no doubt controlled its development. Furthermore, from Caenby Corner southwards — on the high side of the monocline — the Hibaldstow Beds are absent, so that the Great Oolite rests directly on Kirton Beds, providing evidence of a movement during Oolitic times, although, as at Broughton, this was much smaller than the post-Jurassic flexure.

EAST LINCOLNSHIRE

The structures on the Humber and at Grasby are the strongest which affect the Wolds, but the general structure needs some comment. In particular it has been thought that an anticlinal line runs through Louth and Willoughby, and that this marks the site of a more important deep-seated fold.

One line of evidence for such a structure is the presence of numerous dips towards the south-west — opposed to the regional direction — in the southern part of the Wolds. They have been observed near Welton, Candlesby, Alford, South Thoresby, Dalby, Oxcombe, Withcall and Tathwell. No fewer than 17 out of 25 recorded dips in the section of the Wolds south of Louth are to the west or south-west. Re-examination of sections confirms the measurements, shows an absence of glacial disturbance which might produce such an effect, and shows also that many of the records are in places where normal landslip would not occur.

The plotting of elevations of the Red Chalk from outcrop and borehole evidence, however, shows that over the same ground the Cretaceous beds have a regional north-easterly fall, opposed to the majority of these measured dips. The small N.W. – S.E. folds which are present are too small to provide an explanation, for many of the dips are too far west to be on their south-westerly flanks. Furthermore, persistent dips of two or five degrees would produce inliers of Lower Cretaceous rocks in many places. It therefore has to be concluded that the area is cut by a large number of strike faults, which nullify the effect of dip at short intervals. Step faulting on a small scale has in fact been observed at Claxby near Alford ([6]).

Structures of this type are unlikely to be deep seated, and it is most likely that they arise from a slow squeezing out of the Lower Cretaceous clays and a washing out of softer parts of the Lower Cretaceous sands, which has led to an even spreading and collapse of the overlying chalk cover. It is probably significant that the reversed dips only occur over the full width of the Wolds in the section where both eastern and western slopes expose the soft Lower Cretaceous rocks; whereas in the north where the cover of chalk is unbroken to the east these features are confined to the western part of the outcrop. Comparable structures are associated with hilly tracts of Mesozoic rocks at other places in the Midlands ([49]).

Accumulation of data thus removes much of the surface evidence for the Louth – Willoughby anticline, which has been supposed to mark the site of a much more deep-seated and important fold. The only possible representative which now remains is a small N.W. – S.E. roll passing one mile south-west of Louth, which might perhaps be due to superficial movement of the type which has produced the reversed dips, resulting from subsidence towards the Boulder Clay — buried cliff which here flanks the seaward side of the Wolds. Finally, geophysical (seismic and magnetic) surveys carried out by the British Petroleum Company failed to show any indication of an uplift in the Carboniferous or older rocks on this line.

THE LINCOLN DISTRICT

During the search for oil in the region, attention was drawn to the area between Lincoln and Blankney by discovery of abnormally high figures there for both gravity and terrestrial magnetism. This indicated an uplift bringing older and denser rocks nearer to the surface, the centre of the uplift being centred on Nocton Heath. Seismic surveys and borings have since shown that there is a broad anticlinal fold in the buried Palaeozoic rocks, so that the Carboniferous Limestone surface is there about 1000 feet shallower than in the basins on the east and west.

Surface surveys show that the folding which produced this large structure did not entirely cease before the Permian was laid down, but that later earth pressures on a much smaller scale produced slight renewal of the movement. Stratigraphically this is shown by moderate thinning of the Lias in the Nocton wells as compared with Boultham and Dunston, and by the absence of the Lower Estuarine series over an area symmetrical with the uplift. The Lincolnshire Limestone thus comes to rest on the Northampton Ironstone along the outcrop from Coleby to Lincoln, and the Lower Estuarine Beds are seen to be very thin or absent in inliers in the limestone plateau and in shallow borings as far east as Metheringham.

Structurally the deep-seated uplift is reflected in the development of an interruption in the easterly dip of the beds. The area of the Lincolnshire Limestone outcrop between Bracebridge and Blankney is occupied by a broad terrace, over which the beds are either horizontal or dip slightly westwards. This terrace is limited on the east by a N.N.W. – S.S.E. fault, running a little west of Potter Hanworth and Dunston, which has a downthrow of 70 feet to the east. Associated with this are subsidiary minor fractures running nearly east-west, which produce small rifts and blocks in the oolite beds. The main fault coincides in position with the very steep eastern flank of the buried Palaeozoic uplift, and is probably due to renewal of an ancient fracture. It has the important effect of separating the outcropping Lincolnshire Limestone from the part buried beneath the Fenland to the east, cutting off the latter from its source of water. The area from Tattershall northwards is consequently of little value for underground water supply.

SOUTH LINCOLNSHIRE

At the latitude of Sleaford there is a sharp change in the pattern of the Jurassic outcrops. For 70 miles to the north the formations outcrop in regular north-south bands, with only small deviations from straightness where the above described structures cross the outcrops. To the south of it the regularity is lost; outcrops are sinuous and dissected, cut up into inliers and outliers and deeply trenched by river valleys. Structures transverse to the general strike produce very marked effects.

This contrast is due essentially to a sharp change in the regional eastward dip. Accurate plotting of well records shows that north of the dividing line, which runs from Syston (Grantham) past Swineshead, the eastward dip is approximately 100 feet per mile (two degrees). South of the line the dip is 30 feet per mile, or even less. Transverse folds of a size which produce only a minor flexure in contours of the more steeply dipping beds have a much greater effect where the strata are almost horizontal.

The line of change is marked by small faults, arranged *en echelon*, which cross the Lias outcrop in the neighbourhood of Long Bennington and Foston (at the former place there is a shattered area associated with the crossing of this east-west structure and the buried N.N.E. – S.S.W. Eakring – Foston – Bourne anticline), and continue westwards by Syston to Dembleby. In the west the throw of the faults is small, but eastwards the combination of faulting and monoclinal fold produces a northerly downward displacement of more than 100 feet.

From an economic point of view the area of very gently dipping beds is of major importance, for it results in the presence of the water-bearing Lincolnshire Limestone within reach of shallow borings as far east as Spalding. The amenities of the Fenland villages have been enormously improved by this ready availability of good water.

From the theoretical aspect the dividing line is of even more importance. At depth beneath the Jurassic feature is a much larger structure of the same type in the Carboniferous rocks — a monocline or the edge of a fault block, with a northerly downthrow of 1000 feet. Followed westwards the belt of small faults swings north-westwards along the transverse Eakring – Foston line of folding, but a line of sharp change in the strike of the Mesozoic rocks links the Lincolnshire structure with a faulted belt at Nottingham, and so with the faulted monocline which forms the southern limit of the Pennines. Eastwards, in the same line, lies the east-west stretch of coastline of north Norfolk — the largest deflection in the east coast of England. In the west the truncation of the Pennines is due to a southward downfold; on the Trias and Lias outcrops the displacement tends to be very small; in the oolites of Lincolnshire the movement was downwards to the north, and the northward truncation of the Norfolk coast again may also be due to northerly downfolding.

The dividing line has had a long and varied history. The great monocline in the Carboniferous rocks south-west of Sleaford is evidence of a major movement in the Variscan epoch. Later, after the period of peneplanation, the line came to be the southern limit of the Permian sea — the latitude where the marine limestones die out. During the Triassic and Jurassic there seems to have been no distinctive movement, but the line marks the northern edge of a long depositional syncline (see below) in which several of the smaller subdivisions show unusual thickening. Probably in the Tertiary there occurred the 'scissor movement' which produced the main surface structural displacements detailed above. The line is thus a major tectonic feature of the country.

Other structural features in south Lincolnshire are of more local importance. The westward swing of outcrops south of Grantham is due to a shallow east – west syncline, which broadly coincides with a deep trough in the buried Carboniferous rocks, and is aligned with the Old Dalby – Waltham – Dunsby depositional syncline, in which Rhaetic, Lias and Great Oolite series show an unusually thick development ([51]). The same story is thus repeated — an east–west Palaeozoic fold slightly rejuvenated to influence Mesozoic sedimentation, and a final movement in the Tertiary period affecting the surface structures.

In the same area there are small N.W. – S.E. wrinkles, which produce inliers of Lincolnshire Limestone at Irnham and Grimsthorpe. These coincide approximately with N.W. – S.E. folds in the Carboniferous rocks, but they are much narrower structures than the features discussed above, and information is not yet available in sufficient detail to analyse their Mesozoic history.

CHAPTER 14

THE PLEISTOCENE DEPOSITS

Lincolnshire, along with the rest of the country has, since the Tertiary Era, experienced extreme changes of climate ranging from severe spells of arctic cold to periods of temperate or even sub-tropical conditions. During the former extensive fields of snow and ice existed over north-west Europe and minor fields over the highlands of Britain. From these highlands broad glaciers flowed across the lowlands to the sea. Those flowing eastwards encountered a mighty outflow coming across the North Sea from Scandinavia which jostled them out of their courses and forced several of them to turn southwards along the lowlands and the shallow coastal seas east of the Pennines. Passing through Lincolnshire the ice splayed out across the East Midlands and filled up the Wash basin from whence it overflowed on to the adjoining portions of East Anglia and the South Midlands.

Wherever the ice flowed it brought with it soil and rock waste, stones and boulders from the district whence it came and over which it flowed. When in due time the climate ameliorated, the ice melted, leaving this material covering the countryside like a veneer. Much of this material was derived from destruction of clay outcrops, and the mixture of clay with entrained stones and rocks is commonly called Boulder Clay. Locally however the source rocks were sands or chalk (as for example at Hemingby on the western side of the Wolds), and to cover the range of lithology the alternative word Till is now frequently used. The boulders are often faceted and striated and some are of great size — for example in cutting the railway south of Great Ponton a mass of Limestone 450 feet long and 30 feet thick was found embedded in the clay, an impressive illustration of the transporting power of ice. The waters that were released by the melting resorted some of this material and re-deposited it as gravel, sand and silt.

Since that time this veneer has been subjected to the destructive action of frost and rain, of rivers and streams. Whether or not it ever covered the whole of the highest portions of the Jurassic limestone belt and the chalk wolds is a problem that has yet to be solved. In the former area it is absent north of Ancaster and Sleaford but south of these places it occupies much of the upland country east of the Witham valley. In the latter it survives chiefly along the floor of the valleys which open eastwards especially around Kirmington, west of Louth and between South Thoresby and Tetford.

On the low country of central Lincolnshire innumerable valleys have been excavated through the glacial deposits into the rocks below, thus leaving tattered shreds capping the low hills left between. On the lowest ground adjoining the Humber and the Wash the veneer passes from view beneath broad sheets of estuarine silts, alluvium and peat.

Two glacial periods are well known in Lincolnshire. The first of these, named the Wolstonian glaciation was responsible for deposition of the main Boulder Clay cover across the East Midlands — the "Chalky Boulder Clay" of the older literature. (This was not the first British glaciation, but evidence of older episodes has not been recognised within our area). The second was the Devensian glaciation, which covered East Lincolnshire up to the Wolds. The latter is known from radio-carbon dating to have lasted from 70,000 to 10,000 years B.P. The earlier glaciations are not accurately dated in years, but the Wolstonian probably lasted also for some 60,000 years. Country-wide correlation is still however controversial, as is the question as to whether it was a single or double glacial period.

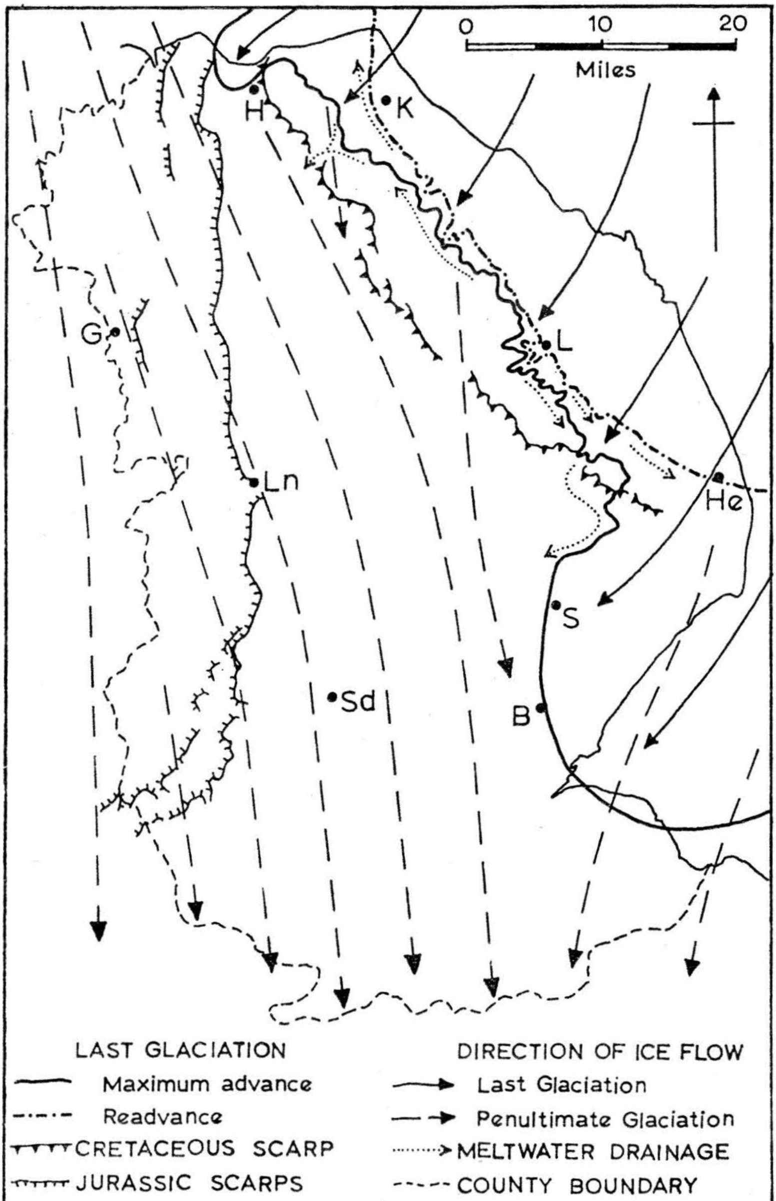
Generally speaking the Devensian Boulder Clays east of the Wolds are coloured brown or various shades of brown tinted more or less deeply with purple. Over the remainder of the county the colour of the Wolstonian tills is predominantly grey and blue in association with that of the Jurassic clays from which much of the matrix was derived. On the whole those south of Grantham and Ancaster are lighter than the clays of the central area. Other colours come into prominence locally. Immediately east of the Trent some of it is red owing to the incorporation of Keuper Marl. Along the eastern margin of the Jurassic limestone belt the colour is often brown. It has been suggested that this is due to weathering of the boulder clay. It seems more probable, however, that at some places the characteristically brown soil which develops on these limestones has contributed a considerable quota to the clay matrix. Around the south-west margin of the Wolds, in the area roughly defined by the line joining Sixhills, Panton, Minting, Woodhall and Mareham le Fen the boulder clay is white for it consists mainly of waste scraped off the surface of the Wolds.

Among the smaller stones chalk and flint are almost universally present, the former in the form of pebbles of various sizes or of innumerable widely disseminated pellets. These have led to the establishment of the descriptive title of Chalky Boulder Clay for these deposits. This title is often prefixed by such terms as Jurassic, Kimmeridgian, Neocomian to indicate the source of origin of a large portion of the matrix, stones, and fossils contained in the clay of any locality. East of the Wolds the matrix of the clays bears no obvious resemblance to any particular formation, since the ice which brought them entered the area from the North Sea.

The place of origin of the Wolstonian ice and its direction of flow have already been indicated in broad outline. There are however interesting problems. The above mentioned distribution of Keuper, Lower Jurassic and Upper Jurassic material shows that the main ice streams were very nearly along the strike of the rocks in the west and centre of Lincolnshire. Nevertheless chalk and flint are also incorporated in the Boulder Clay across the whole width of the county into Nottinghamshire and beyond. Occasionally 'clean' boulder clay of local origin is found beneath a Chalky upper layer: does this indicate a two-phase flow, with the earlier material commonly (but not quite always) incorporated in a later incursion from the northeast?

One source of direct information on the direction of the ice streams is provided by study of the rock surface beneath the Boulder Clay. Thus for example in 1882 when the goods yard at Dunston station was levelled the surface of the Lincolnshire limestone which underlay it was found to have been polished and striated by ice action ([5]). The direction of the striae lay between the bearings N.W. and W.42 N. Evidently that was the direction from whence the ice flowed over that spot. Excavations elsewhere may at any time bring similar surfaces to view. These should be examined.

On the accompanying map the distribution of the types of boulder clay already referred to are shown (Fig. 17). A consideration of this indicates that the general direction of movement of ice over North Lincolnshire accords with that shown by the ice striae. In this connection the stones and boulders in the clay are of particular interest for a number of them are of a distant origin ([55]). They include a rich variety of igneous and metamorphic rocks — granites, basalt, porphyrites, gneisses and schists — from the Lake district, the Cheviots, and even Scandinavia. From the map it will be seen that the Wolstonian ice probably crossed the northern Wolds from a general northerly direction and across the area west of Louth to the valley of the Bain. The latter stream evidently brought with it large quantities of chalky waste from off the Wolds and thus deposited the intensely Chalky Boulder Clay already referred to



(*A. Straw*)

(B – Boston; G – Gainsborough; H – Horkstow; He – Hogsthorpe; K – Killingholme; L – Louth; Ln – Lincoln; S – Stickney; Sd – Sleaford)

Fig. 17

(the Calcethorpe Till). The interesting suggestion has been made that at the time of its formation the lower part of the ice with its main burden of mixed debris (the Welton Till) was banked against the east side of the Wolds, while the upper, cleaner ice passed over the Wolds, stripping the chalk of its soil and waste which it deposited as it entered the area of the oolite clay lowland.

Shallow borings through this clay reveal the fact that it is partly underlain by Kimmeridgian Boulder Clay. Facts of this type suggest a variety of questions. Was the latter clay there first and subsequently buried under chalky boulder clay, or did the ice which brought the latter override the ice which carried the former? Again, did the latter ice push the former ice aside?

Owing to the more extensive and frequent exposures of these deposits in the adjoining regions of Yorkshire and East Anglia glacial studies have been carried on to a much greater extent there than in Lincolnshire which, by reason of its intermediate position, must hold the key to the correlation of the stories of those two areas with one another. In Lincolnshire however the Devensian boulder clays east of the Wolds relate closely to those in Holderness, while the Wolstonian clays of the rest of the county have stronger affinity with those of East Anglia and the East Midlands.

Generally the Devensian clays have been better exposed. The low cliff exposure at Cleethorpes has already been described in detail by former workers ([7]). The upper part of the section consists of reddish brown sandy boulder clay streaked with grey passing down into purplish clay. Lenticular beds of yellowish sand occur near or above the junction.

Further south, along the beach at low spring tide, extensive exposures of boulder clay may be seen around Chapel and Ingoldmells Points. At the former site a dark brown boulder clay overlies a very light brown boulder clay having a slightly purplish tint. Both clays contain pebbles of chalk as well as many other stones and occasional boulders. In the lower clay, however, there are innumerable pellets of chalk and some patches of very chalky clay. The junction between the two is a sharply defined corrugated surface in which the corrugations trend from N.N.E. to S.S.W. At some points the junction is disturbed and the lower is churned up into the upper clay.

At Ingoldmells the same two types of clay occur. About 100 yards north of the Point these are seen to be separated by two distinct gravelly deposits. The upper one has a dark matrix of brown sand which encloses angular stones and flints with only a few chalk pebbles. Patches of similar gravel are enclosed in the upper clay. The lower one varies from a shingle consisting of large chalk pebbles through gravel and coarse sand to a light rusty coloured laminated silt. A considerable expanse of the latter is from time to time exposed opposite the end of the Point. These gravels on one occasion yielded a Mammoth's tooth. There is a close similarity in the features exhibited by this beach exposure and some of those recorded by the Geological Survey for the gravel pits at Burgh ([6]). The section there seen was as follows:

	ft.	ins.
Purple brown boulder clay	3	6
Sand with gravelly layer	6	9
Beds of stones and gravel	3	2
Marly boulder clay like the above.		

Numerous bones including those of *Elephas*, *Rhinoceros*, and *Bos* and a black turfy peat were found at the bottom of the gravel. These facts indicate the occurrence of an interglacial break and suggest that the beach exposure merits very careful and detailed examination.

Near South Thoresby brown boulder clay is seen overlying fragmentary brown gravels resting upon a considerable thickness of chalky gravel. Large quarries between Welton-le-Wold, South Elkington and Little Welton also show brownish tills resting on poorly stratified brown gravels with innumerable brown flints. This in turn rests on sands and pebbly gravels which exhibit clearer bedding. Recent studies (Alabaster & Straw, 1976) have clarified the sequence of deposits and confirm that at some points, brown clay rests on the bevelled margin of a greyish or purplish brown chalky clay, and that the gravels are essentially sediments accumulated within an old valley during a severely cold climate. They contain some derived fossils of animals such as elephant, deer and horse, and even some humanly-fashioned handaxes (Fig. 18).

As revealed by many borings, some 80–90 feet of boulder clays comprising several layers and variable in colour and chalkiness underly the whole of the countryside east of the Wolds. Much of this is hidden under a thin covering of salt marsh silts. In the Middlemarsh the Boulder Clay crops out to the surface. This outcrop is roughly divided into two belts by a broken strip of sand and gravel running parallel to but a mile distant from the margin of the Wolds at between 25 ft. and 50 ft. O.D. These sands and gravels pass some way underground eastwards and separate an upper from a lower purplish boulder clay. At Keelby, Aby, Alford and Willoughby the lower part of this gravel has yielded a wide variety of marine and estuarine shells which compare closely with assemblages of shells found in similar gravels at Kelsey and at Keyingham north of the Humber. Shells have also been found in laminated silts at Kirmington at the base of which a thin peat occurs, at about 64 ft. O.D. Above the silts is a gravelly seam which thickens in the eastern part with battered flint shingle, the remnant of a former

GLACIAL FEATURES OF THE ELKINGTON AREA

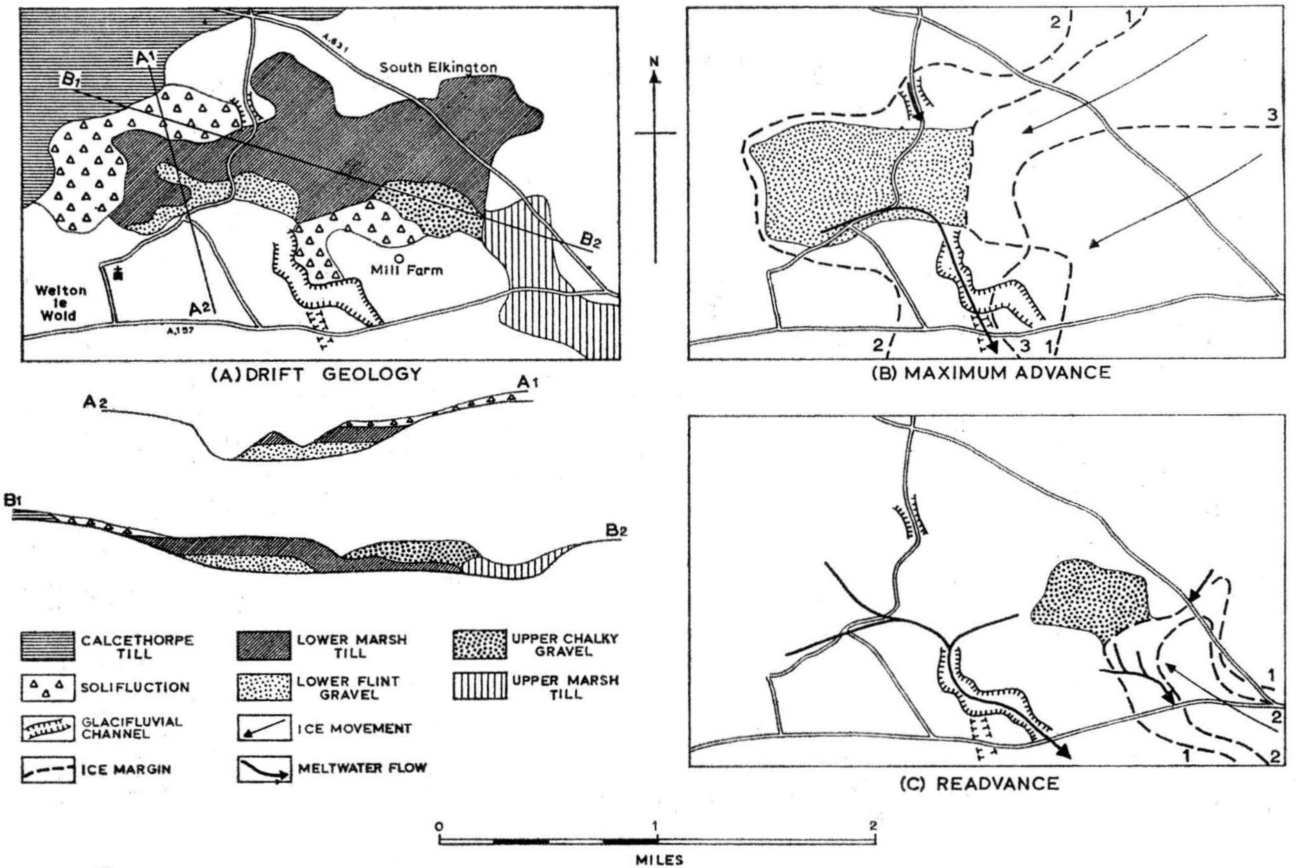


Fig. 18

storm beach. This varied set of deposits is overlain by brown boulder clay believed to be the one beneath the shell-bearing gravels (Fig. 19). Other boulder clays beneath the Kirmington deposits have been proved by boring and are presumably of Wolstonian or earlier age. These two groups of deposits suggest the occurrence of one, possibly two temperate periods between the glaciations which produced the various boulder clays.

The sequence of glacial deposits east of the Wolds is provisionally summarised in the accompanying section (Fig. 19). It would seem on present evidence that it is the lowest boulder clay in its lithological types which extends over the remainder of the county, and that an interglacial period occurred between its deposition and that of the Devensian clays. This can be shown in another way.

When the edge of the Devensian ice stood near Kirmington, meltwater streams passed along the Barnetby valley towards the neighbourhood of Brigg. The materials left by these streams provide one link between the glacial deposits east and west of the Wolds. In the Ancholme valley near to Brigg, Chalky Boulder Clay caps the low rises of ground, but the outwash gravels lie in the hollows. It may be safely assumed that the fragments of Chalky Boulder Clay are relics of a more continuous sheet which has been exposed to denudation long enough for new valleys to be excavated through it to the solid rocks beneath. On the return of glacial conditions, ice invaded east Lincolnshire and washed sands and gravels westwards into the new valleys. The importance of this interlude is illustrated again by the fact that at the southern end of the Wolds, Chalky Boulder Clay caps Warden hill at an altitude of more than 250 feet, while Brown Boulder Clay is banked against the lower slopes of the Wolds margin up to a level of approximately 100 feet. Evidence of a similar kind will no doubt be forthcoming from other parts of the County.

GLACIAL DEPOSITS OF THE EAST LINCOLNSHIRE MARSHLAND

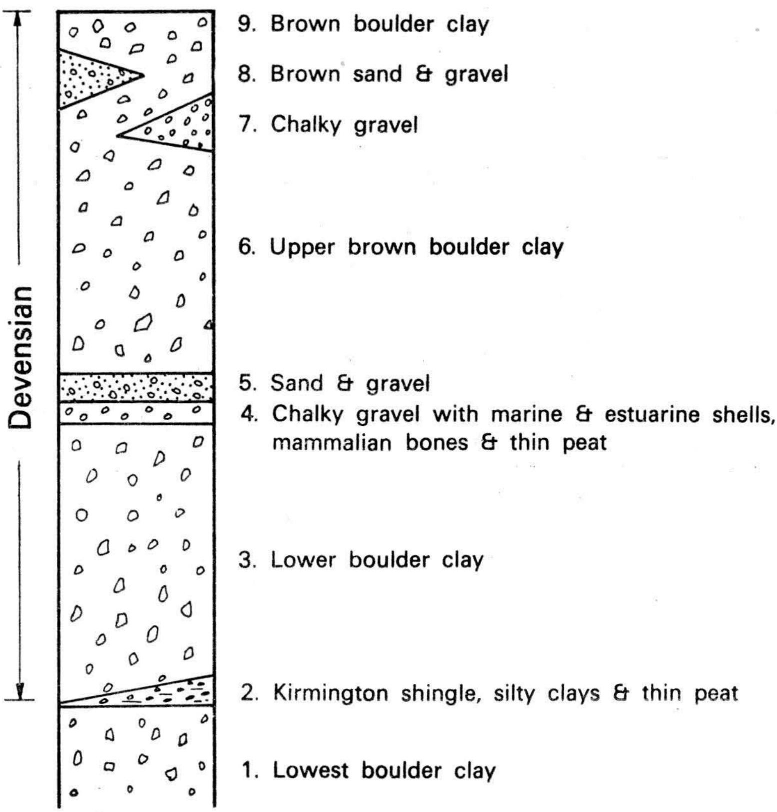


Fig. 19

PLEISTOCENE EVENTS IN LINCOLNSHIRE

STAGES	APPROXIMATE DATES B.P.	CORRELATIVES	MAJOR STRATIGRAPHIC UNITS AND GEOMORPHIC EVENTS	CLIMATE
DEVENSIAN	75,000 – 10,000	Last or Weichsel Glaciation Purple and brown boulder clays	Cover Sands	Periglacial
			Upper Marsh Till	Glacial
			Interstadial: weathering and fluvial activity, Tattershall gravels	Variable: periglacial to temperate
			Lower Marsh Till	Glacial
IPSWICHIAN	110,000 – 75,000	Last or Eemian Interglacial	Valley excavation Marine erosion east of Wolds and within Fen basin Fen margin gravels ? Kirmington fossiliferous gravels	Temperate
WOLSTONIAN	150,000 – 110,000	Penultimate or Saale Glaciation Chalky boulder-clays	Northward diversion of Trent Calcethorpe, Welton, Belmont, Wragby and Heath Tills Welton gravels	Glacial Periglacial
HOXNIAN	200,000 – 150,000	Penultimate or Holstein Interglacial	?? Kirmington fossiliferous deposits Valley excavation Marine erosion east of Wolds	Temperate

compiled by A. Straw

CHAPTER 15

SCENIC CHANGES DURING THE PLEISTOCENE

The Pleistocene lasted for a period which is estimated at more than a million years. Apart from the appearance and disappearance of icefields and glaciers changes took place in the relative levels of land and sea, that is to say in base level. Such movements are said to be positive if the sea moves on to the land and negative if it moves off this. These movements therefore affected the position of the shore line and the rates of deposition of sediments and of the erosion of land by rivers and other denuding agencies. For this reason evidence of changes in base level must first be considered.

The nature of such evidence is well illustrated by the deposits at Kirmington ([56, 64]). Here a thin peat associated with sandy warp occurs at an altitude of 64 feet O.D. The peat contains the remains of subarctic estuarine plants and the warp has yielded such fresh-water shells as *Planorbis* and *Bithynia*. This peat must have been formed at or very close to base level so that the sea level, for the time being, impinged against the land surface along the present 64 feet contour line.

Overlying the peat and warp come about 17 to 18 feet of laminated warp which has yielded estuarine and marine shells including such forms as *Scrobicularia piperata* and *Cardium edule* which have a normal habitat situated near to or below the lowest spring tide level. They therefore indicate a slight positive movement of base level accompanied by shallow submergence. This warp is overlain by a layer of battered flints eight feet thick which is regarded as a beach deposit. The top surface of this is to-day at an altitude of 90 feet O.D. It is evident, therefore, that during the period represented by these 26 feet of deposits the base level oscillated between the present 64 feet and 90 feet contours.

It is reasonable to anticipate that careful search at corresponding levels along the margins of the Wolds will bring to light further evidence in the form of fragmentary raised beaches or of wave cut terraces. Hitherto no salient observations have been recorded from the east margin of the Wolds where the fringing belt of till, in the north, lies well above the 100 feet contour and will accordingly hide any traces of beaches or terraces that may be present. Southwards the level of this fringe sinks and it is interesting to note that as long ago as 1887 the officers of the Geological Survey drew attention to a sand bank lying on a terrace feature which could be traced for some miles along the southern margin of the Wolds from West Keal eastwards ([6]). The datum levels of this feature were not recorded but an inspection of the maps shows that it lies in the vicinity of the 100 feet contour line. This 'sand bank' is not a marine feature; it is a kame terrace formed between the former ice edge and the rising ground (Straw 1958). Its surface at 100 feet O.D. is a response to Lake Fenland/Humber, and is therefore genetically different from the Kirmington deposits. There is a similar feature running west from Barton toward South Ferriby in the Humber gap.

The next set of deposits to be considered consists of gravels and sand interbedded between the Upper and Lower Boulder Clays (Fig. 19). Owing possibly to the overlap of the lower beds by the Upper Boulder Clay or to non-deposition, the outcrop of the gravels and sands is broken north of Aby. At Willoughby it swings south-eastwards, apparently in accordance with a similar trend of the margin of the overlying boulder clay, across the Marsh to the coastline between Chapel and Ingoldmells; an arrangement which suggests the existence here of a major terminal moraine (the Hogsthorpe moraine). In gravel pits at Aby and Alford and in the drain section at Willoughby, the deeper lying portions of the gravel have yielded the marine and estuarine shells *Cardium edule*, *Cyprina islandica*, *Tellina balthica* and a number of others. Their presence indicates that these gravels, though glacial outwash materials, were derived from nearby beach or shallow-water marine deposits. Though some of these shells occur also in the Kirmington deposits the general altitude is about 40 feet lower and lies close to the 25 feet contour, and they were probably incorporated from sediments relating to a lower base-level.

In the two cases just considered in some detail the precise position of the base level at the time of formation is indicated because the deposits must have been formed at or near a beach. The peat bed and overlying bone bearing deposits at Burgh and possibly also the gravels at Ingoldmells may also have been formed near to the lower base level, and therefore indicate a time of emergence of the land or negative movement of base level, when the sea margin must have lain some distance eastwards of its present position.

The situation of these deposits in amongst the Devensian tills leaves no doubt that the corresponding movements took place during the later Pleistocene. Their order of succession in time is, however, not yet clearly established.

Reference has already been made to the wave-cut platform which underlies the whole of the Marshland, to a depth of 100 feet in the vicinity of Mablethorpe (Straw 1961). That it corresponds to a very prolonged still-stand is indicated by the width of the platform and by the degree of truncation of the spurs projecting eastwards from the Wolds ([62]). That this stillstand antedated the formation of the Devensian tills is shown by the fact that they are banked against the truncated ends of the spurs. That it post-dated a period of time during which the general level of the land was much higher than it is now is indicated by the fact that continuations of some of the Wolds valleys can be traced across the wave-cut platform ([59]). Thus, for example, near Immingham dock borings show that the solid floor below the tills sinks to a depth of 246 feet below sea level and more than 150 feet below the general level of the adjoining portions of the platform.

Two main types of scenic change directly associated with the presence of the Devensian ice sheet may be illustrated from the neighbourhood of Louth ([6]). Here two valleys, descending from the crest of the Wolds converge gradually towards a point south-west of the town which lies in the open mouth of the northern valley. The stream which occupies the southern valley follows the normal course until it is about two miles from the mouth of the valley. Here its course in the same direction is barred by a bank of till which occupies the lower end of the valley. The stream there turns suddenly northwards and, flowing through the Hubbards Hills gorge which gashes the hill between the two valleys, pours its waters into the northern stream. This gorge reflects a phase in the glacial history of the district when the margin of the ice-sheet rested against the eastern slopes of the Wolds. The ice thus dammed the lower reaches of the valleys as far south as Alford. During the summer months the winter snows as well as the surface of the ice melted rapidly and these valleys were filled to overflowing with the melt waters. These escaped southwards by flowing from valley to valley across the intervening hills and spurs and excavating gorge-like channels similar to the one referred to above. A series of such overflow or marginal channels can be traced southwards as far as Calceby beck valley. The mouth of this was also blocked by ice. The melt waters from this ice deposited those gravels which form so striking a feature near South Thoresby. These waters, joined by those entering from the north, escaped westwards past Brinkhill, Tetford and Somersby and then flowed south-eastwards along the course now followed by the river Lymn. The presence of outliers of Wolstonian till capping the hills adjoining this valley at Hagworthingham and elsewhere points to extensive excavation, much of which may be ascribed to the action and influence of these melt waters.

Similar but more numerous and extensive outliers of Wolstonian till capping the hills alongside the Ancholme valley point to considerable excavation subsequent to its deposition. Here, however, the presence of the younger Devensian deposits within this valley including the Horkstow moraine in the north, dates this erosion as having taken place during an interglacial period.

In the oolite limestone belt south of Grantham the smaller streams flow eastwards across a boulder clay plateau or down the dip of the solid rocks, but the Upper Witham, the Glen and the Eden have anomalous courses roughly parallel to the strike. Compilation of data from several hundreds of borings for ironstone in that area (Wyatt 1971, Wyatt and others 1971) show that concealed beneath the Boulder Clay core is an east-draining dendritic drainage system, now filled in and buried, quite independent of modern trends, to which the modern drainage shows no relation.

The data show that before the deposition of the Wolstonian chalky boulder clays the Fenland drainage in that area was more extensive. A river comparable in size to the Welland rose west of Melton Mowbray and flowed through a broad gap in the Jurassic scarp past South Witham into the Fens at Thurlby. Tributaries joined it from north and south and the drainage area included part of the Lias outcrop west of Grantham.

The earliest deposits in these valleys included scree, solifluction deposits and alluvium, the last including laminated clays and coarse gravels which contain erratics from an earlier till, now gone. These early deposits were sealed in by the sheet of Wolstonian clays, and the drainage was blocked and buried, so that the former valley system is only seen in quarry cuttings or mapped by trial borings. The modern drainage developed largely independently and on different alignments, for the Upper Witham, Glen and the Eden river valleys may have been cut along the receding margin of a dead ice mass lying in the Fenland.

The history of the Trent drainage (Straw 1963) itself is directly relevant to that of west and mid Lincolnshire. At an early stage, and possibly over a long period, the middle Trent valley continued eastwards, to drain through the Ancaster gap into the Northern Fenland. Gravels loaded with Bunter pebbles in the Ancaster gap and in the Witham valley on both sides (Hough on the Hill and Sleaford) show that this condition continued well into the Pleistocene. At a stage toward the end of the Wolstonian glaciation the Trent was diverted northwards, probably alongside a mass of dead ice relict from the very active glacial tongue which eroded the Lias outcrops of west Lincolnshire, to flow through the next available route — the Lincoln Gap. The continuous valley gravel spreads from this phase still exist from the present Trent valley near Scarle via Eagle to Lincoln. This phase was itself terminated — perhaps as the last of the ice disappeared — when a lower level outlet became available northwards to the Humber. During the Devensian glaciation when the Humber gap was temporarily blocked by ice, the Trent reverted once again to the Lincoln gap, probably depositing the Beeston terrace gravels, and receiving the Witham as a tributary. Later, when the Humber became ice-free, the Trent abandoned its route to Lincoln, leaving the Witham as an obviously under-fit stream.

The gaps through the Oolitic scarpland at Lincoln and Ancaster, together with the Humber gap and others within the Wolds thus have long histories associated with glacial and pre-glacial events (Swinnerton 1937, Linton 1954, Straw 1970). We have already seen how the Trent alternated between the Oolite gaps during the later Pleistocene, and the presence of flint artifacts in the river gravels is of considerable interest. Most of these seem to have been derived, but demonstrate clearly that early Man occupied Lincolnshire at various times whilst the scenic changes were taking place.

CHAPTER 16

THE POST-GLACIAL HISTORY

The oscillation of base level which took place during the Pleistocene continued long afterwards and initiated those important scenic changes which form the subject of this chapter.

The earliest evidence relating to the position of post glacial base levels was provided by the systematic survey of the North Sea floor by soundings. These revealed the presence beneath the sea of an ancient land surface with river channels, hill ranges in alignment with the Jurassic and Cretaceous scarplands, and a series of submarine banks off the Lincolnshire coast between Holderness and north Norfolk. The Theddlethorpe and Protector Overfalls, north-east of Mablethorpe, originated as outwash fans of gravel at the ice-edge during a halt or re-advance stage (A. H. W. Robinson, 1968). Off the north Norfolk coast between Hunstanton and Blakeney is an extensive platform of boulder clay known as the Burnham Flats. In the gap between are the Dowsing Overfalls and Inner Dowsing, of marine sands overlying boulder clay, which probably originated as sand bars across the mouth of the proto-Wash.

Evidence concerning the age of the North Sea floor is forthcoming from lumps of peat (moorlog) which have from time to time been torn from the sea floor and brought up by dredgers from depths varying from 100 to 170 feet. Analysis of the pollen grains in this peat shows that the trees which grew on that landscape were mainly pine and birch, a combination which reflects the cold pre-boreal conditions which existed in Britain about 7500 B.C. ([54]). One of these lumps yielded a bone harpoon of Mesolithic type dating from between 7000–5000 B.C. From this it follows that in pre-neolithic times much of the North Sea area was dry land. At that time

GEOLOGICAL SECTION ACROSS THE COASTAL MARGIN

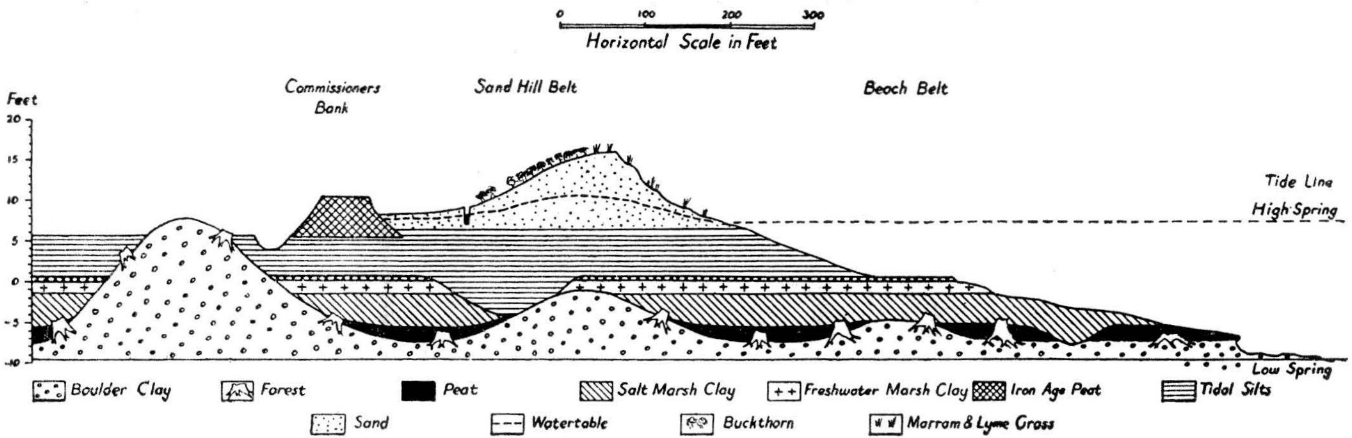


Fig. 20

therefore Lincolnshire was situated far inland and along with the rest of England was directly connected with the continent. An important positive movement of base level now set in which was accompanied by a progressive submergence of this old land surface.

The attention of visitors to the East Lincolnshire seaside resorts is often attracted by the presence, at various points between Skegness and Mablethorpe, of tree stumps projecting from the beach at low spring tide level (Fig. 20, Plates 14 and 15). The roots of these go down into the boulder clay beneath. This shows that when the trees were growing the ground on which they stood must have been out of the reach of the highest tides, and therefore at least 25 feet above their present level. A thick peat covers the boulder clay and laps round the bases of the stumps. Its presence indicates a deterioration of the drainage which may have been due to a lowering of the land relatively to the sea. Analysis of the pollen content of the peat at Ingoldmells shows that this ancient woodland was made up largely of alder with some oak and lime and an occasional pine or birch. This assemblage of trees shows that a warm moist Atlantic type of climate prevailed which also favoured the formation of peat. Neolithic implements found under the peat help to fix this period of forest growth and peat formation somewhere between 5000 and 2000 B.C. Samples of peat having the same constitution have been dredged from the shallower margins of the sea and have also been dug up from a depth of –23·5 feet O.D. near Kings Lynn. Borings put down at Quadring and other points in the Holland division of the county prove the presence of several peat layers, one of which occurs at comparable depths ([60]). These facts show that the level of the land was still higher than now and the coast line was still some distance to the east of its present position.

The subsequent history of the Marshland area has been worked out in broad outline ([61]). The records of that story are contained in those clays which are such an unpopular feature with bathers at the seaside resorts (Fig. 20). The oldest of these clays, which lie exposed from time to time along varying strips of the beach, rests directly upon the peat. They are of buttery consistency and contain the carbonised remains of innumerable root stocks of such plants as arrow grass, thrift, and sea lavender, which may be seen to-day growing around the Wash, converting the dreary wastes of salt marsh into vast flower gardens for a brief period every summer time. These clays are 6–8 feet thick. They evidently accumulated under salt marsh conditions in a sheltered area, into which the sea water crept quietly at high spring tide and deposited its burden of mud and silt. This area must at that time have been shielded from the erosive action of the waves and strong shore currents, which is so much in evidence to-day, by the presence of an off-shore barrier such as might have been provided by the features described above at a time of lower sea levels (Fig. 21). These clays therefore reflect a brief period of subsidence which carried the peat covered land surface down to mid tide or mean sea level.

As with existing salt marshes the retiring waters of the high spring tide drained away along channels excavated on the plan of a rudimentary river system. The main channels cut through the underlying peat and penetrated the boulder clay beneath, thus providing an example of erosion taking place during a time of marine transgression. It has been suggested that the existence of such channels as these in the post-glacial deposits implies a slight uplift; but such a movement would have carried the ground above the level of the highest spring tides and thus automatically put out of action the agency which produced the channels.

The uppermost part of the clay contains abundant remains of reeds and is in turn buried under a thin upper peat. The pollen constitution in this points to an abundance of pine and birch, with some oak and alder. These facts do indicate a slight relative uplift which lead first to the establishment of freshwater marsh and subsequently to woodland.

At various points along the beach near Ingoldmells Point and in inland excavations the remains of early Iron Age or Halstatt salt workings occur in and on this upper peat. These fix the date of this negative movement of base level at about 500 B.C. (Fig. 21). This state of uplift seems to have continued well into the period of the Roman occupation, for at Ingoldmells Point traces of one of these workings were found immediately underlying the occupation earth of a Roman station which existed at that spot until the third century.

The upper peat is everywhere overlain by a sloppy clay which is normally seven feet thick. The bottom few inches of this and the surface of the peat are crowded with the shells of *Cardium* (cockle) and *Scrobicularia*. These creatures live to-day at and just below the lowest spring tide level. Their presence in these deposits shows that the base level had changed once more and submergence was renewed. The upper peat with its primitive salt workings was carried down some 20 feet. During the earliest phases of that sinking, tidal erosional channels were excavated as much as ten feet deep through the earlier deposits to the boulder clay beneath. Subsequent deposition of mud and silt filled these channels and buried the peat, the salt workings and the Roman station.

The Marshland of East Lincolnshire is essentially a northerly continuation of the Fenland, the post-glacial history of which has been reconstructed from data obtained by carefully conducted excavations in its southern portions which lie beyond the bounds of Lincolnshire ([54]). While the two stories are in general accord

LINCOLNSHIRE COAST *c.*500 BC

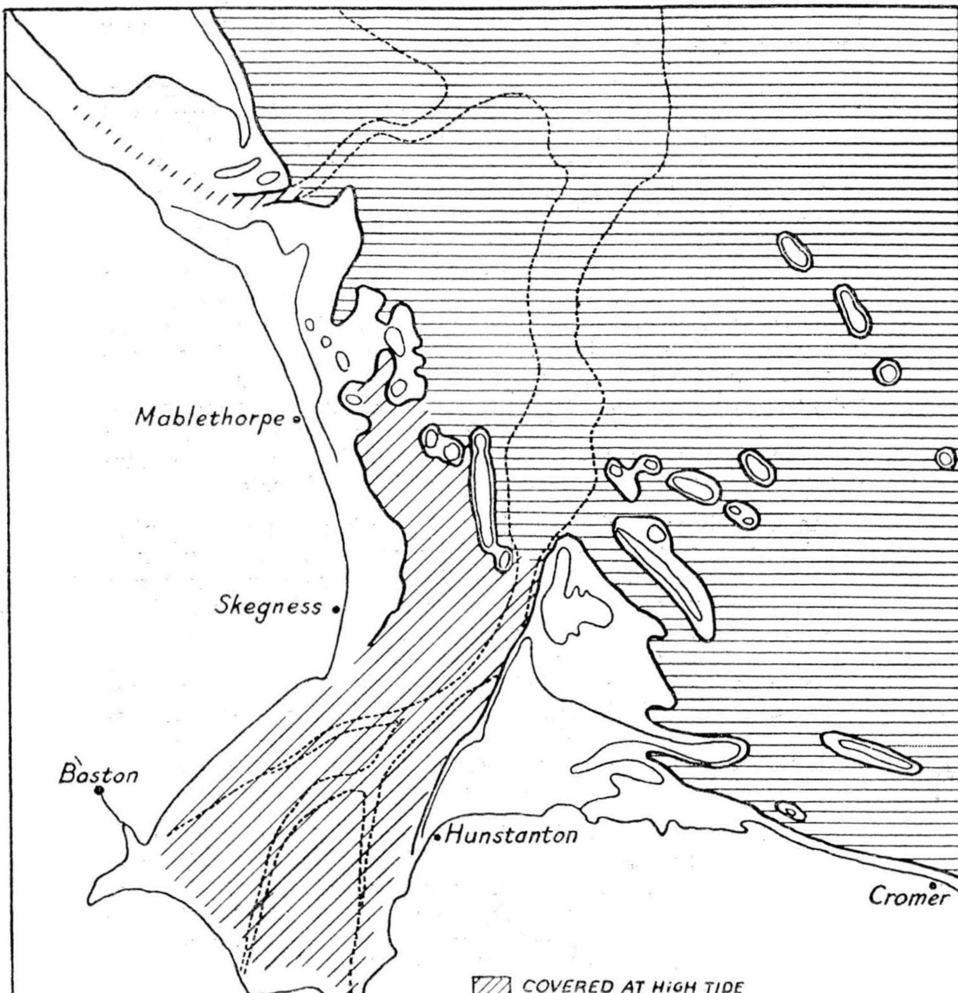


Fig. 21

with one another, the evidence from the fen area points to a depression and an inflowing of the sea about the close of the Iron age and the opening of the Roman period. It may be that further exploration along the east coast will bring to light evidence of a contemporary depression there also.

During late and post Roman times the submerged portions of the East Coast area were still sufficiently sheltered from waves and currents for seven feet of mud and silt to be deposited. When did these quiet conditions give place to those of to-day in which the beach is pounded by long North Sea rollers and scoured by strong currents.? Historic records of the late thirteenth and the early fourteenth centuries refer to unusually severe inundations of the Marshland. It may be that the combined influences of continued sinking and erosive wave action lowered the banks, lying to the east, below sea level and thus exposed the soft Marshland clays to attack by the sea. This attack is still going on along those portions of the coast ranging from Skegness to Mablethorpe and a little beyond. Further north the coast begins to come within the sheltering influence of the Spurn. South of Skegness, at Gibraltar Point, the coastline turns westwards and is thus sheltered by east Lincolnshire and consequently saltmarsh conditions can and do exist.

The later history of the Lincolnshire coast has thus not only been one of loss of land to the North Sea: there have been intervals of accretion, augmented in the last five hundred years by reclamation and drainage of the former salt marshes (D. N. Robinson, 1970). As a result of these factors much of the northerly area has been built up by 5–10 feet above sea level, and an original belt of storm beach dunes one to three miles inland now trends from Mablethorpe northwards to North Somercotes, and occurs again near Humberston. Much of the material which has built out the coast south of the Humber is derived from the erosion of the Holderness area in southeast Yorkshire by long-shore drift.

The later depressions with the associated submergence by the sea exerted a dominating influence upon the distribution of different types of soil and subsoil in the Fen country as a whole including that portion which lies in Lincolnshire. With every incoming tide the marine waters, laden with sediments eroded from the coastlines to the north, flowed relatively rapidly through the bottleneck of the Wash gap. They then spread out over the broad area beyond, losing speed and transporting power as they did so. The coarser silty portions of the sediments were consequently deposited along the inner limits of the Wash entry and there built up a large irregularly shaped bar, which rose steadily up to the highest level reached by the tide. This bar was naturally left high and dry for long periods between the tides. At the time of the Domesday Survey it had already become dotted with human settlements and its fertile silty soil cultivated behind the protection of artificial sea embankments. The western boundary of this bar is roughly defined by a curving line joining Boston, Spalding and Wisbech. The actual boundary was, however, very irregular, like a fingered delta, for the marine waters still crossed the bar along channels and, by the depositing of their coarser sediments, built up long embankments along the crests of which they extended their channels into the quiet waters now almost completely cut off from invasion by the sea.

The fine muddy sediments brought by the earlier influxes of marine water were deposited in the waters on the inland side of the bar. As the bar rose in height the quality of these waters changed progressively from salt to brackish and finally to fresh water. This was due to the influx of such rivers as the Witham, Glen and Nene. At low tide the excess of inland water escaped to the sea by the same channels that still gave entry to the sea water at high tide. Where the water was freshest aquatic plants grew and died and gradually produced deep deposits of peat. This body of inland water, the Fen proper, tended to become cut up by the growth and extension of the embankments or 'roddons' and of similar alluvial features formed by the rivers.

Reference should be made to the spreads of gravel which occur along the land margin of the fens ([60]). Some of these are river gravels. Those which form the long strip from Sleaford to Bourne, however, have hitherto been regarded as beach gravels. These, at some points, overly the till and are presumably post glacial. On the other hand they pass under the Fen peat and silt. In many borings, scattered about the fen country, sand and gravel are found between the fen deposits and the till floor. These are not necessarily marine, and some are known to have been deposited by Fenland rivers, for example the Bain valley gravels at Tattershall, under cold climate conditions. Much more study of these deposits is needed however, before the history of the Fen basin can be clearly appreciated.

Studies of deposits in the Ancholme valley (Smith 1958) have demonstrated that the clays resulting from a marine transgression in Iron Age times occurred during a period of relative emergence in the Fenland, which suggests the possibility of differential isostatic movements between the two areas during the later part of the post-glacial period. Moreover the Marshland deposits appear to be more comparable with those of the Humber region than with those of the Fenland.

CHAPTER 17

ECONOMIC GEOLOGY

Until recent times Lincolnshire has been regarded as one of the counties less rich in economic minerals — it had no coal, no vein deposits of useful metals. Building stone was carried to the surrounding counties, but otherwise Lincolnshire made little contribution to the mineral resources of England.

In the latter half of the nineteenth century there came an important change — the discovery of the Frodingham Ironstone, one of the three most important bedded iron ores in Britain, which led to the development of the industrial area of Scunthorpe. In recent years also the general increase in population and improvement of standards of living has been greatly aided by another mineral, the supremely important WATER, which is available at shallow depths over most of the county. Other minerals have been developed on a smaller scale, notably ironstone, sand and gravel at surface, and petroleum at great depth. Some of the more important matters relating to the economic minerals of the county are mentioned in the following paragraphs.

Water Supply

The porous limestones and sands of the Middle Jurassic and Cretaceous beds serve to collect and store the rainfall, and the influence of the spring lines along their outcrops on the location of settlements is shown in many village names (Hemswell, Greetwell, Redbourn, Welton, and so on). In common with the other outcropping rocks of the county these reservoir rocks dip gently to the east, so that they pass beneath the impervious clays which floor he Fens and Marshland. Wells and boreholes have been sunk through the clays to the underlying rock beds — to the Lincolnshire Limestone beneath the Fens, to the Chalk and Lower Cretaceous sands beneath the Marshland — supplying large quantities of pure water to villages formerly dependent on impersistent and contaminated surface supplies ([67]). The depths to the two main waterbearing horizons are shown on the Structure Contour Map of the Mesozoic rocks Fig. 16. A study of the hydrology of the Lincolnshire Limestone has been published (W.R.B. 1969).

The situation is changing with the wider advance of reticulation, and the piping of irrigation water from rivers and streams. Centralised water production is increasingly important, with the enormous catchments and natural filtration provided by the Lincolnshire Limestone and Chalk forming long-term sources of pure water.

The Lincolnshire Limestone map shows much steeper dips north of the Lincoln – Wragby road than in the Fenland. In the adjoining outcrop the porous Upper Lincolnshire Limestone (Hibaldstow Beds) is poorly developed, the catchment being largely occupied by the dense Kirton Beds. The underground water potential of the area north of the Fens is consequently low.

The latest development is the provision of bulk water for industrial and other purposes by large scale transfer between catchment areas – the Trent to South Humberside via the Witham and the Ancholme in the north; the Nene and the Welland to the new Empingham reservoir in the south. Development of the underground water resources is planned in parallel with this operation.

IRON ORE

Bedded iron ores have been worked at four geological horizons in Lincolnshire ([65]). These all contain a much lower percentage of iron than, say, Cumberland haematite, but are economically important because of the vast quantities available and the ease of quarrying. The earliest of these is the Frodingham Ironstone of the Lower Lias, which is worked along an eight mile outcrop near Scunthorpe and is known to extend down dip to the east beneath the Ancholme valley to the Wolds. Up to the present, working has mainly been in opencast quarries with up to 90 feet of overburden, but mining will become increasingly important as the more easily available ore is exhausted, provided that it can be economically extracted.

At a higher level the Middle Lias Marlstone Ironstone has been worked in south Lincolnshire, but is locally of lesser importance than in the counties to the south as the ore is here less good. Like the Frodingham Ironstone of the north it is a calcareous rock, and has been conveniently used mixed with the siliceous Northampton Ironstone from the Inferior Oolite above. The latter is still worked extensively in Northamptonshire. It was worked at Greetwell and Leadenham in the earlier years of the century and working continued on a large scale into the 1970's near Harlaxton and Colsterworth.

At a much higher level is a fourth ironstone — the Lower Cretaceous Claxby Ironstone of the Wolds, which has been worked by mining in the area south of Caistor. Still another bed, the Roach Ironstone of the south of the Wolds, shows signs of being economically useful, and might be developed in the future.

Availability of much more economic high grade ore from abroad is now (1974) leading to phasing out of the bedded ironstones working, but there remains a large reserve of workable ore which could again be important as the world supply position changes, possibly exploited by entirely new methods.

LIME AND CEMENT

In the past there have been many small limekilns on the outcrops of the Lincolnshire Limestone and Chalk, providing for mainly local requirements of lime. Very few of these are now in operation, the import of cheaper and equally good material from large scale operations in other counties have sent most of them into disuse, together with the working of the softer beds of the Chalk for marling unsuitable soils.

The limestones of the county are worked locally on a large scale for cement manufacture. In the extreme north, near Barton-on-Humber, are several large cement works using Chalk and Recent clays. At Kirton-in-Lindsey an extensive plant works the lower half of the Lincolnshire Limestone, there mis-named 'Blue Lias' from its strong lithological resemblance to the basal beds of the Lias which properly bear that name. The latter (the Hydraulic Limestones) were the original source of hydraulic cement, but are not now worked within the limits of the county, the nearest works being at Barnstone in Nottinghamshire.

BUILDING AND ROAD STONES

From mediaeval times building stones have been one of the riches of the county. The oolite belt which extends through the county to form the Cliff includes limestones of the same character as the Cotteswold stones, and has given rise, especially in the south, to a similar type of architecture. There are many Lincolnshire churches which owe their beauty to the excellence of the stone; their magnificent spires will be standing when the blast furnaces of Scunthorpe are a fading memory. The Lincolnshire Limestone has been exported through the centuries for building elsewhere, from the sixteenth century Wollaton Hall, Nottingham (of Ancaster Stone) to the new House of Commons (of Clipsham Stone).

In recent years the most extensive working of limestone in the county has been for road widening, airfield runway construction and similar operations. The hard lower beds of the Lincolnshire Limestone are particularly favoured for these purposes.

BRICK CLAYS

Fifty years ago many villages had their own clay pits supplying the local demand; now with improvements in transport facilities and lower costs of mass production these have been largely displaced by bricks imported from the great brickmaking centres in the Oxford Clay of Peterborough and the south Midlands. Only a very few local brickworks remain in operation, for example at Crowle, and tileries at Barton on Humber and at Skegness.

For geologists this is a very serious loss. Instead of dozens of exposures at many horizons through the county there are a very few enormous pits further south, and the clay strata of Lincolnshire are now hardly seen except in temporary exposures. It is the more necessary that at any opening the clay should be examined, the lithology recorded and fossils collected, for we shall never go back to the common exposures of local brickworks.

SAND AND GRAVEL

As a county with a wealth of superficial deposits, it is not surprising that Lincolnshire is well provided with sand and gravel. Some of the most extensive deposits are those associated with the later stages of the glacial history, when great quantities of sand and gravel were carried from the Bunter outcrops of Nottinghamshire and spread across the Lias plain from Newark to Lincoln and beyond on the east side of the gap. Large spreads of gravel occur southwards from here along the margin of the Fen country to Bourne. Deep gravel deposits have been found in the valleys of the Wolds west of Louth and at South Thoresby. All these deposits are extensively worked and it seems that there are reserves sufficient to assure supplies for many years. Spreads of sand alone, occurring in the Scunthorpe district, originated as windblown dunes in post-Pleistocene times; these are worked near Messingham and near Westwoodside in the Isle of Axholme.

FOSSIL FUELS

Several oilfields have been found in Lincolnshire, the main oil bearing beds being sandstones of the Coal Measures. The largest field is beneath Gainsborough town, extending into open country to east and west. This has been producing oil for more than 15 years, and moderate quantities of natural gas also exist there. Smaller fields have been located at Corringham, Glentworth and Torksey. One small, non commercial oil accumulation was found in the Carboniferous Limestone beneath Nocton Heath, but major oil reserves are not to be expected in the county.

Good coal seams have been found by oil test borings at Dunston, Stixwould and Spital, and although great depths and the expense of sinking borings through thick water bearing sandstones will postpone conventional development, they form a significant part of the country's proved reserves ([8]).

OTHER MINERALS

Other minerals of potential importance in the county include phosphates, gypsum and coal. Phosphates occur as abundant nodules in the basal beds of the Spilsby Sandstone ([66]). Gypsum is worked extensively in the Newark district of Nottinghamshire, and boreholes show that the beds extend across the county boundary. The thickness of the seams has still to be investigated, but it is very probable that the mineral will eventually be worked in Lincolnshire.

CHAPTER 18

GEOLOGISTS IN LINCOLNSHIRE

It seems appropriate that this booklet on the Geology of Lincolnshire should include some acknowledgment of those whose labours in the past have made such an account possible. As with other branches of Natural History the countryside is the research worker's main laboratory, open to all, free of charge. It is not surprising therefore that much excellent work has been done by many for whom the study of nature was a hobby and a recreation. There have been others, of course, who did much to elucidate the geology of the county in the course of their professional work as members of the British Geological Survey or of University staffs. Some have been natives of the county. Others have sojourned here for longer or shorter periods. A full list of all these up to about 1885, will be found in the bibliographies at the end of the survey memoirs on the Fenland and on South-West Lincolnshire.

Of the earliest workers little or nothing is known beyond their names and their published works, of which a number appeared in the Transactions of the Royal Society. As early as 1700 the Rev. A. de la Pryme, who had been appointed curate of Broughton in 1695, wrote an account of the stone pits in the parish and made references to those of Frodingham and other places. The fossils which occurred attracted much of his attention for he refers to fragments of various shell fish, including "multitudes of belemnites" all of which he interpreted as evidence of the "Noachian deluge." One shell he described as "bending somewhat like a ram's horn and exactly creased on the outside like one."

The buried and submerged forests of the Fens and Marsh lands attracted early and frequent attention. In 1702 Rastrick gave an account of an exposure of these in a sluice at Boston, and in 1795

Correa de Serra wrote a good description of the submerged forests along the coast between Skegness and Grimsby. Among other eighteenth century workers was J. Limbird, surveyor to the Boston Corporation, who published a detailed description of a well sunk under his supervision.

In the early part of the nineteenth century Lincolnshire shared, along with the rest of the country, the invigorating influence of the pioneer of modern geology, William Smith. In the course of collecting information for his monumental geological map of England he must have made frequent journeys in Lincolnshire. The first edition, which appeared in 1815, already showed the main formations in the county. We are indebted to Dr. L. R. Cox for the following specific information about Smith's local contacts. His earliest known visit was to Stamford in 1807. In June, 1821, accompanied by his nephew, John Phillips, he passed through Gainsborough on his way from Hull to Doncaster. A little later they set out from thence on a tour in Lincolnshire from Gainsborough to Harpswell Hill where a good section of the strata had been recently exposed in a road cutting. They then went to Spital and Market Rasen. This journey must have provided them with a good traverse across the outcrops of the formations ranging from the Keuper to the Kimmeridge Clay. They now went on to Lincoln where in the course of a fortnight's stay they identified the rocks from the Marlstone to the Cornbrash and "the rich quarries of Canwick were rifled of fossils." Smith then went alone on foot, tracing the rocks to Sleaford, Grantham and Stamford correcting the outlines of the Oolite, Cornbrash and Oxford Clay. After "a very circuitous course to the east" he went to Northamptonshire.

Among other workers in that early time mention may be made of Dr. A. Wesburgh, of Sleaford*, of E. Bogg and W. H. Dikes. In 1858 the Rev. E. Trollope, of Leasingham, wrote about the alluvial lands and submerged forests. In the same year the Rev. T. Wiltshire, in the course of a general account of the Red Chalk of England, dismissed this county with the unilluminating remark that "here a geological darkness prevailed." Ten years later S. V. Wood and J. L. Rome produced a description of the "Glacial and Post Glacial structure of Lincolnshire and Yorkshire," thus recognising the geological affinity of the two counties. They were followed in 1872 by Jukes-Browne who wrote an important paper on the Boulder Clays of Lincolnshire.

* The attribution to Dr. A. Wesburgh of the geological section of Dr. Richard Yerburgh's "*Sketches illustrative of the topography and history of old and new Sleaford . . . .* " (published by James Creasey, 1825), is based on the bibliography of the *Geological Survey Memoirs*.

The next really serious work on the solid geology of the County was done by John Wesley Judd. Though endowed with an enthusiasm and a natural aptitude for geology he found that at first this interest failed to provide him with a livelihood, he therefore turned to school-mastering. Thus it came about that in 1859 he joined the staff of the Horncastle Grammar School where he remained for three years. He spent much of his spare time doing geology in the field. From thence he moved to Sheffield but as the result of a railway accident became incapacitated for work and so returned to Lincolnshire for rest. Here he found in renewed field work a goodly medicine. As the outcome of these spare time activities he produced several important papers which laid the foundations for subsequent work on the Lower Cretaceous of Lincolnshire (1867, 1870) and its relationships to deposits of the same age at Speeton in Yorkshire. He also did similar fundamental work on the Jurassic rocks of the County: his classic Geological Survey memoir "The Geology of Rutland" (1875) incorporated descriptions of the rocks of South Lincolnshire.

Some of the above references remind us of the great debt Lincolnshire geology owes to the work of the Geological Survey of Great Britain. This work was the joint product of the activity of a team of workers who, by careful enquiry and patient study in the field during the seventies and eighties, rescued from oblivion a vast amount of information which would not otherwise have been recorded and published. The various members of the survey concerned spent considerable stretches of time living in and tramping miles endways through the county. In this connection special reference should be made to the detailed zonal work done by Jukes-Browne on the Chalk.

Of other workers during the latter half of the century reference may be made to the following: Sir Aubrey Strahan, who wrote on the Carstone; J. M. Wilson, on the wells of the Fens; Edward Wilson, of Nottingham, on the Rhaetic and the deep boring for coal at South Scarle; Rev. P. B. Brodie, on the Geology of Grantham; and W. J. Hill, on the Upper Cretaceous. All these appear to have been visitors to the County.

Among natives of Lincolnshire, F. M. Burton, a solicitor at Gainsborough, stands out prominently. His long life, ranging from 1829 to 1912 links the times of W. Smith with modern developments. Like most other amateurs he took an active interest in most aspects of open air natural history, but his main enthusiasm was for Geology. In 1866 he discovered the presence of the Rhaetic as far north as Gainsborough and followed this up, in 1867, with a paper on the beds exposed in the railway cutting at Lea. In addition to various articles and papers on other stratigraphical topics he gave careful attention to landscape formation. As late as 1907 he published a small book on "The Shaping of Lindsey by the Trent." His two presidential addresses to the Lincolnshire Naturalists' Union dealt with similar subjects. Mr. Burton was one of the pioneers in the establishment of that Union. He was its second president, and also secretary and treasurer of its Museum Committee. This latter was dissolved when in 1906 the Lincoln City Council took over the collections and found a home for them as "The City and County Museum of Lincoln." He was an active geologist to the end for in 1909 he wrote a short paper on "Some Lincolnshire Boulders."

Another resident, though not a native, of the county was Henry Preston, who was appointed to the staff of the Grantham waterworks in 1879. He had, however, become previously associated with the county when in 1876 he started journeying to Grantham from Nottingham several times a week to conduct classes in geology and other subjects. These classes were held in a room behind the town hall where he also gathered together a collection of specimens used to illustrate his lectures. This became the nucleus of a museum. In 1880 he started the Grantham Scientific Society which under his inspiration had for one of its main aims the establishment of a Museum. This found fruition in May, 1925, when the Public Library and Museum of Grantham was officially opened.

Mr. Preston was a keen student of Nature, especially of geology. Water supply problems naturally received much of his attention and he provided much valuable information for incorporation in the Survey Memoir on "Water Supply in Lincolnshire." He was not a voluminous writer but he produced a score of short papers and reports on these subjects and on archaeology. In his observations on superficial squeezing movements at Saltersford he proved to be the pioneer of important recent studies on valley bulges. He died in 1940 at the ripe age of 87. He also was a live link between the nineteenth and twentieth centuries.

During the present century a number of geologists, some still living, have taken an active interest in Lincolnshire problems. The lion's share of their attention has been taken up by the Cretaceous rocks. These are dealt with in detail in the General Memoir on Cretaceous rocks published by the Geological Survey. The county also owes a debt to Dr. A. W. Rowe who in the course of his work on the zoning of the chalk of England spent some time in Louth. There he was ably assisted by a small group of three local amateurs. Of these C. S. Carter was born at East Torrington in 1865. Before he was nine years old he became a half time worker on the land. At the age of 15 he was apprenticed to a bootmaker at Donington-on-Bain. He then left the county for some years and during time spent in Manchester developed an interest in Geology. In 1900 he settled in Louth and, when elected President of the Lincolnshire Naturalists'

Union, made a valuable contribution in the form of an address on "The White Chalk of Lincolnshire."

Another member of the group, J. R. Farmery, was also a native of the county, for he was born at Ludborough in 1872. He became a journalist and served as reporter and then editor for several of the Louth and Lincolnshire Newspapers. He, too, was a keen geologist. The fossil *Pachydiscus farmeryi* was named after him. The Rev. C. R. Bower completed the trio. He was minister at the Northgate Baptist Church in Louth in 1910. One important outcome of the activities of these workers was the establishment of the Louth Museum.

An account of past geologists who have worked extensively in Lincolnshire would be incomplete without inclusion of the late Professor H. H. Swinnerton, the senior author of the first edition, much of which has been incorporated in previous chapters.

In the earlier years of this century the contributions of professional geologists were largely limited to the problems of the ironstone fields, but a notable exception was Professor H. H. Swinnerton, for many years head of the joint departments of Geology and Geography at Nottingham University College, (later the University) the primary author of this book.

Swinnerton belonged to a generation of scientists with many interests which it is difficult to match today. He took his degrees in London as a zoologist, and moved to the department of natural sciences at Nottingham to teach zoology, geology and botany, and developed the teaching of geography there; but he made his main scientific impact as a geologist, with archaeology and the study of modern land forms as sidelines. Many of these activities were related to the problems of Lincolnshire, and he published a series of papers on the river development and on the history of the post-Pleistocene sediments on the coast – continuing the story of sedimentation and coastal changes into Iron Age and Roman times.

In the 1930's the availability of cores from water borings at Alford and Spilsby led to a programme of research on the inadequately known Lower Cretaceous rocks of the Wolds and their fossils, which clearly demonstrated for the first time the relationships of different formations which are in some cases lateral equivalents.

In studying fossils from these beds and elsewhere he carried out meticulous dissection of the specimens from their matrices, devising new methods where these were needed for handling extremely delicate material. He undertook a monograph on the Cretaceous belemnites but his large collection of beautifully prepared Neocomian lamellibranchs remains for future workers.

Much of his activity was in the educational field – not only at the University but also in the Adult Education field, and he left a tradition of geological interest in Lincolnshire which still survives. His main work was his "Outlines of Palaeontology", the first text book in this field on strongly evolutionary lines, and a series of popular books on the rocks and their evidence on the development or organic life. He is widely remembered still for his lectures, involving a maximum of demonstration – rockfolding illustrated with a handkerchief, evolution of vertebrate limbs by climbing on a table and illustrating the changing quadruped postures through geological time, and so on.

Apart from science he had a particular interest in young people and their intellectual problems – problems which had worried him while he resolved a personal conflict between religion and science – and he gave a great deal of his time to this in the Methodist Church and in the schools with which he was connected. In retirement Swinnerton continued his work on the Jurassic oyster *Gryphaea*, a highly variable genus of which specimens were available at many horizons in Lincolnshire in numbers sufficient for statistical analysis; his final paper was published a year before his death at the age of 91, in 1966. He was a man remembered with deep affection and respect.

CHAPTER 19

GEOLOGICAL CONSERVATION

In a county like Lincolnshire, with a relatively subdued topography and a mainly accretionary coastline, the geologist is almost totally dependent on inland, man-made exposures of the rocks. Most of these are transitory, ranging from engineering cuts which may be open for only a few hours to major quarries for building stone which may be open and worked for a century or more. They provide the basic data for our understanding of the geology, of the ancient faunas which inhabited the area, of the changing geographies of the past and their influence on the types of rock deposited, and – consequentially – the potential of the rocks for agriculture, water supply, building materials and the other resources which provide the basic elements in our civilisation.

It is, in consequence, a matter of considerable importance that exposures of the rocks should be properly recorded, that the information is filed in such a way to be available to contribute to the data-bank for posterity, and that wherever possible the exposures should be maintained to be available for reference for as long as possible.

There are a number of factors involved in the survival of geological exposures. Some of them are easily controllable, some are not. The most universal cause of deterioration is by weathering – the action of rain and frost, snow and ice, which quickly reduce silts and clays to an uninformative slope, and break down more slowly but equally surely the hard rocks also. Type exposures may, in fact, have to be cleared up from time to time by a task group; the problem is as real for geological exposures as for nature reserves.

The second requirement is to limit the activity of what Professor Swinnerton used to call "student denudation" – a very real activity which has ruined classical localities in other parts of the country. This has reached such a degree on the Welsh Border that use of hammers has had to be completely banned in some areas. We have not reached that stage in Lincolnshire, but the point is a real one: that uncontrolled bashing at the rocks may release inhibitions but is not a proper activity for a geologist. It can only result in restrictions, either by the geological conservation interests or by the landowners whose property is being unjustifiably eroded.

But we must depend also on the help of informed and enlightened owners of the quarries and land, who have a long tradition of encouragement to those seriously interested in our science. We trust that this attitude will continue: that landowners will long provide access to those of us concerned with the rocks beneath the vegetation cover, and that those enabled to take advantage of this facility will return the kindness by consideration for the interests involved, by shutting gates, by avoidance of disturbance of game and flocks, by arranging visits to working quarries where they will cause a minimum of inconvenience, and – again – by showing themselves to be fully responsible in their use of the rock exposures available.

At the present time there are less than ten Sites of Special Scientific Interest in Lincolnshire and South Humberside scheduled by the Nature Conservancy Council primarily for their geological interest. Others are under active consideration in an attempt to cover the full range of rocks in the county.

The future of these sites depends in large part on the co-operation of the landowner. They have been selected because of their key importance in understanding the geology of the county and should be subject to minimum or no disturbance except for serious research work. Examples of such sites are a pit at Elsham exposing contorted glacial sands and gravels, nearby exposures of the Elsham Sandstone, and the famous deposit at Kirmington which has been the subject of continuing research since the investigation by a British Association committee in 1903-4.

Some sites have already become largely covered with vegetation, such as a former brick pit in the Hundleby Clay near East Keal. In more recent years a newly-created exposure of the Red Chalk in the Wold escarpment near Belchford, showing cambering and ice wedges, has rapidly weathered so as to partially conceal the features. In other sites, particularly gravel quarries, features of interest are destroyed in the exploitation. So long as continuous records can be made, further working can produce bonuses such as the mammalian remains from the gravel quarries near Coningsby and Tattershall.

A small number of geological SSSIs are given more permanent protection by being part of nature reserves established and managed by the Lincolnshire Trust for Nature Conservation. They include a quarry in the Lincolnshire Limestone near Wilsford, a quarry in the Lower/Middle Chalk at Claxby near Alford, and the statutory Local Nature Reserve at Red Hill, Goulceby. The latter has a fine exposure of Red Chalk overlying Carstone and is illustrated on the cover of this book. In an attempt to combat human erosion, timber steps and a platform have been constructed giving easier access to part of the exposure without trampling the scree slope. However, no solution has yet been found to weathering but at least it produces a ready source for specimens without hammering the face.

A CODE FOR GEOLOGICAL FIELD WORK
(adapted from that issued by the Geologists' Association)

1. Obey the Country Code.
2. Always seek prior permission before entering private land or quarries.
3. Don't interfere with machinery and beware of sludge lagoons in quarries.
4. Don't litter fields or roads with rock fragments.
5. Avoid undue disturbance to wildlife.
6. Don't take risks on insecure rock faces. Take care not to dislodge rocks, since other people may be below. BEWARE OF ROCK FALLS. Quarry faces may be highly dangerous and liable to collapse without warning.
7. KEEP COLLECTING TO A MINIMUM. Avoid removing *in situ* fossils, rocks or minerals unless they are genuinely needed for serious study.
8. The collecting of actual specimens should be restricted to those localities where there is a plentiful supply, or to scree, fallen blocks and waste tips.
9. Be considerate. By your actions in collecting do not render an exposure untidy or dangerous for those who follow you.
10. Report your observations or findings to the Geology Secretary of the Lincolnshire Naturalists' Union.

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Abbreviation	Full title
East Midl. Geogr.	*East Midland Geographer*
Geol. Mag.	*Geological Magazine*
Mem. Geol. Surv.	*Memoir of the Geological Survey*
Proc. Geol. Ass.	*Proceedings of the Geologists' Association*
Proc. Yorks. Geol. Soc.	*Proceedings of the Yorkshire Geological Society*
Quart. Journ. Geol. Soc.	*Quarterly Journal of the Geological Society*
Trans. Hull Geol. Soc.	*Transactions of the Hull Geological Society*
Trans. Leeds. Geol. Ass.	*Transactions of the Leeds Geological Association*
Trans. Leic. Lit. & Phil. Soc.	*Transactions of the Leicester Literary and Philosophical Society*
Trans. L.N.U.	*Transactions of the Lincolnshire Naturalists' Union*
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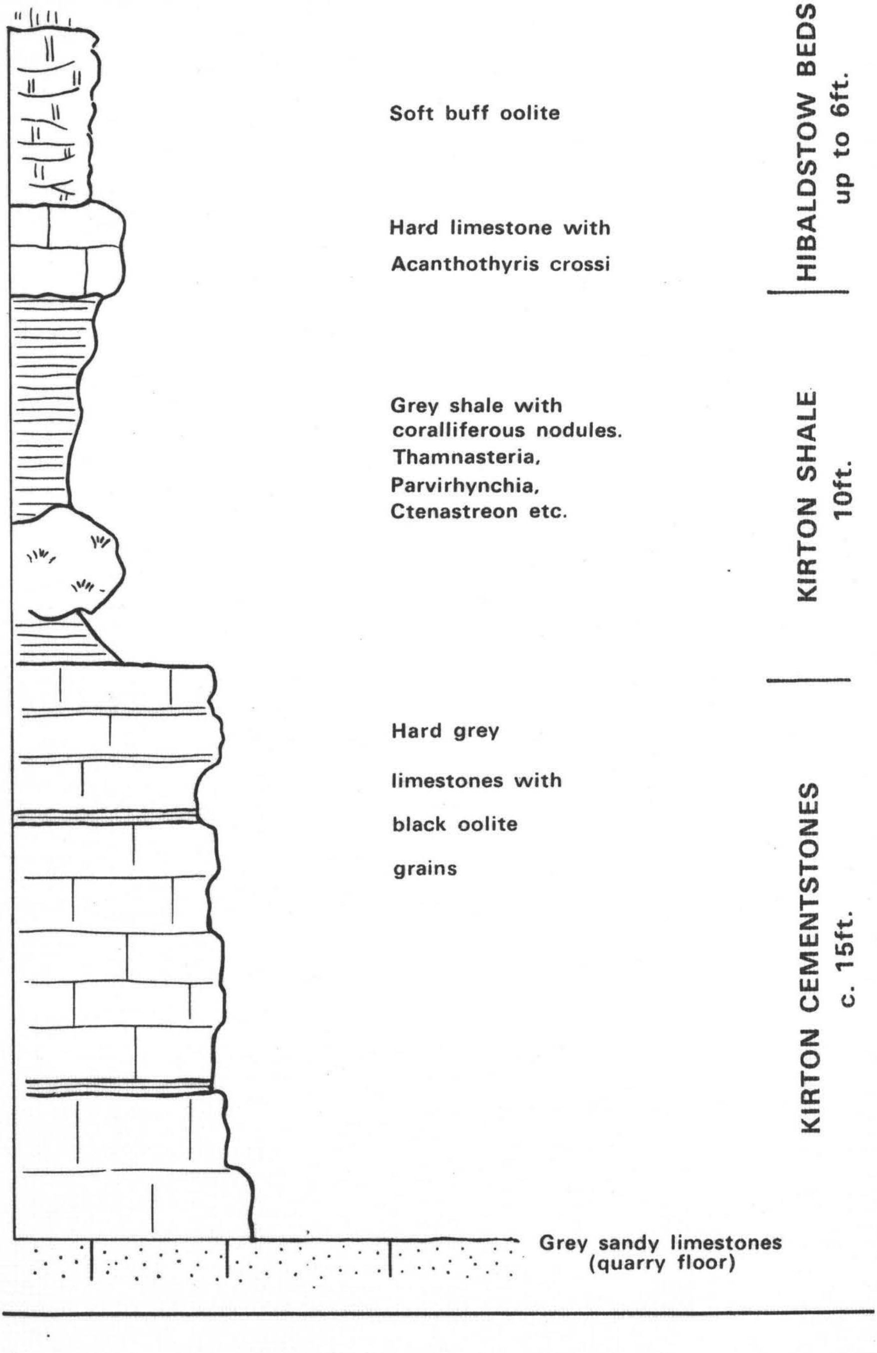

Section at Kirton Lindsey

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Sir Peter Kent, F.R.S., the co-author of the original volume who has carried out the revision for this Second Edition, has had a life-long interest in the geology of Lincolnshire and the adjoining areas. He assisted Professor Swinnerton to write the First Edition at a time when he was responsible for oil exploration in Britain. He has since worked in many overseas areas and published numerous papers linking surface geology with the deeper structure in places as various as the Middle East, East Africa, Arctic America and the North Sea. He was President of the Geological Society of London and is currently Chairman of the Natural Environment Research Council.

Lincolnshire Naturalists' Union

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