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THE STRATIGRAPHY AND PALÆONTOLOGY OF THE JURASSIC ROCKS OF EATHIE (CROMARTY)

BY

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[With Two Plates and Four Text-figures]

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II.—The Stratigraphy and Palæontology of the Jurassic Rocks of Eathie (Cromarty).*

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Synopsis

The stratigraphical succession of the Jurassic rocks of Eathie (Cromarty) is described and a list of the fossils collected by the writer from the Kimmeridgian beds given. The fauna, which is of mixed Boreal and Mediterranean affinity, shows that the strata belong to the three basal Eo-Kimmeridgian ammonite zones proposed by Spath. The occurrence of an abundant microfauna is recorded and the palæontology of the varied molluscan forms is discussed. Three new lamellibranch species are described. A short account of the Upper Oxfordian beds which outcrop at Bow Buoy Skerry, 1 mile south of Eathie, is given.

CONTENTS

I. Introduction

Among the many notable geological features of north-east Scotland, one of the most interesting is the occurrence of isolated exposures of Jurassic rocks on the eastern seaboard of Sutherland and Ross. The largest of these exposures occurs in the Brora–Helmsdale region, where a broken succession, ranging from Lias to Kimmeridge Clay, occurs. The black-shales and boulder-beds of Kimmeridgian Age are of greatest development, having an estimated thickness of 1500 feet (Bailey and Weir, 1932), in which seven of Salfeld's fossil zones (1913) have been identified. Only one other exposure of Kimmeridgian rocks is seen in the Moray Firth area. This occurs 30 miles south-west of Brora at Eathie, the smallest and southernmost of the Jurassic exposures of eastern Scotland, where rocks of the *Rasenia cymodoce* and "*Rasenia*" *mutabilis* zones are found.

Eathie Haven lies on a small sandy bay called the Boat Hard, which interrupts the rocky eastern shore of the Black Isle 3 miles south of Cromarty (text-fig. 1). From the shore the eastern slopes of the Hill of Eathie rise steeply to a height of 600 feet, making difficult direct access to the rocks below. Black-shales and limestones of Kimmeridgian Age are exposed in a narrow shore strip extending from a third of a mile north of the haven to Bow Buoy Skerry, a rocky eminence a mile to the south. The Skerry itself, however, is a minute exposure of carbonaceous sandstone and arenaceous limestone of Upper Oxford Clay Age. Except at low tide, the Jurassic exposures at Eathie and Bow Buoy Skerry are covered by the waters of the Moray Firth.

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The pre-Mesozoic rocks of the district are Moine Gneiss and Old Red Sandstone. Red and yellow sandstones of upper Middle Old Red Sandstone Age flank the hills formed by the metamorphic rocks—Hill of Eathie, Gallow Hill and the Sutors of Cromarty—and extend in a broad syncline over the western part of the Black Isle. The Jurassic rocks of Eathie have been downfaulted against Moine Gneiss and Old Red Sandstone, with both of which they are in contact to the west. The boundary fault is curved. The trend is north-easterly in the southern part of the exposure, but gradually swings round to an east-north-easterly direction

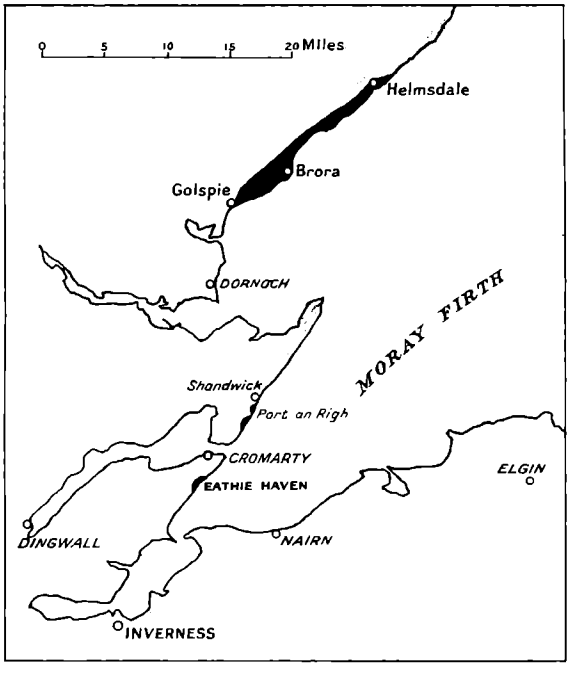


FIG. 1.—Distribution of Mesozoic rocks in north-east Scotland.

in the northern part. The contact of the Jurassic rocks with the Moine Gneiss is exposed on the shore opposite Upper Eathie Farm, while that of the Kimmeridgian rocks with the Old Red Sandstone is seen north of the Boat Hard. The middle part of the boundary fault, however, is covered by the 25-foot raised beach.

II. History of Previous Opinion

An account of the course of geological opinion concerning the rocks of Eathie before the year 1870 is given in the first part of J. W. Judd's masterly paper on "The Secondary Rocks of Scotland" (1873); it is therefore unnecessary to detail the work done during this period. Judd described the physical relations of the Jurassic strata at Eathie, and gave a list of the fossils obtained from them. He considered the deposits to be of Upper Oolitic Age, and correlated them with the Middle and Lower Kimmeridge of England.

In 1889 the younger Hugh Miller's mapping of the Cromarty district was published by the Geological Survey on a scale of one inch to one mile (Sheet 94). Subdivision of the Jurassic, however, was not attempted on this map. The important monograph by A. C. Seward and T. N. Bancroft on "Jurassic Plants from Cromarty and Sutherland" (1913) recorded numerous

plant genera and species from Eathie and descriptions of several new species were given. S. S. Buckman (1922) concluded from a study of some ammonites from the black-shales of Eathie that the beds are of Lower Kimmeridgian Age, and he placed them in the *Amœboceras* (spinous) hemera of his "Rasenian" Age. Two years later the Geological Survey published the memoir on "The Geology of the Country around Golspie, Sutherlandshire" (1925), which contained a description of the Mesozoic rocks of East Sutherland and Ross by G. W. Lee. Twenty invertebrate species were identified in the Survey collection from Eathie, the ammonites being named by Buckman, Kitchin and Pringle. Lee referred the bulk of the strata to the *Rasenia cymodoce* zone of Salfeld, pointing out that a few specimens indicated that part of the overlying "*Rasenia*" *mutabilis* zone is also represented. He considered that the disruption of the beds, due to movements of the boundary fault, made it impossible to establish their order of succession. Lee's conclusions were repeated in Lee and Pringle (1932). In "Scotland: The Northern Highlands" (1936), J. Phemister referred to the Kimmeridgian of Eathie, and correlated with the Studley-Horton beds of Oxfordshire the beds of Bow Buoy Skerry, assigning them to the Lower Corallian.

III. The Succession and Structure

The colour-names and symbols adopted in this section are those used in the Rock Colour Chart prepared by the Committee of the U.S. National Research Council. The Chart is based on the Munsell system of colour identification. The rock colours were matched with the chart when the specimens were perfectly dry.

Although the Kimmeridgian beds have been much disrupted by the movements of the boundary fault, their order of succession can be established. Certain beds, easily recognised by their distinctive lithological or palæontological characters, occur in the otherwise uniform succession of black-shales and oil-shales. It was found that the apparent thickness of the incompetent beds is less than their true thickness, since relative movement has taken place within them during folding, one bed having overridden another producing slickensides and small fractures. Mapping competent "marker beds", such as limestones, on a scale of one inch to fifty feet, showed that their arrangement is orderly and that disruption has been confined to the shales. It was possible therefore to find the order of succession of the beds, but their thickness could not be accurately determined.

The oldest Kimmeridgian beds at Eathie lie at the southernmost part of the exposure and are bounded to the west by the fault junction against the Moine Gneiss. They are greenish-grey (5 GY 6/1) calcareous mudstones interbedded with hard grey (5 GY 7/1) limestones and bands of calcareous nodules. The limestones break with a marked conchoidal fracture and weather to a yellow crust. Cone-in-cone structure occurs in the mudstones. The greenish-grey muds are succeeded by about 5 feet of olive-black (5 Y 3/1) shale which is characterised by the abundance of *Camptonectes*, the small, thin shells of which are flattened and often replaced by iron pyrites. In addition to ammonites, the beds contain crushed specimens of *Astarte eathiensis* sp. nov., *Nuculopsis* (*Palæonucula*) *finlayi* sp. nov., and *Buchia concentrica* (J. de C. Sow.). The immediately overlying strata comprise 30 feet of medium grey shaly mudstone in which bands of calcareous septarian nodules occur. The mudstone is very fossiliferous with the shells lying haphazardly. The bed is rich in *Astarte eathiensis*. It is the only horizon at which gastropods have been found, the largest and most common of which is *Amberleya*. A bed 2 feet thick near the base of the "Astarte muds", which has been hardened by impregnation with calcium carbonate, yielded many perfectly preserved fossils. The ammonites obtained from this bed include *Amœboceras kitchini* (Salfeld), *Rasenia* spp. of the

uralensis group, and *Prorasenia* spp. Except for some "marker beds" the remaining 120 feet of the succession is made up of olive-black (5 Y 2/1) shales and oil-shales. The shales are fairly coarse grained. The oil-shale has a low kerogen content, but the occurrence of marcasite nodules indicates that the sulphur content is large. The shales contain much plant material, and where branches or stems are found the casts are surrounded by a thin layer of bright coal. The shales are richly fossiliferous throughout. The surfaces of many of the bedding planes are covered with flattened shells, the nacreous layer of which is often well preserved. Ammonites such as *Amœboceras kitchini*, *A. beaugrandi* (Sauvage) and *Rasenia* spp. are

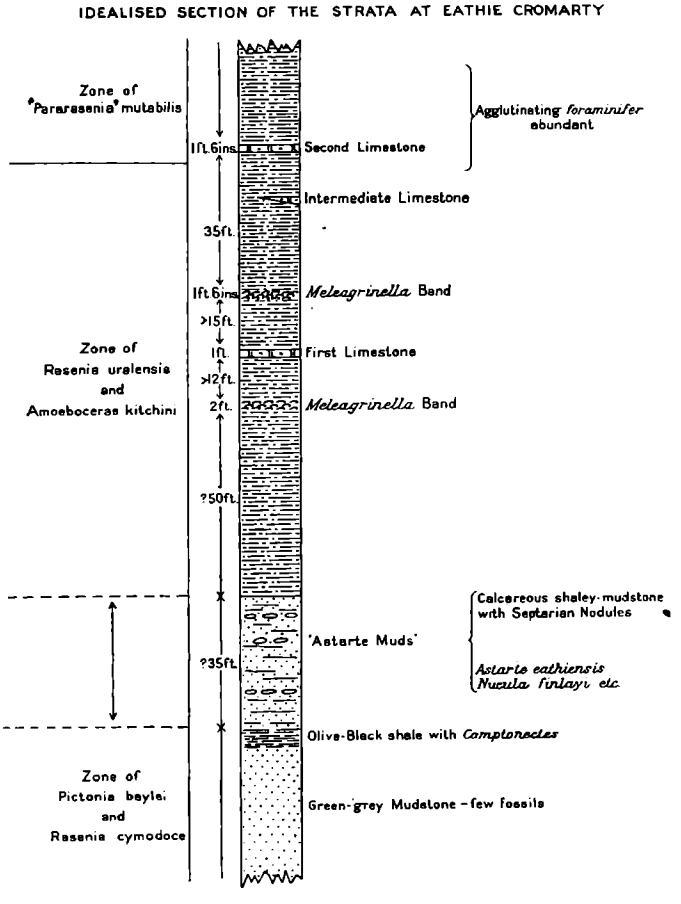
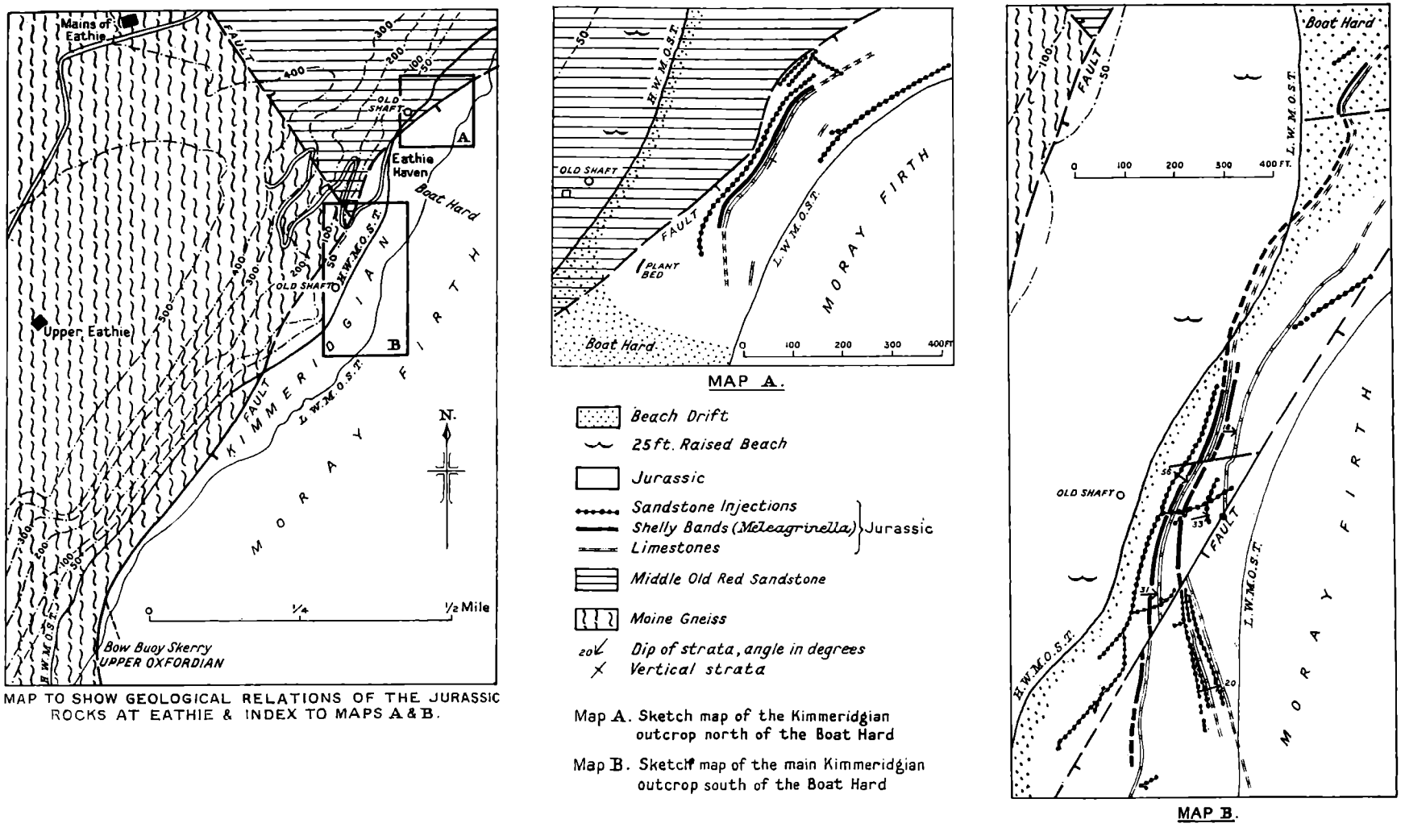


FIG. 2.—General section of the Kimmeridgian rocks at Eathie.

abundant, and belemnites are embedded in the shale at all angles. Crushed specimens of the fine-ribbed "*Rasenia*" cf. *mutabilis* (J. de C. Sow.) are found in the black-shales at the top of the succession. The most common lamellibranch is *Buchia concentrica*, which is found throughout the succession; *Ostrea* spp. are also abundant. Small, round fish-scales with concentric striæ occur throughout the shales, and occasionally aggregates of fish-bones are found. Micro-separation shows that Foraminifera and Radiolaria are preserved in large numbers in the black-shales.

The marker beds are of two kinds: shelly horizons in the shale, and bedded limestones. Approximately 50 feet above the "Astarte muds" there is a shaly bed 2 feet in thickness which is crowded with the left valves of *Meleagrinella leeana* sp. nov. Calcareous nodules found



MAP TO SHOW GEOLOGICAL RELATIONS OF THE JURASSIC ROCKS AT EATHIE & INDEX TO MAPS A & B.

FIG. 3.—Sketch map of the geology of Eathie Haven.

in this bed contain unflattened casts of the shell, but specimens from the shale are crushed. About 12 feet above the first *Meleagrinella* band is the First Limestone, a tough, bituminous, arenaceous limestone 1 foot thick and light olive-grey (5 Y 5/2) in colour, which weathers to a moderate yellow-brown (10 YR 5/4), and is rich in the crushed remains of the species that occur in the black-shales and oil-shales. A second *Meleagrinella* band 1 foot 6 inches thick occurs approximately 15 feet above the First Limestone. In the southern part of the main section there is a limestone wedging out northwards 40 feet above the First Limestone. It is 1 foot thick and dark bluish grey in colour, weathering to a light olive-grey crust, and is less fossiliferous than the First Limestone, containing less sandy material. The Second Limestone, a bedded arenaceous limestone, dark grey (N 3) in colour, weathering to a light olive-grey, is 50 feet above the first. It grades through grey, calcareous, flaggy beds into the black-shale below, and is less fossiliferous than the First Limestone, but contains many crushed specimens of "*Rasenia*" cf. *mutabilis*. Micro-sections show that it is crowded with a small, spherical, agglutinated foraminiferon (? *Psammosphæra*), which is also found in the black-shales above.

The complete succession, although interrupted by minor faulting, is exposed south of the Boat Hard. The relation of the rocks north of the bay with the southern succession is more obscure. It seems probable, however, that the "Inshore Limestone", which outcrops nearest the beach north of the bay, is the northerly extension of the First Limestone, which it resembles. The correlation is supported by the occurrence of *Meleagrinella* bands in equivalent positions above and below both limestones. *Astarte eathiensis* was found in the basal black-shales exposed north of the bay, which suggests that the "Astarte muds" extend northward from the southern exposure, but have been largely cut off by the boundary fault against the Old Red Sandstone. A plant bed was found in the southern part of the northern exposure in the black-shales below the Inshore Limestone. This is a lenticular-shaped bed 30 feet long, its maximum thickness being 2 feet. It is composed of a mass of land plant fragments hardened by a calcite cement. In micro-section the cellular structure of the plants is clearly seen and the different plant tissues can be determined.

The Kimmeridgian beds are cut by small faults which trend in two directions (text-fig. 3). The middle part of the exposure is disturbed by a fault running obliquely across the shore at about 30° east of north, having a downthrow to the seaward side of about 30 feet. A parallel fault zone may be present farther north. Minor faults, most of them too small to map, make up a second group, and cross the strata at about 76° east of north. The beds are penetrated by a complex of sandstone injections (Waterston, 1950). The strike of the Jurassic beds is in the form of an arc running northwards in the southern part of the exposure but changing towards the north to a north-easterly trend. The general dip is 20° east to south-east. The large boundary fault, however, has contorted the beds at their contact with the pre-Mesozoic rocks, the dip gradually increasing towards the fault until the strata are vertical at the contact.

IV. Faunal List

Previous research has shown that a knowledge of the nature and extent of the Jurassic faunal provinces would be of great value in elucidating the palæogeography and climatic zones of the Jurassic. That an accurate record of the faunal assemblage in the Scottish Jurassic rocks should be obtained is therefore of importance, since they lie between those of southern England, with a marked affinity to the Mediterranean province, and the rocks of Boreal aspect in Spitzbergen and Greenland.

The following is a list of the species collected by the writer from the Kimmeridgian rocks at Eathie:

Ammodiscus sp.
Glomospira sp.
Quinqueloculina sp.
Robulus sp.
Lenticulina sp.
Dentalina sp.
Nodosaria sp.
Lagena sp.
Elphidium sp.
Foraminifer (?).

Cyrtocalpis sp.
Eucyrtidium sp.

Nuculopsis (*Palæonucula*) *finlayi* sp. nov.
Grammatadon sp.
Buchia concentrica (J. de W. Sow.).
Meleagrinella leeana sp. nov.
Inoceramus sp.
Camptonectes sp.
Ostrea cf. *bononiæ* (Sow.).
Ostrea cf. *rœmeri* (Quenst.).
Astarte eathiensis sp. nov.

Amberleya sp.
Cerithium sp.

Amœboceras (*Amœbites*) *kitchini* (Salfeld).
Amœboceras (*Amœbites*) *subkitchini* Spath.
Amœboceras (*Amœbites*) sp. nov.
Amœboceras (*Amœbites*) aff. *rasenense* Spath.
Amœboceras (*Amœbites*) *beaugrandi* (Sauvage).
Rasenia aff. *orbignyi* (Tornquist).
Rasenia sp. nov.
"*Rasenia*" cf. *mutabilis* (J. de C. Sow.).
Prorasenia bowerbanki Spath.
Prorasenia aff. *triplicata* (J. Sow.).

Cylindroteuthis obeliscus (Phillips).
Cylindroteuthis spicularis (Phillips).
Pachyteuthis abbreviatus (Miller).

Fish remains (jaws, scales, plates, bones and teeth).

V. Specific Descriptions

(a) *Lamellibranchia*

Family NUCULIDÆ

Genus Nuculopsis Girty, 1911 emend. Schenck, 1934.

Sub-Genus Palæonucula Quenstedt, 1930.

Nuculopsis (*Palæonucula*) *finlayi* sp. nov. (Pl. I, figs. 4*a* and 4*b*).

Type Material.—The holotype (R.S.M. 1949–31–1 *) and one paratype (R.S.M. 1949–31–2).

Diagnosis.—Shell small, ovate, moderately inflated. Umbones small, feebly salient, opisthogyrate but not strongly incurved. Carina from umbo to antero-ventral angle swollen. A strong dorsal shoulder runs anteriorly from the umbo. Antero-dorsal margin sharp, prominent. The antero-dorsal and anterior margins curve regularly with the ventral and posterior margins to form a perfect oval. Postero-dorsal margin truncated, short. Margins smooth. Surface ornamentation wanting except for fine concentric growth-lines.

Measurements of Holotype.—Height 9 mm., length 7 mm. (78 per cent.).
Inflation 5 mm. (56 per cent.).

Remarks.—The antero-dorsal margin of the Lower Kimmeridgian form from Market Rasen, *Nucula obliquata* Blake (Blake, 1875, p. 228, and pl. xii, fig. 5), is not sharp and prominent

* Specimen numbers prefixed R.S.M. are now housed in the Royal Scottish Museum, Edinburgh.

like that of the Eathie species, but forms a nearly straight line from the umbones to the antero-dorsal angle. The umbones of *N. obliquata* are therefore more prominent than *N. finlayi*, resulting in a triangular outline.

The Eathie species resembles certain Cretaceous Nuculas more closely than other Jurassic forms. The Gault specimen from Folkestone of *N. albensis* d'Orb., described and figured by Woods (1899–1903, p. 24, and pl. iv, figs. 9 and 16), is very similar in shape, but is less inflated and not so perfectly oval as *N. finlayi*.

Occurrence.—Zone of *R. uralensis* and *A. kitchini*, Eathie Haven.

Family PTERIIDÆ Meek

Genus Buchia Rouillier, 1845 (=*Aucella* Keyserling, 1846).

Buchia concentrica (J. de C. Sow.) (Pl. I, figs. 2*a–c*).

1827. *Plagiostoma concentrica* J. de C. Sowerby, *Min. Conch.*, vi, 113, pl. 559, fig. 1.
1848. *Buchia bronni* C. Rouillier, *Bull. Soc. Imp. Nat. Moscou*, xxi.
1872. *Lima concentrica* Judd, *Quart. Journ. Geol. Soc.*, xxix, 184.
1888. *Aucella bronni* Lahusen, *Mem. Com. Geol. St Petersburg*, p. 6, pl. 1, figs. 1–11.
1901. *Aucella bronni* Pompeckj, *N. Jb. f. Min. &c.*, B.B. xiv, 319, fig. 1.
1909. *Aucella bronni* Sokolov, *Mem. Com. Geol. St Petersburg.*
1911. *Aucella bronni* Ravn., *Medd. om Grønl.*, xlv, 455, pl. xxxii, fig. 5.
1925. *Lima concentrica* Lee, *Mem. Geol. Surv.*, East Sutherland.
1930. *Lima concentrica* Macgregor, Read, Manson & Pringle, *Proc. Geol. Assoc.*, 77.
1931. *Aucella bronni* Sokolov & Bodylevsky, *Norges Svalbard- og Ishavs- Undersökelser. Skr. Svalbard og Ishavet*, No. 35, p. 34, pl. 1, fig. 3; pl. v, figs. 5 and 6.
1932. (?) *Lima concentrica* Weir in Bailey and Weir, *Trans. Roy. Soc. Edin.*, lvii, 464.
1933. *Aucella bronni* Weir in Tyrrell and Weir, *Trans. Roy. Soc. Edin.*, lvii, 694, pl. 1, fig. 9.
1933. *Lima concentrica* Arkell, *The Jurassic Rocks of Great Britain*, p. 478.
1935. *Buchia* aff. *bronni* Spath, *Medd. om Grønland*, xcix, Nr. 2, p. 53, pl. 3, fig. 2; pl. 8, fig. 3.

Non *Buchia* [*Aucella*) *concentrica* (Fisch).
Buchia [*Aucella*] *concentrica* (Keyserling).

Type Material.—The type material described by Sowerby consists of a right and left valve which are unattached, slightly flattened, and preserved in argillaceous limestone (B.M., No. L 63613). The valves are elliptical, oblique and somewhat depressed, the greatest diameter being two-thirds of the greatest length (28 mm.). The umbones are not salient, but the left umbo is more prominent than the right. Both valves have a well-developed posterior wing, but an anterior auricle is not developed on the left valve as illustrated by Sowerby (*Min. Conch.*, vi, tab. dlix, fig. 1). The valves are ornamented by fine radial costæ, separated by sulci of slightly variable width. The radial ornament is cut by concentric ridges at irregular intervals, giving the shell a cancellated pattern. The interior of the shell and the detail of the hinge line are not visible on the type material.

Remarks.—After J. de C. Sowerby described *Plagiostoma concentrica* from Eathie, British workers accepted this lamellibranch as a species of the Limidæ until Weir (1932, p. 464) drew attention to its marked external similarity to *Aucella bronni* (Rouillier). The name *Lima concentrica* was retained by Weir in 1932, but in 1933 he used the name *Aucella bronni* in recording specimens from Spitzbergen, while pointing out that in his opinion it is a synonym of the former.

The writer was fortunate in obtaining several well-preserved specimens, and was able to excavate the cardinal areas of seven right valves and one left valve. The cardinal area is edentulous. There is a well-developed, small anterior or byssal wing on the right valve which forms a sharp fold in the cardinal area. The area continues anteriorly into a deep byssal

groove, which separates the anterior wing from the rest of the shell. Two small and weakly developed ridges which extend posteriorly along the cardinal region from the anterior wing are separated by a groove. A similar, but larger groove extends along the cardinal area of the left valve on either side of the umbo, and appears to form the only hinge structure on that valve.

The similarity of external form and the structure of the hinge line leaves little doubt that *Lima concentrica* and *Buchia bronni* are synonyms. The genus *Buchia* was proposed by Rouillier eighteen years after Sowerby had described "*Plagiostoma*" *concentrica*. The form should therefore be called *Buchia concentrica*.

Genus MELEAGRINELLA Whitfield, 1885.

Meleagrinella leeana sp. nov. (Pl. I, figs. 5*a–c*).

1925. *Pseudomonotis* sp. nov. Lee, *Mem. Geol. Surv.*, East Sutherlandshire, p. 115.

Type Material.—The holotype (R.S.M. 1949–31–6) and two paratypes.

Diagnosis.—Shell aviculoid. Left valve convex, suboval, slightly inequilateral. Umbo small, rising only to the margin of the cardinal area. The length of the hinge line is rather more than half the length of the shell. Anterior and ventral margins regularly rounded; posterior margin obliquely truncated between the hinge extremity and the postero-ventral angle. Postero-dorsal angle obtuse. Anterior wing rudimentary. Posterior wing large, triangular, unornamented except for growth lines, becoming slightly auriculate in large specimens. Except for the posterior wing, the shell is ornamented by fine, very numerous, sharply defined, irregular, unequal, radiating ribs, interrupted at wide intervals by inconspicuous growth halts. Ribs increase in number ventrally by intercalation just below the umbo. Except for growth lines the left valve of the young stage is unornamented. It is more elongate than the adult, and the posterior wing is not differentiated from the rest of the shell. The umbo is salient.

Measurements of Holotype.—Length 13 mm., height 13 mm. (100 per cent.).

Remarks.—Although the shell occurs in great numbers at certain horizons at Eathie only the left valve has been found. Owing to its fragility and nature of preservation it has not yet been possible to investigate the structure of the cardinal area. The form and external character of the shell leave little doubt as to its generic identity. The species having the closest resemblance to *M. leeana* is the continental, Upper Jurassic form *Monotis similis Goldfuss*.

Occurrence.—*R. uralensis* and *A. kitchini* zone, Eathie Haven.

FAMILY ASTARTIDÆ Gray

Genus ASTARTE J. Sowerby, 1816.

Astarte eathiensis sp. nov. (Pl. I, figs. 1*a–d*).

Type Material.—The holotype (R.S.M. 1949–31–8) and one paratype (R.S.M. 1949–31–9).

Diagnosis.—Shell ovate, slightly to moderately inflated, obliquely inequilateral. Umbones small, depressed, anteriorly directed, situated one-third to one-half of the length of the shell from the anterior margin. Escutcheon elongated. Lunule small, heart-shaped. Anterior margin rounded, more acute than the truncated posterior margin. Postero-ventral extremity subrectangular, varying from obtuse to acute. Ridge connecting umbo to the postero-ventral angle moderately inflated. Ornament consists of conspicuous and

irregular concentric ribs. The sulci are about the same width as the ribs and are concentrically striated. The hinge is composed of two diverging cardinal teeth on both valves, the posterior cardinal tooth of the right valve being large and triangular in shape. The posterior lateral teeth appear to be fairly well developed in both valves. The adductor impressions are ovate, strongly marked and subequal. A strong pedal impression is present above the anterior adductor scar. The pallial line is simple, rather distant from the crenulated margin.

Measurements of Holotype.—Length 16 mm., height 13 mm. (81 per cent.).
Inflation 8 mm. (50 per cent.).

Remarks.—Since the cardinal area was preserved in closed shells, the structure of the hinge line was first investigated by making serial sections through the shell. The shell was ground at right angles to the cardinal area from posterior to anterior. The reconstruction of the hinge line has been confirmed by the cardinal area of a right valve which was obtained later. This specimen (the paratype), although incomplete, shows the cardinal teeth and the long posterior lateral tooth.

Astarte eathiensis is similar in outline and ornamentation to the Corallian species *Prorokia problematica* (Buvignier), but the distinctive characters of the adductor impressions of *Prorokia* are not present in the Eathie specimens.

Occurrence.—*R. uralensis* and *A. kitchini* zone, Eathie Haven.

(b) *Cephalopoda, Ammonoidea*

Family CARDIOCERATIDÆ

Sub-Family CARDIOCERATINÆ

Genus AMŒBOCERAS Hyatt, 1900.
Sub-Genus AMŒBITES Buckman, 1925.
Amœboceras (*Amœbites*) *kitchini* (Salfeld) (Pl. II, figs. 4*a*, *b*).

1935. *Amœboceras* (*Amœbites*) *kitchini* Spath, *Medd. om Grønland*, XCIX, Nr. 2, p. 30, pl. 1, fig. 9.

Measurements of specimens collected by the writer:

Specimens	R.S.M. 1949–31–12	R.S.M. 1949–31–20
Maximum diameter .	80 mm.	57 mm.
Measurements taken at .	78 ,,	56 ,,
Whorl height . .	45 per cent.	44 per cent.
Whorl thickness .	34 ,,	32 ,,
Width of umbilicus	28 ,,	32 ,,

Remarks.—The measurements given above agree in their proportions with those given in the original description of the species by Salfeld in 1915. The specimens figured and described by him, however, were only inner whorls. The outer whorl of the largest example which he figured (pl. xx, fig. 16)—a specimen from Cromarty—is crushed. Spath (1935, pl. i, figs. 9*a* and 9*b*) figured another specimen from Cromarty which he considered typical. The specimens collected by the writer suggest that the umbilical diameter of Spath's specimen is greater than is normal for the species, specimen 1949–31–12 indicating that even large specimens agree with the proportions given in the original description.

Amœboceras (*Amœbites*) *subkitchini* Spath (Pl. II, figs. 3*a*, *b*).

1935. *Amœboceras* (*Amœbites*) *subkitchini* Spath, *Medd. om Grønland*, XCIX, Nr. 2, p. 30, pl. 1, fig. 3.

Measurements:

Specimen	R.S.M. 1949–31–13
Maximum diameter	56 mm.
Whorl height	39 per cent.
Whorl breadth	31 ,,
Diameter of umbilicus	33 ,,

Remarks.—Specimen 1949–31–13 collected from Eathie by the writer has been recognised by Dr Spath as belonging to his species *A. subkitchini*, which he described from a flattened specimen from Greenland (1935, p. 30, and pl. 1, fig. 3). The Eathie specimen is preserved in a limestone nodule, and being unflattened, measurement of the true breadth was possible. It was found to agree with Spath's estimate of 30 to 33 per cent. for the flattened holotype. Although the Eathie specimen is not complete to the aperture, it shows that the body chamber must have occupied at least half of the outer whorl. The suture line is well preserved, its trace being very similar to that of *A. kitchini* figured by Spath (1935, pl. 6, fig. 2).

Amœboceras (*Amœbites*) sp. nov. (?) (Pl. II, figs. 2*a*, *b*).

Measurements:

Specimen	R.S.M. 1949–31–15
Maximum diameter	34 mm.
Whorl height	44 per cent.
Whorl thickness	50 ,,
Width of umbilicus	29 ,,
Ribs number	21 at 34 mm.
	21 ,, 15 ,,
	19 ,, 5 ,,

Remarks.—The robust and involute whorls, the coarse ribs and tubercles, and the finely beaded keel are similar to those of *A. salfeldi* Spath. Ventrally the lateral ribs of the writer's specimen are inclined to the posterior, as are the tubercles on the peripheral margin. In this they differ from the ribs and tubercles of *A. salfeldi*. The lateral ribs tend to bifurcate at the lateral tubercles. Unlike *A. salfeldi* the ribbing appears on the early whorls, where it is fairly coarse. Both the ribbing and the tubercles are coarser than those of *A. pingue* (Salfeld), and the beading of the keel is very much finer. It further differs from both *A. pingue* and *A. salfeldi* in that the ribbing does not extend directly to the keel but is produced anteriorly on the periphery like the ribs of *A. rasenense* Spath.

Family Perisphinctidæ

Sub-Family Pictoninæ

Genus Rasenia Salfeld, 1913.

Rasenia sp. nov. (?) (Pl. II, figs. 8*a*, *b*).

Measurements:

Specimen	R.S.M. 1949–31–16
Maximum diameter	37 mm.
Whorl height	35 per cent.
Whorl breadth	43 ,,
Diameter of umbilicus	41 ,,
Ribs number	17 at 37 mm.
	25 ,, 25 ,,

Remarks.—Specimen 1949–31–16 resembles *R. evoluta* (Salfeld) but differs from it in two particulars. The whorl breadth is much less than that of typical examples of similar diameter belonging to the *R. involuta-evoluta* group (*e.g.* specimens 25551 and 25550 in the Geological Survey Collection). The Eathie form may also be distinguished from the Survey specimens by its finer ribbing, although the pattern is the same. Ribbing is developed on the second whorl, the first being smooth.

Genus *Prorasenia* Schindewolf, 1925.

Prorasenia aff. *triplicata* (J. Sow.) (Pl. II, figs. 6*a*, *b* and 7*a*, *b*).

1935. *Prorasenia triplicata* Spath, *Medd. om Grønland*, XCIX, Nr. 2, p. 40, pl. 12, fig. 2; pl. 14, fig. 5.

Remarks.—The species *P. triplicata* requires redefinition, since the holotype, a small disintegrating nucleus from the Lower Kimmeridge Clay of Portland Roads (B.M. 43955), is too small to show the adult characters of the species. Other labelled specimens of this species in the British Museum and Geological Survey Collections are also nuclei, distinguished by trifurcate branching of the ribs. No larger labelled specimens could be traced. The Eathie specimen is complete to the apertural border, which is partly preserved. The body chamber occupies nearly three-quarters of the last whorl. The whorls are moderately depressed and evolute. The whorl section is rounded with an evenly arched venter and rounded lateral areas. The first whorl is smooth. The three succeeding whorls are ornamented with fairly coarse trifurcating ribs. The trifurcate branching of the ribs is present over more than half the body chamber. The last two primary ribs bifurcate and alternate with a single secondary rib. The primary ribs of the inner whorls are raised to form strong primary ridges which die out before reaching the last whorl. The form may therefore be transitional between *Rasenia* and *Prorasenia*.

Cephalopoda, Belemnoidea

FAMILY BELEMNITIDÆ de Blainville

Sub-Family CYLINDROTEUTHINÆ Naef.

Genus CYLINDROTEUTHIS Bayle, 1878.

Cylindroteuthis obeliscus (Phillips) (Pl. I, figs. 7*a*, *b* and 8*a*, *b*).

1870. *Belemnites obeliscus* Phillips, "British Belemnitidæ", *Palæont. Soc.*, p. 123, pl. xxxiii, fig. 83.
1922. *Cylindroteuthis obeliscus* Naef., *Die Fossilen Tintenfische*, p. 244.

In his description of "*Belemnites*" *obeliscus*, Phillips noted that specimens having unequal proportions were included within the species. To determine the nature of this variation it was desirable to examine as many adult specimens as possible. The writer was fortunate, therefore, in having access to the Hugh Miller Collection, housed in the Royal Scottish Museum, where many fine belemnite guards from Eathie are preserved. The volumes of the guards were determined, since it was found that the variation in suitable linear measurements was not large enough to express adequately the variation in guard shape. As the alveolar part of the guard is often crushed and broken, only the posterior three-quarters were used for volumetric determination. Readings of the volume were taken at $\frac{3}{16}$, $\frac{3}{8}$, $\frac{9}{16}$ and $\frac{3}{4}$ of the total length of the guard from the apex. The volume was determined by the displacement of glycol, since many of the broken guards were reassembled with a water-soluble glue. The ratio of the volume to the length of the guard is a continuous expression, so that the readings for each specimen could be plotted on a graph and the points joined to give a curve representing the shape of the guard.

The graphs of the relations of volume to length show that, among the specimens of

C. obeliscus examined, two distinct forms of guard shape occur. Anterior to the point of maximum inflation, which is about one-quarter of the length of the guard from the apex, the margins of the form designated β continue to diverge throughout the stem and alveolar regions more rapidly than those of the form α. Thus the average ratios of the length to the breadth at the alveolar margins are distinct for the two forms, and for α being 20·4 : 1, whereas that for β is 14·3 : 1.

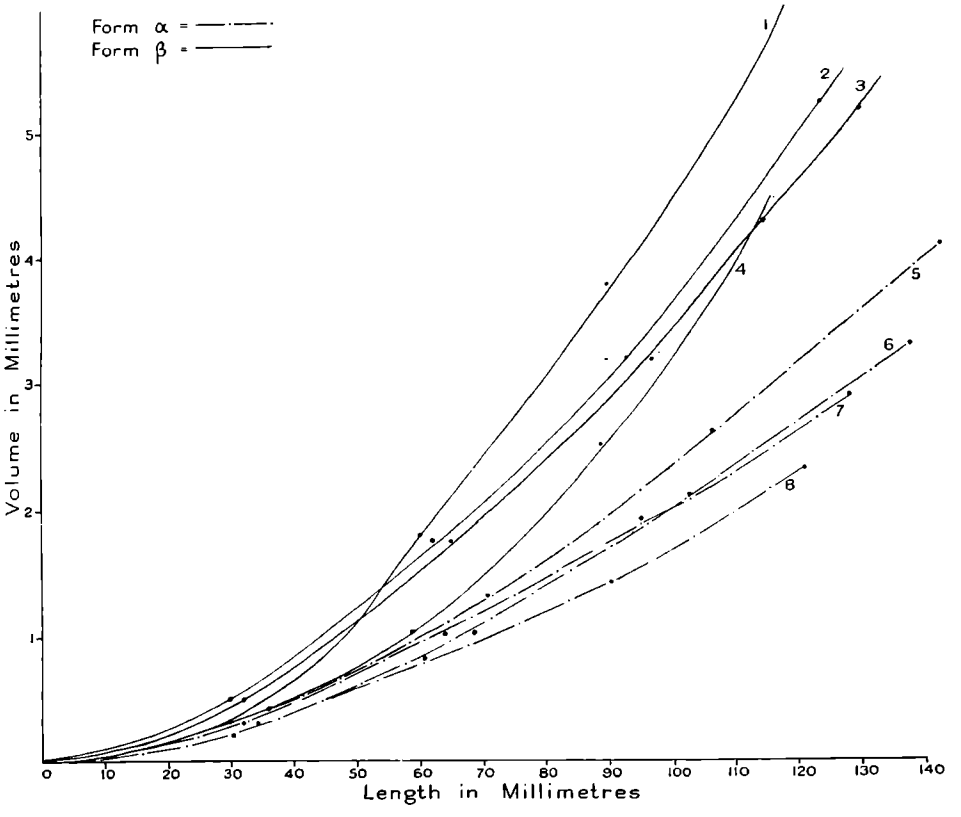


FIG. 4.—Graph illustrating the variation in guard shape of *Cylindroteuthis obeliscus* (Phillips).
1 = R.S.M. 1859-33-86. 2 = R.S.M. 1859-33-84. 3 = R.S.M. 1859-33-85. 4 = R.S.M. 1859-33-83.
5 = R.S.M. 1949-31-26. 6 = R.S.M. 1859-33-77. 7 = R.S.M. 1859-33-79. 8 = R.S.M. 1859-33-78.

The larval stages of both forms are clavate and elongate, and are not distinguishable from one another. The young belemnites are very much more elongate than adults, and the differences in the morphological ratios of α and β do not become apparent until the guard is between 30 mm. and 50 mm. in length. At this stage of growth the shape of the young guard approximates to that of the adult. Comparative measurements of typical examples of the two forms of *C. obeliscus* are given below.

Specimens	Form α R.S.M. 1949-31-23	Form β R.S.M. 1949-31-24
Length of guard (actual)	132·5 mm.	159 mm.
Length of guard (estimated)	151·0 ,,	159 ,,
Length of alveolar region	13·0 ,,	24 ,,
Length of stem region	97·5 ,,	106 ,,
Length of apical region	40·5 ,,	29 ,,
Transverse diameter of alveolar region	6·5 ,,	9 ,,
Transverse diameter of apical region	4·5 ,,	6·5 ,,
Apical angle of alveolus	26°	21°
Radial relation of apical line at alveolus	1 : 1·27	1 : 1·27
Radial relation of apical line at apical region	1 : 1·25	1 : 2·1

Phillips in his discussion of the variation within the species suggested that the differences might be sexual. This hypothesis is supported by the fact that the forms do not appear to grade into one another, and that the differences in form become more pronounced as ontogeny proceeds. Until our knowledge of the group is increased by the measurement of many more adult forms, these observations can only be suggestive, hence the word "form" is used here in a purely morphological sense.

Cylindroteuthis spicularis (Phillips).

1870. *Belemnites spicularis* Phillips, "British Belemnitidæ", *Palæont. Soc.*, p. 122, pl. xxxiii, fig. 82.
1922. *Cylindroteuthis spicularis* Naef., *Die Fossilen Tintenfische*, p. 243, text-fig. 88*f*.

In his description of the species *C. spicularis*, Phillips notes that the morphology of the phragmocone was incompletely known. The longitudinal section of a large specimen collected by the writer (R.S.M. 1949–31–22) shows that the alveolus occupies 21·3 per cent. of the length of the guard. There are two spherical chambers at the base of the phragmocone, the posterior chamber being much smaller than the anterior and separated from it by a fairly thick calcareous wall. The anterior chamber is somewhat flask-shaped and is succeeded anteriorly by the normal septate phragmocone. The section also shows that the embryonic guard is less elongate than that of the adult. It is ten to twelve times as long as it is broad. The maximum diameter lies immediately behind the middle of the guard, which has a clavate form. A cylindrical shape is gradually assumed as growth proceeds, the change being completed when the guard is approximately 40 mm. long. Before the fully cylindrical form is assumed in profile, a sub-clavate form is developed, the dorsal margin having a slight concavity in the anterior portion while the ventral margin exhibits a uniformly convex form. The general profile therefore appears to have an upward tilt posteriorly.

Two specimens collected by the writer have a proportionately shorter axial length than the specimen figured by Phillips (*loc. cit.*, pl. 82), which suggests that a variation occurs within the species *C. spicularis* similar to that found in *C. obeliscus*. Comparative measurements are as follows:

Specimens	Normal Form R.S.M. 1949–31–22	Short Form R.S.M. 1949–31–25
Length of guard (actual)	239·5 mm.	142·5 mm.
Length of guard (estimated)	246·0 ,,	180·0 ,,
Length of alveolar region	52·5 ,,	44·5 ,,
Length of stem region	140·5 ,,	98·0 ,,
Length of apical region	53·0 ,,	37·5 ,,
Transverse diameter of alveolar region	16·5 ,,	17·2 ,,
Apical angle of alveolus	19°	21°
Radial relation of apical line:		
(*a*) at alveolus	1 : 1·2	1 : 1·3
(*b*) at apical region	1 : 1·1	1 : 1·2

Phillips observes of *C. spicularis* that "it is difficult to fix upon any definite characters by which to distinguish this belemnite from *B. owenii*, except the greater proportionate length of the axis and the faintness of the apici-ventral groove". In their relative proportions the two short forms of *C. spicularis* from Eathie approximate to *C. owenii* (Pratt), particularly to the variety designated *puzosianus* by Phillips; the writer hesitates to assign them to this species however, since apart from the shorter guard they appear to be identical with *C. spicularis*, and as no other variety of *C. owenii* was found they have been retained within the species *C. spicularis*.

VI. The Age of the Strata

Ammonites, abundant throughout the strata at Eathie, serve to fix the age of the deposits. The *Rasenia cymodoce* zone of Salfeld (1913, p. 428) includes the strata from the base of the exposure to the black-shales immediately below the Second Limestone. The occurrence of the fine-ribbed "*Rasenia*" cf. *mutabilis* in the Second Limestone and in the black-shales above it indicates that the lower part of the overlying "*R.*" *mutabilis* zone is represented. Using Spath's Ammonite Zoning of the Eo-Kimmeridgian (1935, p. 74), it is found that three zones are present at Eathie. The whole of the *Rasenia uralensis* and *Amœboceras kitchini* zone appears to be represented and comprises most of the succession. The presence of *Prorasenia* spp. near the base of the "*Astarte* muds", however, suggests that the grey muds occurring at the base of the succession, the black-shales with *Camptonectes*, and possibly the lower part of the "*Astarte* muds" are of pre-*uralensis* age, and would therefore be included in the zone of *Pictonia baylei* and *Rasenia cymodoce*. As with Salfeld's classification, the Second Limestone and the black-shales above fall within the "*Rasenia*" *mutabilis* zone.

Ths occurrence in the lower part of the "*Astarte* muds" of *Prorasenia bowerbanki* and *Prorasenia* aff. *triplicata* with forms bearing affinity with the *Rasenia uralensis* group is peculiar. This assemblage has been recorded previously only in the Abbotsbury Iron Ore of Dorset (Arkell, 1947). *Prorasenia* is characteristic of the Lower Kimmeridge Clay of the Wootton Bassett horizon, which is older than the horizon exposed at Market Rasen in which *Rasenia* spp. of the *uralensis* group are common, but in which *Prorasenia* has not been found. It was suggested by Spath (1935, p. 72) that "In a slowly accumulating deposit like the Abbotsbury Iron Ore the separation of these elements may be very difficult". It is improbable, however, that the "*Astarte* muds" at Eathie were of slow accumulation, the green-grey shaly muds being of fairly coarse texture. It appears, therefore, that the *Prorasenia* and *Rasenia uralensis* elements are not strictly successive. There is probably an intermediate horizon at which both are present.

VII. Stratigraphical Comparisons and Conclusions

No study of the microfauna of the Jurassic rocks of eastern Scotland appears to have been made hitherto. A microscopic examination of five selected specimens from the Kimmeridgian shales and limestones of Eathie, however, revealed the presence of at least nine genera of Foraminifera and two genera of cyrtoid Radiolaria. The forms are small, the majority having diameters of 0·2 millimeters or less; many are pyritised. The variation in the abundance of species and individuals of the macrofauna at different horizons of the succession is paralleled in the microfauna of the horizons. The grey muds at the base of the succession, containing only a few specimens of lamellibranchs and cephalopods, have not so far yielded any fossil micro-organisms. The prolific "*Astarte* muds" above, however, rich in the number and variety of their molluscs, are rich also in Foraminifera. Twelve specimens of Lagenidæ comprising five genera and at least seven species were found in the sample of shale taken from this horizon. The genera present are *Robulus*, *Lenticulina*, *Dentalina*, *Nodosaria* and *Lagena*, the most numerous being the "*Cristellaria*" and *Dentalina* groups. The black bituminous shales below and above the First Limestone contain many specimens of *Ammodiscus*, Radiolaria being abundant in the shales below the limestone. Radiolaria again become abundant in the Second Limestone and in the shales above. With the Radiolaria in both the Second

Limestone and in the shales above occur great numbers of an agglutinated form (?) *Psammosphæra*. An exhaustive study of the microfauna of the area has been beyond the scope of the present research; the results obtained, however, suggest that such a study offers a profitable field for further investigation.

Corals, echinoderms and brachiopods, which are well developed in the three basal zones of the Eo-Kimmeridgian in Sutherland, have not been found at Eathie. Lee (1925, p. 115), in noting the absence of these groups in the Eathie beds, remarks that "whether the difference is to be attributed to physical conditions or to the incompleteness of the section cannot be ascertained". In the light of later research by Bailey and Weir (1932, pp. 443 and 457), however, it seems probable that the difference is due to physical conditions. Bailey and Weir did not find brachiopods, sea-urchins or corals in the black-shales. They were present in the sandy matrix of the boulder-beds. This observation, with additional seismic evidence, led them to conclude that in Kimmeridgian times the submarine fault-scarp of the Loth-Helmsdale fault separated a comparatively shallow water facies containing brachiopods, sea-urchins and corals from a comparatively deep-water facies characterised by mud, debris of land plants and ammonites. They further supposed that contemporaneous movement of the fault caused the shallow water organisms along with unconsolidated Mesozoic rocks from the upthrow side, along with Old Red Sandstone boulders from the fault-scarp, to spread over the deeper water muds below in the form of boulder-beds. The absence of boulder-beds at Eathie shows that similar fault-scarp conditions did not exist in the Cromarty area. The similarity of the black-shale facies of Sutherland with the black-shale facies of Eathie suggests that both have accumulated under similar ecological conditions.

The Eathie fossils, apart from those newly described by the writer, have been compared or identified with characteristic Mediterranean forms found in southern England, or with Boreal forms abundant in the Kimmeridigian beds of Spitzbergen and Greenland. The contrast between the Mediterranean and Boreal types is well seen in the ammonites. *Rasenia*, *Prorasenia* and "*Rasenia*", which form part of the unbroken Perisphinctid succession of the Mediterranean province and predominate in southern England, are well developed at Eathie. *Amœboceras*, a genus widely distributed in the Arctic and a characteristic member of the Boreal province, is also abundant at Eathie. The belemnite genus *Cylindroteuthis* and the lamellibranch genus *Buchia* are also widely distributed forms of boreal aspect. The mixed Boreal–Mediterranean assemblage at Eathie, occurring in an intermediate geographical position between the faunas of true Boreal and Mediterranean type, supports the hypothesis that the formation of biological provinces is influenced by ocean currents and climate, and that the faunal gradation between the Mediterranean and Boreal provinces may be due to the existence of climatic zones in Jurassic times.

VIII. Bow Buoy Skerry

Bow Buoy Skerry is 1 mile south-west of Eathie Haven, and can be reached only at low spring tides. It is a minute exposure of Jurassic strata which has been downfaulted against the metamorphic rocks of Rosemarkie. The fault runs between the skerry and the beach where, 50 feet to the west, the metamorphic rocks outcrop. The Jurassic rocks are visible for only some two hundred feet along their strike. They are made up of hard arenaceous limestones and carbonaceous sandstones, and have a very steep east-north-easterly dip. The rocks are severely slickensided owing to their proximity to the fault. Examination of the

arenaceous limestone in microsection shows it to be oolitic. The carbonaceous sandstone is very similar in appearance to that which outcrops at Ardassie Point, Brora.

The following fossils were collected by the writer from the skerry:

Cucullæa contracta Phillips.
Placunopsis radiata (Phillips).
Chlamys (*Æquipecten*) cf. *fibrosus* (J. Sow.).
Pinna sp.
Pholadomya aff. *æqualis* J. Sow.
Cardioceras (*Cardioceras*) cf. *costicardia* S. Buckman.
Cardioceras sp. (Fragment of large body whorl, smooth, bearing only faint striæ.)
Belemnites sp.

The most common fossils at Bow Buoy Skerry are small specimens of two varieties of *Cucullæa contracta*. An oblique form, having a postero-dorsal angle at 130°, was found. It is similar in outline to the specimens from the *Trigonia perlata* beds of Highworth drawn by Arkwell (1929, p. 44, fig. 3), and is of the type of *C. elongata* Phillips (1829, pl. iii, fig. 33). More common at this locality, however, is the less elongate form figured by Phillips as *C. contracta* (1829, pl. iii, fig. 30). It closely resembles *C. ardassiensis* Arkell in its small size and lack of surface ornamentation, but it cannot be identified with this species since it lacks a median valley. Unlike the giant specimens found at Ardassie Point, the *Placunopsis radiata* from Bow Buoy Skerry is of normal size. Unfortunately the ammonites are fragmentary and crushed. In addition to *Cardioceras* cf. *costicardia* the Geological Survey have obtained *C. costellatum* and *C.* aff. *cardia* from this locality (Phemister, J., 1936, p. 82). This suggests that the Bow Buoy Skerry beds are of the same age as the Studley-Horton clays of Oxfordshire, which belong to the Costicardia sub-zone of the Cordatus zone of the Upper Oxford Clay (Arkell, 1947).

IX. Acknowledgments

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XI. DESCRIPTION OF PLATES

Plate I

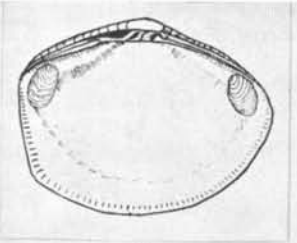
Fig. 1*a*. *Astarte eathiensis* sp. nov., lateral view of the right valve, the holotype, R.S.M. 1949–31–8. ×2.
Fig. 1*b*. Reconstruction of the interior of the left valve. ×2.
Fig. 1*c*. Reconstruction of the interior of the right valve. ×2.
Fig. 1*d*. Reconstruction of the hinge structures.
Fig. 2*a*. *Buchia concentrica* (J. de C. Sow.), interior of the left valve showing hinge structures, R.S.M. 1949–31–5. ×2.
Fig. 2*b*. Interior of the right valve. The background has been masked to show up the hinge structures. R.S.M. 1949–31–4. ×2.
Fig. 2*c*. The type specimens. British Museum, No. L 63613.
Fig. 3. *Amberleya* sp. Specimen R.S.M. 1949–31–11. ×2.
Fig. 4*a*. *Nuculopsis* (*Palæonucula*) *finlayi* sp. nov., lateral view of the left valve, the holotype R.S.M. 1949–31–1. ×2.
Fig. 4*b*. Dorsal view.
Fig. 5*a*. *Meleagrinella leeana* sp. nov., lateral view of the left-valve, the holotype R.S.M. 1949–31–6. ×2.
Fig. 5*b*. Left valve of young stage, paratype, R.S.M. 1949–31–7. ×3.
Fig. 5*c*. Left valve of large specimen showing the auriculate nature of the wing, paratype, Scot. Geol. Surv. Col. No. 3539.
Fig. 6. *Camptonectes* sp. Specimen R.S.M. 1949–31–10. ×2.
Fig. 7*a*. *Cylindroteuthis obeliscus* (Phillips), form β, lateral view, specimen P. 64, C.D.W. Col. Natural size.
Fig. 7*b*. Ventral view.
Fig. 8*a*. *Cylindroteuthis obeliscus* (Phillips), form α, lateral view, specimen R.S.M. 1949–31–26. Natural size.
Fig. 8*b*. Ventral view.

Plate II

Fig. 1*a*. *Amœboceras* (*Amœbites*) aff. *rasenense* Spath, ventral view of specimen R.S.M. 1949–31–14. Natural size.
Fig. 1*b*. Lateral view.
Fig. 2*a*. *Amœboceras* (*Amœbites*) sp. nov. (?), lateral view of specimen R.S.M. 1949–31–15. Natural size.
Fig. 2*b*. Ventral view.
Fig. 3*a*. *Amœboceras* (*Amœbites*) *subkitchini* Spath, lateral view of specimen R.S.M. 1949–31–13. Natural size.
Fig. 3*b*. Diagram of the suture line. ×4.
Fig. 4*a*. *Amœboceras* (*Amœbites*) *kitchini* Spath, lateral view of specimen R.S.M. 1949–31–12. Natural size.
Fig. 4*b*. Ventral view of the same.
Fig. 5. *Prorasenia bowerbanki* Spath, lateral view of specimen R.S.M. 1949–31–19. Natural size.
Fig. 6*a*. *Prorasenia* aff. *triplicata* (J. Sow.), lateral view of specimen R.S.M. 1949–31–17. Natural size.
Fig. 6*b*. Ventral view.
Fig. 7*a*. *Prorasenia* aff. *triplicata* (J. Sow.), lateral view of specimen R.S.M. 1949–31–18. Natural size.
Fig. 7*b*. Ventral view.
Fig. 8*a*. *Rasenia* sp. nov. (?), lateral view of specimen R.S.M. 1949–31–16. Natural size.
Fig. 8*b*. Ventral view.

CHARLES D. WATERSTON, on "The Stratigraphy and Palæontology of the Jurassic Rocks of Eathie (Cromarty)".—PLATE I.


1a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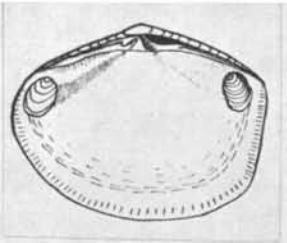
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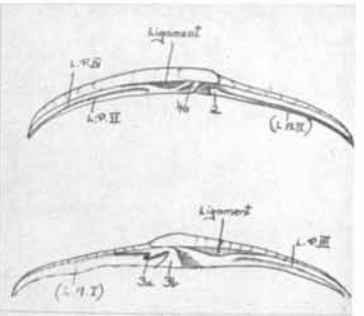


1d


2a


3


4a 4b


2b


2c


6

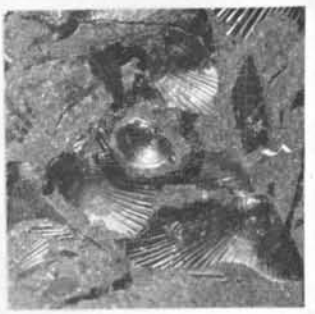

7a


7b


8a


8b

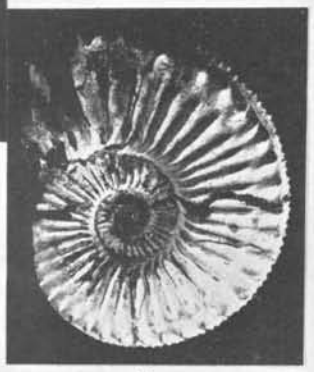

5a


5b


5c

CHARLES D. WATERSTON, on "The Stratigraphy and Palæontology of the Jurassic Rocks of Eathie (Cromarty)".—PLATE II.


1a


1b

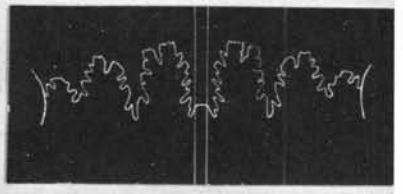

4b


2a


2b


3a

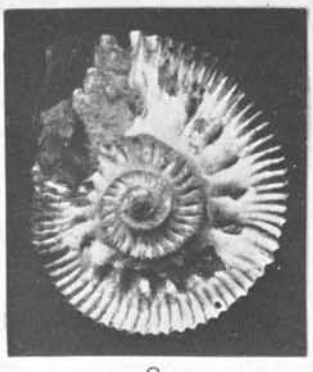

4a


3b


5


6a


6b


8a


8b


7a


7b