THE STRATIGRAPHY AND PALAEONTOLOGY OF THE RHAETIC BEDS (RHAETIAN: UPPER TRIASSIC) OF BARNSTONE, NOTTINGHAMSHIRE

by

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Summary

The history of previous geological work carried out at the Barnstone Railway Cutting is reviewed. The Rhaetic beds at this locality are recognised and delimited. They are measured at a series of equally spaced exposures and examined in detail. The Rhaetic fauna is described, figured and analysed palaeoecologically. The fauna includes molluscs, branchiopods, ophuiroids and fish and reptile remains. The Scymnorhynid teeth described herein are the first specimens of this family to be recorded below the U.Cret. The much confused teeth of the fishes Gyrolepis albertii Agassiz, Birgeria acuminata (Agassiz) and Saurichthys longidens Agassiz are clearly differentiated and fully described.

Introduction

The name "Rhaetic" was for long applied to a separate, small geological system, placed between the Triassic and the Jurassic. It has now, by international agreement, been reduced to a stage (the Rhaetian) and placed into the uppermost Triassic. However, in this country it remains a convenient name for a group of beds laid down in the shallow waters of an encroaching sea, which spread from West Europe over the previous Triassic landscape as a prelude to marine Jurassic conditions. These beds consist of a comparatively thin series of rocks and are persistent at the junction of the Triassic and the Jurassic rocks from Dorset to Yorkshire. Their thickest development is in the South, and near Watchet in Somerset the following composite sequence has been described by Arkell (1933, p. 99).

Watchet Beds	8'
Langport Beds	20'
Cotham Beds	5-7'
Westbury Beds	46'
Sully Beds	14'

In the Midlands the highest and the lowest of these beds are absent. There are very few natural exposures and the rocks are only rarely seen in quarries. They usually form a small but distinct scarp which overlooks the Triassic plains. The spreading of the railways in the 1860's and 70's opened up a number of cuttings through the Rhaetic rocks, which had hardly been known in this area before that period. These cuttings were recorded at the time though were soon grassed over. Since that time, the Newark section has been reinvestigated (Johnson 1950) and various minor sections described. The long road section at Bunny has been measured in detail and the general variation of the Rhaetic over the whole East Midlands area worked out from borehole data (Kent, 1953 and 1968).

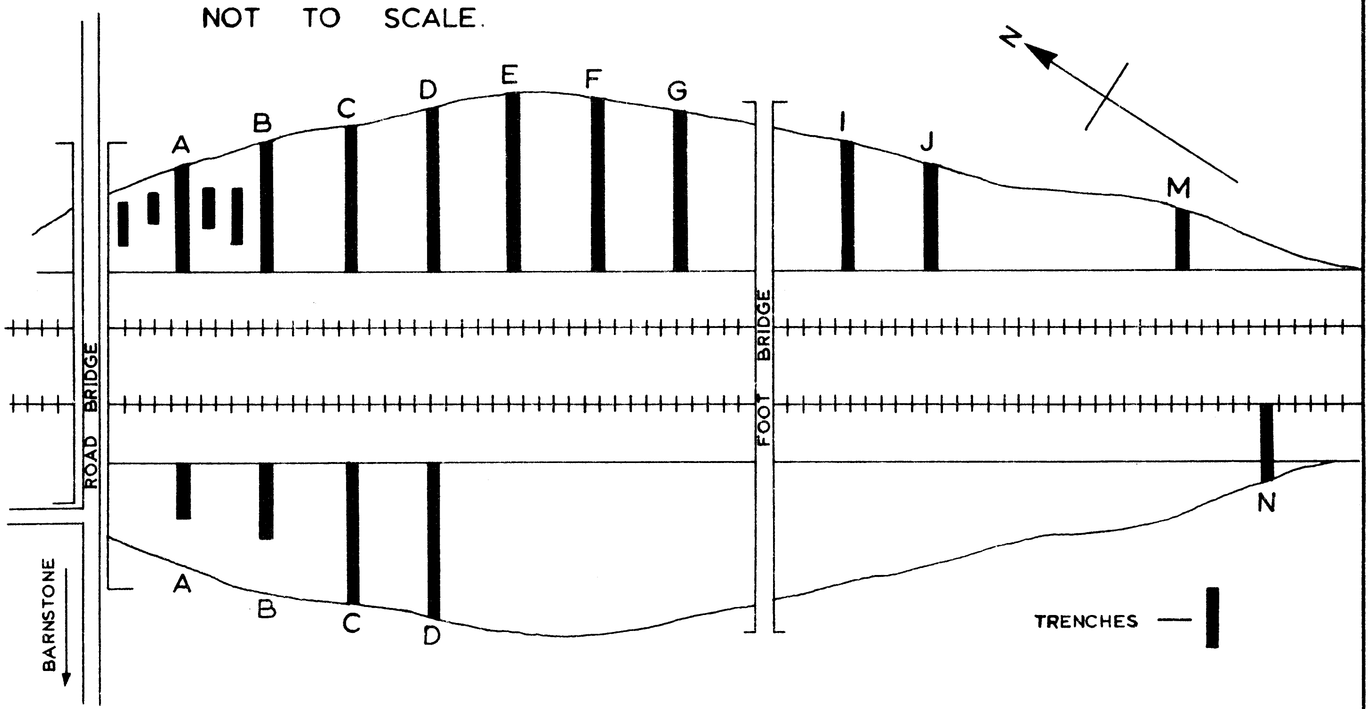
In 1876 the new Bingham branch line of the Great Northern and London and North-western Railway Companies opened up a section of the Rhaetic and Lower Lias rocks in a cutting at Barnstone, approximately ½ mile East of the village (SK 739358). The exposure was examined at the time by Wilson (1877), who sent a letter to the Geological Society of London in which he made brief notes on the succession and said that he hoped to make a full report later. In the thickness of the Rhaetic beds he noted about 15' of "paper shales" and, on top, an estimated 18-19' of dark blue earthy shales. Brodie (1876, p. 7) identified a collection of fossils from the Bone Bed at Barnstone and stated (on information received from Wilson) that all the rest of the beds were unfossiliferous. Wilson's next reference to the cutting (1882) added no further information, but this time stated the same thickness for the beds without the ambiguity of the words "about" and "estimated" in their description. It is evident that his proposed further investigations had not been carried out. Further work, however, was done by Wilson on the Liassic rocks (Jukes-Browne, 1885, p. 24).

Jukes-Browne (1885) reported that the cutting was then obscured by grass. He gave the following section and a fossil list which summarised all the information given by Wilson and Brodie with the addition of a list of bivalves. (The fossils recorded by Jukes-Browne are included in the synonymies given in the following fossil descriptions, with the exception of the following species which were not found in the present study:
Ceratodus altus Agassiz, Nemacanthus filifer Agassiz, Saurichthys sp.

LIAS	Thin-bedded blue limestones and brown clays, at the base a compact or concretionary bed of limestones from 3" to 7" thick.	10'	0"	
WHITE LIAS	Layer of limestone nodules.		6"	
	Thick-bedded, earthy, dark-blue shales with frequent nodules of limestone.	3'	0"	
	Similar shales with occasional nodules near the centre	15'	0"	about
AVICULA CONTORTA BEDS	"Paper shales" (Avicula contorta zone) with thin, variable sandstones in the upper part	13'	0"	
	Bone bed, with the usual fish remains		2"	
	Paper shales, sharply divided from	1'	6"	
KEUPER	Hard, light blue marls			
	Red Keuper Marls with thin gypsum bands.	12'	0"	

Lamplugh (1908, p. 58) gave exactly the same description. Johnson (1950) investigated the section, specifically examining the bivalve fauna. He stated that Pteria (= R. contorta) only occurs high in the succession (ibid., p. 117) and suggested that Barnstone lay just beyond the limits of a lagoonal area to the North West.

In the early 1960's the railway line was closed and the rails were taken up. Eventually it was realised that an excellent opportunity was available for the re-examination of the cutting and this was taken on as a project by the East Midlands Geological Society. In April 1968 work was started and this paper is the outcome of the activities by members participating in the project.



TEXT-FIG. 1. SKETCH-MAP OF BARNSTONE CUTTING.

Description of beds

The Barnstone cutting lies almost at right angles to the scarp face and therefore exposes the whole succession of the Rhaetic, some of the underlying Keuper, and the lowermost Liassic. After the cutting was excavated a thick layer of clay was placed on the exposed shales to protect them and prevent seepage of water. Now the whole of the sides are completely covered with grass. Trenches were dug into both sides of the cutting at 100ft. (30.5 m) intervals measured from the road bridge (Text-fig. 1). A Surveyors' Level was used to measure the relative heights of the main beds. The dip of the beds was found to be 1 deg. 9 mins. in the direction S.34 degs. E., which is also the direction of the cutting. Much of the section near the bridge was found to have been built up when the cutting was made and, as that end is also the scarp face, it probably accounts for the more extensive weathering of the rocks which is to be found there. The beds are named and their contents summarised in Table 1.

Trias

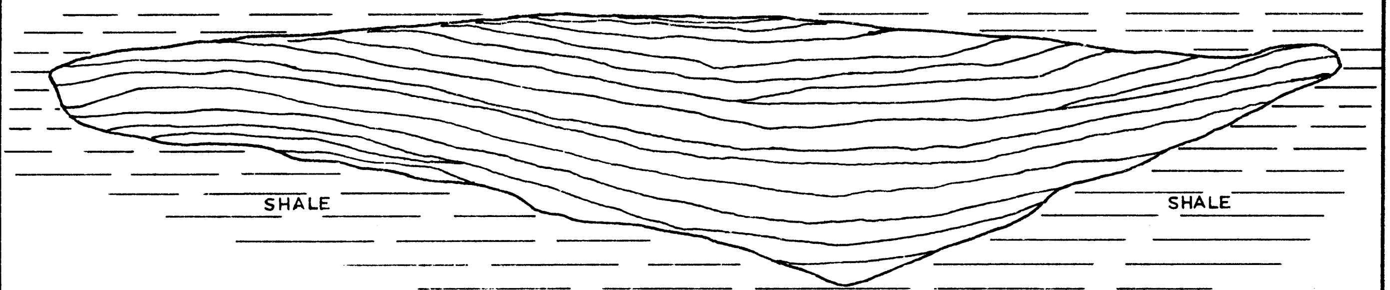
The Tea Green Marl (More than 2 ft. (.6 m.))

The Tea Green Marl which underlies the Rhaetic is a grey green, non-calcareous mudstone which easily breaks down into mud when broken in water. It is unfossiliferous. A 3 lb. sample was carefully cleaned, processed in water and washed through sieves of 18, 60 and 240 mesh. The residue left in the sieves was approximately 1.4% of the whole and consisted of clean quartz sand, with a sprinkling of grains of nodular pyrite. Only a few grains were found in the coarsest sieve (pyrite up to $2\frac{1}{4}$ mm. across and quartz up to $1\frac{1}{4}$ mm. across) and the finest sieve held about 65% of the residues. The quartz grains are well rounded and most of them have a scored surface; a few of them are coloured rose-pink, brick-red or green.

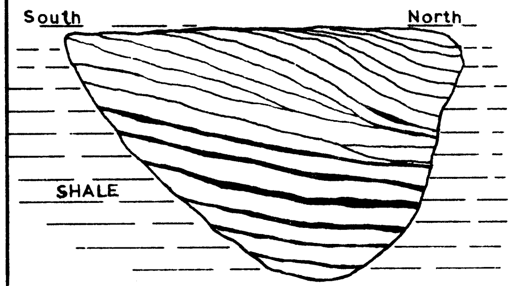
The Pre-Bone Bed Black Shale (1 ft. 6 ins. (0.4 m.))

At the base of the Rhaetic there is a sharp break from the grey-green marl to black shale; however, a close examination shows that the lowest $\frac{1}{2}$ in. (13 mm.) or so contains small patches of black shale isolated in the underlying marl. The greater part of the lowermost shales contain a fair amount of coarse quartz grains, occasionally up to about 1/8 in. (3 mm.) across, though some of the shale is laid directly on the Tea Green Marl without this content. These lowermost shales also contain small fragments of Tea Green Marl, patches of pyrite, phosphatic material, selenite crystals and circular green patches of (?) chamosite. They also contain scattered teeth, scales and finrays of fish, some of which are found flat on the contact plane.

Though superficially the shales of these beds appear to be all alike, slight but significant changes take place in their composition from the bottom upwards. The lowest beds have sandy partings of fine quartz and also coarser quartz grains and fish remains scattered through the rock. Between approximately 3 to 7 ins. (76 to 178 mm.) above the base, there is more sandiness with some thin patches of coarser deposits. At one horizon there is an impersistent layer of sandy rock up to $\frac{1}{2}$ in. (13 mm.) thick. Many more fish remains are present, generally associated with the quartz, and these shales could be classed as an incipient bone bed. Near the middle of the Pre-Bone Bed Shales there are fewer sandy partings and less quartz generally. The fossils are fewer and more conspicuously associated with the coarse sandy patches. Approaching the top the conditions change and the coarse content is only present in a few small patches, the fish remains found with these being only fin rays and occasional Gyrolepis scales. The shale is more fissile with an increasing amount of mica. The upper beds are devoid of sandy partings or quartz and fish remains are rare.



A. Longitudinal section of a sand-filled channel, showing the shallowing of the extremities, the flattened top, and the concentric bedding, which roughly follows the base of the channel. Length of channel 127 mm.



B. Cross-section of a sand-filled channel, showing the dip of the bedding towards the steeper wall. Width of channel 39mm.

C. a broken piece of shale with sandy partings, showing distortion of the bedding. Length 79 mm.

TEXT - FIG. 2. STRUCTURES FROM THE SANDY BEDS.

The Bone Bed (Up to 3 ins. (76 mm.))

The Bone Bed is accessible at the surface for about 250 ft. (76.2 m) along the cutting, and in this distance it varies considerably, though it is difficult to assess just how much of this is accounted for by weathering. It is first found about 50 ft. (15.2 m.) from the road bridge as a thin layer of sandy material with a few fossils. At exposure A it has changed to a pyritous Bone Bed with a thin crumbly layer on top, though much of its phosphatic material is in a weathered condition. Along the cutting the fossil content of the bed improves, and where it is found just below the water table at exposure C, it is in the best state of preservation and also the most prolific in fossil specimens. Here the Bone Bed is between 2 and 3 ins. (50 to 76 mm.) thick; the bottom half is solid with a pyrite matrix and the upper part is a friable mudstone with patchy layers of shale. Apart from the shale patches, the whole bed is crowded with vertebrate bone and teeth, coprolites, phosphatic nodules, fine and coarse quartz sand grains together with pebbles up to 1in. (25 mm.) across. Some of the quartz grains are coloured. Parts of the Bone Bed are slightly calcareous and the rare closed bivalves which have been found there are filled with calcite. In the lowest inch or two of the succeeding Black Shales, where the bivalves are absent, there are slight signs of continued Bone Bed deposition. Small patches of coarse deposits are found, either locally concentrated or scattered on a bedding plane. Associated with these are sparse Bone Bed fossils.

The Black Shales (6 ft. 1 in. (0.9 m.))

These beds are a remarkably constant lithological unit consisting of finely laminated black shales. They are thinly bedded except for about 2 ft. 6 ins. (0.8 m.) above the base where they are flaggy in beds up to 3 ins. (76 mm.). These beds, however, soon weather down, either to paper shales or to unevenly bedded shales. The shale on the south west side of the cutting is less weathered than that on the north east side. Water drains through the south west side and probably inhibits the weathering, as it does below the water table which is just below the base of the cutting. When weathered the shale contains masses of tiny selenite crystals, often arranged in rosettes, on the bedding planes. Some bedding planes are covered with a rust-coloured iron deposit and on some partings there is some sulphurous yellow clay. These secondary products are probably formed from the decomposition of pyrite to iron oxide and sulphuric acid. The sulphuric acid reacts with calcareous material in the ground water to produce selenite.

In the unweathered shale there is evidence of pyrite. Small nodules occur here and there, and 4 ins. (101 mm.) above the Bone Bed there is a $\frac{1}{4}$ in. (7 mm.) bed of solid pyrite associated with many flat, circular pyrite nodules. There is not very much silty material in the shales; thin layers of fine, silty quartz found near the Bone Bed become rare higher up.

Fossils are difficult to find in the unweathered shales because they are difficult to split, though if they are allowed to weather naturally, the fossil layers become exposed. The fossils are chiefly thin-shelled bivalves (Text-fig. 4). Nothing but their moulds remain upon the bedding planes. They are spread sparsely through the rock, though some bedding planes are covered with innumerable specimens. The shells vary randomly in size but sometimes a whole bedding plane will have specimens of a limited size range, usually small. Many of the *Eotrapezium* and *Protocardia* are found with their shells open and joined together; some are upright in the sediments only partly open, a few are closed.

The Sandy Beds (4 ft. 6 ins. (1.4 m.))

Though these are well defined beds, the contents vary along the cutting. The base of the beds is recognised by a change of the weathering colour, by the appearance of strong sandy partings or by a sandstone at the base. The weathering changes from a 'rusty' reddish-brown to an ochrous yellow-brown. The main mass of the rock is black shale, though most of it contains many partings and layers of sandy material. The thicker layers constitute thin sandstones, a few of which are up to 4 ins. (0.1 m.) thick and occur either in lenses or impersistent beds. Some of the thicker ones are current bedded. On fracture, some of the sandstones are white whilst others are black, although both weather to an ochrous yellow-brown colour. Selenite does not occur, but pyrite is found in both the shales and the sandstones.

On both sides of the cutting at exposure C, many horizons show slight disturbance of the sediments leaving striations and ripple-like markings. Some of these are emphasised and sand filled, leaving isolated channel fillings (Text-fig. 2). All these phenomena are orientated in the same general direction of 5 deg. S of E. The channel fillings differ in length and depth but characteristicly are approximately $6\frac{1}{2}$ ins. (160 mm.) long and 1 in. (25 mm.) deep near the middle, tapering in depth towards each end. Some are curved, all are flat topped. A section across them shows that the wall on the northern side is steeper than the wall on the southern side. When cut along their length, the bedding is roughly horizontal but curves up towards the ends of the channel (Text-fig. 2). Across their breadth the bedding is either almost horizontal or dipping to the north (the channels being filled up last on their northern side), this being shown best in the deepest ones. At this exposure some of the beds are curved in association with a minor fault which strikes about E.-W.

At exposures D, E and F, the upper part exhibits contorted bedding, varying from fine plications of the sandy partings, through folds and overfolds, to completely distorted sediments. These tie in with the previously described phenomena, since they show horizontal bedding on an E.-W. line.

Small specimens of Eotrapezium are the only fossils found in these beds. In the shales they are rare and scattered, except in two layers 1 ft. 2 ins. (0.4 m.) and 1 ft. 4 ins. (0.4 m.) above the base which are crowded with specimens. In the sandstones the bivalves are larger and, apart from those found on the base of a sandstone, all the specimens have their valves closed. These are sometimes spread plentifully through the rock, though (apart from rare pyritised ones) they are poorly preserved, being filled with a white, fibrous, non-calcareous mineral. About 1 ft. 6 ins. (0.5 m.) above the base the shales become calcareous. This is a general boundary at Barnstone, the exception being the Bone Bed below which is slightly calcareous in parts.

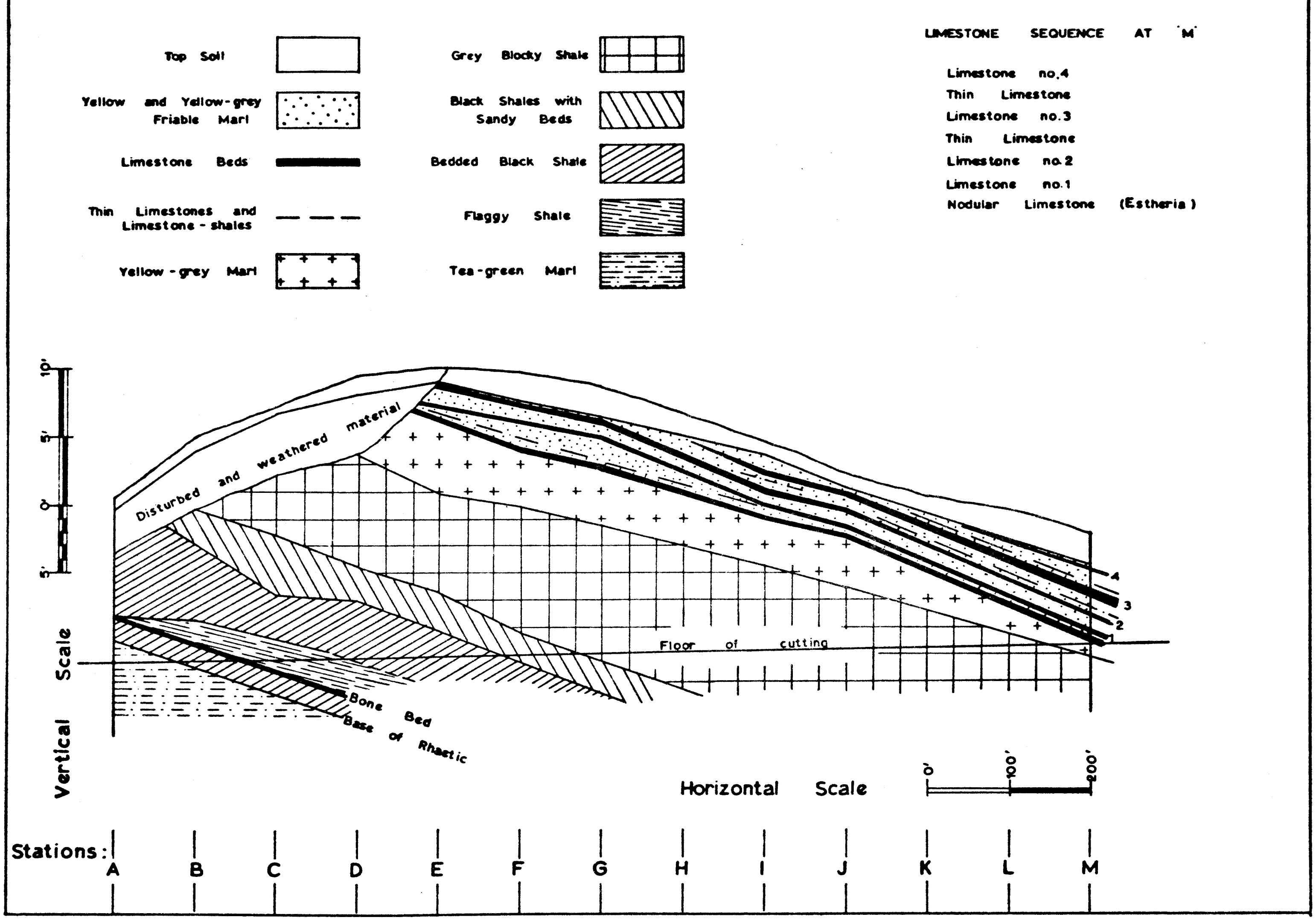
The Blocky Beds. (9 ft. (2.7 m.))

These beds consist of black to grey calcareous shales and siltstones which vary in lithology and fossil content from the base to the top, though a characteristic 'blockiness' of the material is present throughout. The basal beds have some thin partings of white sand and the black shale weathers to light grey without any iron staining. There are beds of undisturbed sediments alternating with distorted beds showing folding and plication of sandy streaks. Although these basal beds will split along their bedding, they will just as easily break into blocks. The only fossils present are occasional single valves of Eotrapezium.

Towards the middle of the Blocky Beds the bedding becomes less noticeable and the rock breaks naturally into sub-cuboidal pieces, some of which are rounded and smooth like cobbles. Eotrapezium occurs as rare isolated valves.

In the upper part the marine bivalves are absent and rare; indeterminate fossils have been found which may be insect remains. The rock is either completely unbedded or with very faint bedding, and also breaks into blocks which tend to be smaller than those below. In the

TEXT - FIGURE 3. SECTION - BARNSTONE CUTTING



upper part the blackness of the rock fades progressively upwards to where the unweathered rocks are light grey in colour. These middle and upper beds are siltstones and sieved residues leave granules of light grey material with quartz grains, mica, small nodules of pyrite and pieces of cemented sandy material.

The boundary between the Block Beds and the Cotham Marls above is an indeterminate one, there being a gradual change from one to the other. The change is characterised by a transition from blocky to shaly bedding, from a grey to a yellow-grey colour and by an increase in the calcareous content.

The Cotham Marls (6 ft. (1.8 m.))

These beds consist chiefly of grey marls which turn yellow on weathering. Most of the material exposed was weathered to some extent, the yellowness first appearing in patches. Much of these beds has bands of hard crumbly shale alternating with layers of softer rock. Some of the marl is almost a whitish grey, due to an increase of calcareous material. Scattered through the marl, but particularly in the upper part, there are many pieces of white and light buff coloured calcitic material which ranges in size from extremely minute up to about one inch (25 mm.) across. The larger ones are found only at exposure J. They have internal hollows and bizarre shapes. At exposures E and F, about 1 ft. 9 ins. (0.5 m.) from the top of the marl, there is about 10 ins. (0.3 m.) of light grey calcareous shales. At the base of these shales there is a ½ inch (12 mm.) layer of flattened, buff-coloured, calcareous nodules, many being sub-circular in shape with rounded, radially cracked edges. In the Cotham Marls at various horizons, there are occasional nodules of limestone up to 2 ft. (0.6 m.) across. These are of a similar rock to that of the limestone bed above and they contain rare branchiopods (Euestheria minuta). E. minuta has also been recorded in the Rhaetic beds of the Barnstone quarry (Kent, 1937, p. 165).

The Nodular Limestone (3 to 6 ins. (76 to 152 mm.))

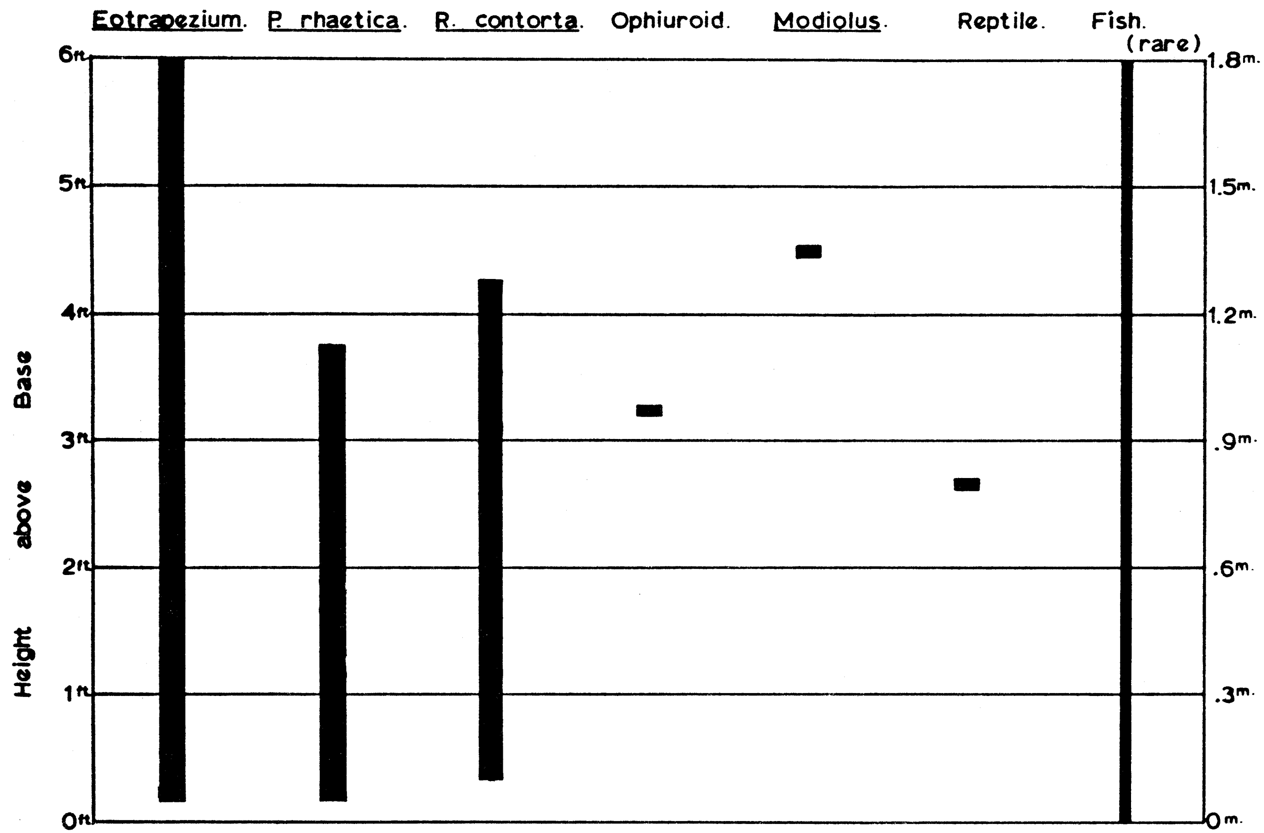
The Nodular Limestone occurs at the top of the Cotham Beds and is sporadic in its development. In one place it is found as a solid 6 ins. (0.2 m.) bed of limestone but mostly it is in the form of a layer of separate nodules 2 to 3 ins. (50 to 75 mm.) thick which are sometimes rather scattered. The limestone has a conchoidal fracture, is fine grained, light grey, weathering creamy and is unbedded. There is much calcite in the form of veins and layered tufa on the outer surfaces. Rare Euestheria minuta are the sole fossils found.

Jurassic

The Pre-Planorbis Beds (5 ft. 5 ins. (1.6 m.))

The beds above the Nodular Limestone consist of thin limestones, limestone shales and marls. The lowest bed comes in at the top of the cutting just N.W. of exposure E and the highest bed is just below ground level at exposure N (Text-fig. 3). The beds are fairly consistent along their length with the exception of the lowest. This is separated from the Nodular Limestone by 3 ins. (75 mm.) of marl, except between exposures E and J where the marl thickens up to 1 ft. 10 ins. (0.6 m.) and contains a minor limestone bed. The lowest limestone has a lumpy undersurface. The marls are grey to buff and range from shales to clays. Between these and the limestones there are sometimes some hard, transitional limestone shales. The limestones are thinly bedded, being medium grey with bluish centres and occasionally purple stained, one exception being the top 1½ ins. (38 mm.) layer of the third which is brown and sandy.

These beds have a distinctive fossil suite which is found, either fully represented or in



TEXT-FIG. 4. THE OCCURRENCE OF FOSSILS IN THE BLACK SHALE BEDS.

part, in each separate bed. The marls have sparse, poorly preserved foraminifera and occasional ostracods. The limestone shales are similarly poorly fossiliferous, though also with occasional bivalve impressions. The limestones are much more fossiliferous. Modiolus minimus J. Sowerby is found mostly in the first and second limestones. Modiolus sp. is found in them all, though most abundantly in the brown, sandy upper bed of the third limestone. This is a type intermediate between M. hillanus J. Sowerby and M. minimus (Kent, 1953, p. 136). Liostrea hisingeri (Nilsson) is rare throughout, whereas echinoid spines increase from being rare in the first limestone to abundant in the fourth. Pleuromya tatei (Richardson and Tutcher) is found in all the limestones but is only abundant in the purple-stained lower part of the third limestone. Ostracods and foraminifera (Cornuspira sp.) are scattered in the limestones, though these also become abundant in the top bed of the third limestone.

Palaeoecological Discussion

At Barnstone there is no fossil evidence to suggest that open marine conditions were present before the deposition of the Rhaetic Beds. The transition from the Tea Green Marl to the lowermost shale of the Rhaetic is suggestive of a gentle invasion by the sea, causing little disturbance to the previous deposits. It must be considered, however, that the incursion occurred after a long period of peneplanation, and that the supply of material available for deposition will have come from the surrounding low-lying Triassic plains. At Barnstone this material may have possibly been laid in a pre-existing body of water. The sedimentology of the Tea Green Marl shows that it has a comparable composition to that of the Rhaetic shales above, so that they were probably derived from a common source. However, the sediments are more sorted in the Rhaetic, where partings of current concentrated, white sandy quartz are characteristic of much of the shales. The multi-coloured grains of the Tea Green Marl can also be found matched in the Bone Bed.

With the first deposition of black shale we find that a variety of fishes were living in the open water, but locally there is no evidence of a benthonic fauna. It is only higher up the succession, above the Bone Bed, that bivalves appear. As all the shales have broadly the same lithology it is suggested that bivalves were slow to migrate into the area.

The presence of concentrations of vertebrate remains in bone beds is the outstanding feature of Rhaetic rocks, and many widely differing theories have been advanced to explain them. These theories may be divided into three categories:-

1. That mass deaths of vertebrates provided an enormous amount of material for preservation.
2. That concentrations were formed by the lack of deposition of any associated sediments.
3. That any sediment deposited with the bones was subsequently winnowed away.

Throughout this country the Rhaetic Bone Beds differ lithologically, but all appear to contain coarse sand and sometimes pebbles. This is the case at Barnstone, where there seems to be a special relationship between coarse sediments, phosphatic nodules and vertebrate remains. Phosphatic remains occur in association with coarse deposits in patches within the black shales below the Sandy Beds. It would appear that the conditions which produced one also produced the other. The presence of unfossiliferous lenses of fine sediment within the fossil-packed Bone Bed emphasises that vertebrate remains and fine sediments are not usually associated. The presence of rare and randomly scattered fish and reptile remains, together with the absence of coarse quartz

STRAT. DIVS.	BEDS	LITHOLOGY	FAUNA	THICKNESS ft.	ins	metres
HETT-ANGIAN	PRE-PLANORBIS BEDS	Blue-centred, grey limestones with light grey L/st. shales, yellow-grey marls and clays between. 3rd limestone with purple-stained base and sandy top.	Pleuromya tatei, Modiolus minimus, Modiolus sp., Liostrea hisingeri, Echinoid spines, Ostracods, and Foraminifera.	5	5	1.6
UPPER RHAETIC	NODULAR LIMESTONE	Light grey limestone, weathering creamy	Rare Euestheria minuta		3-6	0.1
	COTHAM MARLS	Light grey shaley marl, weathering yellow, with calc. nodules and limestone boulders	Rare Euestheria minuta in the boulders.	6	0	1.8
LOWER RHAETIC	BLOCKY BEDS	Black, blocky shales and siltstones becoming grey towards the top.	Eotrapezium in the lower part.	9	0	2.7
	SANDY BEDS	Black shales with thin sandstones, also many sandy partings and layers.	Eotrapezium concentricum and Eotrapezium sp.	4	6	1.4
	BLACK SHALE BEDS	Bedded black shales, flaggy towards base.	Protocardia rhaetica, Rhaetavicula contorta, Eotrapezium concentricum, E. sp., ?Modiolus, Ophiuroid, rare fish and reptile remains	6	1	1.9
	BONE BED	Crumbly mudstone with shale patches on a layer with pyritic matrix. Pebbles, quartz grains and phosphatic nodules, etc.	Fish and reptile remains with rare bivalves and many coprolites. (All the fish and reptile specimens described are from the Bone Bed).		3	0.1
	PRE-BONE-BED BLACK SHALE	Black shales with sandy partings, occasional quartz grains and phosphatic nodules.	Fish remains	1	6	0.5
KEUPER	TEA-GREEN MARL	Grey-green indurated marl.	More than	2	0	0.6

TABLE 1. STRATIGRAPHICAL COLUMN WITH CONTAINED FAUNA

concentrates, shows that vertebrates were being continually deposited in the black shales overlying those just above the Bone Bed. In the Bone Bed there was obviously increased water movement in bottom currents to transport the coarse material and to roll, break up, and abrade the bones deposited. In considering the origin of the Bone Bed, one of the main problems to be explained is how such a thick concentration of vertebrate remains came to be formed contemporaneously over such a wide area. It is possible, however, that the Bone Bed exposed at different localities does not belong to one continuous bed. This is supported by its variable occurrence at Barnstone, its absence at Cotham (in Lincolnshire, not the famous locality) and Bunny, and also its occurrence at more than one horizon at such places as Gainsborough and Aust. If the bed is not continuous but occurs as discrete lenses at slightly different levels, it makes the depositional theory of coarse transported sediments more feasible. Variations in the lithology and horizon of the Bone Bed and the diverse theories of its origin are more fully discussed by Kent (1968).

Apart from the Bone Bed the Black Shales are the most fossiliferous Rhaetic rocks, containing mostly thin-shelled marine bivalves. Near the base of the Black Shales occasional slight increases in water movement produced silty layers, although higher up, quieter conditions are indicated by the absence of silt and by bedding planes covered with bivalves. Some small groups of shells are found broken up in the Black Shales, yet on the layers containing numerous specimens they are mostly undamaged and many of them are still joined together. These crowded layers often contain individuals of a small size range and may have been sorted by short distance transport, which would not have broken or dissociated the valves. The blackness of the shales and the contained pyrite indicates that anaerobic conditions were probably present within the sediments. The bottom conditions, however, must have been fairly saline and oxygenated, because ophiuroids which occur in these beds require these conditions.

After the quiet conditions of the Black Shales, the overlying Sandy Beds contain disturbed sediments which indicate greater current action. The black shale within the Sandy Beds has a similar lithology to that in the beds below which shows that the same anaerobic influences were still active. When bivalves are present within this shale, a few still have their valves joined and open. However, these conditions were periodically disturbed by increased water movement bringing in an influx of a new type of sandy deposit. The sandstones were probably deposited quickly because the bivalves are scattered indiscriminately and occur with their valves closed. Further evidence is the current bedding of some of the sandstones. There is also evidence of contemporaneous movement of the sediments after deposition, as demonstrated by the alternating layers of disturbed and undisturbed sediments. At exposure C, some black shale horizons show a 'rippled' surface, although, according to Twenhofel (1950, p. 567) ripple marks cannot be formed in muds. In addition the sides of some of the sand-filled channels are too steep to be ripple marks. The orientation of all these structures is in the same general direction. It is therefore concluded that these phenomena are not depositional features but are due to lateral pressure on the sediments. The structures figured (Text-fig. 2) show that these channels were filled from the South. Regionally, the Rhaetic thickens to the North and thins towards the South (Kent, 1968, p. 179) and movement of material from the South to the thicker beds of the North is consistent with the deposition of these channels. Exposures at D, E and F show distorted beds, which are due to the same influences as described above, since they orientated in the same direction. The folding here could have been caused by slumping due to slight local tilting which also gave rise to the lateral pressures. Flat-lying beds are found laid on top of distorted beds, which could indicate slight pauses in deposition whilst the distortion was taking place. The transition to calcareous conditions is found widely in the Rhaetic, and this transitional horizon occurs about one third of the way up these beds.

The outstanding character of the Blocky Beds is their development of jointing and their general paucity of bedding. Pressure or tension on rocks results in jointing and, on partly indurated muds, causes splitting into well defined blocks, some of which become rounded by movement and abrasion (Boswell, 1961, p.102). The definitely calcareous nature of these beds could influence their fracture on weathering. They were, however, probably affected by stress a short time after their deposition, producing the many smoothly rounded blocks. Near the base, these sediments show sorting and the fact that they have alternate deformed and undeformed layers indicates that the same influences were in operation as in the beds below. Silty layers are not present higher up, although silt grains are still present in the sieved samples. When the supply of sediment is much greater than can be carried by the transporting agent, the sorting of silt and sand does not take place. This would imply that these beds were laid down fairly rapidly. This is supported by the progressively greater rarity of the marine bivalves upwards, caused either by their aversion to rapid silt deposition or by their sedimentological dilution. Near the top of the Blocky Beds a marine fauna is absent, and this suggests a transitional period to the conditions of the beds above. The presence of paler sediments near the top is possibly due to a lessening of the previously existing anaerobic conditions.

No distinct line can be drawn between the Blocky Beds and the Cotham Marls, for one merges slowly into the other. However, a progressive change in lithology is shown by the residues, which contain an increasing quantity of shale fragments, pyrite and calcite granules, becoming yellow rather than grey. There is no unconformity or non-sequence at the top of the Blocky Beds. Although Wilson (1877) placed them in the Upper Rhaetic, these beds are here placed in the Lower Rhaetic because of their continuity with the fauna below and their lithological difference from the Cotham Beds here and in other parts of the Midlands. These are possibly a set of rapidly accumulated, localised deposits.

The Cotham Marls at Barnstone have yielded few fossils. It has been suggested that Midland equivalents of these beds show a return to conditions approaching those found in the Keuper (Kent, 1968, p.178). The branchiopods (Euestheria) which have been found near the base and at the top of these beds helps to bear this out, since they are considered to have lived in fresh or brackish water (Jones, 1862; Thompson, 1966).

There are some indications of a non-sequence at the top of the Rhaetic. The lowest of the Pre-Planorbis Beds varies in thickness and the overlying limestone seems to have been laid down on an eroded surface. Above the Nodular Limestone a new suite of fossils appear which are characteristic of the Pre-Planorbis Beds. These are very sparsely represented in the lowest marls, but are fully represented in the lowest limestone. Only the lower part of the Pre-Planorbis Beds is present in the Barnstone cutting. The bivalve Pleuromya tatei is the main fossil found there and it is the dominant fossil of this horizon elsewhere in this country (Tutcher, 1917, p.281). A full sequence of the Pre-Planorbis Beds is described by Kent (1937). The specimens of the bivalve Modiolus sp. found associated with these beds are thought to occupy a definite horizon in this area and have been considered as a possible indicator of the White Lias (Kent, 1953). However, at Barnstone they are found only in association with the Pre-Planorbis Beds.

Fossil Descriptions

The fossil descriptions have selected synonymies only. The figured specimens have been deposited in the Department of Palaeontology, British Museum (Natural History).

Phylum Mollusca

Class Bivalvia

Rhaetavicula contorta (Portlock)
(Pl. 18, Fig. 12)

1962 Rhaetavicula contorta (Portlock): Cox, 4, pt. 4, p.594, fig. 1.
MATERIAL: Numerous detached left valves and a few right valves.
DESCRIPTION: An adequate and easily obtainable description of this species is available (Cox, 1962).

Protocardia rhaetica (Merian)
(Pl. 18, Fig. 14)

1853 Cardium rhaeticum Merian in Escher v.d. Linth, p.19, pl. 4, figs. 40-41.
MATERIAL: Many crushed, discrete or associated valves.
DESCRIPTION: The valves are rounded in outline, with fairly prominent umbones situated a little anterior of the centre. The anterior margin is concave near the umbo and sweeps round in a convex curve to the gently rounded, rather flattened, ventral margin. The dorsal margin is short and straight and is separated from the posterior margin by a distinct angle. The posterior margin is nearly straight and steeply inclined, and is separated from the ventral margin by a rounded angle. The posterior portion of the valve is gently folded on a line from the umbo to the postero-ventral corner. The posterior area is ornamented by an average of thirteen low radial ribs, four of which are anterior to the fold. The surface of the shell is ornamented with faint concentric rugosities which are impressed on the radial ribs.

Eotrapezium concentricum Moore
(Pl.18, Fig. 11)

1861 Axinus concentricus Moore: Moore, pl. 15, figs. 19-21, p. 503.
1969 Eotrapezium concentricum (Moore): Ivimey-Cook and Elliot, p. 145.
MATERIAL: Numerous specimens with separate or joined valves.
DESCRIPTION: The valves are moderately inflated, ovate, with the umbones a short way anterior of the centre. The anterior margin is concave near the umbo and sweeps round in a convex curve to the gently rounded ventral margin. The dorsal margin behind the umbo is gently inclined, straight, and produced to give an obtuse angle with the very gently rounded posterior margin. The posterior margin is almost vertical and has an angular junction with the ventral margin. There is a sharp carina from this angle to the umbo. The posterior area is inclined at an angle to the rest of the valve. The surface of the valve is ornamented with very fine striations which follow the margin.

? Eotrapezium sp.
(Pl. 18, Fig. 13)

MATERIAL: Several solid phosphatic specimens and a few crushed moulds in shale.
DESCRIPTION: (Based on phosphatised specimens). The valves are slightly inflated, ovate, with the umbones about one third of the length from the anterior margin. The margins are gently rounded, there being no posterior truncation.
REMARKS: It has not been possible to accurately determine this species and it is only tentatively allocated to Eotrapezium.

Phylum Arthropoda

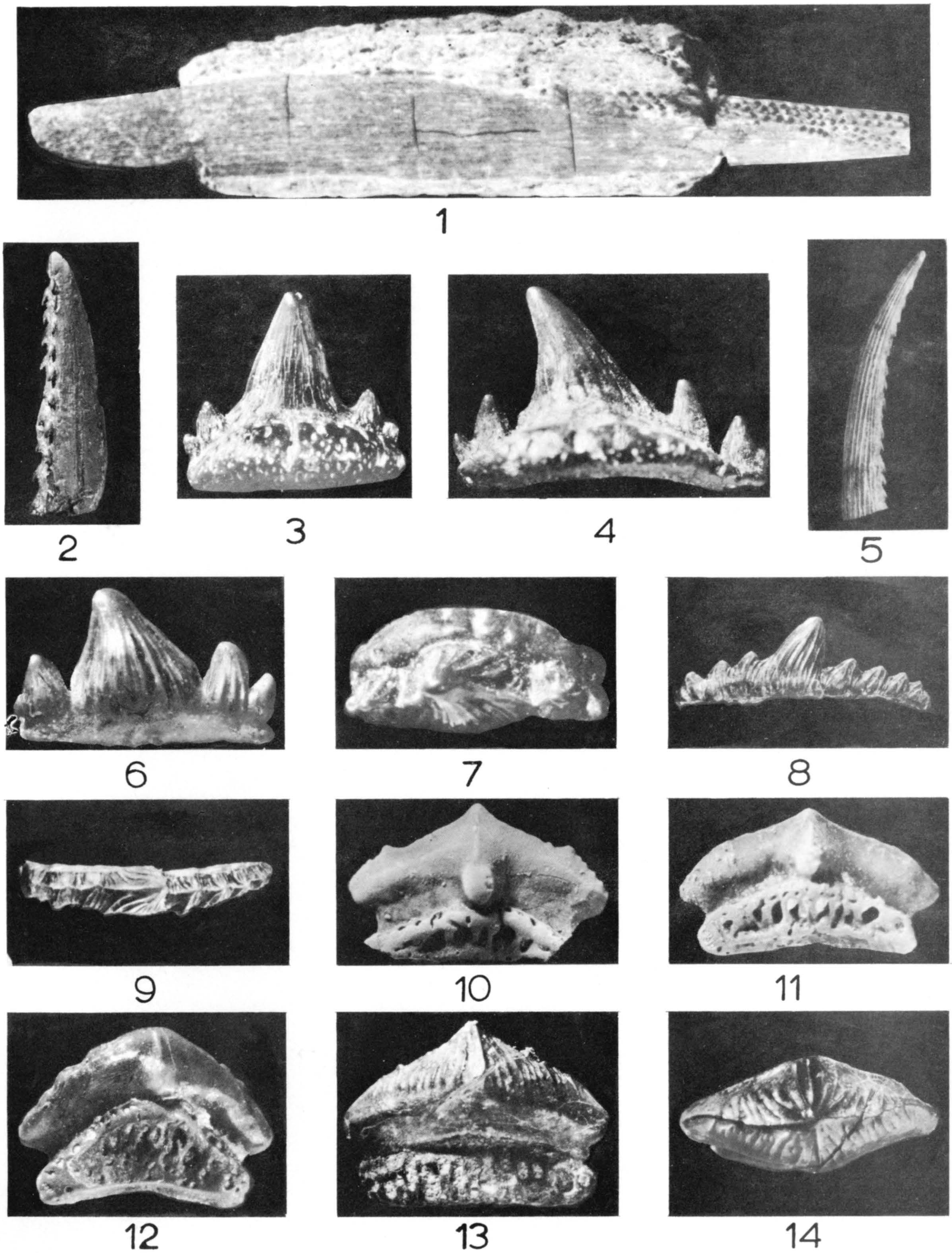
Class Crustacea
(Pl.18, Fig. 10)
Euestheria minuta (Alberti) var. brodieana Jones

1862 Estheria minuta var. brodieana, Jones: Jones, p. 67, pl. 2, figs. 8-15.
MATERIAL: A few carapaces.

EXPLANATION OF PLATE 15

Figs. 1 & 2	Nemacanthus monilifer Agassiz.
Fig. 1	Lateral view of fin spine. (18.6 x 151.6 mm.)
Fig. 2	Lateral view of tip of fin spine. (17.6 x 4.7 mm.)
Figs. 3-7	Hybodus minor Agassiz.
Fig. 3	Inner view of anterior tooth. (5.3 x 6.3 mm.)
Fig. 4	Inner view of lateral tooth. (2.3 x 3.5 mm.)
Fig. 5	Lateral view of fin spine. (51.7 x 9.1 mm.)
Fig. 6	Outer view of posterior lateral tooth. (1.5 x 2.9 mm.)
Fig. 7	Apical view of same. (1.5 x 2.9 mm.)
Figs. 8 & 9	Hybodus cloacinus Quenstedt.
Fig. 8	Outer view of lateral tooth. (4.8 x 14.8 mm.)
Fig. 9	Apical view of same. (2.6 x 14.8 mm.)
Figs. 10-14	Acrodus minimus Agassiz.
Fig. 10	Outer view of posterior lateral tooth. (1.8 x 2.8 mm.)
Fig. 11	Outer view of posterior lateral tooth. (1.8 x 3.4 mm.)
Fig. 12	Outer view of anterior tooth. (3.1 x 4.8 mm.)
Fig. 13	Inner view of lateral tooth. (4.0 x 5.0 mm.)
Fig. 14	Apical view of same. (2.6 x 5.5 mm.)

All quoted measurements are of the heights and widths respectively in each of the given views.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DESCRIPTION: The carapace of this branchiopod is ovate, moderately inflated, with the maximum inflation about half way down the carapace below the umbo. The hinge border is straight and just over half the length of the carapace. It curves downwards at the posterior end into a rounded, rather oblique, posterior margin. The rounded umbo is situated about one quarter of the length from the anterior end. The anterior border is straight and inclined for a short distance before forming a gently, more acute curve than the posterior margin. The ventral margin is slightly curved. The carapace has a small smooth area around the umbo and the rest is ornamented with a series of fourteen concentric rugosities.
REMARKS: These specimens compare well with Jones (1862) description.

Phylum Echinodermata
Subphylum Eleutherozoa
Class Stelleroidea
Indeterminate Ophiuroid
(Pl.18, Fig. 9)

MATERIAL: One complete specimen and a few fragmentary arms.
DESCRIPTION: The complete specimen consists of a roughly pentagonal central disc and five long, narrow, radiating arms. The disc shows the bases of the arms converging inwards towards a central mouth. This is suggestive of an under surface of a disc. The arms are gradually tapering and originate at the angle of the disc. Some of the fragmentary arms clearly show the shield plates.
REMARKS: This ophiuroid is strictly indeterminate but on stratigraphical grounds may be referable to Ophiolepis damesii, which has been found in Leicestershire (Harrison, 1876).

Phylum Chordata
Class Chondrichthyes

Nemacanthus monilifer Agassiz
(Pl.15, figs. 1-2, text-fig. 5, fig. 3)

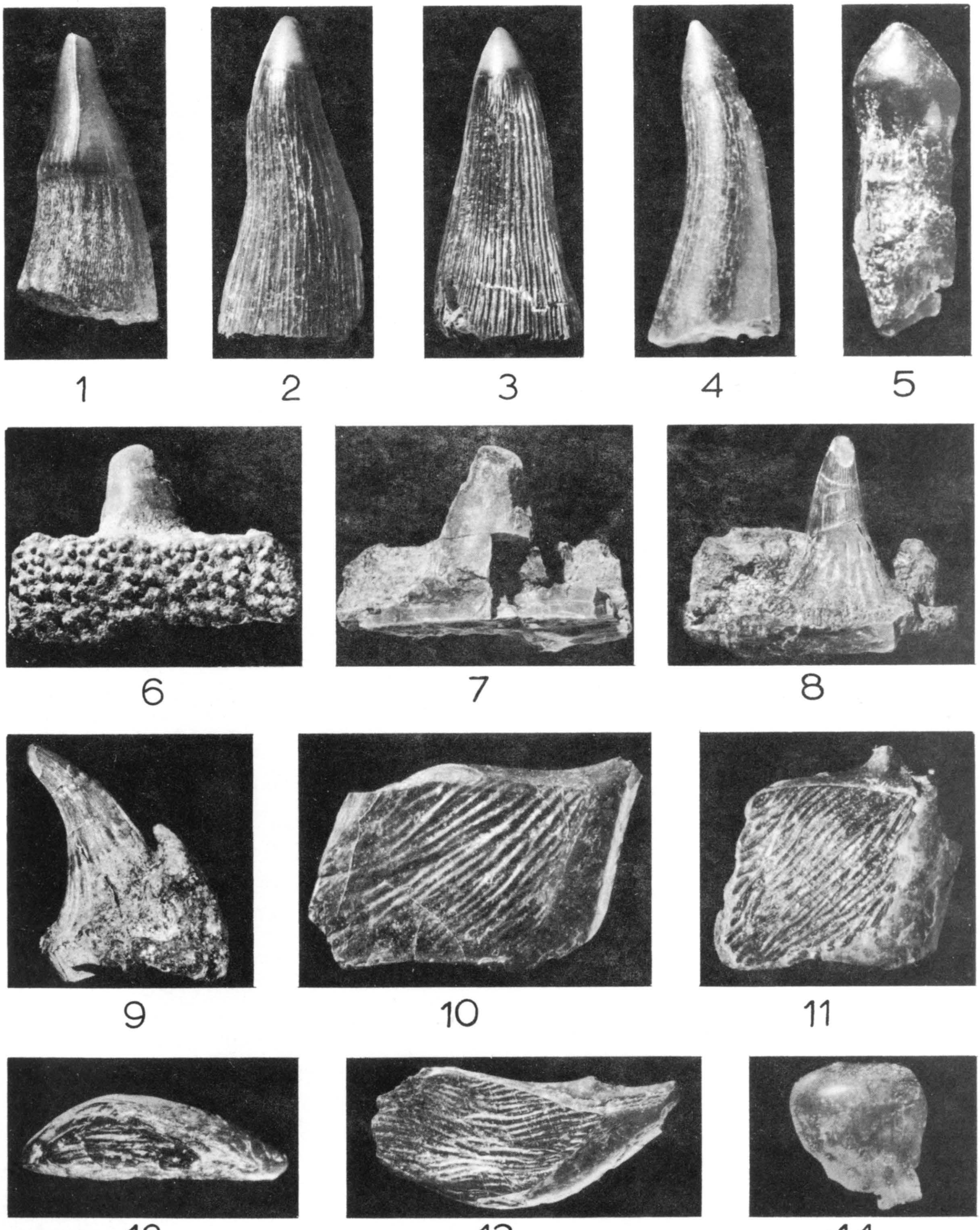
1837 Nemacanthus monilifer Agassiz: Agassiz, 3, p. 26, pl. 7, figs. 10-15.
1858 Desmacanthus cloacinus Quenstedt: Quenstedt, p. 34, pl. 2, fig. 13.
1872 Nemacanthus monilifer Agassiz: Etheridge, p. 64, pl. 2, fig. 1.

MATERIAL: One nearly complete spine and many isolated fragments.
DESCRIPTION: The spine is elongate, solid, and laterally very compressed. The anterior margin is gently convex and bears a distinct, rounded enamel keel whereas the posterior margin is straight and has a rounded, longitudinal, median furrow. It is roughly triangular in cross section, with an anterior acute angle and a posterior narrow face with rounded edges. It has an acutely pointed tip bearing two rows of downwardly directed tubercles on the posterior face. The spine is very finely striated throughout its full length. The distal half of the spine is mostly ornamented with regular, rounded enamel tubercles. These are absent near the tip and extend to about one third the way to the proximal end on the anterior margin, producing an oblique boundary with the rest of the spine. None of the specimens shows a clearly defined insert portion.

EXPLANATION OF PLATE 16

Fig. 1	Birgeria acuminata (Agassiz). Lateral view of tooth. (10.5 x 5.2 mm.)
Figs. 2 & 3	Saurichthys longidens Agassiz.
Fig. 2	Lateral view of tooth. (13.3 x 6.3 mm.)
Fig. 3	Inner view of same. (13.3 x 6.3 mm.)
Fig. 4	Gyrolepis albertii Agassiz. Lateral view of tooth. (2.8 x 1.1 mm.)
Fig. 5	?Sargodon tomicus (Plieninger.) Lateral view of tooth. (5.4 x 1.9 mm.)
Figs. 6 & 7	Birgeria acuminata (Agassiz).
Fig. 6	Outer view of jaw fragment. (7.1 x 10.3 mm.)
Fig. 7	Inner view of jaw fragment. (7.1 x 10.3 mm.)
Figs. 8 & 9	Saurichthys longidens Agassiz.
Fig. 8	Inner view of jaw fragment. (20.5 x 25.6 mm.)
Fig. 9	Lateral view of jaw fragment. (20.5 x 16.2 mm.)
Figs. 10-13.	Gyrolepis albertii Agassiz.
Fig. 10	Outer view of anterior scale. (4.6 x 6.6 mm.)
Fig. 11	Outer view of dorsal scale. (5.2 x 5.4 mm.)
Fig. 12	Outer view of posterior flank scale. (1.1 x 3.2 mm.)
Fig. 13	Outer view of flank scale. (5.1 x 10.0 mm.)
Fig. 14	?Sargodon tomicus (Plieninger.) Lateral view of tooth. (1.8 x 1.8 mm.)

Plate 16



Hybodus minor Agassiz (Jukes-Browne, 1885)
(Pl.15, Figs. 3-7, text-fig. 5, figs.4-b)

1843 Hybodus minor Agassiz: Agassiz, 3, pp. 48 and 183, pl. 8, figs. 2-3, pl. 13, figs. 21-24.
1858 Hybodus cloacinus Quenstedt: Quenstedt, p. 34, pl. 2, fig. 14.
1872 Hybodus minor Agassiz: Etheridge, p. 64, pl. 2, figs. 12-14.
1889 Hybodus minor Agassiz: Woodward, 1, p. 250.

MATERIAL: Numerous isolated teeth and three fin spines, one complete.
DESCRIPTION: The teeth consist of a central crown generally with one to three lateral crowns on each side rising from an interiorly extended root platform. The central crown rises from the aboral margin of the root, curves slightly inwards, and is upright or inclined posteriorly. It is broadly to moderately conical, has two cutting edges and is coarsely ribbed. The lateral crowns also rise from the aboral margin of the roots and resemble the main crown with respect to ribbing and shape. They decrease in size away from the centre, and occasionally the outermost have an incipient crown which is developed as a lateral protruberance. The root is basically a flat, semicircular platform with the crowns rising at about a right-angle from the straight aboral margin. The roots are regularly perforate and vary from thin to bulbous forms.

The spines are elongate, hollow for approximately half their length, the distal portion being curved posteriorly. They are laterally compressed and oval in cross section. They have strong, broad, rounded ribs on each side, which increase by bifurcation from four near the apex to a maximum of nine. One of these ribs is situated along the anterior margin. There is a narrow area either side of the posterior angle which is pitted and lacks ribbing. The posterior margin possesses a row of downwardly directed denticles for about half the length of the spine. The upper end of each denticle is extended and wraps around the side of the one above, alternatively to the right and the left. The insert portion is distinguished from the exsert portion by its lack of ribbing and also its finely striate and pitted surface. The junction between the insert and exsert portions is diagonal, at an angle of about 45° to the posterior margin.
REMARKS: The fin spine figured by Agassiz (1843, pl. 8, figs. 2-3) is incomplete and lacks the distal end, which is the largest part of our figured specimen. This specimen differs only from those found at Barnstone in being more inflate.

Hybodus cloacinus Quenstedt
(Pl.15., Figs. 8-9)

1839 Hybodus reticulatus Agassiz: Agassiz, 3, pl. 24, fig. 26. (Jukes-Browne, 1885).
1858 Hybodus cloacinus Quenstedt: Quenstedt, p. 34, pl. 2, fig. 15.
1872 Hybodus reticulatus Agassiz: Etheridge, p. 64, pl. 2, fig. 11.
1889 Hybodus cloacinus Quenstedt: Woodward, 1, p. 256.

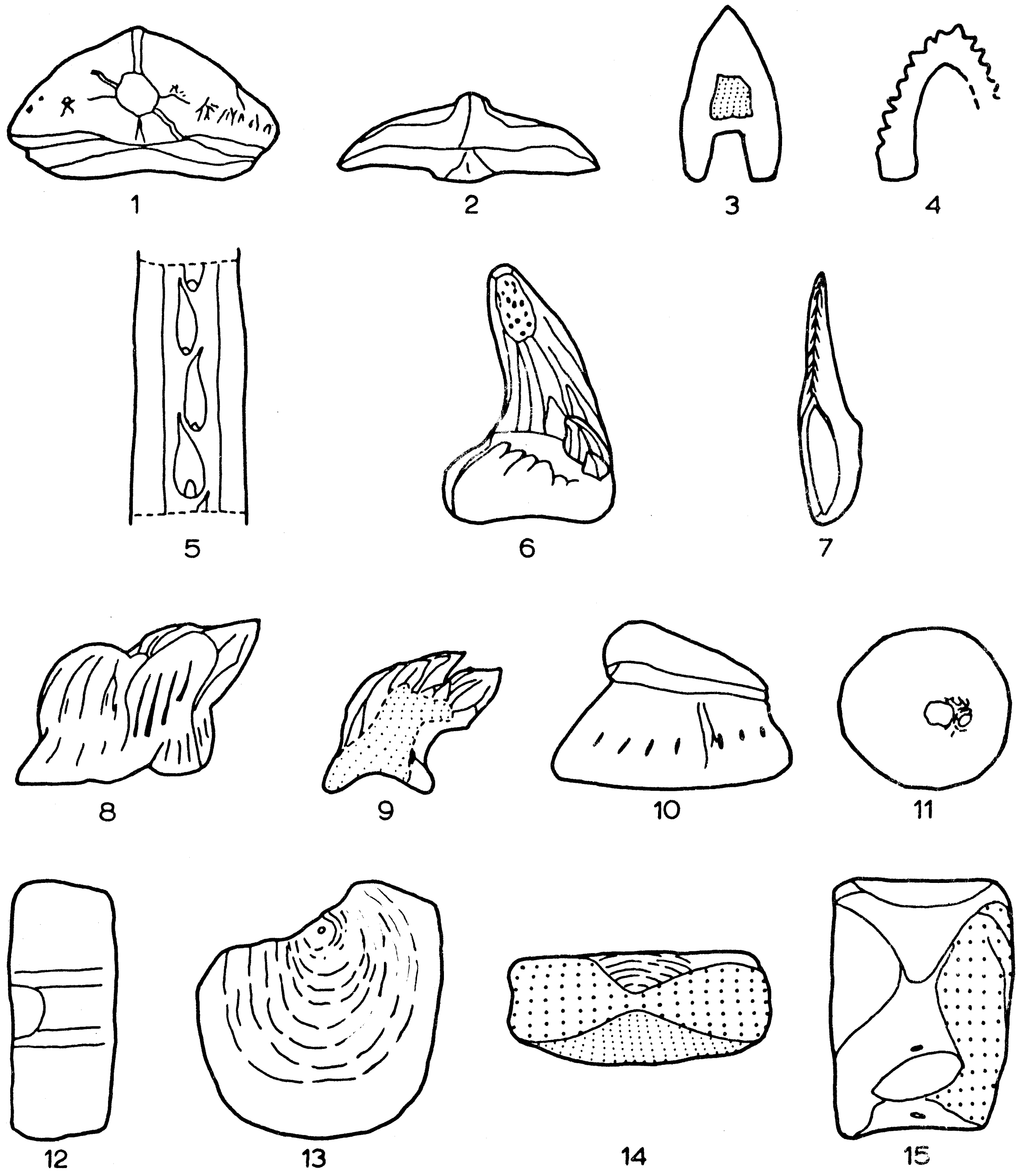
MATERIAL: A few isolated teeth, none with roots attached.
DESCRIPTION: The tooth, minus its roots, consists of an arched band of enamel with upright posteriorly inclined crowns which are low and coarsely striate. The centre crown is higher than the rest, there being about four lateral crowns on either side. Unlike H. minor, where the root forms an integral part of the tooth, no specimen has been found with root attached.
REMARKS: The teeth, although similar to those of H. minor, may be easily distinguished by their lateral extension, curved shape, low central crown and larger number of lateral crowns. The root attachment also differs; the under surface is concave and inclined upwards to the oral side because the tooth is longer aborally than orally, this is not the case in H. minor.

EXPLANATION OF TEXT-FIGURE 5

Figs. 1-2	Acrodus minimus Agassiz.
Fig. 1	Upper view of anterior tooth (same specimen as that figured on pl.15, fig. 12). (2.8 x 4.8 mm.)
Fig. 1	Upper view of posterior lateral tooth (same specimen as that figured on pl.15, fig. 11). (1.7 x 3.4 mm.)
Fig. 3	Nemacanthus monilifer Agassiz. Cross section of fin spine. (19.1 x 11.4 mm.)
Figs. 4-6	Hybodus minor Agassiz.
Fig. 4	Cross section of proximal part of fin spine. (15.7 x 11.0 mm.)
Fig. 5	Diagram showing details of denticles on posterior edge of fin spine (same specimen as that figured on pl.15., fig. 5). (9.8 x 4.3 mm.)
Fig. 6	Lateral view of anterior tooth (same specimen as that figured on pl.15, fig. 3). (5.3 x 3.5 mm.)
Fig. 7	Scymnorhinidae gen. undet. Lateral view of tooth (same specimen as that figured on pl.17, fig. 8). (4.3 x 0.7 mm.)
Figs. 8-9	Indeterminate Hybodont.
Fig. 8	Lateral view of type D dermal denticle. (1.2 x 1.9 mm.)
Fig. 9	Lateral view of type E dermal denticle (same specimen as that figured on pl.17, fig. 5). (1.3 x 1.8 mm.)
Fig. 10	Indeterminate Selachian. Lateral view of dermal denticle (same specimen as that figured on pl. 17, fig. 6). (1.7 x 2.4 mm.)
Fig. 11	?Sargodon tomicus Plieninger. Upper view of tooth (same specimen as that figured on pl. 16, fig. 5). (1.9 x 2.0 mm.)
Figs. 12-14	Indeterminate Ichthyosaur.
Fig. 12	Lateral view of type 1 vertebra centrum (same specimen as that figured on pl. 17. fig. 14). (35.3 x 14.7 mm.)
Fig. 13	Anterior view of type 2 (caudal) vertebra centrum). (75.1 x 73.2 mm.)
Fig. 14	Upper view of same. (32.0 x 70.4 mm.)
Fig. 15	Indeterminate Plesiosaur. Lateral view of vertebra centrum (same specimen as that figured on pl. 17, fig. 10). (60.9 x 43.0 mm.)

All measurements quoted are of the heights and the widths respectively in each of the views given.

TEXT - FIGURE 5



Acrodus minimus Agassiz (Jukes-Browne, 1885)
(Pl. 15, Figs. 10-14, text-fig. 5, figs. 1-2)

1839 Acrodus minimus Agassiz: Agassiz, 3, p.145, pl. 32, figs. 6-12.
1872 Acrodus minimus Agassiz: Etheridge, 3, pt. 2, p.64, pl. 2, figs. 15-17.
1889 Acrodus minimus Agassiz: Woodward, 1, p.282.

MATERIAL: Numerous isolated teeth, mostly detached from the roots.
DESCRIPTION: The teeth consist of an elongate low crown which is attached to a narrow elongate root. From above they are straight to slightly incurved, and sometimes possess an angular curve towards the ends. The crown consists of a central cusp with one to three minor cusps on each side. They may be broadly conical to depressed and rounded. Most cusps are radially, coarsely to finely striate from their apices; some have striations arranged in a 'herring bone' pattern. Cutting edges on the crowns join up to form a continuous edge passing through the apices. There is a centrally placed tubercle, sometimes accompanied by a row of minor tubercles at the base of the outer face of the crown. The crowns curve under to the roots. On the inner side there is a smooth, flattened area which extends obliquely below the crowns to the root contact. The teeth are inclined inward at an angle to the roots which are perforate and when detached leave a concave undersurface to the rest of the tooth.
REMARKS: By comparing these teeth with those of Liassic hybodonts, it is possible to refer the triangular shaped ones to the symphyseal area of the fishes mouth, the more elongate ones to the lateral region and the simplest teeth to a rear lateral position.

? Indeterminate Hybodont
(Pl.17, Figs. 1-5, text-fig. 5, figs.8-9)

MATERIAL: Many minute dermal denticles.
DESCRIPTION:
Type A - This resembles the minute teeth of Hybodus minor, with the typical root, nearly cylindrical crown, and inconspicuous lateral denticles.
Type B - The blunt, strongly fluted crown is round or oval when viewed from above and narrows near the flat root.
Type C - This type is similar to the last, but differs in possessing two to six closely-packed crowns and in being often more depressed.
Type D - This type is again similar to the preceding, but possesses one or more rear crowns which are laterally extended and bent to the rear.
Type E - This type is laterally elongate and consists of flattened and bent crowns.
REMARKS: These denticles bear a strong resemblance to those of Liassic hybodonts and may therefore be assigned to this group. The type A denticles probably came from the mouth area and the type E denticles from the flank. Those in between come from intermediate positions.

Scymnorhinidae gen. undet.
(Pl.17, Figs. 8-9, text-fig. 5, fig. 7)

MATERIAL: Several teeth.
DESCRIPTION: The teeth consist of a roughly triangular crown situated on a rectangular root. The crown is very compressed, pointed at the top and has pronounced serrated edges. The crown is slightly incurved either upright or laterally inclined, and usually rises from almost the full width of the root. It thins towards the edges, on which are three to nine upwardly directed, strong serrations. The serrations increase in size towards the apex, which is prominent. The root

has two upright lateral grooves which are either both on the inner side or on opposite sides. There is sometimes a transverse thickening below the lateral grooves, beneath which are two small circular canals near the middle of the root which are inclined inwards. The tooth is covered with parallel crack-like striations in its enamel.
REMARKS: These teeth compare closely with those of the Recent Scymnorhinus licha (Bon.) [see Casier, 1961, pp. 7-61, figs. 7-9.] None of the teeth recoverd from Barnstone is complete, however, and the best appear to lack the lower half of the root. Even so, the similarity with the Recent species leaves no doubt that they can be referred to the family Scymnorhinidae. They differ from Scymnorhinus particularly in the coarse serrations of the crowns and in the presence of two(not one) foramens in the root. They may well prove to belong to a new genus.

? Indeterminate Selachian
(Pl. 17, Fig. 6, text-fig. 5, fig. 10)

MATERIAL: A few minute dermal denticles.
DESCRIPTION: These denticles consist of a rounded to sub-quadrate base surmounted by a smooth rounded cap with undercutting sides. The base narrows sharply upwards and is radially grooved. The cap is more elongate than the base is inclined lengthwise and possesses a depressed upper surface.
REMARKS: These denticles are very similar to those of Hypolophus sylvestris White from the lower Eocene (White, 1931, p.72, figs. 109-112) but they differ in their smaller size and relatively larger caps. They presumably belong to a similar type of fish so far unrecorded.

Class Osteichthyes

Gyrolepis albertii Agassiz
(Pl. 16, Figs. 4 & 10-13)

1835 Gyrolepis albertii Agassiz: Agassiz, 2, p. 173, pl. 19, figs. 1-6.
1888 Gyrolepis albertii Agassiz: Dames, 4, p. 143, pl. 1, fig. 1.
1891 Gyrolepis albertii Agassiz: Woodward, 2, pp. 510-512.

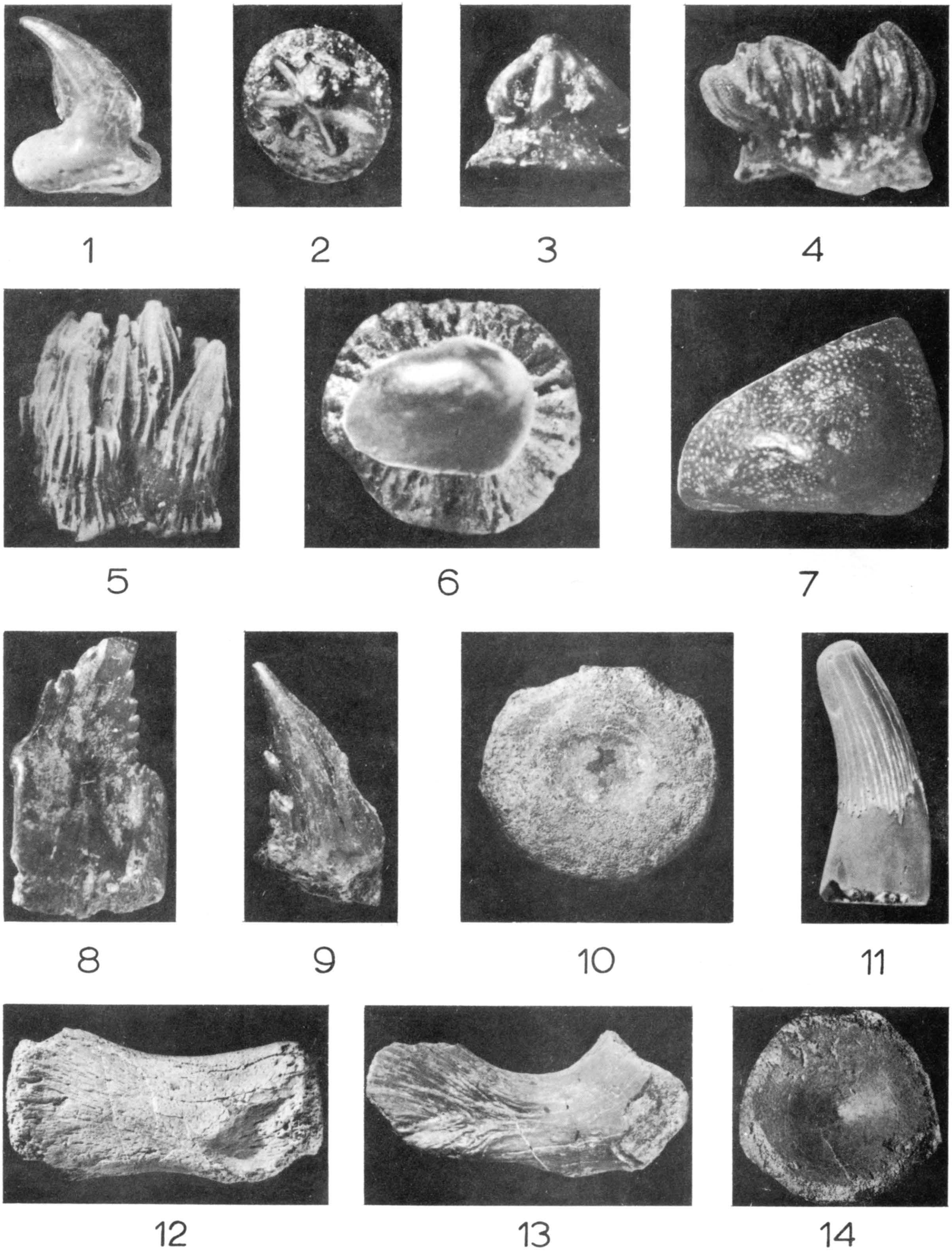
MATERIAL: Many isolated teeth and scales.
DESCRIPTION: The teeth are conical and gently tapered with a small, distinct cap. They curve inwards sometimes with a rather angular bend and they also incline slightly to the rear. The cap is smooth, sometimes translucent, and is directed upwards, i.e. not inwards. The rest of the crown is fairly smooth but the enamel is covered with parallel cracks. Some specimens are broadly striated at the base of the inner face.

The scales are quadrilateral in shape, varying widely from nearly square forms to types which are nearly rectangular, rhomboidal or elongate parallelograms. The outer surface is characterised by an enamel area which is variable in relative size. The under surface of the enamel possess low concentric ridges, which are clearly impressed on the outer face of worn scales which lack enamel. The enamel is ornamented by fine, diagonal, wavy striations. The enamel is made up of numerous thin layers which can be seen on worn specimens. The insert portion of each scale is wedge shaped and fits under the scale or scales anterior to it. The more rectangular and square types have one insert edge on the antero-ventral margin, which is often prolonged upwards to a varying degree. This type sometimes possess a small locking peg on the antero-dorsal margin and a corresponding notch on the under surface of the postero-ventral margin. The rest of the scales conform basically to this type but may possess two insert edges on the anterior margin.

EXPLANATION OF PLATE 17

Figs. 1-5	Indeterminate Hybodont.
Fig. 1	Lateral view of type A dermal denticle. (2.2 x 1.5 mm.)
Fig. 2	Upper view of type B dermal denticle. (1.4 x 1.1 mm.)
Fig. 3	Lateral view of same. (1.2 x 1.1 mm.)
Fig. 4	Lateral view of type C dermal denticle. (1.5 x 2.9 mm.)
Fig. 5	Upper view of type E dermal denticle. (2.0 x 1.8 mm.)
Fig. 6	Indeterminate Selachian. Upper view of dermal denticle. (2.2 x 2.4 mm.)
Fig. 7	?Ceratodus latissimus Agassiz. Upper view of dental plate fragment. (9.1 x 12.5 mm.)
Figs. 8-9	Scymnorhinidae gen. undet.
Fig. 8	Inner view of tooth. (4.3 x 2.5 mm.)
Fig. 9	Inner view of tooth. (3.5 x 1.8 mm.)
Figs. 10-12	Indeterminate Plesiosaur.
Fig. 10	Anterior view of vertebra centrum. (60.9 x 66.0 mm.)
Fig. 11	Lateral view of tooth. (22.8 x 9.2 mm.)
Fig. 12	Lateral view of paddle bone. (19.5 x 40.0 mm.)
Fig. 13	Indeterminate Archosaur. Upper view of ?pelvic bone. (18.2 x 40.9 mm.)
Fig. 14	Indeterminate Ichthyosaur. Anterior view of type 1 vertebra centrum. (33.2 x 35.3 mm.)

Plate 17



Fin rays of the tail are composed of a series of minute, discrete elements, each with the typical ornament found on the enamel of the scales described above.
REMARKS: Agassiz (1835) based this species on scales alone, which were said to be prevalent in the Trias and Rhaetic. It is possible to allocate the position of different scale shapes by comparison with articulated specimens of G.albertii from the Muschelkalk of Germany (Dames, 1888), and with the modern ganoid Lepisosteus. The scales of the rectangular type come from the neck region and those more square in shape come from behind these in the dorsal region. The trapezoidal elongation increases along the flank and in the ventral area, becoming extremely elongate in the tail region.

By these more complete fishes it was possible to associate the Rhaetic scales and teeth of the above form (Dames, 1888).

Birgeria acuminata (Agassiz)
(Pl. 16, Figs. 1 & 6-7)

1844 Saurichthys acuminatus Agassiz: Agassiz, 2, p. 86, pl. 55a, figs. 1-5.
1872 Saurichthys apicalis Agassiz: Etheridge, 3, p. 64, pl. 2, figs. 5-6.
1921 Birgeria mougeoti Hogard: Stensiö, p. 151, pl. 24, figs. 1-2.
1929 Birgeria mougeoti Hogard sp.: Corroy, p. 99, pl. 12, figs. 16-19.
1966 Birgeria acuminata (Agassiz): Savage and Large, 9, pt. 1, p. 135, pl. 20.

MATERIAL: Numerous isolated teeth and several jaw fragments.
DESCRIPTION: The teeth are broadly conical with a well defined cap which is often more than half the length of the shaft. They are upright and gently curved inwards; the crown is covered with enamel, which is often transculent near the apex. The cap has two cutting edges and is coarsely striated from the base to near the apex on the inner face; these striations are restricted to near the base on the outer face. The base of the cap is emphasised by a raised collar. The lower half of the crown is finely striated and broadly oval or round in cross section. A few specimens possess a short sub-cylindrical root which is smooth throughout and widens towards the base. The root shows no trace of a strongly infolded surface.
REMARKS: This is a well characterised species recorded from most Rhaetic Bone Bed exposures in this country. The isolated teeth figured by Corroy (1929) appear to be conspecific with acuminata.

Saurichthys longidens Agassiz
(Pl. 16, Figs. 2-3 & 8-9)

1844 Saurichthys longidens Agassiz: Agassiz, 2, p. 87, pl. 55a, figs. 17-18.
1929 Birgeria acuminata (Agassiz): Corroy, pl. 12, figs. 20-23.

MATERIAL: Numerous isolated teeth and several jaw fragments some with teeth attached.
DESCRIPTION: The teeth have a broad to elongate conical shape with a small distinct cap. They are upright with a moderate curvature inwards, some of the more curved ones being sigmoidal. The crown is covered with enamel which is often translucent at the apex. The cap is smooth and has an acute to obtuse tip which tapers more than the rest of the crown. The crown is circular in section and is coarsely striate between the cap and root, especially on the inner face. The hollow roots broaden widely to their base which is attached to a flat shelf of bone on the inside of the jaw. The walls of the root have a deeply infolded structure of labyrinthine type, giving externally a shallow ribbed surface.
REMARKS: More than a thousand teeth of the class Osteichthyes, from Aust Cliff, Somerset, were examined by Dr. J. Griffiths (unpublished MS.) who placed them into three groups:-

1. Teeth without striations or only light ones Gyrolepis albertii Agassiz .
2. Strongly striated teeth with distinct edges (Birgeria acuminata)(Agassiz).
3. Strongly striated teeth but round in section. These latter ones he named as Saurichthys longidens Agassiz, the type teeth having come from Aust Cliff.

The teeth from Barnstone also fall into these three types. Much confusion has occurred in the past over the two latter types. However, in the present work it has been possible to show that the root of S.longidens differs from that of B.acuminata and also that the ornamentation of their respective jaws is not the same.

Some jaw fragments, complete with roots only, resemble presumed labyrinthodont specimens labelled 'Metoposaurus ?' in the British Museum (Natural History) [Catalogue No. R2722] (Miall, 1875; Brodie, 1876). Some of the specimens recovered from Barnstone are very similar to these but undoubtedly belong to Saurichthys on the basis of the associated teeth. We therefore consider that all these jaw fragments belong to Saurichthys.

? Sargodon tomicus (Plieninger) (Jukes-Browne 1885)
(Pl.16, Figs. 5 & 14, text-fig. 5, fig. 11)

1847 Sargodon tomicus Plieninger: Plieninger, J.H., p.165, pl. 1, figs. 5-10.
1889 Sargodon sp. Plieninger: Woodward, 1, pt. 11, p.20.
1895 Sargodon sp. Plieninger: Woodward, 3, pp. 67-68.

MATERIAL: Several tritorial teeth, mostly fragmentary.
DESCRIPTION: The crowns are minute and have a smooth shiny surface. From above they are oval, often almost circular. Laterally they widen from the root to a depressed dome, sometimes with a naturally worn surface. A few of the specimens have a small chisel-shaped tubercle on top of the crown. One specimen still possesses a straight cylindrical root.
REMARKS: Sargodon tomicus Plieninger was described from its front incisive teeth, which are chisel-shaped. These teeth are common at many Rhaetic Bone Bed exposures and have been found at Barnstone, though not by the present authors. Woodward (1895) considered the teeth with a depressed dome to be the tritorial teeth on the inner bones of the mouth of Sargodon. The few possessing tubercles are transitional in shape between those with the depressed domes and those definitely belonging to S.tomicus. This strongly supports the suggestion that these types are conspecific.

? Ceratodus latissimus (Agassiz)
(Pl.17, Fig. 7)

1838 Ceratodus latissimus Agassiz: Agassiz, 3, p.131, pl. 20, figs. 8-9.
1889 Ceratodus latissimus Agassiz: Woodward, 1, pt. 11, p.21.

MATERIAL: One tooth fragment.
DESCRIPTION: The specimen consists of a roughly triangular domed fragment with a broken under surface. A series of minute parallel pores pass through the bone which has a pitting effect on the outer surface.
REMARKS: The fragment is identifiable by it shape and distinctive pore structure. It is the tip from a ridge on a dental plate. Its rounded dome suggests that it came from C.latissimus rather than more laterally compressed ridges of C.parvus.

Class Reptilia

Indeterminate Ichthyosaur

(Pl. 17, Fig. 14, Pl. 18, figs. 3-4 & 7-8, text-fig. 5, figs. 12-14)

MATERIAL: Several teeth and vertebrae, a paddle bone and possible jaw fragments.
DESCRIPTION: The teeth consist of a roughly cylindrical root surmounted by a broadly conical crown, which is about a third the length of the tooth. The rather stubby crown is slightly incurved and is moderately striate throughout, with fine striations superimposed. There is no distinct cap and the enamel is usually worn off the tip, leaving an oval exposure of dentine. The oval cross section of the crown is accentuated by two lateral cutting edges. The crown is often round at the base and is gently angled inward from the root. The hollow root is somewhat wider than the crown, is straight and narrows towards the base. The walls are deeply infolded longitudinally in a labyrinthine manner, externally forming broad shallow ribs. The crowns do not break cleanly from the roots, which are sometimes completely flattened.

The vertebrae are represented by only a few flattened, roughly circular centra. These are biconcave, with the centres of concavity near the centre of the concentrically striated posterior and anterior surfaces. The shape varies somewhat, depending on which part of the animal they come from. The dorsal vertebrae (Pl. 17, fig. 14) are equidimensional and roughly pentagonal, whilst the caudal vertebrae are more elongate (Text-fig. 5, figs. 13-14). The dorsal surface has two lateral raised regions for the articulation with the discrete neural arch. The dorsal vertebrae also possess two similar processes for the attachment of the ribs.

The paddle bones are flattened and polygonal usually elongate hexagonal though sometimes pentagonal. They are slightly concave on all surfaces. One of the specimens is slightly worn and shows an elongate pitting on the upper and lower surfaces which is radially orientated.

The jaw fragments consist of short regular lengths of bone with a characteristic cross section. In section they consist of an upright wall which is thickened at the base producing an upward-facing groove on the inner side.
REMARKS: Fragmented remains such as these are not sufficient for accurate determination beyond a statement that they are ichthyosaurian. The jaw fragments are only tentatively placed here as they possess a tooth groove similar to that of ichthyosaurs but not so pronounced (compare with that figured by Zittel, 1932, p. 275, fig. 379).

Indeterminate Plesiosaur

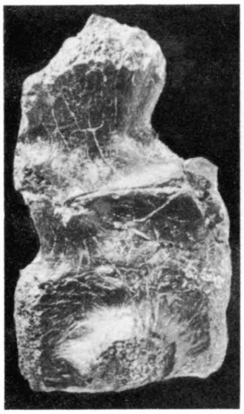
(Pl. 17, Figs. 10-12, text-fig. 5, fig. 15)

MATERIAL: One paddle bone definitely referable to a plesiosaur, and two centra, a few teeth and rib fragments, possibly plesiosaurian.
DESCRIPTION: The paddle is elongate and flattened; in outer view it is roughly quadrilateral and concave on both the anterior and posterior margins. In anterior view it is nearly straight, although it appears to be slightly sigmoidal.

Only one of the centra is here described. This centrum is moderately flattened and is roughly equidimensional, being slightly wider than high. The depth of the centrum is about two thirds the height and the anterior posterior surfaces are slightly concave. The base of the neural canal is preserved and forms a raised, flattened ridge across the dorsal margin. On either side of this the surface is excavated down as far as the widest part of the centrum. The ventral margin is roundly angled, with two prominent pores, one on either side of the ridge. Half way between the ventral margin and the widest portion of the centrum, on either side, there is a slightly

EXPLANATION OF PLATE 18

Figs. 1 & 2	Rhysosteus oweni Owen.
Fig. 1	Lateral view of type 1 (dorsal) vertebra. (27.5 x 16.2 mm.)
Fig. 2	Anterior view of same. (27.5 x 12.3 mm.)
Figs. 3 & 4	Indeterminate Ichthyosaur.
Fig. 3	Lateral view of tooth. (24.6 x 7.1 mm.)
Fig. 4	Possible jaw fragment. (33.1 x 13.0 mm.)
Figs. 5 & 6	Rhysosteus oweni Owen.
Fig. 5	Lateral view of type 2 vertebra centrum. (9.1 x 16.8 mm.)
Fig. 6	Anterior view of same. (9.1 x 8.2 mm.)
Figs. 7 & 8	Indeterminate Ichthyosaur.
Fig. 7	Upper view of paddle bone. (12.2 x 17.3 mm.)
Fig. 8	Lateral view of same. (12.2 x 7.0 mm.)
Fig. 9	Indeterminate Ophiuroid. (23.0 x 42.0 mm.)
Fig. 10	Euestheria minuta (Alberti) var. brodieana Jones. (2.1 x 3.2 mm.)
Fig. 11	Eotrapezium concentricum Moore. (5.1 x 4.2 mm.)
Fig. 12	Rhaetavicula contorta (Portlock) Left valve. (8.3 x 9.6 mm.)
Fig. 13	?Eotrapezium sp. (6.4 x 9.0 mm.)
Fig. 14	Protocardia rhaetica (Merian). (11.5 x 11.5 mm.)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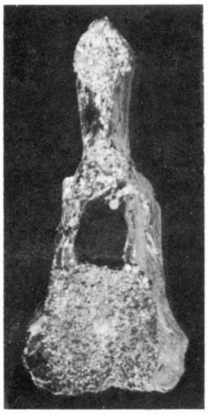
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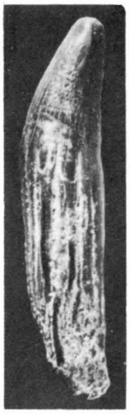
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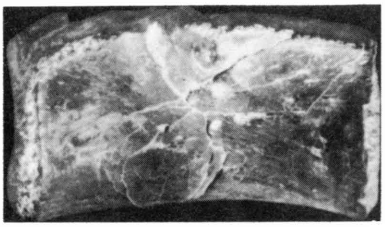
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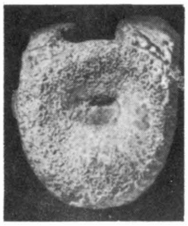
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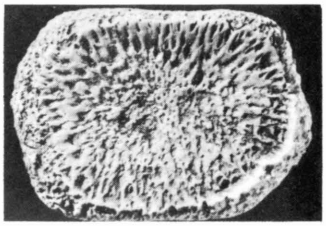
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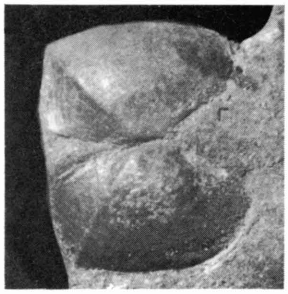
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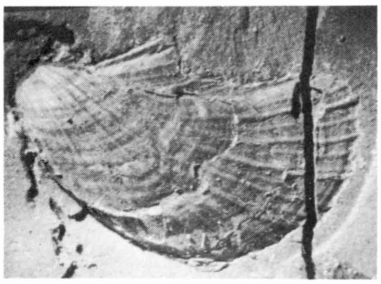
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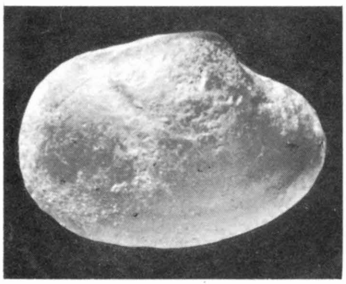
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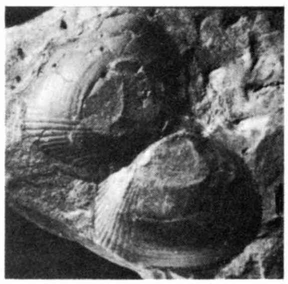
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oblique oval pit for the articulation of the ribs.

The teeth, which all lack their roots, are conical and curve strongly inwards. They are very worn but appear to possess strong striations throughout. The crown is moderately oval in section, becoming circular towards the base. The only specimen with the top preserved is flattened by wear.

The rib fragment consists of the articulatory end and the majority of the shaft. The articulation surface is concave and elongate oval, comparing fairly closely with the corresponding area on the centrum. The shaft is narrow and strongly curved, becoming sharply inflated towards the articulatory end and broader near the ventral end. In cross section it is roughly oval with a keel down one side.
REMARKS: Small fragments such as these cannot be determined, beyond a tentative allocation to the plesiosaurian type.

Indeterminate Archosaur
(Pl.17, Fig. 13)

MATERIAL: Several fragmentary limb and ? pelvic bones.
DESCRIPTION: All the Archosaur remains recovered from Barnstone are too imperfect to be worthy of description. The limb bones include two proximal ends of tibias. The rest of the remains are only tentatively ascribed to this group of reptiles. It may be worth noting here a large indeterminate limb bone fragment (4 ins., 95 mm. across) which has also been recovered from Barnstone.

<u>Rhysosteus oweni</u> Owen
(Pl.18, Figs. 1-2 & 5-6)

1841 <u>Rhysosteus oweni</u> Owen: Owen, pp. 60-204.
MATERIAL: Several vertebrae.
DESCRIPTION: Two types of vertebrae were recovered which presumably come from different regions of the vertebral column. Type 1 (Pl.18, Figs. 1-2) is a dorsal vertebra of indeterminate position. The centrum is elongate, about twice as long as high, and is roughly rectangular in anterior view. The articulating surfaces are both badly eroded, but were probably slightly concave. The ventral surface is somewhat excavated. Each side is nearly flat and is dominated by the central, ventrally placed, broken end of the transverse process. The neural arch is high, with broad, thin walls which are nearly parallel but converge slightly upwards. The canal is roughly equidimensional in anterior view and becomes slightly laterally constricted posteriorly. Although the zygopophyses are missing, the orientation of the vertebra is given by the positions of their worn bases. The neural spine is broad, laterally compressed and directed forwards. It is somewhat constricted at the base and widens and thickens towards the top, where it is very worn.

Type 2 (Pl.18. figs. 5-6) is also a dorsal vertebra, and is probably a cervical. It is represented by six specimens from Barnstone, all but one of which are badly worn, and all lack the neural arch. The centrum is about twice as long as high and is broadly oval in end view, varying from narrow laterally to narrow vertically. The articulating surfaces are concave. The ventral surface is rounded and narrows towards the middle. The dorsal surface has a deep median longitudinal channel (floor of the neural canal) which deepens in the middle. This is bounded on each side by evenly raised ridges (base of walls of neural arch) which projects outwards in the middle and are ornamented by obscure broad, radial hollows radiating from points at the middle of the inner margins. In lateral view, the centrum is deeply excavated and the ventral margin is slightly concave.

Two specimens of discrete neural arches show additional details to those given above. These possess an elongate, laterally compressed neural spine which widens slightly upwards and is inclined

slightly posteriorly. The dorsal surface of the spine is flattened and has fine transverse rugosities. The sides are ornamented with downward oblique ridges in the upper half. The base of the spine widens considerably to form the broad roof of the neural canal. Both specimens have one of the posterior zygppophyses preserved,which project slightly posteriorly from the base of the neural spine and are directed downwards and outwards. The anterior zygopophyses are missing. On the right side of the larger specimen there is the broken end of a transverse process, just anterior of the centre of the specimen.
REMARKS: The type 2 vertebrae described above are closely comparable with those originally described by Owen as Rhysosteus oweni. The types of this species have their neural arches preserved, and compare closely with those described above. The also conform to that type 1 vertebra, which is therefore here allocated to this species.

Class uncertain
Indeterminate Coprolites

MATERIAL: Numerous coprolites.
DESCRIPTION: These are generally roughly cylindrical, sometimes curved, with irregular transverse furrows caused by the individual faecal pellets. In thin section they are not homogenous, and sometimes contain undigested fish remains, such as teeth and scales.
REMARKS: The coprolites recovered from Barnstone are very variable in shape and preservation. They are typically like the ones described by Pollard (1968). It is not possible to allocate these to the organisms that formed them, both reptiles and fish being probably responsible.

Conclusions

The Rhaetic rocks at Barnstone show that, after a quiet invasion of the sea, fine black muds were deposited in fairly quiet marine conditions. Within this environment, concentrations of coarse sand grains, phosphatic nodules and vertebrate remains were formed by current action. The influx of more sand from a different source resulted in slight movements of the deposits and possibly slightly intermittent deposition. This was followed by more rapid deposition of mud and silt, associated with conditions transitional to brackish water. Possibly a pause in deposition occurred at the end of Rhaetian times, after which the incursion of the Jurassic sea brought new sediments and a new fauna.

The prolific Bone Bed has yielded representatives of most Rhaetic species of fish and reptile previously recorded in this country.

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