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Petrography of the Mesozoic Succession of South Wales

By C. B. Crampton

ABSTRACT

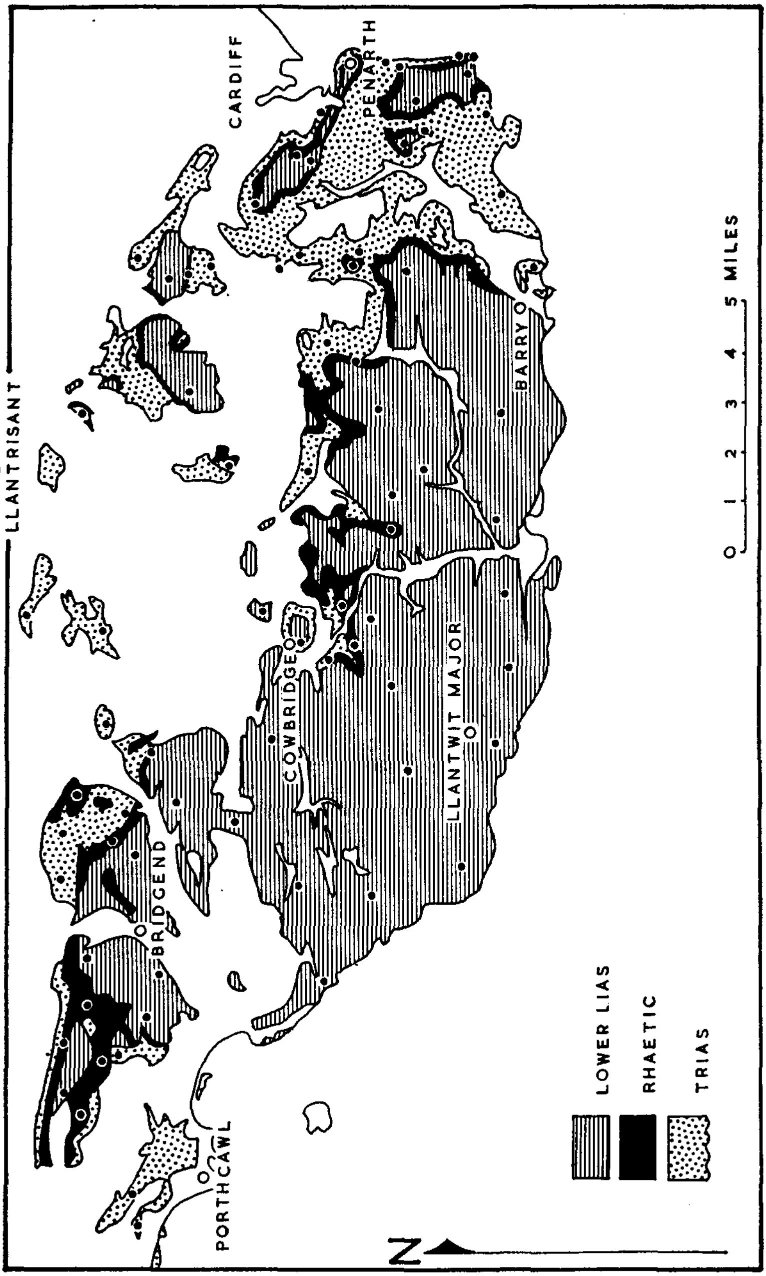
The heavy mineral suites of the Trias, Rhaetic and lowermost zones of the Lower Lias in the Vale of Glamorgan of South Wales are described. The northerly coastline of the Mesozoic sea, roughly coincident with the present-day periphery of the Coalfield, consisted mainly of Carboniferous Limestone and in places, the Old Red Sandstone and Millstone Grit. The mineral assemblage at any particular point in the littoral zone was determined largely by the nature of the outcropping rocks of the coastal mainland, the derivation of detritus being very localized. Within this zone some degree of gravity sorting of the detritals occurred, this implying a relatively steeply inclined coastal sea-bed. An off-shore current carried detritus from the Armorican land-mass of Britanny and granite of South-West England to this area where the detritals were dispersed thinly throughout the locally derived sediment.

INTRODUCTION

MESOZOIC strata outcrop in the Vale of Glamorgan against the southern margin of the South Wales Coalfield and are comprized of the Trias, Rhaetic and part of the Lower Lias. The distribution of these rocks is shown in the sketch-map (Text-fig. 1). These strata follow one another conformably except for a sharp plane of erosion between the Rhaetic and Trias. The Trias has been investigated, amongst other authors, by Miskin (1919), the Rhaetic by Richardson (1905), and the Lias by Woodward (1888) and Trueman (1920, 1922 and 1930). These authors were concerned chiefly with the stratigraphy and palaeontology of the strata whilst the study now described concerns an interpretation of the heavy mineral suites of this Mesozoic succession.

Pringle and George (1948) have reviewed the geology of this area. " The earlier sediments were laid down on an irregular subsiding floor of a great salt-lake basin, . . . and the overlap and overstep of the beds provide a clear picture of the progressive submergence of the land. As each of the formations approaches the old shore-line the normal facies is replaced by one of littoral type, so that the margins of the basin and the sites of ridges which rose as islands may be clearly recognized. . . . As a result of continued depression, however, it is likely that the whole of the region was submerged before the close of the Mesozoic era . . . ".

Off the mainland, which lay to the north and north-west, there were islands generally composed of Carboniferous Limestone. Near the shore-line and around such islands the littoral deposits accumulated. Within the Trias the marls, deposited at some distance from the shore, tend to give way to breccias, conglomerates and limestones near the shore-line. The Rhaetic shales tend to give way to interbedded sandstones, oolitic limestones and shales, whilst the Lower Lias limestones



TEXT-FIG. 1.—Geological sketch-map showing distribution of the Mesozoic rocks of the Vale of Glamorgan and approximate location of the collecting points of some specimens (based on 1-in. maps, published by H.M. Geological Survey).

and shales tend to give way to limestone conglomerates in the littoral zone.

Experimental Procedure

Over 100 specimens were collected from the Triassic, Rhaetic and Liassic strata, and the sketch-map (Text-fig. 1) indicates approximately the position of many of the collecting points. The samples of sandstone, shale and marl were crushed, and a sandy residue obtained from the limestone specimens by treatment with cold concentrated hydrochloric acid. All samples were then dispersed in a weak solution of sodium hexametaphosphate, and particles of 0·02 mm. diameter and below removed by repeated decantation after sedimentation. The coarser material (0·2 mm. diameter and above) was separated by sifting with a 70 I.M.M. sieve. The residue corresponds to fine sand and optical study was concentrated chiefly upon this grade since it contained the bulk of the heavy minerals. These were separated in bromoform, identified, and their relative proportions determined by microscopic counts of up to 300 grains in each sample. Unfractionated samples from each specimen were also examined in order to study the light minerals and to pick up any heavies that might have been trapped in the light fraction.

The iron oxides and dolomite are very abundant and widespread, occurring in all samples examined. Chlorite is likewise widespread and locally abundant. Barite, selenite and aragonite are not widespread but locally can be very abundant. Hence these mineral species have not been included within the grain counts as they would obscure the remaining data.

Description of the Heavy Mineral Species Identified

During the course of the work the following minerals have been found:

Cubic:—fluorite, galena, garnet, magnetite, pyrite.

Tetragonal:—anatase, rutile, zircon.

Hexagonal-trigonal:—apatite, calcite, dolomite, haematite, ilmenite, quartz, tourmaline.

Orthorhombic:—aragonite, barite, brookite, dumortierite, hypersthene, staurolite, topaz, zoisite.

Monoclinic:—biotite, chlorite, clinozoisite, pistacite, hornblende, monazite, muscovite, selenite, sphene.

Triclinic:—kyanite.

Non-crystalline:—leucoxene, limonite-goethite.

The occurrence of the heavy minerals and their relative proportions in the various stratigraphical divisions and lithological types are shown in Table 1.

Iron oxides:—Limonite is the most abundant and widespread opaque heavy mineral. It is apparently present in considerable quantities in all strata, although a cautionary note has to be introduced. Within the Triassic sandstones of the Bristol region investigated by Ollier (1954), goethite, identified by X-ray diffraction analysis, is the most abundant iron oxide, but the external appearance of the grains is frequently affected by a coating of limonite.

Haematite is quite widespread, and in coastal sediments dominated by detritus from islands of Carboniferous Limestone it is virtually the sole opaque heavy mineral present in the mineral assemblage.

Ilmenite is neither abundant nor widespread. It rarely dominates the heavy mineral assemblage as it does within the specimen of Liassic limestone collected near Dunravon Castle approximately four miles south-south-west of Bridgend (grid reference—28841732). The surface of an ilmenite grain is often altered to leucoxene completely or in patches.

Magnetite octahedra, and *pyrite* and *galena* cubes are of rare occurrence, the latter only within the Liassic limestones.

Carbonates :—Calcite and *dolomite* are not confined to the limestones but occur in all samples examined and serve, within the Triassic and to a lesser extent the Rhaetic sandstones, as cementing media. Within the crushed, separated sample the calcite generally occurs as irregularly broken plates and the dolomite as rhombs. The variable friability of the sandstones is a reflection of the differing amounts of cementing material present. The white Rhaetic sandstones are relatively friable and the cementing material at a minimum. Most Triassic sandstones, usually red and seldom grey, are much harder and well cemented with calcite and particularly dolomite, which may be present as very large rhombs. The amount of cementing material present may be considerable and the quartz grains not in contact, indicating, as Ollier (1954) notes, that chemical deposition of the calcium carbonate took place concurrently with deposition of the sand grains.

There is a complete transition from carbonate cemented sandstones, through sandy limestones, to very pure limestones. Although for convenience, whilst comparing the data of the heavy mineral assemblages shown in Table 1, specimens have been described as sandstone or limestone, in some cases this division is somewhat arbitary. With increase of the silt and clay fraction there is a similar transition from the red Triassic sandstones to red marls. Albeit, as outlined in the introduction, the marls dominate the lithology of the Trias in the east of the Vale of Glamorgan and are particularly well displayed in the cliffs south of Penarth, whilst the calcareous sandstones, sandy limestones and pure limestones become more important in the west of the Vale where they are interbedded with marls and the limestone conglomerates, and represent the littoral facies of the Trias. Altogether the lithology and

TABLE 1.

Relative (%) proportions of heavy mineral species in grain counts. * indicates less than 1%	LOWER LIAS				RHAETIC										TRIAS						
	Limestone		Shale		Sandstone				Limestone				Shale		Sandstone		Limestone			Marl	
	Combined counts	Sample 1	Combined counts	Sample 2	Combined counts	Sample 3	Sample 4	Sample 5	Combined counts	Sample 6	Sample 7	Sample 8	Combined counts	Sample 9	Combined counts	Sample 10	Combined counts	Sample 11	Sample 12	Combined counts	Sample 13
Zircon	49	50	54	49	30	23	28	58	51	61	27	50	51	48	62	71	60	57	32	73	81
Garnet	9	8	10	14	28	41	0	0	24	15	61	0	20	19	14	13	12	14	54	1	0
Tourmaline	17	16	10	10	20	14	31	35	10	11	4	15	8	10	9	5	11	9	8	5	2
Rutile	12	10	17	17	12	12	18	7	11	9	6	11	12	14	10	8	9	7	6	13	9
Epidote	3	4	2	5	*	1	0	0	2	2	1	4	4	6	1	1	2	4	0	1	1
Anatase	2	3	2	2	2	0	7	0	*	0	0	0	2	0	*	0	2	3	0	*	1
Apatite	2	2	0	0	5	6	0	0	*	0	0	6	1	1	1	0	*	0	0	5	3
Monazite	3	5	4	2	0	0	0	0	1	2	0	0	1	1	1	1	1	2	0	*	1
Fluorite	1	0	0	0	0	0	0	0	*	0	0	7	0	0	0	0	*	1	0	*	0
Brookite	1	1	0	0	2	0	11	0	0	0	0	0	*	0	*	0	*	1	0	0	0
Staurolite	1	1	1	0	1	2	0	0	*	0	0	0	0	0	1	1	1	0	0	1	0
Hypersthene	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	2	0	0	0
Hornblende	0	0	0	0	0	0	0	0	0	0	0	0	*	0	0	0	0	0	0	0	0
Kyanite	0	0	0	0	0	0	0	0	0	0	0	0	*	1	0	0	*	0	0	0	0
Sphene	0	0	0	0	*	0	3	0	0	0	0	0	0	0	0	0	*	0	0	0	0
Topaz	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	1
Dumortierite	0	0	0	0	*	1	0	0	*	0	0	7	*	0	0	0	*	1	0	0	0

the status of the carbonates within the Triassic rocks is very similar to that described by Ollier (1954) and Thomas (1940) who describes the Triassic rocks of North-West Somerset.

This investigation has not been extended to the limestone conglomerates within the Trias and Lias since it would then become, essentially, a study of the Carboniferous Limestone which has already been undertaken (Crampton, 1960). In the Lias the conglomerates have been termed the Southerndown or Sutton Stone type of lithology and they usually rest directly against the surface of the Carboniferous Limestone as often occurs, but by no means always, in the Trias.

Aragonite is not widespread in the Trias but can be locally abundant. For example it constitutes, together with calcite and dolomite, the cementing medium of a specimen of sandy marl collected near Wenvoe approximately three miles north of Barry (grid reference—31281738). It occurs in the sample as colourless, irregularly broken plates showing twinkling and very strong birefringence. The most useful feature was the often located, biaxial, negative interference figure showing a very low optic axial angle of about 20°.

Sulphates :—Barite is widespread throughout the Mesozoic rocks examined, but never abundant. It can occur as angular fragments determined by fracture and cleavage, or as small irregular fragments, the shape being determined by the interstices which they originally filled before the crushing of the specimen. The fragments usually display a yellow-brown staining and contain many minute inclusions. In addition to its high refractive index and moderate birefringence, occasionally the positive biaxial interference figure was located.

Selenite is not widespread in the Trias and is abundant only very locally. Veins of this mineral can be seen in the cliffs south of Penarth. When located, it usually occurs as pseudo-rhombohedral cleavage fragments showing a low refractive index. Haematite, the carbonates and sulphates are all of authigenic origin.

Chlorite is common in all the strata investigated, and is sometimes abundant. Typically, it occurs as colourless to green plates, sometimes slightly pleochroic, and showing ultra-blue polarization tints. A few grains may display granular extinction, may be fibrous, and may show considerable indentation of the margin, even in samples not treated with concentrated hydrochloric acid.

Zircon is the most abundant and widespread non-opaque constituent of the assemblage for which grain counts are available. It is generally colourless, but a few purple, pink, red and brown grains have been located. Pleochroic brown zircon tends to be more common in the Trias. The grains are usually clear, but some have become clouded with inclusions and a very few are nearly opaque. The zoning of colour and inclusions infrequently occurs. From a sample of the Triassic limestone collected near Llanharry, approximately six miles east of Bridgend (grid reference—30031801), a large proportion of the zircons have been heavily stained red-brown, a colour that remained after treatment with concentrated hydrochloric acid. Rich haematitic ore is mined from the Carboniferous Limestone in this area and Pringle and George (1948) suggest the local replacement of the top of the Carboniferous Limestone by haematite iron ores from percolating Triassic waters.

Most zircon grains show pronounced rounding and in some cases, fracturing. A less frequent but persistent form of zircon is the markedly euhedral crystal showing only slight rounding of the crystal edges, an appearance of rounding in a few cases being due to excessive faceting at the terminations. This form has been described, in particular, in the suite of the Millstone Grit (Crampton, 1960).

Garnet shows a pronounced uniformity in all the Mesozoic strata investigated. The grains are colourless or tinged with pink and usually display a strong hackly outline. Less common are the more rounded or splintery fragments. Inclusions are often quite numerous. Only a few grains show anomalous incomplete extinction, most being isotropic. A rich local source of garnets of this character is the Old Red Sandstone (Heard and Davies, 1924).

Tourmaline generally occurs as rounded flakes which are often pleochroic in roughly equal proportions of green and brown within the Lias, with brown tourmaline showing a slight preponderance in the Rhaetic and green tourmaline in the Trias. Pink, mauve, blue and yellow or parti-coloured grains are much less common. Some opaque inclusions are often present. Near-euhedral prisms with rhombohedral terminations showing only slight evidence of abrasion are widespread but less common.

Rutile usually occurs as well-worn, oval-shaped grains. Most are yellow, except in the Rhaetic where red and yellow rutile occurs in approximately equal proportions. Near-euhedral rutile, showing only slight rounding, tends to be yellow in colour and shows striations parallel to the principal axis of the crystal or oblique to the prism edge due to polysynthetic twinning. Table 2 shows the generally even distribution of this mineral throughout the Mesozoic rocks.

The following mineral species are present in much smaller amounts compared with the four most common species, zircon, garnet, tourmaline and rutile. The *epidote group* includes pistacite and both zoisite and clinozoisite. Yellow *anatase* and colourless rounded plates of *apatite* are quite widespread. *Monazite* grains are usually well-rounded, yellowish, with their margins clouded with alteration products. Pleochroic yellow *staurolite* grains displaying a hackly fracture; isotropic, colourless, authigenic *fluorite* crystals, and yellow *brookite* showing incomplete extinction are successively less common. Irregular but somewhat rounded *dumortierite* prisms, showing a patchy colouring of blue, brown and green, display maximum absorption when the {100}-cleavage lies parallel to the vibration direction of the polariser. Ragged, green basal flakes of *hornblende* ; pleochroic green to pink prisms of *hypersthene*; colourless and elongated *kyanite* crystals showing some cleavage traces; wedges of *sphene*, and irregular, glassy grains of *topaz* showing a delicate blueish tinge, are rare.

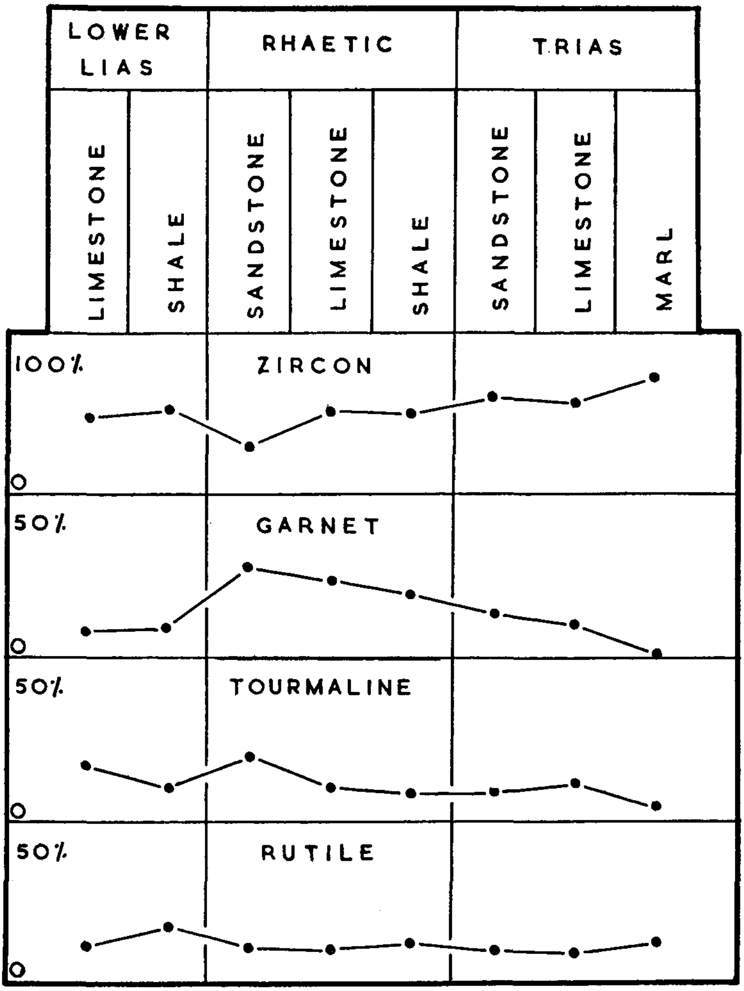
Distribution and Interpretation

(*a*) *Sorting in the Littoral Zone*

Text-fig. 2 shows the distribution of the four most common heavy mineral species throughout the various Lower Lias, Rhaetic and Triassic lithological types. An interesting feature of this distribution is the increase in rutile content in the argillaceous deposits of these strata (least pronounced in the Rhaetic) over that of the sandstones and limestones. The relative proportion of zircon shows a similar increase from the shallow-water sandstones to the deeper-water shales or marls. In particular there is a striking rise in the zircon content within the heavy mineral suite of the Trias, showing a maximum, in the marls where the proportion can rise to 81 per cent (sample 13, Table 1, collected near Ruthin, approximately three and a half miles east-north-east of Bridgend; grid reference—29701802) or higher. In contrast the zircon content of the Rhaetic sandstones of the littoral zone drops to 30 per cent, and garnet and tourmaline can be of equal quantitative importance within the assemblage.

Text-fig. 2 reveals the contrasting relationships regarding garnet and tourmaline. An extremely small amount of garnet was deposited in the deeper Triassic waters represented by the marls. Nearer the shoreline considerably greater quantities of garnet were present in the accumulating sediment. Garnet is more plentiful throughout the Rhaetic deposits, but there is a similar increase in relative proportion from the deeper-water sediments to the sandstones of the littoral zone where garnet was more abundant than at any other time in the Mesozoic of this area. There is a sharp drop in the quantity of garnet deposited in the Liassic sediments. Possibly much of the outcropping Old Red Sandstone, a rich local source of these garnets, was submerged by Liassic times in the steadily extending Mesozoic sea. The slightly higher garnet content of the shales is at variance with the previous results. Within the Trias, Rhaetic and Lias there is a noticeable increase in the tourmaline content from the shales to the limestones and sandstones.

Thus garnet and tourmaline bear a reciprocal relationship with



TEXT-FIG. 2.—Graphical representation of the relative proportions (%) of the four most common heavy mineral species within the combined grain counts for the various Lower Lias, Rhaetic and Triassic lithological types.

zircon and rutile; the former increase in quantitative importance towards the shore-line whilst the latter decrease. The increase of garnet and tourmaline towards the mainland could be taken as an effect of the source of material being in that direction, but the opposite relationship of the zircon and rutile is somewhat difficult to explain on this basis. However, assuming a local source for much of the material contributed to these sediments, it would appear that garnet and tourmaline, the lighter of the four most common heavy mineral species, tend to be retained in the littoral zone, whilst zircon and rutile, the heavier mineral species, tend to migrate out to deeper waters, a certain degree of large-scale " gravity sorting " occurring within the coastal waters of the Mesozoic sea.

(*b*) *Local content of Detritus*

As Trueman (1922) remarks, the content of the conglomerates of the littoral zone, particularly those within the Triassic and Liassic rocks, in which there is a remarkable scarcity of argillaceous and arenaceous material from the inner mainland where extensive areas of Coal Measures were undergoing denudation, suggests a very localized source of material with few large rivers contributing large quantities of sediment from the hinterland to the littoral zone. The combined grain counts shown in Table 1 can be deceptive to the extent that there may be marked variations in the relative proportions of the more common heavy minerals present in the sediments from point to point. Locally garnet can be very abundant, as for example within the very limited mineral assemblage of the Triassic limestone sample 12, collected just south of Llanharan (grid reference—30061828). Isolated outcrops of the Old Red Sandstone probably occurred on the mainland near the shore-line, distributing garnet generally throughout the Mesozoic sea and particularly in the littoral zone, and also giving rise to concentrations in the immediate vicinity of the outcrops.

The Rhaetic shallow-water sediments offer particularly striking evidence of the localized derivation of material. As in the Trias there are marked variations in the garnet content. The sandstone sample 3, collected one and a quarter miles south of Cowbridge (grid reference—29961727), and limestone sample 7, collected three miles south-east of Cowbridge (grid reference—30321713) contain unusually abundant garnet, suggesting proximity to a shore-line outcrop of Old Red Sandstone. The Old Red Sandstone hill of Stalling Down probably represents an uncovered relic of this shore-line outcrop. In or near the littoral zone but outside the immediate vicinity of outcropping Old Red Sandstone there should be a corresponding sharp decrease in the garnet content. The assemblage of the sandstone sample 5, collected three miles north-east of Bridgend, (grid reference—29511817) contains no garnet whatsoever.

A further sample of Rhaetic sandstone collected at St. Mary Hill approximately four miles east-south-east of Bridgend (grid reference—29661787) contained abundant angular flakes of haematite and numerous broken quartz euhedra in addition to much dolomite in an otherwise limited suite of zircon, tourmaline, rutile and anatase. This assemblage, particularly the haematite and quartz euhedra, is characteristic of the Carboniferous Limestone (Crampton, 1960). The presence of quartz euhedra which although broken still retain very sharp edges, indicates a very localized source of material. The Carboniferous Limestone at St. Mary Hill undoubtedly formed an island ridge within the Rhaetic sea and contributed nearly all the material within this specimen. Quartz euhedra were frequently located in the Rhaetic sandstones suggesting that the Carboniferous Limestone constituted an important part of the mainland and near-by islands.

A final example is afforded by sample 4, collected two miles northwest of Bridgend (grid reference—28771816). Table 1 illustrates the unusually rich titanium suite of rutile, brookite, anatase and sphene. Both Simpson (1932) and Griffiths (1939) refer to work by Stuart and Pascoe concerning a similarly rich suite in the Basal Grit of the Millstone Grit. These rocks outcrop to the north of the Rhaetic sandstone in question and probably formed part of the shore-line of the Rhaetic sea from which this suite was derived.

These examples illustrate the pronounced local derivation of material, particularly along the Rhaetic shore-line. This coast-line, roughly coincident with the present-day escarpment enscribing the South Wales Coalfield, was characterized by considerable outcrops of Carboniferous Limestone, and also Old Red Sandstone and Millstone Grit similar to those of the present-day. As Trueman (1922) suggests, the present landscape of South Wales is essentially that of the pre-Liassic period being re-exposed by the removal of the softer Mesozoic cover. There was no pronounced deltaic development along the Mesozoic coastline.

The mainland outcrops described above were capable of supplying many of the heavy mineral species located within the Mesozoic sediments. Predominantly rounded grains of zircon, tourmaline and rutile could have been derived from the Old Red Sandstone (Heard and Davies, 1924), Carboniferous Limestone and Millstone Grit (Crampton, 1960), or Coal Measure sandstones (Heard, 1922) if these contributed any significant amount of material. Near-euhedral zircon could have been derived, in particular, from the Millstone Grit, and the garnets chiefly from the Old Red Sandstone. Although locally the Millstone Grit suite has contributed material to the Rhaetic littoral deposits, the very small amounts of red garnet in the Mesozoic sediments suggests that the outcrop of this Grit along the coastline was very limited.

(*c*) *Far-travelled content of Detritus*

There remain the few minerals, staurolite, kyanite, topaz, hornblende, hypersthene and dumorierite, which are present in the Mesozoic strata in very small amounts. These could not have been derived from local strata and a distant northerly source is unlikely because of the dominantly local character of the coastal sedimentation described above. To the south there are the granitic masses of South-West England and the metamorphic rocks of Brittany.

Brammall (1928) has described the heavy minerals within the Dartmoor granite and the detritals dispersed from this granite at the present day. He adds, " The nature and distribution of the exposed granites indicate that similar types were among the earliest granites to be exposed on the Moor. Hence the mineral associations characterizing the detritals of today may have been characteristic of detritus dispersed from the granite during a long geological period dating back from the present to some remote post-Carboniferous epoch still to be determined ". Many of the more common heavy minerals within the Mesozoic strata of South Wales could have been derived from this granite mass, but it is more probable that they were derived locally from the sediments outcropping along the Mesozoic shore-line. Topaz within the Triassic marls, and hornblende, located in the Rhaetic shales, could have an origin within the granites. The strongest evidence of detritus being carried north from the granite, is however, the presence of dumortierite which is uncommon but widely distributed throughout the Rhaetic littoral and deeper-water deposits, and is present in unusual amounts in the limestone sample 8, collected just south of Penarth (grid reference—31871707). Dumortierite has also been located within the Triassic limestones, but not in the Lias.

This mineral is associated with andalusite, green spinel and sillimanite and greater amounts of cordierite, the assemblage being widely distributed among the normal granites but particularly in marginal and high level types carrying xenoliths of cordierite-bearing hornfelsed shale. Brammall notes their generally rare occurrence in present day detritus but adds that this " . . . must differ markedly from the detritals dispersed from the area while early denudation was effecting the removal of the country rocks roofing the granite. These rocks doubtless included an extensive development of altered sedimentaries comparable to xenoliths of hornfels in the granite and to contact-altered rocks now exposed around the granite margins ". That cordierite, the most abundant mineral in this particular assemblage, has not been located in the Mesozoic sediments of South Wales is probably due to the unlikelihood of cordierite surviving the conditions prevailing in detrital accumulations before their consolidation.

The minerals kyanite and staurolite in particular are, if a northerly source is excluded, probably derived from the old Armorican land-mass, with Brittany as a present-day remnant. This source of stress minerals has been suggested for the diachronic sands of Upper Lias and Lower Inferior Oolite age in the West of England by Boswell (1924), and for the Bunter Pebble Beds of the South-West of England by Thomas (1902). Thomas concluded that the heavy mineral species and their distribution in the finer material of the Pebble Beds indicated that a current bearing sediment from the Armorican massif to the south was joined about twenty miles north of the coast by a westerly minor current bearing material from the high land of Devon and Cornwall to the west. It would seem that the heavy mineral species in the Mesozoic rocks of the Vale of Glamorgan indicate a continuation of this current northwards from South-West England to the South Wales area, bringing detritus from both the Armorican massif and granitic highlands of South-West England. This current, having distributed material along the coastal deposits of the Bunter Pebble Beds during Triassic times, also caused a drift of pebbles along the Lower Liassic shore-line of South Wales according to Trueman (1922). Boswell (1924) also concludes that a current-drift northwards along the coast carried material from the two sources described as far as Wiltshire and Gloucestershire during Upper Lias and Lower Inferior Oolite times.

Conclusions

Apart from one short break the Trias, Rhaetic and that part of the Lower Lias represented in South Wales were laid down, outside the littoral zone, as a continuous sedimentary succession within a steadily extending Mesozoic sea, bordered by land to the north approximately coincident with the present-day periphery of the Coalfield, and to the north-west. The geology of the old land surface at present being re-exposed by denudation of the Mesozoic cover, and the coastal conglomerates of the Trias and Lower Lias, indicate that the coastal mainland and near-by islands consisted mainly of Carboniferous Limestone. The heavy mineral suites of these Mesozoic strata suggest that the sea was also bordered in places by the Old Red Sandstone and, to a lesser extent, the Millstone Grit.

The derivation of material deposited within this sea was very local, little detritus being carried from inland regions by large rivers. Thus the mineral assemblage at any particular point in the littoral zone was determined largely by the nature of the outcropping rocks of the coastal mainland. This is particularly evident within the Rhaetic sandstones. It is suggested that much of the Old Red Sandstone was submerged by Lower Lias times, leaving predominantly Carboniferous Limestone outcropping along the coast. Within the littoral zone some degree of gravity sorting of the detritals occurred, the lighter minerals such as garnet and tourmaline tending to be retained in the littoral zone whilst the heavier minerals such as zircon and rutile tended to migrate out to deeper waters, possibly under the influence of a drift along-shore. This process implies a relatively steeply inclined coastal sea-bed.

An off-shore current carried detritus from the Armorican land-mass of Brittany and granite of South-West England to this area where the detritals were dispersed thinly throughout the locally derived sediment. This current is probably synonymous with that responsible for the deposition of the Bunter Pebble Beds of South-West England and the diachronic sands within the Upper Lias and Lower Inferior Oolite of the West of England.

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REFERENCES

BOSWELL, P. G. H., 1924. The Petrology of the Sands of the Upper Lias and Lower Inferior Oolite in the West of England. *Geol. Mag.*, lxi, 246–264.

BRAMMALL, A., 1928. Dartmoor Detritals: a Study in Provenance. *Proc. Geol. Assoc.*, xxxix, 27–48.

CRAMPTON, C. B., 1960. Analysis of Heavy Minerals in the Carboniferous Limestone, Millstone Grit and soils derived from certain Glacial Gravels of Glamorgan and Monmouth. *Trans. Cardiff Nat. Soc.*, (*in press*).

GRIFFITHS, J. C., 1939. The Mineralogy of the Glacial Deposits of the Region between the Rivers Neath and Towy, South Wales. *Proc. Geol. Assoc.*, l, 433–462.

HEARD, A., 1922. The Petrology of the Pennant Series, East of the River Taff. *Geol. Mag.*, lix, 83–92.

—— and R. DAVIES, 1924. The Old Red Sandstone of the Cardiff District. *Quart. Journ. Geol. Soc.*, lxxx, 489–519.

MISKIN, F. F., 1919. The Triassic rocks of South Glamorgan. *Trans. Cardiff Nat. Soc.*, 17–25.

OLLIER, C. D., 1954. The Triassic Sandstones of the Bristol Region. *Proc. Bristol Nat. Soc.*, xxix, 57–70.

PRINGLE, J. and T. N. GEORGE, 1948. The Geology of South Wales. *Mem. Geol. Survey.*

RICHARDSON, L., 1905. The Rhaetic and Contiguous Deposits of Glamorganshire. *Quart. Journ. Geol. Soc.*, lxi, 385–424.

SIMPSON, B., 1932. Note on the Petrology of the Drybrook Sandstone of the Forest of Dean. *Geol. Mag.*, lxix, 421–425.

THOMAS, A. N., 1940. The Triassic Rocks of North-West Somerset. *Proc. Geol. Assoc.*, li, 1–43.

THOMAS, H. H., 1902. The Mineralogical Constitution of the Finer Material of the Bunter Pebble Bed in the West of England. *Quart. Journ. Geol. Soc.*, lviii, 620–632.

TRUEMAN, A. E., 1920. The Liassic Rocks of the Cardiff District. *Proc. Geol. Assoc.*, xxxi, 93–107.

——, 1922. The Liassic Rocks of Glamorgan. *Proc. Geol. Assoc.*, xxxiii, 245–284.

——, 1930. The Lower Lias (Bucklandi Zone) of Nash Point, Glamorgan. *Proc. Geol. Assoc.*, xli, 148–159.

WOODWARD, H. B., 1888. Notes on the Rhaetic Beds and Lias of Glamorganshire. *Proc. Geol. Assoc.*, x, 529–538.

ROTHAMSTED EXPERIMENTAL STATION,
HARPENDEN, HERTS.