VOL. XVI.]

[PART I.

PROCEEDINGS
OF THE
YORKSHIRE GEOLOGICAL SOCIETY.

EDITED BY W. LOWER CARTER, M.A., F.G.S., AND
ARTHUR R. DWERRYHOUSE, D.Sc., F.G.S.

1906.

ON THE ORIGIN OF THE BRITISH TRIAS.

BY PROFESSOR T. G. BONNEY, SC.D., LL.D., F.R.S.

In opening this discussion on the Origin of the Trias* I shall restrict myself, as far as possible, to what we can learn about the physical geography and climate of that period from the petrology of the system, leaving one or two points to be more fully described by others. Once for all let me express my obligations for many necessary facts to the Memoirs published by the Geological Survey, especially that on the Triassic and Permian rocks of the Midland Counties, drawn up by Professor Hull in 1869, to suggestive papers on India and Persia by the late Dr. F. Drew and Dr. W. T. Blandford, and to one or two other writers, whom I shall mention in due course.

The name Trias, I need hardly say, was given because the rocks of this system in the typical districts of North Central Europe fall naturally into three groups, which in Germany were called, in ascending order, the Bunter, the Muschelkalk, and the Keuper. In our own country the second is missing,

* At the York Meeting of the British Association, August 7th, 1906.

and the third is sometimes uncomformable with the first. But, though I think these two represent very distinct chapters in the physical history of Britain, I would not like to assert that no part of the Muschelkalk had a time equivalent in our islands.

The Keuper deposits, speaking in general terms, may be followed continuously from the South Devon coast to the Midlands, whence they extend along both sides of the Pennine Range, on the eastern to beyond the Tees, and on the western to North Lancashire. Here they come to the sea, but may then be traced through the Isle of Man to the neighbourhood of Carlisle on the one hand and the north-east of Ireland on the other. In Scotland also, outlying patches of that age occur on the north-eastern and western coasts. The Bunter, however, as we shall see, is absent from the more southern part of the Midlands, its "beds, in fact, form a wedge, lying diagonally across the central counties, with the apex pointing towards the mouth of the Thames."* It is again found in the south-west, where deposits of that age are exposed on the coasts of Devon and thin out in similar fashion towards the north and east, disappearing in the former direction before reaching the Bristol Channel.

The following facts must be taken into account in any attempt to picture the physiography and climate of the Trias in this part of Europe. Speaking of the Bunter group first, we find that it also very often admits of a triple sub-division, namely, into the Lower Sandstone, the Pebble Beds, and the Upper Sandstone. The first of these deposits, usually unconformable with the Permian beds below, occupies a more restricted area, at any rate in the western Midlands, than the second. Putting aside its representative in northern Lancashire, about the identification of which there has been some dispute, we can trace it from the estuaries of the Mersey and Dee southwards along the borders of Wales and Shropshire. Near Liverpool it is about 400 feet thick; in the neighbourhood of Bridgenorth it attains the unusual amount of about 650 feet. A fault near Bewdley forms its southern limit, but it thins rapidly both

* Hull, Permian and Trias (Survey Memoir), p. 61.

in that direction and towards the east, for it does not occur on the northern shore of the Bristol Channel or in the neighbourhood of Manchester and Stockport (having thinned down to 250 feet even at St. Helens), of Leek, the Potteries, Ashbourne, Derby, Wolverhampton, on the southern margin of the Clent and Lickey Hills, and on the western or northern side of the South Staffordshire coalfield. But it forms "a continuous though narrow band extending through Nottingham into Yorkshire." It is usually a soft friable rather homogeneous sandstone, of reddish brown, yellow, and bright red colours, often showing very marked current-bedding, the laminae of which, in the Bridgenorth district, dip towards the south-east; it is said to be "entirely devoid of pebbles," and beds of well-rolled sand grains are a rather frequent characteristic. These also occur in its Flintshire representative, where, according to Professor Hull, they are sometimes as large as mustard seed.

The pebble beds occupy a wider area, generally overlapping the Lower Sandstone. They attain in the neighbourhood of Liverpool the great thickness of 1,000 feet, though here sand dominates over pebbles, are about 300 feet thick in the neighbourhood of Trentham and on Cannock Chase, but die out along a line drawn south-east through Leicester. But they appear in Nottinghamshire, where their thickness is said to be also about 300 feet and can be traced northward through Sherwood Forest into Yorkshire. The base sometimes is rather a breccia than a conglomerate. Throughout the mass we find current-bedding and occasional sandy partings, more or less lenticular, the dominant colour being red or reddish-grey.

The Upper Sandstone is generally well developed in South Lancashire and Cheshire, being about 500 feet thick near Wigan, perhaps a little more at Liverpool, from 300 to 250 about Wolverhampton and Birmingham, becoming rather less at Grinshill in Salop, though it may be traced southward as far as the Abberley Hills. In Cheshire this group also thins towards the east; it is not found along the borders of the Warwickshire and Leicestershire coalfields, and is commonly not represented "along the band of country which stretches in a northerly direction from the valley of the Trent at Nottingham to the

Humber." It varies in colour from red to yellow, exhibits current-bedding, contains "millet seed" beds, and much resembles the Lower Sandstone, but is rather finer grained.

Thus the Bunter as a whole disappears south of a line running through the southern parts of Leicestershire, Staffordshire, and Warwickshire, and is not again found north of the Bristol Channel.* In the southern area its chief development is between the mouths of the Exe and the Axe, where the Pebble Bed reaches a thickness of about 100 feet, the Lower Sandstone is apparently wanting, and the Upper is represented by a soft sandstone measuring about 450 feet. Some differences of opinion exist about its exact limits, but into these we need not enter. Suffice it to say that the dimensions of the southern Bunter are much inferior to those of the northern, for it thins rather rapidly towards the north and the east, dying out in the course of some 30 miles from the coast.

The Keuper, as a whole, exhibits no such interruption, and its deposits differ considerably in their mineral character. It also (I exclude the Rhætic) often admits of a triple sub-division—the Lower Sandstone, the Waterstones, and the Red Marl. The first, more often grey than red in colour, is occasionally pebbly and has a breccia at its base, the third is a red clay, banded with pale greyish-green, sometimes containing masses of rock salt and of gypsum, and with occasional lenticular intercalations of sand or breccia, the latter having been formed near shore lines, while the second deposit, the Waterstones, is obviously a transitional one, rather thin beds of sandstone, commonly grey in colour, alternating with layers of Red Marl. East of the Pennines the Keuper sandstone is sometimes wanting, but it is about 120 feet thick near Nottingham, and is well developed around Derby. In South Lancashire, Cheshire, Staffordshire, and Shropshire it is often some 200 feet thick, probably attaining, according to Professor Hull, its maximum thickness, from 400 to 450 feet, in the neighbourhood of Stourbridge. Its basement often consists of breccia, like that of the Bunter,

* I have not taken account of the St. Bees sandstone, now generally regarded as Bunter, because so far as I am aware we have no means of determining its exact position in that group. Mr. H. B. Woodward says it varies in thickness from 500 to 2,000 feet.

angular fragments of more or less local rocks being mixed with pebbles, characteristic of the latter formation ; similar pebbles, frequently of quartz, but sometimes of clay, and generally rather small, occurring occasionally in the sandstone itself.

The Waterstones consist generally of alternating layers, usually not thick, of similar greyish sandstone and red marl, like that in the uppermost division. Its maximum thickness, so far as I can ascertain, is about 300 feet, but it seldom exceeds half that amount and is often thinner, so that, as it is obviously a transitional formation, we may pass on to the Red Marl. This overlaps even the Lower Keuper sandstones, and maintains its lithological characteristics, as already mentioned, from the north-east of Ireland on the one hand and Yorkshire on the other to the extreme south on the Devon coast. Probably it extends beneath the sea to France, for the Keuper Marl in Normandy, where I saw it, closely resembled that of our own country. This formation apparently attains its greatest thickness in Cheshire, where Professor Hull makes it about 3,000 feet ; in the central parts of Staffordshire it may be some 1,500 feet, but in the neighbourhood of Coventry and Warwick this is reduced, according to Mr. Howell, to 600 feet. That is about its measurement in Gloucestershire and Nottinghamshire ; apparently it becomes thinner in the neighbourhood of the Bristol Channel, but thickens again towards the south, attaining from 1,000 to 1,350 feet on the shores of the English Channel. Where it abuts on older rocks, intercalated breccias are not unfrequent, obviously formed near shores with a rising strand line ; of these the so-called Dolomitic Conglomerate in the Mendip region is a conspicuous example. The Keuper Marl, indeed the Trias as a whole, obviously thins out in the neighbourhood of Northampton, for its total thickness in a boring near that town was just under 60 feet, while it was not found beneath the London and North Western railway station, or under Kingsthorpe, Kettering, or Orton. It has not been struck in any of the borings in the eastern counties from Suffolk to Kent. In saying this I do not forget the red rocks found beneath Kentish Town, Crossness, Richmond, and Streatham, but I am convinced that these are really Palæozoic.

I now pass on to some lithological details in these deposits and take first the most conspicuous, the pebbles in the Bunter conglomerate of the northern and southern areas, in both of which no small variety of rocks is represented. The majority are at least sub-rotund. On Cannock Chase, where I have chiefly studied them (though I have sampled other places from Birmingham to Liverpool), the pebbles vary much in size. Those from a horsebean to about two inches in diameter are common; very many are between three and four inches; a few run still larger, up to six inches, and occasionally even exceed that. Several kinds of rocks are represented, but in regard to this, as I have already discussed the petrography of the pebbles,* I shall restrict myself to a brief summary. Vein-quartz and quartzite are the most abundant; the former are usually white, but include, though rarely, black tourmaline; some are brecciated. Quartzites are numerous and have their grains in a large number of cases very perfectly cemented. They vary in colour from almost white to a dark tint; some are reddish, and the characteristic liver-coloured variety is not rare; sometimes they are speckled with red felspar and thus graduate into a rock exactly resembling the noted Torridon sandstone. Pebbly quartzites also occur, and others shade off into hard sandstones, some of which are fossiliferous. Various mudstones, to use an inclusive term, are also present. Pebbles varying from dark green to almost black in colour are not uncommon. These are generally fine grained quartzites, darkened by interstitial chlorite, tourmaline, or iron oxide, some of the most compact proving to be porcellanites or cherts, the latter occasionally containing radiolaria. Chert also occurs with the well-known casts of crinoid stems, and limestone with characteristic Lower Carboniferous fossils. Neither are common, though the latter is perhaps a little more so towards the base of the pebble beds, and has recently been found rather more abundantly in one of the pits on the Satnall Hills, between Rugeley and Stafford.

The fossils, however, which have attracted most notice occur in the quartzites. In that large compact group, mentioned above, we find only a very few annelid tubes, often rather large;

* Quart. Jour. Geol. Soc., lvi. (1900), p. 287.

the majority form casts in a pale greyish or reddish sandstone, usually so hard as to be almost a quartzite. The pebbles are generally, but not always, about as well rolled as the others, and range with them in size. After what has been written, I need only say that at least the majority belong to the Upper Llandovery. A few other Silurian fossils have been found in more argillaceous rocks, and two or three bits of silicified wood, perhaps Permian.

Passing to the crystalline rocks, we find that granites, gneisses, and mica-schists occur but rarely and are usually much decomposed. Felstones, however, to use a convenient field term, are rather common. After the descriptions which I have given of these, it will be enough to repeat that they have evidently travelled far, have very little resemblance to the so-called Uriconian felstones of the Midlands, or to any known to me in the Lake District, and none to those in North Wales. Many of them, however, correspond closely with the felstones so abundant in the Highlands and other parts of Scotland, though they often contain tourmaline, which is a rare mineral in that country.

I pass on to the contents of the pebble bed in the southern Bunter. I described those at Budleigh Salterton in 1895, and may refer for particulars to the paper published in the *Geological Magazine*.*

Most of the rocks mentioned above also occur there, but not in the same proportion. The fossiliferous hard grits or quartzites which, though more numerous, are not abundant, attracted the attention of palæontologists many years ago. They were found to represent Lower Devonian, Bala, and Arenig grits (the last occurring very sparingly), and often have a closer lithological resemblance to corresponding deposits in Normandy than to those in Britain. The non-fossiliferous grits or quartzites are perhaps rather more frequently speckled with minute grains of felspar than in the Midlands, but the most marked difference is one of form. "Pebbles which are nearly prolate spheroids occur in both deposits, but that is the common shape in Staffordshire, while those in Devonshire are usually oblate." Corre-

* Volume for 1895, p. 75.

sponding with this is the comparative rarity of the almost vitreous quartzites of the Midlands, those common at Budleigh Salterton bearing a general resemblance to quartzites such as I have seen in the Gorran Haven district. Tourmaline-bearing grits are, I think, more common, often in rather larger and more rectangular pieces than in Staffordshire, but the felstones are less abundant; the very characteristic rocks of the Lizard peninsula, with the granites of Devon and Cornwall and the Devonian limestones, so far as I could see, did not occur.

Such pebbles as I have examined from the Keuper, when not of local origin, as in the breccias, correspond with those in the Bunter, being usually quartzites and vein-quartz, and are seldom large. They prove, however, that the source from which the latter may have been derived continued, though more sparsely and intermittently, to supply materials until the setting in of the Red Marl.

We must not, however, forget the smaller clastic materials. The Bunter sandstones of the Midlands are largely composed of quartz, stained externally with ferric oxide. In the upper and lower divisions well-rounded grains, as I have said, are abundant at certain horizons, but they are less common, so far as I have seen, in the matrix of the pebble bed. Grains of iron oxide may be observed, and no doubt rarer minerals will be found if sought for. Mr. H. H. Thomas has shown by his admirable investigation of the sands in the Devonshire Pebble Bed how rich a harvest awaits the investigator.* Among its rarer minerals he found garnet, anatase, rutile, zircon, apatite, brookite, sillimanite, staurolite, cyanite, and titanite, with micas and feldspars, besides fluorspar, cassiterite, and tourmaline. These suggest a derivation from rocks, the representatives of which still occur in southern Cornwall and may now be concealed beneath the waters of the English Channel.† It is noteworthy that nearly all those in the first-named group, together with tourmaline, have been detected by Mr. A. B. Dick and others in the Lower Bagshot sands (at Hampstead), the materials of which are generally supposed to have travelled from the south-west.

* Quart. Jour. Geol. Soc., lviii. (1902), p. 620.

† See W. A. E. Ussher, Q.J.G.S., xxxv. (1879), p. 245.

What inductions then, as to the physical geography and climate of the British Trias, follow from these facts of distribution and petrographic character ? In the first place, as I have already said, the history of the Bunter is one thing, that of the Keuper another. Assuming that the Pennine Range existed throughout the Trias, I proceed to inquire whether the materials of the Mid-England Bunter came from a northern or a southern direction. The former inference is supported by the gradual thinning out of the three members as they are traced from South Lancashire towards a line which may be drawn from rather north of Worcester to Leicester, and on the whole by the petrography of their materials. For the abundant sand we may look to more than one source in Scotland, augmented by the grits of Carboniferous age in the Pennines. No other source of supply is visible ; the Old Red Sandstone of South Wales mostly lies too far to the south-west ; only slight hints have been found of any similar rock beneath Mesozoic deposits to the south-east of the above-named line ; the vein-quartz pebbles help us little, for that rock occurs in so many places ; the more characteristic quartzites do not closely resemble any exposed in Wales, Shropshire, or Warwickshire, but are exactly like those which occupy large areas in North-western Scotland and are abundant to the south of it in the Old Red conglomerates. The same may be said of the quartz-felspar grits ; they are exactly like the Torredonian which underlies that quartzite and do not so closely resemble that of the Longmynd, which in Triassic times cannot have occupied a much larger area than it does now. The felstones also can only be identified in Scotland, where many of them occur abundantly both *in situ* and as pebbles in the Old Red Sandstone conglomerates.

But this hypothesis of a northern derivation of these Bunter pebbles involves two difficulties. One is the not unfrequent occurrence of tourmaline in felstones, quartzites, and vein-quartz. This mineral is abundant in the south-west of England, from which general direction I have no doubt the South Devon Pebble Bed derived its materials, but it is very rare in the north. It has, however, been found by Mr. C. T. Clough in vein-stones and in pebbles of an Old Red Sandstone conglomerate on the

English side of the Cheviots,* as well as in Scotland, and is not rare as a vein product and in a schistose slate in the Isle of Man, so it may have been more abundant in the rocks which disappeared in forming these Midland pebbles. The other difficulty is also serious, that the pebbles are more abundant in Staffordshire and its immediate neighbourhood than they are in the district round Liverpool. They are, however, more frequent there and of greater size than is sometimes supposed, but they are more largely mixed with sand, for the pebble bed as a whole is, as already stated, fully three times as thick in the latter as it is in the former district. Near Liverpool we seem, as I have more than once observed, to be out of the main course of pebble deposit and in that of sand deposit, so that the difficulties are to some extent antagonistic. I think they may be reconciled by supposing that in what is now Lancashire the main current of the river happened to occupy a narrower channel than it did in Staffordshire.

Here, however, I have anticipated a little in speaking of a river, for some have considered the Bunter to be a marine deposit. But in that hypothesis one difficulty appears to me insuperable. Pebble beds formed by the sea are always limited in one of their three dimensions; if thick they are narrow, if widespread they are shallow. The Bunter Pebble Bed in Staffordshire is broad, and long, and thick. To this I may add that it presents a remarkable resemblance to the pebble beds formed by rivers issuing from mountain regions. For some 20 years I have paid considerable attention to the Alpine gravels. The Nagelfluhe—a Miocene deposit—resembles in many respects the Bunter gravels, and the Molasse, with its occasional seams of pebbles, is not unlike the Keuper sandstone. The Pleistocene or very late Pliocene *löcherige Nagelfluhe* or *Deckenschotter* closely resembles the Bunter in mode of deposit and distribution, but is a little coarser and more “tumultuous” in aspect, while the older Alpine river gravels, except that they are restricted to narrower channels, present a still closer resemblance.

* Geol. Survey Memoirs, The Cheviot Hills (English Side), C. T. Clough (1888), p. 16.

So we can hardly be wrong in claiming the Bunter as a fluviatile deposit. But some of those, who admit this, deny, for the reasons indicated above, that the river or rivers which brought the materials to the Midlands came from the north. The pebbles, as I have more than once pointed out, must have had a long journey, and could only have been transported by a strong stream—not less than that of the Rhône between Martigny and the Lake of Geneva. Volume and velocity demand that such a stream should have been fed by a mountain region.* Were such a region buried under the post-Triassic Mesozoic deposits in the south-eastern half of England, it must have disappeared with remarkable celerity. Hills there may have been in this direction, but the Lickey and Clent ridges, and the rugged Charnwood upland, besides being composed, with rather rare exceptions, of rocks differing in character, cannot, even in that age, have been much more elevated than at the present day. But, it has been urged, the river, after depositing the Budleigh Salterton pebbles, made its way to the Midlands by some buried channel. The grave keeps its secrets, but, as I have already said, the dominant quartzite pebbles at the former locality differ widely from those of the Midlands, and the idea that the latter have been sorted from the former, because their shape made them travel more easily, seems to me rather like expecting the riddlings of a peck to fill a bushel. In considering this question we must not forget, as some authorities appear to do, the great volume of material which must be broken up and transported to make not only the Bunter as a whole, but even its pebbles. The latter alone, as I pointed out in an address to this Section at Birmingham in 1886, is probably equivalent in bulk to a hill range twenty miles long, two miles wide and a thousand feet high. Neither Wales nor the Lake District could supply the right rocks, even if Dr. Marr would allow the latter to be visible at this epoch. In the north alone do we find almost all the rocks needful, and from this quarter volumes of material—sand and mud—as Professor Hull showed in two very suggestive papers more than 40 years ago,† must have travelled

* See "Rounding of Alpine Pebbles," *Geol. Mag.*, 1888, p. 54.

† *Quart. Jour. Geol. Soc.*, xvi. (1860), p. 63, and xviii. (1862), p. 127.

southwards in the later Palæozoic and earlier Mesozoic periods, during which also, and for even longer, we have evidence of a similar transference from a somewhat similar region lying to the south-west of England. Of this great mountain region, as I have often pointed out, Scandinavia, the Highlands, North-west Ireland, Cornwall, and Brittany may be fragments, the present 100 fathom line possibly giving some clue to the position of its watershed.

If the Bunter group were deposited by a river flowing northward we can only dispose of its waters by supposing them to have been absorbed, for an outlet in that direction would require some startling and yet temporary changes in physical geography. The former fate would not, I think, be in itself improbable. The upper and lower Bunter, with their wind-worn sands and widespread fragmental deposits, are very suggestive of a desert lowland, and in such regions absorption is always possible; an ending which must not be forgotten even supposing the river to have flowed southward or south-eastward, for we find it rather difficult to ascertain its ultimate course in that direction. It may, however, have passed through a restricted channel on one or the other side of the Charnwood Hills. A southward drift of material, generally no doubt argillaceous, during Jurassic times and along a channel opening towards North-western France is more than suggested by the results of borings in South-eastern England, especially by that at Netherfield near Battle.

As I have been forced to dwell at considerable length on the Bunter sub-division, and there is a more general agreement about the Keuper, I shall pass rather briefly over that. The lower Keuper sandstones may well have been deposited under somewhat similar conditions to the Bunter, but which corresponded more closely with those of the Swiss Molasse. Fossils, as Mr. Lomas will tell you—Reptilian or Amphibian, with fish, annelids, a few mollusca, very imperfectly preserved, and some plants—are not altogether wanting in the Keuper Sandstone or the Waterstones,* and both, but especially the latter, with their footprints, ripple marks, sun cracks, and rain prints, are

* They are not quite absent from the Red Marl.

highly suggestive of incipient salt-lake conditions, where the level of the water is liable to rhythmic oscillation. That the Red Marl was an inland sea deposit is, I think, now generally admitted, and confirmation is found, if that were needed, by Professor Watts' remarkable discovery of sand-worn rock surfaces at Charnwood and Mr. T. O. Bosworth's finding of "millet seed" grains, both in the intercalated sandstone and even, as he has recently informed me, in the marl itself in more than one part of Leicestershire. In regard to the former, I may say that I now think it probable that a slight planing off of the surface ridges of rock at Charnwood and near Narborough, which formerly I thought might be due to grounding ice, may really have been the effect of sand-drift. Mr. Strahan also has called attention to the fact that the paucity of organic remains in the Keuper is suggestive of desert conditions,* and the evidence collected in the Reports published by the Association after the last three meetings points in the same direction. But I think that the Red Marl as a whole is an aqueous rather than an aerial deposit, or in other words that it differs from the rest of the great Mesozoic clays only in being formed in an inland sea instead of in one communicating with the ocean. The frequent shore breccias, especially in the south of England, as I stated in my paper† on the relation of such deposits to the physical geography of their age, suggest a climate rather liable to extremes and not improbably arid, something like that of Persia, or perhaps even Eastern Turkestan at the present day, and such a climate may very well have continued from the beginning of the Permian, with its important breccias of Rothliegende age, to the end of the Keuper, when the sea again invaded the British lowlands, over which it ebbed and flowed till almost Mid-tertiary ages. How far this episode of a marked Continental climate was due to a combination of Caledonian and Armorican foldings is an inquiry into which, though full of interest, time forbids me to enter. Enough to say that, if a mountain chain, capable of feeding rivers, comparable with those which now issue from the Alps, were situated anywhere

* Geol. Survey Memoirs, South Wales Coal-field (Bridgend).

† Quart. Journ. Geol. Soc., lviii. (1902), p. 185.

near the present 100 fathom line, and precipitated the vapours coming from an ocean yet farther west, the climate in the lowlands, of which I have been speaking, might very well be much more arid and extreme than it is at the present day.*

* See F. Drew, *Quart. Journ. Geol. Sci.*, xxix. (1873), especially pages 442-43; also W. T. Blandford, *id.*, p. 493, etc.