THE BUNTER FORMATION AT THE BELLINGTON PUMPING STATION OF THE EAST WORCESTERSHIRE WATERWORKS COMPANY

by

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Summary

A very complete section through the whole of the Bunter Formation has been revealed by the cores of four boreholes on Bellington Farm, 3 miles east of Kidderminster. In place of the Shingle Beds at the bottom of the Bunter Pebble Beds Series a thick breccia-conglomerate occurs with a unique pebble composition indicating a derivation from a catchment with outcrops of hitherto unknown volcanic rocks. The Bunter succession is shown to consist of five cyclothems, each beginning with a suite of coarser sediments and ending with a suite of finer ones. The finer sediments show signs of desiccation and, in four out of the five cyclothems, also yield footprints and other trace fossils.

General

Introduction

Between 1962 and 1969 the East Worcestershire Water Company sank four boreholes at their new Pumping Station (SO 877768), three miles east of Kidderminster. I thank the Company for allowing me to publish the results of my examination of the cores which I carried out in collaboration with Professor F.W. Shotton to whom I am indebted for much information and discussion, and the use of his logs.

I also thank Dr. Isles Strachan and Dr. W.A.S. Sarjeant for help with the fossils and trace-fossils, and Mr. W.G. Hardie, Dr. P.A. Sabine and Mr. P. Embrey for help over the mineralogy and petrology of the breccia pebbles.

Notes on the first two holes * have been included in a paper submitted to the 'Symposium on the Trias' held by the Geological Society on 1st November 1967, now in the Press; but Nos. 3 and 4 were not then finished. The present paper deals particularly with No. 4, which has supplied the most complete section.

* The first hole to be drilled was No. 2 on the plan and the second was No. 1. They were known by these numbers at the time, and all the specimens collected, which are now in the Geology Department Museum at Birmingham University, are numbered accordingly. Therefore, although the Company has, since 1967, renumbered the holes in the order of drilling, the original numbers were used in the Symposium paper and are also employed here.

The geological importance of the Bellington boreholes stems in part from the fact that the cores were for the most part logged as they were drawn or soon afterwards. This allowed Professor Shotton and me to observe features that can be lost or damaged at once through exposure to drought, rain and frost. This applies particularly to the trace-fossils which are often preserved in thin friable sandstone and marl. In the cores of the Upper Mottled Sandstone from No.1 which had stood in the open and weathered for a year or more, only two footprints were discovered in a single tiny piece; whereas the cores of No.3 and No.4, which were examined at frequent intervals during the boring, yielded footprints at several levels in both the Bunter Pebble Beds and the Upper Mottled Sandstone, and *Planolites* at two levels.

The Bellington site is situated on the outcrop of the Upper Mottled Sandstone about 500 yards from the base of the Keuper Sandstone escarpment. Owing to absence of exposure and the possibility of faulting, it is impossible to make an exact estimate of the amount of upper Mottled Sandstone that is missing through erosion, but it is unlikely to exceed about 30 feet. This, added to the 627 feet of Upper Mottled Sandstone and 558 feet of the Bunter Pebble Beds penetrated in No.4. bore, makes a total thickness of about 1215 feet for the Bunter Formation. The Dune Sandstone (Lower Mottled Sandstone), traditionally classified as Lower Bunter but now regarded as Permian (Wills, 1948, 1956; Shotton, 1956), was proved in Nos. 1, 3 and 4.

The great thickness of the Bunter Formation at Bellington is probably related to the position of the site, which is approximately on the N. - S. axis of the Worcester Triassic Basin, from which the Formation thins eastwards towards the South Staffordshire Coalfield Horst and the Lickey Axis (Table 1). It will be noted that the reduction in thickness is most conspicuous in the Upper Mottled Sandstone. This is, in part, due to pre-Keuper erosion, which is known to have produced a definite unconformity in the Lichfield-Birmingham area (Barrow et al. 1919; Eastwood et al. 1925; Wills, in press).

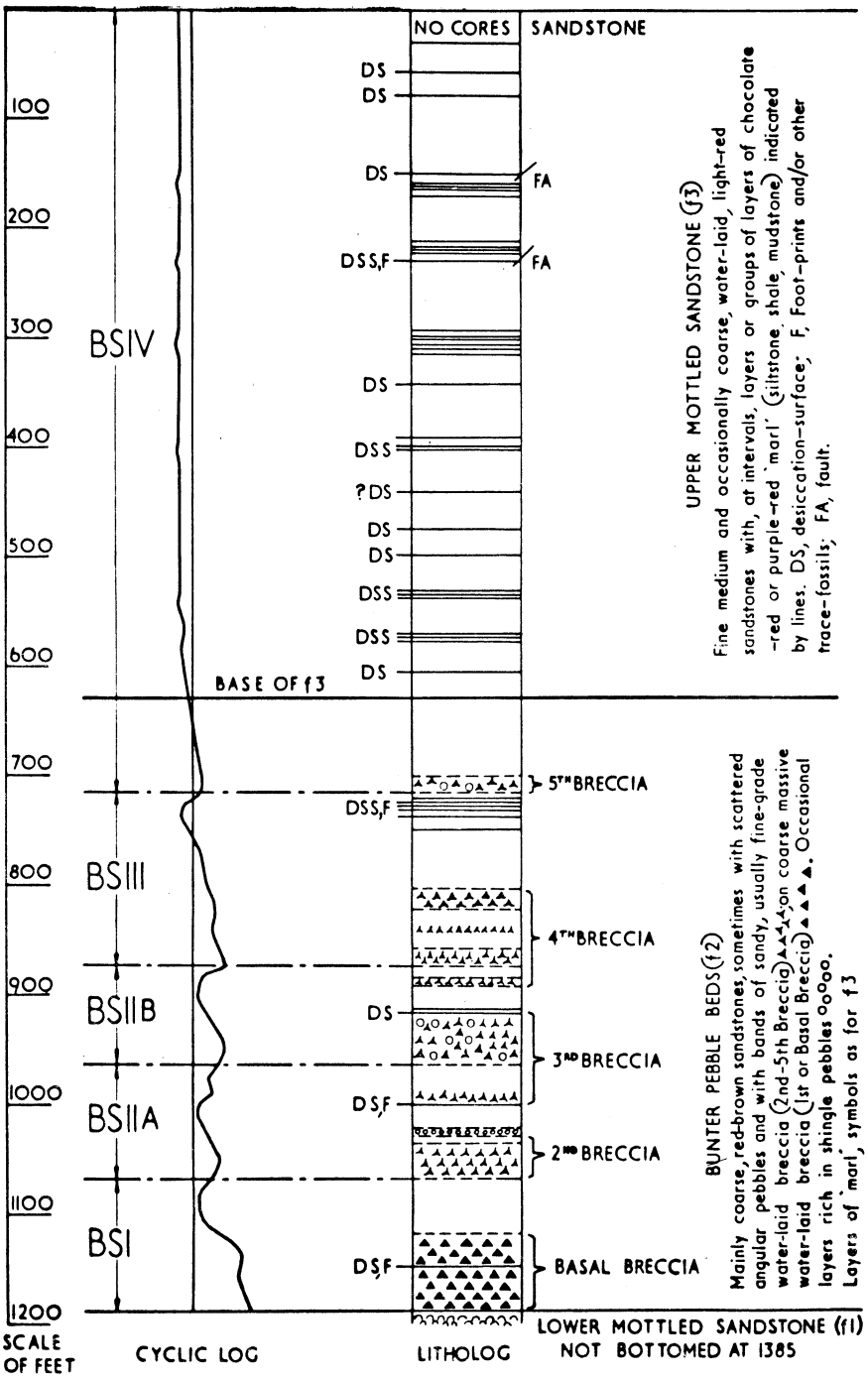
The sediments

An outline statement of the lithology of the Bunter Formation as developed at Bellington is set out on Figure 1. The most surprising feature in the succession is the coarse Basal Breccia at the bottom of the sequence, where the Shingle Beds had been expected. The 'litho log' shows the distribution of the rudaceous elements in the Bunter Pebble Beds to be rhythmic (the unornamented parts are mainly red-brown sandstones). There is also a faint suggestion of rhythmic alternations of bands rich in layers of marl (shown by lines) and sandstone (unornamented) in the Upper Mottled Sandstone. These sandstones are mainly light red.

The 'cyclic log' on Figure 1 was deduced from the lithology on the hypothesis that the rocks are the record of

(a) seasonal and/or episodic flooding of alluvial flats and/or dry lake-bottoms, that are evidenced by rudaceous, and coarse and medium arenaceous material, sometimes with intraclasts of mudstone or siltstone. A group of such flood-deposits constitutes a 'floods-sequence'. The floodings alternated with

(b) a reduction of inflow and the drying-up of the flooded plains and lakes, which are evidenced by fine-grained sandstones and/or 'marls' *i.e.* shale, siltstone, mudstone), sometimes with indications of complete or nearly complete desiccation (mud-cracks, worm-trails, foot-prints, ripple-marks - the last two often in association). A group of such drought-deposits constitutes a 'droughts-sequence'. The drought-deposits were particularly liable to destruction by later floods, and in many cases the former existence of a drought-deposit can only be demonstrated by the intraclasts of marl in a sandstone or breccia.



Text Fig. 1.

EAST WORCESTERSHIRE WATER WORKS CO. BELLINGTON P.S., 3m., E. OF KIDDERMINSTER. LOGGED BY F.W. SHOTTON & L.J. WILLS, 1968. NO. 4 BOREHOLE. O.D. 228 SO 876766.

The cyclic curve set out on Figure 1 purports to represent the larger (miocyclic) changes in the amount of inflow to the cuvette and the velocity of the depositing currents (with the maximum to the right of the vertical line). This miocyclic curve has been produced by smoothing out a micro-cyclic curve, made by plotting every change in grade of sediment from coarsest on the extreme right to fine on the left, with marls showing evidence of desiccation on the extreme left.

The beginning of each cycle is marked by the onset, whether sudden or gradual, of the dominantly coarser sediments of the floods-sequence which is followed upwards by the dominantly finer sediments of the droughts-sequence. For a discussion of the theoretical basis of cyclic curves, see Wills (in press).

Accurate correlation of microcyclic curves has been found impossible, even within the few acres of a four-hole pumping station like Bellington; yet the miocyclic curves deduced from well-documented borings through the Bunter have proved to be remarkably similar within an area extending from Tettenhall, just outside Wolverhampton, through Churchill, Bellington, Hagley, Wildmoor and Burcot near Bromsgrove to Brockhill near Redditch; and even as far afield as Smethwick (for localities see Table I). It has also been possible by using the curves to show what parts of the full sequence have been cut out by the faults observed in the Bellington No.1 core, by comparing the curve deduced for that hole with the curves for the almost complete sequences in Nos. 2 and 4. Again, over the same area, the base of the Upper Mottled Sandstone, the whole of which is here regarded as the droughts-sequence of Bunter Miocyclothem IV (B.S.IV), can be defined by the presence below it of the coarser floods-sequence of the same miocyclothem, which on the standard classification forms part of the Bunter Pebble Beds. This has proved valuable because there are, at some sites, sandstones in the Bunter Pebble Beds identical in colour and general appearance to those characterising the Upper Mottled Sandstone which, had they been found in a surface exposure, would undoubtedly been classed as Upper Mottled Sandstone. This was first noticed in the cores of the Wildmoor boreholes 3 miles north of Bromsgrove.

Environment of deposition

The deposits of the Bunter Formation at Bellington suggest a semi-arid climate with high seasonal or episodic rainfall in the source areas, if not in the Midland Cuvette itself, which may have remained a desert under more truly arid conditions. On the other hand, the discovery of foot-prints at intervals through the whole 1200 feet of sediments at Bellington proves that this part of the reception area was never lifeless. In this connection, it is worth recalling E.I. White's (1950) discussion of what can be inferred from the discovery of a discrete fragment of the scaly flank of a fish in the Upper Mottled Sandstone at Kidderminster.

Stratigraphy

General

The Bunter Pebble Beds at Bellington consist of the floods-sequences of Miocyclothems BS I, IIA, IIB, III and IV (Fig.1 and Wills, in press) and the droughts-sequence of Miocyclothems BS I, IIA, IIB and III. The Upper Mottled Sandstone is the prolonged droughts-sequence of Miocyclothem BS IV.

Floods-sequences in the Bunter Pebble Beds

The breccias found at Bellington have proved to be of more than local interest. None of them is a scree deposit: all are water-laid.

TABLE 1

The thickness (in feet) of the Bunter Pebble Beds (f2) and the Upper Mottled Sandstone (f3).

	WEST OF SOUTH STAFFS COALFIELD - LICKEY AXIS				EAST OF S. STAFFS - LICKEY	
	BELLINGTON	WILDMOOR	BURCOT	BROCKHILL	SMETHWICK	N.E. B'HAM
	SO 877760	SO 955716	SO 985716	SP 001701	SP 037869	SO 095899
f3	c.660	c.363	c.220	c.150	340+	NIL
f2	558	562 (estimate)	480	475 (estimate)	345	175
TOTAL	1218	c.925	c.700	c.625	685	175
UNDERLYING FORMATION	DUNE SANDSTONE	? CLENT BRECCIA	CLENT BRECCIA	? CLENT BRECCIA	WARLEY BRECCIA	NECHELLS BRECCIA

The Basal Breccia at Bellington varies in thickness in the four holes from about 60 to about 75 feet. In Nos. 1 and 3 the bottom few feet were unconsolidated coarse sandstone (probably derived from the underlying Dune Sandstone) with a few scattered pebbles and a basal layer of large stones. The stones recovered from this bottom layer in No. 1 were, with one exception, smooth shingle pebbles indistinguishable from the usual 'Bunter pebbles' of the Shingle Beds, as these are developed from near Redditch northwards to Stourbridge. Their presence at the very base of the Basal Breccia suggests that this is not older than the Shingle Beds and is therefore Triassic and not Permian.

The stones recovered from the lowest rudaceous layer in No.3 hole, on the other hand, were large angular cobbles, up to 7 or 8 inches diameter, of quartzite, arkose, soft purple tuffs of varying size and white crystalline limestone. These three rock-types are the normal dominant constituents of the breccias at all levels at Bellington.

In No.4 hole the base of the Bunter Pebble Beds was quite different. It consisted of a medium breccia resting directly on an even surface of Dune Sandstone. A specimen showing the contact is preserved in the Geology Museum of Birmingham University.

The above observations show that the flood-waters in a distributary of one river, the Budleighensis River (Wills, 1956, fig. 17, p.112), at times carried a gravel of Bunter Shingle Beds pebbles into the terrain of another river, the Bellington River (see p.395). They also demonstrate the localized action of torrential flood-waters, which accounts for the churning up of the coarse sand at the base of the Basal Breccia in Nos. 1 and 3 holes, whilst only a stones-throw away in No.4 hole, the Basal Breccia lies on undisturbed Dune Sandstone.

The rest of the Basal Breccia varies greatly in the size of fragments, the amount of sand and the degree of consolidation and calcretion. In No.4 hole, one boulder of coarse tuff had been trimmed by the 20-inch boring tool, yet what had escaped still measured about 14 x 12 x 12 inches. For the most part, however, the fragments are cobbles, 3 x 2 x 2 inches or less, with the odd one ranging up to 6 or 7 inches across.

In the midst of the Basal Breccia there was, in each set of cores of Nos. 1, 3 and 4 holes, a thin bed of chocolate marl and marly sandstone. In No.1 hole this had been baked hard and parts of it had been eroded later into large lumps that were incorporated in the overlying breccia. In No. 4 hole numerous small foot-prints were found in what may be the same bed - a second feature testifying to the drying up of the mud deposited as the flood-waters evaporated away. The intercalation of a thin drought-deposit within a dominant floods-sequence of sandstone or breccia (and *vice-versa*) is not an uncommon feature of the Worcestershire Bunter succession, and has added to the difficulty of defining the limits of the miocyclothems.

In the rest of the Bunter Pebble Beds there are four more floods-sequences (Fig.1), in which there are bands of fine breccia with fragments rarely more than $1\frac{1}{2}$ inches across. These are mainly composed of the same assemblage of quartzites, tuffs and limestones as characterize the Basal Breccia. The breccias also contain rounded pebbles, which occasionally become dominant. These rounded pebbles are mainly of quartz, such as could have been derived from any of the numerous Midland conglomerates, and do not include the rounded pebbles of quartzite, so abundant in the Shingle Beds. Some of the pebbly horizons contain only scattered, usually angular, pebbles in massive coarse red-brown sandstone.

It is uncertain whether the angular pebbles, in the floods-sequences above the Basal Breccia, were derived first-hand from the source outcrops or second-hand from breccia-gravels of Permian or Bunter age, flooring the valleys through which the floods descended.

Droughts-sequences in the Bunter Pebble Beds

The four droughts-sequences in the Bunter Pebble Beds consist mainly of medium to coarse sandstones which are uniformly red-brown when dry, but turn to a gingerbread or 'foxy-red' colour when wet. Usually they are massive but sometimes show false-bedding. Occasionally there are a few, usually angular, pebbles. At certain levels the sandstones have streaks, layers and/or thin beds of 'marl', *i.e.* chocolate mudstone or siltstone. These marls may be micaceous; and there are also a few thin (1 to 4 inches) beds consisting almost exclusively of mica flakes. A bed of this type is completely incoherent and can easily be lost from the cores, yet one was logged in Nos. 1, 3 and 4 holes but at different stratigraphical levels. It is the marly horizons that record the times of desiccation by mudcracks, ripple-marks and trace-fossils (DS in Fig. 1).

The upward change from a droughts-sequence may be gradual or abrupt, with a breccia succeeding a marly series. The latter arrangement probably implies that part of the droughts-sequence was eroded by the flood-waters that later threw down the breccia.

The Upper Mottled Sandstone

The Upper Mottled Sandstone at Bellington consists of uniformly light-red, fine and medium sandstones with numerous thin layers of 'marl', of which at least 15 show signs of desiccation, ripple-marks, suncracks (at one level the mud-polygons were 10 inches across) and trace-fossils (foot-prints, worm-trails and *'Planolites'*). In addition there are levels in which streaks of 'marl' are interbedded with the sandstone (at 150-170, 295-316 and 550-585 in No. 4 hole; and at 160-180, 295-302, 393-396 and 469-475 in No.3 hole).

On account of the characteristics set out above, the whole of the Upper Mottled Sandstone is, as already mentioned, to be regarded as one protracted droughts-sequence deposited in a periodically flooded lake-basin by temporary rivers of less transporting capacity than those that functioned during the deposition of the Bunter Pebble Beds (see also Wills, in press).

The Pebbles

The pebbles are mainly of three types, quartzites, tuffs and limestones, which on a rough estimate make up 10%, 40% and 40% respectively of the pebble grade of the breccias.

The quartzites

Many of the quartzite pebbles, particularly the larger ones, resemble the Cambrian quartzites of the Malvern and Lickey Hills. The larger fragments are very angular and barely water-worn.

The tuffs

The soft purple tuffs vary in texture from very fine (easily mistaken for earthy sandstone) to coarse, with fragments up to $\frac{1}{4}$ inch across, some of which are trachytic. Quartz may also be present. The boulders, cobbles and pebbles of purple tuffs form a homogeneous suite, but so far no source for them has been found. A dozen of them were identified by W.G. Hardie and later submitted to P.A. Sabine for comparison with the I.G.S. petrological collections. He wrote as follows -

> "Concerning the tuffs, we have been disappointed not to find a source despite a lengthy search. We have examined such tuffs as we have from Tortworth, South Wales Exeter and the North East Midlands, and also from Shelve, Builth, the Bristol area and

elsewhere. We have a slide (but no rock specimen) presented by W.G. Shannon from Bickington, Devon. The slide has some similarities with those of Bellington, but is far from identical and in the absence of a rock specimen the match cannot be relied on; the hand specimen could be considerably different.

I would have expected that the older tuffaceous rocks of Britain would have shown the effects of shearing easily, but this is not always discernible with any certainty, and is sometimes very difficult to see in a hand specimen of normal size.

The hand specimens of the tuff show some resemblances to the Exeter traps (many of which are however more basic) but we have found none which is a good match nor are any of our thin sections very similar."

The Bellington volcanic pebbles are so different from the hard Uriconian volcanics which form such a large proportion of the stones in the Clent and other Permian Breccias, like the Warley and Nechells Breccias near Birmingham, that derivation second-hand from these breccias or first-hand from their Precambrian source-outcrops must, I consider, be ruled out. This conclusion, together with the general absence of shingle pebbles from the Bellington breccias and the absence of tuff pebbles from the Shingle Beds as developed at outcrop to the east and south-east of Bellington, would appear to make derivation from those directions impossible.

I incline towards a hypothesis which dates the tuffs as late-Carboniferous or Permian, and derives the Bellington pebbles from a not distant source to the south or south-west of the site, which source has either been denuded away entirely (if it lay to the south-west beyond the Malvern-Abberley line) or remains undiscovered below the Trias of the Worcester Basin.

The limestones

The limestones are white-grey, crystalline and dolomitic. Each pebble has one or more druses lined with rhombohedra of calcite usually covered by a film of some dark mineral (possibly another carbonate or limonite). In some druses there are also small clear colourless crystals of dolomite. (These identifications are by P. Embrey). It seems clear that re-crystallization of the limestone, the formation of the druses and the growth of the crystals that line them, all post-date the incorporation of the pebbles in the breccia, and that the same characteristics virtually preclude any close matching of the pebbles with other limestones. Nevertheless it is possible that the pebbles were derived from a fairly local source, for it has long been known that some of the Silurian limestones outcropping in the Malvern-Abberley Range are dolomitic with MgO content varying from 3% to 18%. King (1899, p.120) argued that outcrops of such rocks could have supplied many of the pebbles in the Calcareous Conglomerate Group of the Enville Beds in S.E. Shropshire. Apart from one crinoid ossicle, no macrofossil has been collected from these limestone pebbles, but Sarjeant has extracted two acritarchs by digesting four pebbles in acid. They are *Baltisphaeridium longispinosum* (Eisenack) and *B. trifurcatum* (Eisenack) which indicate an Ordovician to Silurian age; and to that extent support a derivation of the pebbles from a sub-local Silurian source rather than a Carboniferous Limestone one.

Other Pebbles

A few small pebbles of earthy limestone were found, with *Isorthis orbicularis* (J.de C.Sowerby), *Coolinia* sp., polyzoa and crinoid ossicles (identified by L.R.M. Cocks, who dated them as "anywhere from Lower Ludlow to Gedinnian").

A small sandstone pebble was collected, with Acanthodian spines and scales, and Thelodont scales (identified by H.A. Toombs, who said it "looks like Holgate Sandstone [Downtonian] but could just as well match with [Downtonian rocks in] Spitzbergen or Podolia"). This and the fossiliferous earthy limestone pebbles may be of sub-local origin, as comparable Upper Ludlow and Downtonian rocks occur on the west side of the Malvern-Abberley Range and may well have been present in an extension of it beneath the Trias of the Worcester Basin.

A small rounded chert pebble with ostracods was found, and a chert pebble with a large coral (? Carboniferous Limestone).

Pebbles of various types of feldspathic quartzite and metamorphic chert were found.

A small ($\frac{1}{2}$ inch) pebble of fresh feldspar crystal and a second pebble of decomposed feldspar showing good cleavage were of particular interest in view of the abundance of fresh feldspar chips and small pebbles in the lower part of the Keuper Sandstone as developed near Bromsgrove. Until the discovery of these two crystal fragments at Bellington, it had been thought that the presence of fresh feldspar chips in a Triassic breccia was diagnostic of its Keuper age. The original source of these fragments is still unknown, but is probably somewhere to the south (see Wills, in press).

The smooth rounded quartzite pebbles characteristic of the Shingle Beds have already been noted and are considered to be pebbles from the Budleighensis River system washed into the gravel train of the Bellington River.

Palaeogeographical deductions

Before the first hole at Bellington had been drilled, it had been assumed that the basal beds of the Trias would prove to be the Bunter Shingle Beds, resting on the Permian Dune Sandstone (f1), as at Stourbridge and northwards. The discovery of the water-borne Basal Breccia lying directly on the Dune Sandstone, though a complete surprise, has shown that in both areas there was the same sudden geographical change; the advent of torrential floods down rivers whose distributaries built out great alluvial fans of sand and gravel in the Midland Cuvette which, for a long time previously, had been a true desert with bare rock surfaces, desert screes and the dunes of a 'Saharah' sand-sea (Wills 1956, pp. 100-113). Several rivers flowed into this area, of which the most important was the Budleighensis River with its gravels of typical water-worn, smooth 'Bunter pebbles', dominantly of quartzite and quartz, but with an admixture of durable rocks from southerly sources (Wills 1956, fig. 17, p. 112; Campbell Smith, 1963). To these rivers must now be added a Bellington River whose gravels are characterized by angular, yet somewhat water-worn, pebbles of quartzite volcanic tuff and limestone (usually rounded), as described above.

Taking all the evidence into consideration one is driven to the following tentative palaeogeographical conclusions about the Bellington River area:-

(a) The pebbles in the Basal Breccia were for the most part derived sub-locally from a smallish catchment floored by outcrops of Cambrian, Upper Silurian and Downtonian rocks similar to those seen in the Malvern and Abberley Hills, plus a considerable spread of volcanic tuffs unlike the Precambrian and later volcanic rocks at present outcropping in the Midlands, Gloucestershire, and south and central Wales. One can only guess that these volcanics date, most probably, from the late Carboniferous or Permian times, and that they outcropped, in Triassic times, in some part of what is now the Worcester Basin.

This conclusion does not exclude the possibility that the immediate source of the pebbles in the Bellington breccias may have been Permian scree breccias, such as the Haffield and Abberley Breccias, themselves derived from the outcrops named above.

(b) The catchment lay to the south or south-south-west of Bellington and at first had considerable surface-relief. It was an intermont valley within the Malvern Hills of New Red Sandstone times, but now lies buried below the Triassic rocks of the Worcester Basin.

(c) The catchment was drained by a short, intermittent (impersistent) river (too short to round and grind smooth the pebbles), entering the main Midland Cuvette in north Worcestershire where its distributaries mingled at times with those of the mighty Budleighensis River on a piedmont plain. Here the floods died out by evaporation, leaving spreads of gravel, sand and mud, sometimes here and sometimes there.

(d) Deposition and contemporaneous erosion took place on alluvial fans, flood-plains and in temporary lakes. Both agencies were dependent on the volume and velocity of the inflow and on evaporation.

(e) The rhythmic nature of the resulting sediments was due to cyclic geographical changes in the source areas, that produced both seasonal and long-term alternations of flood and drought conditions. (The sediments of a drought phase were often destroyed by a succeeding flood. This explains the rhythmic (ABCABC) rather than cyclic nature (ABCBA) of much of the succession). In any small area the deposits from an individual flood tended to divert the currents of the next into a different course, and successive deposits came to accumulate side by side rather than one above the other; hence the frequent differences in the microcyclic successions in adjacent boreholes. On the other hand the larger and longer cycles of change produced a miocyclic pattern of sedimentation that can be recognized over wide areas.

(f) The great thickness of essentially shallow-water alluvial and lacustrine deposits of the Bunter Series at Bellington implies persistent subsidence of the reception area relative to the source-area, although the gradual decrease in particle size, from the base to the top, would seem to imply that the difference in level between source-area and reception-area was being concurrently reduced. (A reduction of the rainfall in the source-area might have produced the same effect).

(g) In drought-deposits throughout the whole Bunter Formation at Bellington, even when such a deposit lies in the midst of a coarse breccia, vertebrate footprints have been found. This proves that, during the whole period, terrestrial animals were able to survive in the area (perhaps only near water-holes). Their presence also implies the co-existence of plants, worms, arthropods, fish and other organisms, though the only actual fossil so far discovered is part of one fish (White, 1950). The footprints have been described by Sarjeant (Wills and Sarjeant, 1970), who considers them to have been made by small reptiles, including pseudosuchians, coelurosaurs, rhyncocephalians or early lizards, and (possibly) cotylosaurs. The absence of the large footprints that previously have been the only ones recorded from the Lower Trias of Europe and America is perhaps an accident of collecting. The large ones have usually been found in quarrying, in which the chances of small prints being discovered are bleak. On the other hand, it may be that the conditions in the Midlands were too arid during the drought-phases or the drought phases were too long for the survival and proliferation of large animals. Insect trails have also been recognised (Wills and Sarjeant, 1970) and there are also two or three surfaces covered with tiny mounds, referable to the problematic trace-fossil *Planolites*.

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