45. *On the RELATIONS of the EOCENE and OLIGOCENE STRATA in the HAMPSHIRE BASIN.* By Prof. JOHN W. JUDD, F.R.S., Sec. G.S. (Read April 26, 1882.)

I. *Introduction.*

SINCE the publication of my paper "On the Oligocene Strata of the Hampshire Basin" *, I have been favoured with many valuable suggestions and criticisms from geologists, both in this and other countries; and the time has now perhaps arrived when some of the interesting questions thus raised may be discussed with advantage.

The great object of my former memoir was to determine the age and relations of a series of marine beds which contain a highly interesting fauna—a fauna presenting the closest affinities with that of a well-defined system of strata very widely distributed in Central Europe.

In framing his classification of the Hampshire Tertiaries, the late Prof. Edward Forbes gave no place to this important series of beds—a fact which does not seem to have been sufficiently considered by those among my critics who have demurred to my proposed modification of Forbes's classification as unnecessary and, therefore, unwarrantable.

The history of the discovery of this interesting marine series does not appear to be generally known. The late Sir Charles Lyell spent his earliest years in the New Forest, residing at Bartley Lodge near Lyndhurst. At that time shelly marls appear to have been in great request among agriculturists, being employed by them as a manure on some of the poorer soils, like the similar materials of the French Fahluns and our own Craggs. Now, in the hills lying on the north side of the town of Lyndhurst such marls were found to occur, and numerous pits were opened for their excavation. In his visits to these marl-pits Lyell found the beds to be crowded with beautiful and well-preserved marine shells, of which he made a considerable collection, sending examples of them to Webster and Sowerby.

At that time all the marine bands which occur in the Hempstead, Bembridge, and Headon series were confounded with one another under the name of the "Upper Marine Formation;" and it is not surprising, therefore, that Webster at once claimed these marine marls of Lyndhurst as being of that age†. Sowerby, however, seems to have recognized the fact that the fauna of the Lyndhurst beds is a peculiar one; and he described and figured two of the most remarkable and distinctive of its fossils, namely *Voluta geminata*, and *Cardita deltoidea*‡.

The employment of these marls, or shelly clays, of the New Forest for agricultural purposes soon ceased, however; but the numerous abandoned workings and the names given to certain

* Quart. Journ. Geol. Soc. vol. xxxvi. (1880) p. 137.

† Trans. Geol. Soc. 2nd ser. vol. i. p. 94.

‡ Min. Conch. t. 398. f. 8, t. 259. f. 1.

localities prove to what an extent it was at one time carried. Fragmentary specimens of the fossils of these beds may still be found in the old workings; but the late Mr. F. Edwards, in bringing together his fine collection of the Mollusca from the British Lower Tertiaries, found it necessary to employ workmen to reopen some of these pits, in order to obtain well-preserved specimens. There were also at that time two brickyards in which the strata in question were exposed, those namely of Whitley Ridge and Roydon, the former of which has been long closed.

But in the year 1858 the construction of a railway-cutting at Brockenhurst afforded an opportunity for collecting the fossils of this interesting series of marine beds, of which opportunity Mr. Edwards and the Geological Survey made excellent use; Mr. Henry Keeping and Mr. Richard Gibbs, the fossil-collector of the Survey, were both for some time employed in collecting the fossils from this interesting deposit.

In 1863 M. von Könen visited this country; and in the group of fossils which Mr. Edwards had collected from Lyndhurst, Whitley Ridge, Roydon, and Brockenhurst he at once recognized the peculiar and remarkable fauna of the Tongrian of Belgium and the Lower Oligocene of Northern Germany. He also placed on the same horizon certain beds at Colwell Bay and Whitecliff Bay in the Isle of Wight*.

Dr. Duncan's subsequent study of the rich coral-fauna of these beds amply confirmed Von Könen's views as to their Lower-Oligocene age†.

Now in my former memoir I have argued that the Barton Clay and its continental equivalents ought to be regarded as forming the highest member of the Eocene. The Headon-Hill Sands and Clays, which overlie the Barton beds, exhibit intercalated bands of brackish-water origin, and yield a considerable fauna. Among the most abundant and characteristic fossils of both the Headon Sands and Clays are the different varieties of *Cerithium concavum*, Sow. In many parts of the continent a series of beds with a similar fauna has been found, overlying the richly fossiliferous representative of the Bartonian; and this series of strata has long been recognized by Mayer, Sandberger, and other authors as "the zone of *Cerithium concavum*." To this horizon, therefore, I have referred both the Headon Sands and Clays.

The richly fossiliferous marine beds of Lyndhurst and Brockenhurst I believe to altogether overlie the Headon group or Zone of *Cerithium concavum*; and I have proposed for it the name of "the Brockenhurst series," inasmuch as it constitutes a mass of strata of considerable thickness and importance, and possesses a very rich and characteristic fauna. I have grouped the Headon and Brockenhurst beds together as the Lower Oligocene, and the overlying Bembridge and Hempstead as the Middle Oligocene, the Upper Oligocene being altogether wanting in this country.

* Quart. Journ. Geol. Soc. vol. xx. (1864) p. 98.

† Monograph of British Fossil Corals, 2nd ser., Pal. Soc. 1866.

To this proposed classification exception has been taken by various critics, on very different and often quite opposite grounds. Many esteemed continental correspondents, who entirely agree with me as to the order of succession of the strata, point out that in the Paris basin the zone of *Cerithium concavum* appears to be simply an upper and subordinate member of the Bartonian; they argue, therefore, that the line of separation between the Eocene and Oligocene should be drawn at the base of the Brockenhurst series, thus including the Headon Clays and Sands in the Bartonian or Upper Eocene. My reason for not, in the first instance, adopting this line as the limit of the Eocene and Oligocene was the great inconvenience which would result from breaking up our fluvio-marine series into two portions, and grouping one with the Eocene and the other with the Oligocene. It is true that the interesting observation made by Messrs. Keeping and Tawney, that at Whitecliff Bay an actual unconformity appears to exist at this horizon, lends some support to the view that this is the line of demarcation between the two great series; and, in order to prevent the inconvenience of adopting different limits between the great geological divisions in this country and on the continent, it may be advisable to waive the objection to breaking up what appears to be, locally, a natural grouping of the strata.

But other critics, while agreeing with M. von Könen, Dr. Duncan, and myself as to the Lower-Oligocene age of the Brockenhurst beds, maintain that I have altogether misunderstood the order of succession of the strata*. They assert that the Brockenhurst beds do not overlie the Headon group, but lie in the midst of it, forming a basement bed to the so-called "Middle Headon series." To the very obvious objection that this places what nearly all continental palæontologists regard as an Upper Eocene fauna below one belonging to the Lower Oligocene, one of the authors has replied by asserting that the name of the zone of *Cerithium concavum* is properly applicable only to the sands at the base of the Headon series, and not to the overlying clays†. More matured study of the question, however, appears to have led Mr. Tawney to greatly modify his views on the whole question; for in a later memoir we find him maintaining that the term Oligocene "is less applicable to the English Tertiaries than the older and more classical division into Eocene &c.," and, again, "the break between Oligocene and Eocene is an unnatural one, and the introduction of the term in our opinion obscures the affinities between the members of the English series"‡.

In the same paper this author abandons his former views as to the English representatives of the zone of *Cerithium concavum*, and states that the Headon Sands are characterized by the *Cerithium pleurotomoides*, Desh., while he now admits that *Cerithium concavum* is especially abundant in the overlying clays. With the great

* "On the Beds of Headon Hill and Colwell Bay in the Isle of Wight," by H. Keeping and E. B. Tawney, Quart. Journ. Geol. Soc. vol. xxxvii. (1881) p. 85.

† Quart. Journ. Geol. Soc. vol. xxxvii. (1881) p. 127.

‡ Proceedings of the Cambridge Philosophical Society, vol. iv. p. 147, note.

majority of continental palæontologists, I maintain that *Cerithium concavum* and *C. pleurotomoides*, are mere varieties of one well-marked species, and that both the Headon Sands and Clays belong to the zone of *Cerithium concavum*.

In the discussions which have taken place with respect to these Lower Tertiary strata, two perfectly distinct questions are involved—first, as to the order of succession of the beds in the Hampshire basin, and, secondly, as to the correlation of those beds with the deposits formed during the same great geological periods in other areas.

It will manifestly facilitate our fair consideration of these two questions, if we treat each of them separately; and such a course is fortunately rendered possible by the fact that at Whitecliff Bay, in the Isle of Wight, we have a continuous section of about 1900 feet of nearly vertical strata belonging to the Eocene and Lower Oligocene periods; so that here, at all events, the matter is not complicated by any doubt as to the true order of succession. The vertical position of these beds is not very favourable for the collection of fossils from them; but many of the strata are admirably displayed at low water, especially during spring-tides, and yield rich and abundant faunas. The admirable section of Professor Prestwich* enables us to refer without risk of being mistaken to any particular stratum; and the thicknesses of the whole of these beds have been carefully corrected by Mr. Codrington with the aid of the 25-inch maps of the Ordnance Survey †.

I am greatly indebted to Mr. Codrington for the loan of the manuscript of his detailed section of the beds seen in Whitecliff Bay, which has been of great service to me in my studies.

II. *Geological Age of the several Series of Beds exhibited in the Whitecliff-Bay Section.*

The references made to the several portions of the Whitecliff-Bay section in the following pages will be facilitated by the accompanying woodcut (p. 465), in which the nature of the several beds is indicated by shading. The engraver, in reducing the section to the limits of the page, has not very accurately preserved the relative thickness of the several beds. These thicknesses, however, are stated in the text. The numbers are those of Prof. Prestwich's section.

With respect to the portion of the Whitecliff-Bay section which represents the Lower Eocene, there is fortunately little ground for difference of opinion. The widely distributed Plastic Clay series of the Paris, Hampshire, and London basins is, at Whitecliff Bay, represented by Mr. Prestwich's bed 2, here 200 feet in thickness, and is seen to be overlain by a series of sands and clays (beds 3 and 4 of Prestwich) with a tolerably abundant fauna. That this series of beds, which is about 300 feet in thickness, is correctly referred to the London Clay has been shown by the valuable researches

* Quart. Journ. Geol. Soc. vol. ii. (1846) pl. ix.

† *Ibid.* vol. xxiv. (1868) p. 519.

of Mr. Mejer * and Mr. Caleb Evans † concerning the equivalent strata which were exposed during the Portsmouth-Dockyard extension works. The Portsmouth sections, as described by these authors, supply us also with the means of bringing into correlation the fossiliferous rocks of Bognor, the stratigraphical position of which was before uncertain, and the beds of the Whitecliff-Bay section, which have not yielded a very abundant fauna.

When we proceed westward, however, to Alum Bay, which is distant 22 miles from Whitecliff Bay, there is more difficulty in determining the exact limits of the Lower Eocene. The carefully measured section of the Geological Survey shows the Plastic Clay to be only 84 feet thick, while it assigns 219 feet of strata to the London-Clay series. Mr. Gardner ‡ has argued in favour of including the next 176 feet of strata in the London-Clay series; and there are good grounds for adopting his suggestion. This would make the Lower Eocene beds at Alum Bay 480 feet thick, while at Whitecliff Bay they are 500 feet. Both the divisions of the Lower Eocene are represented at Studland Bay: but the characters of the exposures are not such as to readily admit of the relative thicknesses of the series of strata being accurately determined.

But when we come to the Middle Eocene strata, we find the greatest diversity between the views of different authors, both as to the limits of the several divisions and their correlation with the strata of the London and Paris basins respectively.

In 1847, Mr. Prestwich announced his very important discovery that the Bracklesham and Barton beds of the Hampshire basin do not represent, as had formerly been supposed, the London Clay, but that the former is the exact equivalent of the Calcaire grossier, and the latter of the Grès de Beauchamp, or Sables moyens, of the Paris basin §. Contemporaneous with this important determination was the same author's recognition of the Lower Bracklesham fauna in the Middle Bagshot strata of the London basin ||.

Above the strata which at Whitecliff Bay have been shown to be the representatives of the London Clay, there occurs a series of unfossiliferous sands (Bed 5 of Prestwich), in all probability of freshwater origin. The thickness of these beds has been estimated at 142 feet by Mr. Codrington: and they were correlated by Prof. Prestwich with the Lower Bagshot series in the London basin.

The beds numbered from 6 to 14 by Prestwich were, with the exception of the upper 9 feet, referred by that author to the Bracklesham series, which, as thus defined, had a thickness of about 450 feet. The beds 15 to 19 inclusive, in all about 260 feet of strata, were referred to the Barton Clay. But in 1862 the Rev. O. Fisher proposed to remove more than 200 feet of the Whitecliff-Bay beds from the Barton series and to include them in the Bracklesham

* Quart. Journ. Geol. Soc. vol. xxvii. (1871) p. 74.

† Proc. Geol. Assoc. vol. ii. pp. 61, 149.

‡ *Ibid.* vol. vi. p. 86.

§ Quart. Journ. Geol. Soc. vol. iii. (1847) p. 353.

|| *Ibid.* p. 378.

series *. Mr. Fisher's reason for proposing this great change in the classification of the Whitecliff-Bay beds was that he considered certain fossiliferous bands could be traced continuously wherever the Bracklesham series is exposed over the whole Hampshire basin. In each of these fossil-beds, which vary in thickness from 6 inches to 6 feet, he assures us that a similar matrix and the same assemblage of fossils can be recognized, and he assumes the continuity of these fossiliferous bands over the whole of the wide area through which the Bracklesham series can be followed—an area measuring 40 miles from east to west, and 20 miles from north to south.

But it is only fair to remember that the occurrence of these fossil-beds is capable of a different explanation. Among the inconstant strata deposited (as the Brackleshams undoubtedly were) near the estuary of a great river, similar materials with the same assemblage of fossils would be deposited wherever the same physical conditions prevailed; and it is not necessary to assume that similar fossil-beds exposed at widely separated localities are necessarily parts of one continuous stratum. Mr. Fisher's argument in favour of including so great a thickness of the Whitecliff-Bay beds in the Bracklesham series rests to a great extent also on his reference of the fossiliferous strata of Hunting Bridge to that geological horizon; and this is a conclusion which is far from being free from doubt. Although it is difficult among the poorly fossiliferous beds of Whitecliff Bay to fix the exact line of demarcation between the Bracklesham and Barton series, yet there are good grounds for believing that the Barton Clays have a greater thickness and importance at that locality than is ascribed to them by Mr. Fisher.

With respect to the correlation of the richly fossiliferous strata of the Hampshire and Paris basins, Mr. Prestwich's admirable papers left little to be accomplished, and the discovery of fresh species in the two areas has completely confirmed the conclusions arrived at by that author with the assistance of Prof. Morris and the late Mr. F. Edwards. As early as 1847 † it was proved that the Bracklesham beds contain the same fauna as the Calcaire grossier; and in 1857 the exact correspondence of the Bracklesham series and the Barton series with the Middle and Upper Eocene of France and Belgium was established beyond all chance of controversy ‡.

But the correlation of the richly fossiliferous Hampshire beds with the barren Middle Eocene of the London basin has proved a far more difficult task; and the views generally accepted on this question are, to say the least of them, still open to very grave doubt.

The Lower Bagshot beds of the London basin have a thickness of from 100 to 150 feet; they contain only a few obscure vegetable remains, and are in all probability of freshwater origin. The sands and pipe-clays which at Studland Bay, Alum Bay, and Whitecliff Bay are seen immediately overlying the representatives of the

* Quart. Journ. Geol. Soc. vol. xviii. (1862) p. 65.

† *Ibid.* vol. iii. (1847) p. 354.

‡ *Ibid.* vol. xiii. (1857) p. 90.

London Clay were regarded by Mr. Prestwich as probably representing the Lower Bagshot of the London basin, and as being, like it, of freshwater origin*. The pipe-clays with abundant vegetable remains at Corfe, Branksea, Studland, and Alum Bay, all appear to be in this part of the Middle Eocene series. It is worthy of note that Mr. Prestwich confined the term Lower Bagshot beds to his stratum 5 of Whitecliff Bay, which he had previously called the "Lower Bracklesham Sands"†.

The Middle Bagshot of the London basin is only from 40 to 60 feet in thickness; it is of somewhat argillaceous composition, and of undoubted marine origin. So inconstant are its characters, however, in different parts of the London basin, that the line of demarcation between this and the other divisions of the Bagshot beds which was adopted by Mr. Prestwich, has evidently not been followed by the officers of the Geological Survey.

The Middle Bagshots contain only a few marine fossils; but these are sufficient to enable us to correlate them, without doubt, with the lower part of the Bracklesham series in the Hampshire basin. The Upper Bagshot of the London basin has a thickness varying from 100 to 150 feet, and only differs from the Middle Bagshot in its more purely arenaceous character, a distinction which is far from being constant. The Upper, like the Middle Bagshots, are of marine origin; but the fossils are exceedingly rare and very badly preserved.

With regard to the portions of the Hampshire Eocenes with which the Upper Bagshot of the London basin ought to be correlated, the greatest difference of opinion has prevailed. Mr. Prestwich's views are clearly stated in the following passage:—

"How far the Upper Bagshot Sands are related to the Bracklesham series it is difficult to say. The few fossils I have found in those sands are not sufficiently distinctive to enable me to pronounce a decided opinion. As, however, the fossiliferous Middle Bagshot Sands are very thin, and represent apparently only the lower or middle part of the Bracklesham series, I think it probable that it is the upper beds of sand and clay of the latter which pass northwards into the thick sands of the Upper Bagshot Sands. Still it is possible that part of them may represent the Barton series; for we see at Barton how shifting the upper part of that series is—how clay predominates at one place and sands at another"‡.

In the various publications of the Geological Survey, however, the thin division of the Middle Bagshot is correlated without any expression of doubt with the whole of the Bracklesham and Barton series, a mass of strata which at Whitecliff Bay exceeds 700 feet in thickness, while a series of sands overlying the Barton Clay is regarded as the representative of the Upper Bagshot.

Mr. Gardner's studies of the beds in the Bournemouth area have led him to another, and much more probable, correlation of the Middle Eocenes of the Hampshire and London basins, a view which

* Quart. Journ. Geol. Soc. vol. iii. (1847) p. 395.

† *Ibid.* vol. xiii. (1857) p. 90, note.

‡ *Ibid.* vol. xiii. p. 132.

is much more in harmony with the conclusions of Mr. Prestwich as given in the paragraph cited above. Like the latter author, Mr. Gardner restricts the name of Lower Bagshot to the oldest part of the Middle Eocene, which immediately overlies the London Clay, and he finds a probable representative of the Middle Bagshot in his "Bournemouth Marine," and of the Upper Bagshot in his Roscombe Sand with its remarkable pebble-beds*.

In his memoir on the London basin, Mr. Whitaker admits that the grounds on which the classification of the Geological Survey is based are far from being satisfactory. As an explanation of the difficulties he feels, he suggests that the Barton Clay may be absent, and in this way the representative of a higher series of beds may come to rest on the strata of Lower-Bracklesham age†. But of the existence of any lacuna between the Upper and Middle Bagshots no evidence has ever been produced; and the difficulty experienced by Mr. Prestwich and the officers of the Geological Survey in fixing upon a clear line of demarcation between them seems to point to the conclusion that the one series graduates insensibly into the other.

Still more recently Mr. Herries has brought forward the evidence of some additional species of Mollusca, which he has found in the Upper Bagshot beds of the London basin, as throwing fresh light on the vexed question of their geological age‡. These fossils are unfortunately all casts in ironstone, and it is admitted that their identification is in most cases very doubtful; nevertheless it is argued that the balance of evidence is in favour of associating the Upper Bagshot with the Barton rather than with the Bracklesham series. As there are, however, only three species said to be certainly recognizable, which are peculiar Barton forms (though one at least of these has certainly been found in the Bracklesham series), it must be admitted that the additional evidence is not of any very great weight. Mr. Herries, however, concludes from his study of this fauna that while the Upper Bagshot is the equivalent of the Barton Clay, "that part at least of the Hampshire-basin Upper Bagshot which at its summit, immediately under the freshwater Lower Headon at Hordwell, contains *Oliva Branderi* and *C. (Vicarya) concavum*, is a distinct and probably higher horizon"§. A still later paper on the subject by Mr. Tawney makes the same admission as to the imperfection of the evidence on which the "Upper Bagshot" of the London and Hampshire basins are placed on the same horizon. The author, however, argues in favour of the continued use of the term for the strata of the Hampshire basin, or, in other words, of applying the same name to two sets of strata of admittedly different age.

It will be seen from this review of opinion upon the subject that, while the general correlation of the beds of the Hampshire and Paris basins is undisputed, the exact age of the Bagshots of the London

* Quart. Journ. Geol. Soc. vol. xxxv. (1879) pp. 210, 227.

† Mem. Geol. Surv. Gt. Britain, vol. iv. pt. i. p. 333.

‡ Geol. Mag. new ser. dec. ii. vol. viii. p. 171.

§ *Loc. cit.* p. 173.

area is still a subject of much doubt; and this arises principally from the fact of the unfossiliferous character of these last-mentioned strata. According to the views of the officers of the Geological Survey, 660 feet of the beds seen at Alum Bay ought to be ranked as Lower Bagshot, while Mr. Gardner would restrict that name to 73 feet of those beds. What, if any such exist, are the Hampshire representatives of the Upper Bagshots of the London basin, is a question about which there is still greater and apparently hopeless divergence of opinion.

From this state of confusion into which the nomenclature of the Middle and Upper Eocenes of the Hampshire basin has unfortunately fallen, there is one and, as it appears to me, only one means of escape. It is clear that the Upper and Lower Bagshots of the London basin have not yielded a sufficient number of well-preserved organic remains to enable us to determine their exact place in the geological series. The naming of beds in the Hampshire basin, the age of which is clearly determinable, after these doubtful deposits, has been the source of an immense amount of confusion in the past. I would therefore advocate, as the only way of getting rid of this confusion, the total abandonment of the terms Upper and Lower Bagshot, as applied to strata in the Hampshire basin.

The beds in the Hampshire basin to which the term Lower Bagshot has been restricted by Mr. Prestwich and by Mr. Gardner, were formerly called "the Lower Bracklesham Sands" by the first-named author. This name appears liable to be misunderstood, and has been withdrawn by its author. I would venture therefore to suggest as a convenient name for this series of beds, which is represented in Whitecliff Bay by Mr. Prestwich's bed 5, in Alum Bay by his beds 15 to 18, and on the Hampshire coast by the sands and pipe-clays of Poole, Corfe, Branksea Island, and Studland Bay, the term "Studland Series." The Studland beds are of purely freshwater origin; and they yield an abundant flora, which has now been shown to be perfectly distinct from that of the overlying Bournemouth beds*.

The Studland Series forms the lower part of the Middle Eocene in the Hampshire basin; and the upper part of that division is formed by the mass of strata which in its easterly development is purely marine but in its westerly development passes into brackish-water and freshwater deposits. The way in which this takes place has been admirably illustrated in the memoirs of Mr. Prestwich and Mr. Gardner. The marine type of this formation is the Bracklesham, the freshwater the Bournemouth series. Both the marine fauna and the terrestrial flora of these beds seem to be highly characteristic, so as to clearly distinguish it alike from the underlying and overlying deposits.

The Barton Clay, of which the limits, as defined by Mr. Prestwich, appear to me to agree much more closely with the continental classification than does the grouping proposed by Mr. O.

* Pal. Soc., British Eocene Flora, 1879, p. 16.

Fisher, is everywhere recognized as the representative of the Upper Eocene.

The series of sands immediately overlying the Barton Clay, and called by the Geological Survey the "Upper Bagshot Sands," has long been known by the alternative name of the "Headon-Hill Sands;" and by this name, in order to avoid hopeless confusion, I would in the future propose to call it.

At Whitecliff Bay this series of sands is well exposed, forming a mass 200 feet in thickness, immediately overlying the representative of the Barton Clay. It is almost equally well seen at Headon Hill, where its thickness has been variously estimated at from 100 to 200 feet.

On the Hampshire coast these sands are exposed between Long-Mead End and Beacon Bunny, and again at Eaglehurst near Calshot, and they have been dug at many localities inland.

At Whitecliff Bay the sands in question are generally quite fossiliferous; but the late Mr. Richard Gibbs, the excellent fossil-collector of the Geological Survey, found a band in which a number of ferruginous casts of shells were recognizable. These were too friable for removal; but Professor Edward Forbes examined them *in situ*, and recognized them as belonging to the marine genera *Cardium**, *Panopæa*, and *Tellina*, and stated that so far as these forms were determinable they appeared to be identical with species found in the underlying Barton Clay.

At Headon Hill and at Eaglehurst, only comminuted and water-worn fragments of shells occur in these sands; but at Long-Mead End a band near the top of these sands contains a tolerably abundant fauna. The beds are evidently of brackish-water origin; for both marine and freshwater forms occur in considerable abundance in them.

These brackish-water Headon-Hill Sands, then, are intermediate in position between the marine Barton Clays below and the freshwater Headon-Hill strata above. They represent the passage from marine to freshwater conditions; and that they are equally related to both these deposits is shown by the fact that Barton and Headon forms occur in them in about equal proportions†.

Above the Headon-Hill Sands we find at Whitecliff Bay a series of clays with bands of lignite attaining a thickness of about 40 feet. The fossils found in these beds appear to be entirely of

* Mem. Geol. Surv., The Geology of the Isle of Wight, 1862, p. 51: *Cardinia* here is clearly a misprint for *Cardium*.

† Mr. Tawney has recently stated that, of 28 species of shells found by him at Long-Mead End, only 21 per cent were Headon forms, while 35 per cent. were Barton forms. He therefore argues that the Headon-Hill Sands have closer affinities with the underlying Barton than with the overlying Headon Clays. But in a comparison of this kind every thing depends on the identification of species; and in some cases Mr. Tawney's identifications differ from my own, and, I believe, from those of other palæontologists both in England and on the continent.

The study of the fauna appears to me to show that the beds are almost exactly intermediate in age, as they are in position, between the Barton and the Headon Clays.

freshwater and terrestrial origin; and no brackish-water beds have been detected in this part of the series at Whitecliff Bay. But at Alum Bay, and at Hordwell Cliff on the opposite coast of Hampshire similar beds of clay and lignite occur attaining a greater thickness and containing bands with an admixture of freshwater and marine fossils, the latter almost always in a dwarfed condition. I will reserve what I have to say concerning the Headon Clays at Alum Bay, and proceed to point out the characters presented in the equivalent strata at Hordwell Cliff.

These strata at Hordwell Cliff have attracted much attention from geologists, owing to the rich harvest of mammalian and reptilian remains which they have yielded to the late Mr. Searles Wood, the Marchioness of Hastings, and other collectors. Many of the beds have received local names from fossil-collectors; and more or less detailed descriptions of the succession of the strata have been published by Webster, Lyell, Searles Wood, the Marchioness of Hastings, Dr. T. Wright, and the Rev. O. Fisher.

It is a remarkable fact, as pointed out by the late Edward Forbes*, that the published descriptions of these sections, though professing to give the most minute details, arrived at by measuring down the beds inch by inch, differ from one another in a very striking manner. My own observations on this section, carried on during the last twenty years, convince me that these strata, like most deposits of estuarine origin, are of the most inconstant character, varying in thickness within very short distances. Mr. Codrington estimates that this coast-line is receding, in consequence of the action of the sea, at the rate of a yard per annum; and he thus accounts for the remarkable discrepancies of different observers as to the thickness of the gravel†. Among such variable strata as these are, the section exposed to observers at different dates may vary considerably. I have in a previous paper pointed out the impossibility of relying upon the constancy of the thin beds of limestone, lignite, &c. in tracing the order of succession among these estuarine beds; but I think there can be no doubt as to the general succession of strata at Hordwell Cliff.

The Headon-Hill Sands, which at Beacon Cliff are much thinner than in the Isle of Wight, contain an admixture of freshwater and marine shells, and, as Mr. Searles Wood and Dr. Wright long ago pointed out, are of estuarine origin. The lowest bed of the overlying Headon-Clay series consists of green and blue laminated clays with much carbonaceous matter, occasionally passing into thin lignite seams. This bed, which is about $3\frac{1}{2}$ feet thick, is known locally as the "Lignite-bed." Above this Lignite-bed there is found a series of sands and sandy clays containing freshwater and terrestrial remains—plants, shells, and bones. From the fact that these beds, which are about twenty feet thick, have yielded to collectors the remains of *Palæotherium*, *Palæotherium*, and *Dichodon*, they are known as the "Mammalia-bed." The top of this series is marked

* Quart. Journ. Geol. Soc. vol. ix. (1853) p. 268.

† *Ibid.* vol. xxvi. (1870) p. 532.

by a bed of dark-coloured clay about 2 feet thick, containing numerous impressions of leaves. Overlying this "Leaf-bed" is a series of white and grey sands with irregular bands of clay about fifteen feet thick. As this division yields many bones of *Crocodylus*, *Trionyx*, and *Emys*, it is well known, especially the upper part of it, to collectors, by whom it is called the "Crocodile-bed." About four feet higher we come to a thin, somewhat nodular band of marly limestone crowded with specimens of *Limnæa* and *Planorbis*. The thickness of this limestone varies, but may average about six inches. Above the limestone band we find a series of grey and green shelly marls and sands with occasional bands of lignite, measuring together about 20 feet. The total thickness of the beds so far described may be estimated at 65 feet.

Throughout this thickness of strata the fossils appear to be generally of freshwater and terrestrial origin. I have found some exceptions to this rule; for at three different horizons specimens of *Cerithium* occur, with other indications of the temporary coming in of brackish-water conditions. Resting on these strata, however, is the celebrated "Marine bed" of Hordwell, which has attracted such a considerable amount of attention from geologists.

Mr. Webster and Sir Charles Lyell, who published the first accounts of the Hordwell cliff, failed to find any trace of a marine formation there, although it is evident that their attention was particularly directed to the question of the existence of marine strata at this horizon. Both these authors, however, record the finding of specimens of *Cerithium* in fragments which had fallen from the cliff. But in 1840 Mr. F. Edwards detected a thin band containing numerous marine shells, which band he succeeded in tracing in the cliff for a distance of 300 yards. In 1843 Mr. Searles V. Wood, who examined the cliffs with great minuteness, could only trace this band for 100 yards; while in 1851 Dr. Wright only found it exposed at one place for a distance of about 10 yards. In 1853 the Marchioness of Hastings said that the bed was nearly worked out. Messrs. Keeping and Tawney thought that it had not been exposed for 28 years; but within the last twenty years, I have had the good fortune to find it on two occasions, though during numerous other visits I have altogether failed to do so.

Mr. Searles Wood estimated the thickness of this bed at only 9 or 10 inches, while Dr. Wright thought it a little more. The Rev. O. Fisher estimates it at 5 feet, but admits he had never seen the bed in section. I found myself that the marine shells were confined to a very thin band, certainly not more than a foot in thickness. Whether this thin seam has altogether disappeared through the wearing away of the cliff, as may well happen with such thin lenticular patches, or whether it is only concealed under the gravels and fallen detritus, I am not able to state; but the fact that the band could at one time be traced from the point where it rises on the shore to a place where it crops out in the cliff, and that I have frequently searched the place where it ought to occur

without success, leads me to entertain the view that the former supposition is the correct one*.

Above the "marine bed" at Hordwell there are seen about 20 feet of sands and marls with freshwater fossils. But, as Mr. Searles Wood pointed out long ago, the forms of Mollusca and Vertebrates occurring in these upper freshwater beds are precisely the same as those found in the beds underlying the "marine bed."

When these marine beds were first discovered, the whole of the fluvio-marine beds of the Hampshire basin were grouped according to Webster's classification into the Middle Freshwater, the Upper Marine, and the Upper Freshwater. The thin marine band of Hordwell was therefore at once claimed as the representative of the Middle Marine formation. The proofs brought forward by Prestwich and Forbes of the existence of a number of marine or brackish-water beds of different ages in the fluvio-marine series, while they have caused this classification to be abandoned in many points, do not seem to have altogether dispelled the old notions on the subject; for we find the Rev. O. Fisher still claiming this thin and inconstant band of Hordwell Cliff, which abounds with dwarfed marine shells mingled with freshwater forms, as the undoubted representative of the Middle or Marine Headon, the "*Venus*-bed" of collectors; and he even identifies the thin limestone band below it with the Hæw-Ledge limestone of the Isle of Wight†.

But, as long ago pointed out by Mr. G. B. Sowerby, and admitted by Sedgwick and other observers, the division of the Headon beds into three series, the upper and lower of which are of freshwater, and the middle of marine origin, is one that will not bear the test of exact examination. All through the Headon series, bands containing some forms of marine mollusca, usually much dwarfed, occur; such brackish-water beds exist alike in the so-called Upper, Middle, and Lower Headon; and the utmost that can be said of these brackish-water beds, in which both marine and freshwater genera are mingled, is that they are perhaps most abundant in the central parts of the series. The so-called "marine band" of Hordwell is only one of the brackish-water intercalations of the Headon series.

The whole series of strata at Hordwell cliff is therefore as follows:—

	feet.
(1) Sands and marls with freshwater shells	12-20 seen.
(2) Sand with brackish-water shells ("Marine band").....	1 or less.
(3) Grey and green shelly marls and sand.....	20
(4) Linnæan limestone.....	$\frac{1}{2}$
(5) Green marls	4

* If the measures of the Marchioness of Hastings and Mr. Wise could be trusted, we must admit the existence of two marine bands in the Hordwell Cliff; for whereas these authors place their marine band 43 feet above the limestone bed, Dr. Wright reckons only 16 feet of strata between those two beds. My own measurements and those of the Rev. O. Fisher support the views of Dr. Wright as to the true place of the marine bed; Prof. Ed. Forbes (Quart. Journ. Geol. Soc. vol. ix. 1853, p. 263), however, thought the Marchioness of Hastings's section more reliable than that of Dr. Wright.

† Geol. Mag. new ser. dec. ii. vol. ix. (1882) p. 139.

STRATA OF THE HAMPSHIRE BASIN.

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	feet.
(6) White sands and clays, with "Crocodile-bed" at top ...	15
(7) Sandy bed with lignite ("Leaf-bed")	3
(8) Greenish sands and clays ("Mammalian bed") with a band near the base containing estuarine fossils.....	20
(9) "Lignite bed"	3½
(10) Seam of sand crowded with estuarine shells ("Olive- bed")	1
(11) Sands with occasional brackish-water shells	30-40

These beds graduate so imperceptibly into the underlying Barton clays that it is difficult to fix the exact limits between them*.

As studied at Hordwell Cliff, then, the Headon sands and clays are seen to pass into one another by insensible gradations, they are both of estuarine origin, and they contain essentially the same fauna. What that fauna is, there is not the smallest room for doubt. The French geologists have long recognized at the top of their Grès de Beauchamp, which represents our Barton clay, a series of sands well exposed at Mortefontaine, Monneville, and even under Paris itself, containing a peculiar assemblage of fossils, and to which the name of the zone of *Cerithium concavum* has been given by Carl Mayer and Sandberger. Hébert, Carl Mayer, and many other foreign geologists have recognized in our Headon and Hordwell beds the representatives of the zone of *Cerithium concavum* of the continent. As in the continental beds, so in both the Headon sands and clays the very characteristic fossil *C. concavum* occurs in enormous abundance; and many other fossils are common to the English and French deposits. On the question of the position of this zone of *Cerithium concavum*, and the correlation of our Headon and Hordwell beds with them, all the most eminent Tertiary geologists of France, Germany, and Switzerland are perfectly agreed.

At Eaglehurst, near Calshot, variegated clays and sands with *Potamomya* and other freshwater shells are found overlying the representatives of the Headon-Hill sands just as at Hordwell. These clays are dug in the Solent brick-works; and by the aid of Mr. E. Westlake and Mr. Hooper I have been enabled to recognize among the bones found here remains of *Crocodylus Hastingsia* and of the well-known forms of *Trionyx* and *Emys* of Hordwell.

The Headon beds are 240 feet thick at Whitecliff Bay; at Alum Bay their thickness is variously estimated at from 300 to 400 feet; at Hordwell they exceed 120; while at Eaglehurst their thickness cannot be exactly determined.

The next series of strata exposed at Whitecliff Bay is the very interesting one for which I have proposed the name of the Brockenhurst series. The freshwater Headon clays are suddenly succeeded

* Mr. Searles V. Wood has obligingly furnished me with some notes which he made when working in company with his father at Hordwell in the years 1843 and 1845. He assures me that the whole of the vertebrate fossils obtained by his father, both reptilian and mammalian, were taken from the bed (6) which is called the "Crocodile-bed." Vertebrate fossils, however, appear to abound in both the divisions (6) and (8).

by a deposit of most unmistakably marine origin having a thickness of nearly 100 feet. So far as I have been able to discover, there is no appearance whatever of a gradual passage between these freshwater and marine series of beds, the lowest portion of the latter abounding in marine Mollusca, Bryozoa, and even Corals. The break between the Headon and Brockenhurst beds appears to be a complete one.

Messrs. Keeping and Tawney state that they found this marine series to lie upon an eroded surface of the underlying Headon beds*. This fact is in marked agreement with the sudden change in the nature of the fauna. At Roydon I have found an equally abrupt transition from the freshwater beds of the Headon to the marine ones of the Brockenhurst.

The lowest 15 feet of these beds, which are of an argillaceous character, contain the most numerous fossils; and these can be collected in great numbers at low water during spring tides. In the succeeding 45 feet of strata, which are of a sandy nature, marine fossils (and only marine fossils) are found, and such species as occur agree entirely with those found in the underlying argillaceous beds. The highest beds consist of sands and clays 40 feet in thickness, in which marine fossils become more numerous; at the top of the series there is an admixture of marine and freshwater forms, indicating a gradual passage into the overlying freshwater beds.

Now, with regard to the age of this marine series there is fortunately no room for doubt. There occurs in the New Forest a series of marine strata which Von Knen, Duncan, and after them many other authors have identified with the Tongrian of Belgium and the Lower Oligocene of Northern Germany. The identity of the fauna found in this marine series of Whitecliff Bay with that found in the New-Forest bed has been pointed out by the Rev. O. Fisher, Messrs. Codrington and Jenkins, and has been amply confirmed by the collections made by Messrs. Keeping and Tawney.

This continuous marine series of Whitecliff Bay Messrs. Keeping and Tawney propose to break up into four divisions. To the lowest two feet they give the name of "the Brockenhurst zone;" and the next 12 feet they call "the Roydon zone." These two divisions they unite to form the "Brockenhurst beds." The next division, "the *Sanguinolaria*-sand," 42 feet thick, they admit contains a number of distinctive Brockenhurst forms; but the highest division, 15 feet thick, they follow the Geological Survey in calling "the *Venus*-bed:" and the whole marine series, including the overlying 19 feet of sands, they group as the Middle Headon.

According to the view propounded by those authors the Brockenhurst zone is a thin, highly fossiliferous deposit, 2 feet thick at Whitecliff Bay, and varying from a few inches to a foot in thickness at the Brockenhurst cutting. Yet at Roydon brickyard, less than two miles away from Brockenhurst, this zone is stated to be altogether absent, nor could any trace of it be found at Hordwell, Headon, or

* Quart. Journ. Geol. Soc. vol. xxxvii. (1881) p. 109.

Colwell Bay in the position which, according to these authors, it ought to occupy.

The "Roydon zone" has been established to include those portions of the Brockenhurst series in which certain fossils were thought to be absent or rare. My own collections, that of Mr. Edwards in the British Museum, and one made by Mr. E. Westlake and placed at my disposal, show that the strata at Roydon are much richer than Messrs. Keeping and Tawney appear to have concluded from their visit to the locality. Von Könen and Edwards had no doubt whatever of the contemporaneity of the Roydon and Brockenhurst beds; and the arguments by which it has been endeavoured to separate them are of the slightest character.

The identification of the overlying strata as "the *Venus*-bed," and its reference to the so-called Middle Headon are, I believe, equally unfounded. *Cytherea incrassata* (the "*Venus*" of collectors) is a species of wide range. It is said by the officers of the Geological Survey to have been found in the Barton Clay, though this is doubtful. All through the Headon series, however, from the top to the bottom, it makes its appearance wherever brackish-water or marine conditions occur. It equally abounds in the Brockenhurst beds and the Bembridge, a band crowded with examples of this shell overlying the Bembridge Limestone. Before the time of Edward Forbes this bed was unhesitatingly accepted as the "*Venus*-bed," the Bembridge Limestone being confounded with that of Headon Hill. In the marine Brockenhurst series of Whitecliff Bay, *Cytherea incrassata* occurs in great abundance in the bottom 15 feet; it is more sparingly scattered in the overlying 45 feet of sand, but again becomes very abundant in the overlying clays, its abundance or rarity being clearly determined by the nature of the sea-bottom at the time. Why one particular portion of the marine series should be singled out and called "the *Venus*-bed," I am quite at a loss to imagine. A considerable number of highly characteristic Brockenhurst forms, such as *Voluta spinosa*, *Strepsidura armata*, *Ostrea ventilabrum*, *Psammobia compressa* and *Cardita deltoidea*, occur in these upper beds, which at the top exhibit the gradual return to freshwater conditions by the presence of *Cyrena*, *Melania*, *Melanopsis*, &c.

But what is more fatal to the view that these beds belong to the Headon series, or zone of *Cerithium concavum*, is that the characteristic fossils of that horizon are wholly wanting in them. *Cerithia* (*C. pseudocinctum* &c.) abound in these beds; but, so far as my observations go, there is not a trace to be found of *C. concavum* and *C. ventricosum*.

The attempt to split up this series of marine strata into a number of distinct and widely distributed fossil-beds, is, I believe, an example of that misleading method which has already led to a considerable amount of confusion in the case of the Bracklesham series, as I have already pointed out in the earlier part of this paper.

Over the thickly gravel-covered area of the New Forest it is quite hopeless to attempt to follow the different divisions of the Eocene and Oligocene series. At one or two points, however, the marine

Brockenhurst series can be traced. In the banks of the stream called the Dark Water, near the village of Langley, and again in the sides of the Beaulieu river, just below the town of Beaulieu, the marine strata are exposed, where the great plateaux of gravel so well described by Mr. Codrington * have been cut through by the streams. At the latter of these localities a brickyard once existed, which has long since been closed and the pits filled in †. I have been able to collect in the river-banks the very characteristic *Voluta geminata* and other fossils of the Brockenhurst series. We meet with no further traces of them, however, till we come to the valley of the Lymington river, at Roydon and Brockenhurst and the localities in the immediate neighbourhood of Lyndhurst. We have no means of determining the total thickness of the Brockenhurst series in the New Forest: but at Roydon and near Lyndhurst it certainly exceeds 25 feet ‡.

III. *The Correlation of the Strata of Headon Hill and Colwell Bay.*

While the order of succession of the strata as seen in Whitecliff Bay at the eastern end of the Isle of Wight is clear and undisputed, such is far from being the case at Colwell Bay and Headon Hill, at the western end of the island: the strata containing the peculiar fauna of the Brockenhurst series appear, at first sight, to be entirely wanting at these localities; certainly no trace of such a formation can be detected in the position assigned to it by Messrs. Keeping and Tawney, namely at the base of the so-called "Middle Headon." If, then, we accept the interpretation of these authors, we must believe that while the Brockenhurst beds are well developed both at Whitecliff Bay and in the New Forest, they are wholly wanting at the intermediate localities.

But another explanation of the facts of the case has been suggested by M. von Knen and myself. The brackish-water beds of Colwell Bay yield a number of characteristic Brockenhurst fossils; and we have therefore been led to regard these Colwell-Bay beds as the brackish-water representatives of the Brockenhurst series, though we admit that in the New Forest they have a "richer and true marine fauna" §.

But it has been maintained that the brackish-water beds of Colwell Bay are clearly identical and continuous with the so-called Middle Headon of Headon Hill. On this point the greatest diversity of opinion has long existed. Prof. Hbert and Dr. Wright believed the brackish-water beds of Colwell Bay and Headon Hill respectively to be on different horizons; and Mr. G. B. Sowerby, Prof. Sedgwick, and Prof. Edward Forbes all admit that there are

* Quart. Journ. Geol. Soc. vol. xxvi. (1870) p. 528.

† An account of some of these New-Forest sections was given by Mr. J. C. Moore, Quart. Journ. Geol. Soc. vol. v. (1849) p. 315.

‡ Although the whole of the fluvi-marine beds of the New Forest are coloured by the Geological Survey as belonging to the Headon series, there can be little doubt that a considerable portion of them belongs to the Bembridge series.

§ Quart. Journ. Geol. Soc. vol. xx. (1864) p. 98.

considerable differences between these two sets of beds and the faunas which they contain.

The officers of the Geological Survey, it is true, treat these two sets of strata as being upon the same horizon ; but they at the same time maintain the identity of the Headon-Hill and How-Ledge limestones ; and nothing can be more certain than that, while the Colwell-Bay brackish-water beds *overlie* the How-Ledge limestone, the Headon-Hill brackish-water beds *underlie* the Headon-Hill limestones.

The great difficulty in arriving at a satisfactory conclusion concerning the order of succession of the strata at the west end of the Isle of Wight is due to the fact that, near the summit of the anticlinal in Totland Bay, there is an interruption in the sequence, owing to denudation, to the beds being covered up by later deposits, and possibly also to faulting. While a substantial agreement exists between the various detailed sections which have been published of the strata in Colwell Bay and Headon Hill respectively, the attempts to correlate these two sections have given rise to the greatest divergences of opinion.

Since the publication of my own attempt to explain the relations of these sections, several other memoirs have appeared dealing with the same question. Prof. Blake*, while differing from me on many points, expresses his dissent with perfect courtesy and fairness. Messrs. Keeping and Tawney have also published their interpretation of these sections†. The two sections recently published, though measured down bed by bed, differ in many important particulars from one another, from the sections of Mr. Prestwich, Dr. Wright, the Geological Survey, and from that published by myself. This arises, as I believe, from too great a reliance being placed upon the constancy of particular bands among these very variable estuarine deposits.

In dealing with the stratigraphical evidence, Messrs. Keeping and Tawney state that I have altogether misrepresented the position of the "Marine or Middle Headon." Any one who will refer to my former paper will at once see that the position which I assume is that of altogether denying the existence of any such group as the Middle or Marine Headon. Under the circumstances I may perhaps be forgiven for quoting what I actually did state on the subject. Speaking of the Headon group, I said "this group of freshwater and estuarine beds is more than 400 feet in thickness, and exhibits many indications of the prevalence from time to time of brackish-water and marine conditions;" and, again, "in all the lower part of the series we find a tendency to the recurrence of brackish-water conditions ; and in these intercalated fluvio-marine bands we find numerous *Cerithia*, *Cyrenæ*, and dwarfed *Ostracæ*."

Precisely similar conclusions to those which I had arrived at were announced by Professor Sedgwick as the result of the careful study of the Headon-Hill strata, which he made with the assistance of Prof. Henslow. Professor Sedgwick states that "in Headon Hill the middle argillaceous group contains innumerable freshwater shells,

* Proc. Geol. Assoc. vol. vii. p. 151.

† Quart. Journ. Geol. Soc. vol. xxxvii. (1881) p. 85.

greatly predominating over the marine, and bands of lacustrine marl differing in no respect from that of the upper and lower groups”*.

That brackish-water shells occur in certain bands in the strata usually ranked as the Upper and Lower Headon, may be seen by an inspection of the sections of Dr. Wright, Prof. Prestwich, the Geological Survey, and Prof. Blake; and these brackish-water bands occasionally contain *Cytherea incrassata*. On the other hand the central portions of the Headon series contain so few purely marine forms, and such as do occur are in such a dwarfed condition, that Mr. G. B. Sowerby strongly insisted on the inaccuracy of styling it a marine formation; while Sedgwick, Forbes, and nearly all other observers have admitted that nowhere in Headon Hill do we find marine conditions so strongly marked as at Colwell Bay.

The fact is, as I have pointed out in my preceding paper, that the division of the Headon series into an Upper Freshwater, a Middle Marine, and a Lower Freshwater formation, is the last relic of a classification the inapplicability of which Sedgwick had begun to see in 1830, and which was rendered quite untenable by the subsequent discoveries of Prestwich and Forbes. The limits and divisions of this supposed Middle Marine Headon, as adopted by Messrs. Keeping and Tawney, are quite different from those given in the sections of the Geological Survey; and while the former authors include in it only from 31 to 33 feet of strata, Prof. Blake finds the brackish-water beds intercalated with about 45 feet of strata. A careful study of the published sections long ago convinced me that different authors had referred to different parts of the Headon group in describing the Marine or Middle Headon, and that no part of the series can be justly separated under that appellation.

The great difficulty which all authors have found is to correlate the strikingly different sections exposed in Headon Hill and Colwell Bay.

The method which was adopted by Dr. Wright, Mr. Bristow (in one of his sections †), and myself, was to select what appeared to be the most constant series of beds in the two sections, and to bring them into comparison.

All through Headon Hill there can be traced a great mass of sandstones and limestones having a united thickness of over 40 feet. It is true that, when examined in detail, this series of calcareo-arenaceous beds exhibits many variations; the thick masses of limestone which are seen at some points are at others broken up into several thinner ones by intervening sands or clays; and in some places the limestone contains fewer shells, and passes into a sandstone rock. But, in spite of its minor variations in composition, this mass of strata maintains its thickness and general characters for a distance of more than a mile, and forms the most conspicuous feature in the

* Proc. Geol. Soc. vol. ii. p. 294.

† The Tertiary Fluvio-marine formation of the Isle of Wight (1856), p. 132; The Geology of the Isle of Wight (1862), p. 62. In the table of Vertical Section No. 4, the difficulty in identifying the beds of Colwell Bay and Headon Hill has been attempted to be met in another way still.

mural face of Headdon Hill. Only half a mile off, on the other side of the Totland-Bay anticlinal, a similar mass of sands and limestones appears in Warden Cliff, and, dipping below the sea-level, forms the dangerous reefs known as How Ledge and Warden Point, stretching away towards Hurst Castle. Indeed the lower part of this series can be traced continuously all through Totland Bay. It is true that in Warden Cliff the beds are generally of a more arenaceous character, and the limestone bands are thinner and in most cases more inconstant than at Headdon Hill; but the series does not differ more at these two localities than it does in its course through Headdon Hill, and the same species of freshwater Mollusca abound in both. Further, the Upper Limestone, that of How Ledge, is seen to greatly increase in thickness as we trace it in the direction of Headdon Hill, and the sandy beds to become more calcareous.

Now, it has appeared to myself and other geologists that this well-marked mass of strata, which can certainly be traced without interruption through the whole of the Headdon-Hill section, ought to be found in the Colwell-Bay section; but, according to the interpretation of Messrs. Keeping and Tawney, it there thins away to an insignificant nodular band not above 1 foot 4 inches thick*.

But if the Headdon-Hill limestone series be identified with that of Warden Point, it is clear that the brackish-water beds of Colwell Bay overlying these limestones cannot be identical with those of Headdon Hill, which underlie the limestones—a correlation which my critics so positively affirm.

The position which they take up is as follows:—Rejecting the identification of the beds at Warden Point and Headdon Hill†, they proceed to indicate what they believe to be a surer means of correlation between the Colwell-Bay and Headdon-Hill sections.

At the east end of Headdon Hill, a little above Widdick Chine, the authors find a series of brackish-water beds, which they profess themselves to be able to identify, without the smallest possibility of error, with the well-known brackish-water beds of Colwell Bay. More than this, they assert that the series of beds at these two

* These authors (*loc. cit.* p. 90) have endeavoured to establish a curious *tu quoque* argument. They say that if they make a limestone 27 feet in thickness thin out to 1 foot 8 inches in a distance of 1 mile 926 yards, I have made the same bed thin out to 5 feet, and ultimately to 3 feet, in a distance of 1½ mile. But in this, as in many other points, my critics have quite misunderstood my views; for I have not identified the How-Ledge limestone, but the whole mass of limestones and sands of Warden Point, with the similar series in Headdon Hill.

† The officers of the Geological Survey have, in their memoir 'On the Tertiary Fluvio marine Formation in the Isle of Wight' (p. 132), and in their general memoir 'On the Geology of the Isle of Wight' (p. 62), deliberately expressed their opinion that the correlation of the limestones at Warden Point and Headdon Hill is the true one. Messrs. Keeping and Tawney state these repeated observations to be "an oversight or clerical error." Dr. Wright's equally distinct statement they in the same way characterize as "a mistake." The fact is, that the officers of the Geological Survey have expressed in their different writings three quite irreconcilable views. I have adopted one of these, Messrs. Keeping and Tawney another; but I am quite at a loss to understand the grounds on which these authors claim to be regarded as the defenders of legitimate authority.

points are not only in perfect agreement as to thickness and general characters, but that the numerous minor subdivisions at the one place are found exactly repeated at the other.

Let us examine these statements and the supposed proofs of them a little more closely. The distance between the point where the Colwell-Bay beds rise from the shore and that where their supposed representatives are seen at Headdon Hill is $1\frac{1}{2}$ mile or 2640 yards. For a distance of about 1200 yards from Headdon Hill to the Totland brickyard we have no trace of these brackish-water beds; but for the remaining 1440 yards they can be traced with occasional interruptions.

Near Bramble Chine, where the beds are exposed on the shore at low water, the Colwell-Bay brackish-water series is divisible into a number of local bands, which were well described by Dr. Wright, and may be distinguished by the names of the *Cerithium*-bed*, the Oyster-bed, the *Venus*-bed, the *Psammobia*-bed, and the *Neritina*-bed, the total thickness of these brackish-water beds being about 30 feet. These local divisions can be traced in the cliff for a short distance; but less than 300 yards away from the point where the beds rise on the shore, their characters are seen to undergo a total change; instead of the several distinct bands we have noticed, we find the brackish-water beds represented by a mass of dwarfed oysters between 20 and 30 feet thick. Tracing the beds in the cliff for a distance of another 350 yards, we find the characters of this so-called Marine or Middle Headdon series undergoing another complete change: masses of light-brown and ferruginous sands come down to within 8 or 10 feet of the How-Ledge limestone; the brackish-water beds are reduced to a thickness of 5 or 6 feet only, and their fauna exhibits a much smaller admixture of marine forms: *Cerithia* and a few dwarfed *Ostreae* occur, with great numbers of *Cyrenae*; but many of the marine genera found in the exposures to the eastward appear to be here quite unrepresented. At Warden Point the brackish-water beds are now concealed; but in the tumbled cliffs on the other side of the point we again find their representatives†. A careful study of this part of the cliff shows that the marine and brackish-water shells are confined to several thin and inconstant bands. At a distance of less than 500 yards from the point where the brackish-water beds are lost in the cliffs, through denudation, we are able to trace their representatives in the Totland-Bay brickyard. This brickyard has been opened for a

* Messrs. Keeping and Tawney differ from previous observers in calling one of the forms of *Cerithium* which occur here *C. ventricosum*. The species is quite distinct from the shell known by that name in the zone of *C. concavum*.

† My original section, drawn on the true scale, both horizontal and vertical, when reduced to the size of a plate in the Quarterly Journal of the Society, was too small to allow of some of the relations of the beds being clearly shown. I therefore, for the sake of clearness, added a second section, in which the vertical scale was exaggerated. In this latter section the position of the Colwell Bay marine bed at Warden Point is clearly shown, as my critics admit; they nevertheless refuse to accept this section as illustrating my views, but severely criticise the other section for its want of clearness. In the same way they dwell at great length on some obvious printer's errors in the lists of fossils.

number of years ; and I have had frequent opportunities of tracing the succession of beds exposed in it, which the Rev. O. Fisher and Mr. A. H. S. Lucas* rightly place on the horizon of the brackish-water beds of Colwell Bay and Warden Cliff. The strata exposed here are as follows :—At the top we find a mass of clays containing a few freshwater shells. These clays are more than 6 feet in thickness ; and at their base is found a band containing dwarfed oysters and other brackish-water shells. *Cytherea incrassata* I have not found in this band, though it very probably may occur there. The brackish-water band, however, which is never more than 18 inches thick, is so inconstant that in parts of the pit which I have seen excavated it is found to thin out and disappear altogether ; it is underlain by 10 or 12 feet of finely laminated white sands passing into sandy clays. In the foundation of a kiln these clays were seen to pass down into others crowded with *Potamomya* and other freshwater shells.

Now in Headon Hill, where these beds are next supposed to be seen, it is argued that we find the “Middle Marine” of Colwell Bay not only having the thickness, but exhibiting all the minor subdivisions exposed at the point where it rises from the shore, each little band with precisely the same series of fossils in it.

Between the two points compared, there is a distance of a mile and a half ; for more than half this distance we can trace the series of beds at frequent intervals, and we find it undergoing four complete changes ; and at the last place where it is seen it appears to be on the point of thinning out and disappearing altogether. Yet, in the next three quarters of a mile it is supposed to recover all its old characters, its original thickness, and even every minute subdivision is supposed to be recognizable in it !

The strata seen at Headon Hill, however, have in fact very little in common with those of Colwell Bay. In order to make a “Middle Marine series,” a number of brackish-water beds have been grouped with a number of purely freshwater strata, including limestones crowded with *Limnæa*, *Planorbis*, and *Paludina*, and beds of lignite. In the one set of beds *Cerithium concavum* occurs in prodigious abundance, in the other it is exceedingly rare. The difference between the two series of beds compared was long ago pointed out by Mr. G. B. Sowerby, and has been admitted by Sedgwick, Forbes, and the officers of the Geological Survey. The one point which they have in common is an abundance of the conspicuous and showy *Cytherea incrassata* ; and hence the local fossil-collectors call each of them a “Venus-bed.”

My critics have collected about 50 species of fossils from both these beds, and state that they find them to be identical. But it is clear, from what is stated about certain species, that they differ, not only from myself, but from other English and continental palæontologists as to the identification of many forms of Mollusca. They have collected, too, only the shells of the highest brackish-water bands at Headon for comparison with those of the Colwell-Bay bed,

* Geol. Mag. dec. ii. vol. ix. (1882) pp. 102, 138.

while I have compared the whole of the Headon marine forms with those of Colwell Bay. Nearly 100 species are known and have been recorded by competent authorities from both of these localities.

I, on the contrary, find that the same genus is constantly represented by the different species at the two horizons, and, like Von Kōnen, I recognize a considerable proportion of the Colwell-Bay forms as identical with those of the Brockenhurst series.

At the same time, as both Von Kōnen and I have admitted, the Colwell-Bay beds exhibit much more estuarine characters than do the strata at the New Forest localities. At Lyndhurst and Brockenhurst the beds appear to be truly marine, containing, as Dr. Duncan has shown, reef-forming corals; but at Roydon there occur a few specimens of *Cyrena* and *Melania*, which may have been washed in from a neighbouring river, while some of the most characteristically marine forms are absent or rare. At Colwell Bay, however, the admixture of freshwater with marine Mollusca becomes much more marked; many of the marine shells are dwarfed, while the corals and such genera of marine Mollusca as could not tolerate any admixture of fresh water are altogether absent. Further, as I have shown, the mass of brackish-water strata passes within a very short distance into a great oyster-bank; and this, when traced westward, is replaced by a number of thin brackish-water beds which at Totland-Bay brickyard appear on the point of thinning out and disappearing altogether*.

If the interpretation which I have advocated requires us to believe that the Brockenhurst beds, which at Colwell Bay begin to exhibit markedly estuarine characters, have, within less than two miles, thinned out altogether or passed into freshwater deposits, the theory opposed to it labours under still greater difficulties; for we are called upon by it to believe that the thick masses of the Headon-Hill limestones have almost entirely thinned out and disappeared at Colwell Bay. The Brockenhurst beds are said to form the base of the "Middle Headon;" and of this Middle Headon there are said to be clear sections at Headon Hill, Colwell Bay, and Hordwell. Has any one ever detected at any one of these localities a bed that can be regarded as this Brockenhurst bed? The whole of the Headon beds, both sands and clays, abound with *Cerithium concavum* and its varieties. *Cerithia* occur in considerable abundance in the Brockenhurst beds; but *Cerithium concavum* is absent from

* I have stated, in my paper and section, that the places where the Colwell-Bay marine bed, if it be continuous, should occur in Headon Hill are concealed by gravel and landslips. My critics declare that at one particular point there is no gravel, and take great exception to my description. They state that only "local taluses" occur. I can only ask any one who has taken the footpath from the keeper's lodge to Headon Cottage, to judge if my statement is not strictly correct. The thinness and inconstancy of the brackish-water bed at Totland Bay brickyard points to the conclusion that it is on the point of dying out altogether. Mr. Gardner has obligingly furnished me with some sections he had made by digging at the east end of Headon Hill, which seem to show that the Brockenhurst marine band has entirely disappeared. But, as Mr. Prestwich's section long ago showed, traces of brackish-water beds are found on this horizon at the other end of the hill.

these beds at all the typical localities*. Quite apart from the evidence afforded by the equivalent strata of the Continent as to the relative positions of the beds which contain the Brockenhurst fauna and those belonging to the zone of *Cerithium concavum*, it seems to me that the theory of Messrs. Keeping and Tawney labours under insuperable difficulties.

If the Colwell-Bay estuarine strata be not the fluvio-marine representatives of the Brockenhurst series, then it must be maintained that the last-mentioned series, which is so well represented both at Whitecliff Bay and in the New Forest, has altogether thinned out and disappeared from the sections of the west end of the Isle of Wight, or that the marine beds are represented by others of purely freshwater character. This appears to be the view adopted by Messrs. Keeping and Tawney. I believe, however, that the interpretation which I have given is the one which best accords with the facts of the case; and it has the additional merit of bringing our own series of strata into perfect harmony with the succession made out by the labours of continental observers with respect to the equivalent deposits in France, Belgium, and Northern Germany.

IV. Conclusion.

The Lower Tongrian, as is well known, has no marine representative in the Paris basin, the great freshwater gypsaceous series occurring on this horizon; but in the small basin of the Cotentin, as M. G. Dollfus has so well shown, the Lower Tongrian or Brockenhurst series is represented by the "argile à Corbules"†.

The Headon series, including both the sands and overlying clays, contains a fauna which, by Hébert, Sandberger, Mayer, and other authors, has been recognized under the name of the zone of *Cerithium concavum*. The Brockenhurst series contains a fauna which has been quite as universally recognized as agreeing with that of the continental Tongrian or Lower Oligocene.

Now, if my interpretation of the section be the true one, the beds containing the Tongrian fauna in the Hampshire basin overlie those containing the fauna of the zone of *Cerithium concavum*; and this is the relation which is believed to exist between their continental representatives. Most geologists, indeed, group the zone of *Cerithium concavum* with the Upper Eocene or Bartonian, and the representatives of our Brockenhurst series with the Lower Oligocene.

But, according to the views of Messrs. Keeping and Tawney, the beds which in this country contain the Lower Oligocene fauna

* I have pointed out that the several geological horizons in the Oligocene are characterized by different forms of *Cerithium*, just as different zones in the Mesozoic rocks are characterized by different species of *Ammonites*. My critics take the same exception to my views as has been urged by those who oppose the zonal classification of the Jurassic rocks: they assert that *C. concavum* is occasionally found at higher horizons than the zone of *C. concavum*. While *C. concavum* occurs in prodigious abundance in the Headon clays and sands, it is exceedingly rare at Colwell Bay, and altogether absent at Whitecliff Bay and the New Forest localities.

† Mém. Soc. Géol. de Normandie, 1880, p. 510.

form a thin and very inconstant bed in the midst of the strata containing the fossils of the zone of *Cerithium concavum*.

At Whitecliff Bay, where the order of succession is clearly exhibited, the brackish-water bands containing the fossils of the zone of *Cerithium concavum* are absent, but the Brockenhurst beds are well displayed and of considerable thickness. At Headon Hill the zone of *Cerithium concavum* is well seen, but the Brockenhurst beds seem to be altogether wanting. At Colwell Bay there occurs a series of beds which I take to be the estuarine representative of the Brockenhurst series, but which my critics declare to be only the zone of *Cerithium concavum* with a somewhat more marine character.

However this subsidiary question may be settled, I do not believe that the main facts of the correlation which I advocate are in any danger of being impaired. My critics have altogether failed to show that, at any point in the Hampshire basin, beds containing the characteristic fauna of the zone of *Cerithium concavum* overlies beds containing the Brockenhurst fauna; and on the Continent the latter are always superimposed upon the former. My critics hold that between the New Forest localities and those at the west end of the Isle of Wight the Brockenhurst beds have thinned away or passed into freshwater deposits; my contention is, that they appear in an estuarine form at Colwell Bay, and thin out or graduate into freshwater deposits between that place and Headon Hill.

In conclusion, I must point out that the vexed question of the order of succession of the beds at Colwell Bay and Headon Hill has only an indirect bearing on that of the position and correlation of the Oligocene strata of the Hampshire basin, which it was the main object of my paper to establish. If my interpretation be the correct one, then we have here, as I pointed out in my previous paper, an additional confirmation of the succession so clearly established by the study of the Whitecliff-Bay section. But if, on the other hand, the views advocated by Messrs. Keeping and Tawney be adopted, it adds no support to their views as to the position of the Brockenhurst beds; for these authors admit that nothing like the Brockenhurst beds can be detected either in the Colwell-Bay or Headon-Hill section.

I still firmly maintain the necessity of separating these beds from the Upper Eocene, with which they are usually grouped by English authors. The Hempstead series of the Isle of Wight is the undoubted representative of the Fontainebleau sandstones, a formation which no continental geologist would think of grouping in the Eocene. Either with Lyell and Hébert we must place the Hempstead beds in the Lower Miocene, or we must admit the term Oligocene as a convenient and now well-recognized name for these deposits which are intermediate in age between the Eocene and Miocene. Nothing could possibly be more detrimental to the progress of geological science than to attempt to perpetuate the use of the term Eocene in a sense quite distinct from that in which it is employed by all other geologists, alike in France, Belgium, Germany, Switzerland, and Italy.

DISCUSSION.

Prof. PRESTWICH said he had listened with great interest to the paper concerning this most difficult subject. Over the whole area only two zones were well marked, that of the London and that of the Barton Clay. The Bracklesham beds, on the other hand, were clear in the Whitecliff section, but were not indicated by fossils in the Alum-Bay sections. Further west still, about Poole, Bournemouth, &c., the beds became still more sandy, and more difficult of correlation. So, again, in the London basin, where, perhaps, we had nothing above the Bracklesham series. In all the fluvio-marine series there were great variations. Still he felt some difficulty in accepting the explanation offered by Prof. Judd. One thing was that the author failed to point out on the same horizon in Headon Hill any marine beds corresponding with the Colwell-Bay beds. At the same time he admitted that the variation of the beds rendered identification very difficult.

Mr. J. STARKIE GARDNER said that Mr. Monckton, in the neighbourhood of Wellington College, had got good Bracklesham forms in the green beds, and in the white sands above had found true Barton forms. He asked why the beds marked 20 in the section were classified with the Headon. He had recently trenched on Headon Hill from the Bembridge Limestone to the Upper Headon limestone, but had found no fluviomarine deposits.

Mr. TAWNEY said that he would not delay over matters of classification; for the question of the adoption or not of the term Oligocene was one that it might be hoped would be settled by the International Congress of Geology. Among all the beds exposed in the section exhibited at Whitecliff Bay he would only refer to those between the Upper Bagshot Sands and the Osborne series. With regard to his late paper in the Proceedings of the Cambridge Philosophical Society, the point raised was that the fossils of the said sands at Hordwell allied them to the Barton beds more nearly than to the Headon. So far as he understood Prof. Judd's communication, it was a reiteration of his former paper; and as no new facts were adduced, he would answer with no new arguments, and must apologize for repeating what has already appeared in the 'Journal' of the Society. He had shown, like previous observers, that the Brockenhurst fossils only occurred at the base of the Middle Headon; both at Whitecliff Bay and in the New Forest they lie immediately on the freshwater Lower Headon. He had not made four new series, but three zones were discriminated as subdivisions of the Middle Headon at Whitecliff. The characteristic Brockenhurst fossils did not pass up into the upper zone at Whitecliff; nor did they occur at all at Colwell Bay, the Brockenhurst zone being entirely absent there. Above the Middle Headon at Whitecliff came the freshwater Upper Headon, precisely as in the New Forest, Colwell Bay, and Headon Hill, and then the Osborne beds. These series were easily identifiable by their fossils.

Passing to the west end of the Isle of Wight, he must repeat that

it has been shown that *Cerithium concavum* occurred at Colwell Bay; and in all its other fossils the marine bed there was identical with the Middle Headon of Headon Hill, and which was no "superstition." Touching the physical evidence, the Colwell-Bay bed could be followed with the eye as absolutely continuous up to Weston Chine; it was therefore waste of time to talk of the variations of this bed in Colwell Bay as proving any thing; the only place where it was not perfectly continuous was between Weston and Widdiek Chines; but the beds below, viz. the Warden sands and certain *Chara*-beds, could be shown to be continuous; and so the series was continued on into that of Headon Hill without any difficulty. He considered it a very elementary problem in geology. It has been previously shown that Prof. Judd has misplaced the position of the *C. concavum* beds under Heatherwood Cottage, and has added over 100 feet here by counting part of the series twice. Moreover, if the Colwell-Bay bed existed higher up in Headon Hill, as Prof. Judd stated, it ought to be found; but in the position indicated quite other and freshwater beds existed. The speaker maintained all that had been printed in the paper referred to, and felt convinced that the orthodox view was correct.

Mr. BORR asked what came in between the two series. The argument of the alteration cut both ways. The beds, after changing for a while, might return to their former condition.

Mr. KEEPING said that the correlation of the Bracklesham beds at Whitecliff Bay, Stubbington, and Selsea Bill was certainly correct, and in the New Forest probably so. There could be no doubt about the correlation of the Middle Headon beds at Hordwell, Colwell Bay, and Whitecliff Bay. The zone of *Voluta geminata* was some 20 feet thick above the Brockenhurst zone. He regarded the Upper Headon as a truly lacustrine series, never having found any marine fossils in it; nor had he done so in the Lower; but in the Middle Headon freshwater forms were mixed with marine. He thought that the Geological Survey would be found to be correct in their reading.

Mr. WATTS said that he had searched very carefully above the Upper Headon limestone, and had found no marine beds, and could more readily understand that the former bed had thinned rather than that the Middle Headon group of the latter character should have disappeared.

Prof. JUDD was glad to find that Prof. Prestwich agreed with him as to the variability of the fluvio-marine series, and also as to the main facts of the classification of the Oligocene strata. As regarded one point remarked on, viz. the absence of the Colwell-Bay marine bed in Headon Hill, he had indicated that by the time it had reached Totland-Bay brickyard it had become reduced as a marine band to a bed not 18 inches thick. These brackish-water bands thinned out very rapidly. Hence it was very probable that the bed had died out before reaching Headon Hill. As regards the *Cerithia*, he had not been able in Whitecliff Bay to find *C. concavum* in the series he had called Brockenhurst. His opponents rested their case on the identity

of zones of fossils in Colwell Bay and Headon Hill; but he had shown that these beds when traced towards Totland Bay varied greatly. It was vain to talk of the work of Prof. Forbes. No one respected Edward Forbes more than he did; but many facts were before us now which were not before that most eminent geologist. If Messrs. Tawney and Keeping were right, the foreign geologists were wrong. He, however, inclined to think that it was possible to interpret the English section so as to agree with their reading.