

NO. X.—THE SANDSTONES OF THE UPPER RED BARREN MEASURES TO THE EAST OF GLASGOW. By WILLIAM R. SMELLIE, M.A., B.Sc., Baxter Demonstrator in Geology, Glasgow University.

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INTRODUCTION.

THE Upper Red Barren Measures cover an area of considerable extent and of vast economic importance, occupying at the one time the heart of the mining district and the centre of the Glasgow Basin. They occur mainly as one uninterrupted mass in the Uddingston district, extending N. and S. for 8 miles and E. and W. for 6 miles. Scattered around this main mass are several small outliers, the chief one on the north side being bounded by the east-and-west fault at Shettleston, and on the south side the main outlier is bounded by the east-and-west fault at Rutherglen. They attain their maximum thickness in the Uddingston district (roughly 800 feet in the Hallside Colliery), and overlie the Productive Coal Measures without unconformity, the position of Skipsey's Marine Band being taken as the line of demarcation. The lower half of the Barren Measures consists of sandstones, shales, and fireclays, with occasional thin seams of coal and cream-coloured limestone. The upper part, with which this paper deals, consists mainly of massive Red Sandstone. Historically they are interesting both to the geologist and to the student of the economic development of the land they occupy, for prior to 1840 they were considered to be Old Red Sandstone. The men who corrected this error have left no record of their work, so that we are in ignorance of the methods by which they arrived at their conclusions.

These sandstones occupy the level plain about the Clyde, and, having a plentiful supply of overburden, boulder clay, and alluvium, they are exposed in few good natural sections, so that here again the geologist is dependent on the quarryman for facilities of study. The Bothwell Park Quarry is the most suitable in the area. It is large and extensive, exhibits most

of the types of rock to perfection, and is convenient to an old exposure, Bell's Quarry, which dates back two hundred years, and thus is valuable for studying the weathering.

TYPES OF ROCK.

In the quarries the sandstone is exposed in many large vertical faces, invariably red, so that at first sight the deposit appears to be massive and uniform. On chipping with the hammer it is found that fresh surfaces appear very much lighter in colour, and it is evident that there are varieties of the rock. The rock at the top, which may be called the White Top Rock, is almost white when fresh. Beneath this come bands of micaceous sandstone, sometimes not more than a few inches thick, but persisting at a fairly constant horizon. These pass down into a very fine-grained, finely bedded sandstone, below which comes the Liver Rock, which is grey to liver coloured, and well bedded. All types possess in common the peculiar property of assuming a deep red colour on being subjected to friction. The same colour is taken on on weathering, and is due to the spreading of the little grains of hæmatite.

The White Top Rock.—This is an even-grained, false-bedded sandstone composed of particles averaging .25 mm. diameter. Ordinarily the bedding is little seen, but in places limonite staining has worked along the planes of sedimentation, exhibiting the bedding with artificial brightness. Along joints, however, the limonite more often stains the stone without any relation to the bedding planes. A thin section (Fig. 3, at end) shows this sandstone to be composed of interlocking, angular, and sub-angular grains of quartz and felspar, with fairly common muscovite and very occasional biotite. The cementing materials are plentiful in number, but greatly lacking in quantity. Hæmatite is the most common cement; it does not coat the particles in a thin film, as in the New Red Sandstones, but occurs as small botryoidal grains unevenly distributed, and occasionally as larger areas replacing some mineral grain. Secondary silica is present to some extent, as is shown by the remarkable manner in which some of the irregular quartz grains fit each other. Low-polarising aggregates of kaolinite occur distributed very irregularly, and act as a third cementing material.

Lastly, calcite, though often absent, is found in minute quantities in this rock. In spite of this formidable array of cements, the stone is found to have as much as 22 per cent. of interspaces, so that it is very friable, and lacking in mechanical strength. Its sp. gr. is 1·94.

The Liver Rock.—The description of the White Top Rock applies also to the Liver Rock, with the following important differences:—The White Top Rock may be considered to be composed of one size of particles averaging ·25 mm. diameter. The Liver Rock, on the other hand, is composed of particles of two distinct sizes—(a) ordinary particles like those of the White Top Rock, ·25 mm. diameter; and (b) particles of a larger size ranging up to ·9 mm. in diameter. Also, cementing material, especially hæmatite, is more abundant. The two sizes of particles is a repetition of the old case of the cannon balls and the small shot, and this, together with the increase of cement, has the effect of reducing the interspaces, which are only 18 per cent., as compared with 22 per cent. in the White Top Rock.

The Sandstone as a Building Stone.—Since the two foregoing types are the only two of economic importance, it might be well to digress here to consider their value as building stones before going on to the other types of rock. Analyses¹ show them to have the following constitution:—

CHEMICAL ANALYSES.

White Top Rock.				Liver Rock.			
Free Silica, -	-	81·87	} 93·37	Free Silica, -	-	80·12	} 91·23
Silicates, -	-	11·50		Silicates, -	-	11·11	
Iron (as Hæmatite),	-	2·34		Iron (as Hæmatite),	-	2·81	
CaO - - -	-	1·47		CaO - - -	-	2·47	
Al ₂ O ₃ - - -	-	1·46		Al ₂ O ₃ - - -	-	1·09	
Water, - - -	-	·94		Water, - - -	-	·58	
CO ₂ - - -	-	A Trace.		CO ₂ - - -	-	1·70	
		<hr/>				<hr/>	
		99·58				99·88	
		<hr/>				<hr/>	
Sp. Gr. - - -	-	1·94		Sp. Gr. - - -	-	2·21	

From a consideration of the chemical analyses it would appear that these stones should be good weather stones, the noticeable points being the complete absence of carbonate from

¹ The analyses have been made by Mr. A. Scott, M.A., B.Sc.

the White Top Rock and the very small quantity present in the Liver Rock. Going on the quantity of carbonate present as the criterion of a good weather stone (as is done by most architects), the White Top Rock would be considered superior, but consideration of chemical analyses alone is quite inadequate evidence to base an opinion on. However, when we add the thin section under the microscope, and an examination of quarry faces and buildings which have been exposed to time and weather, then the equipment is complete. The main constituents of the rock are quartz, felspar, and muscovite, with cements of hæmatite, quartz, kaolinite, and carbonate. As can be seen from the chemical analyses there are practically 80 per cent. quartz and 10 per cent. felspar. Felspar is a source of weakness in some sandstones but here it is no drawback whatever, for the felspars are almost all perfectly fresh, and the majority are potash felspars, chiefly microcline and orthoclase, although some of the soda-lime plagioclases have been recognised also. The other and most fruitful source of weakness in a sandstone is the cement, carbonate being least desirable. This is where the White Top Rock would appear to score off the Liver Rock, but the microscope shows the reverse to be the case. The Liver Rock possesses all the advantages of the other, and, in addition, has two sizes of grains and a little carbonate, which reduce the pores, and make the rock more compact and coherent. This renders the stone less liable to disintegration mechanically by percolating water and frost, so that this is exactly the exceptional case where the presence of carbonate is rather advantageous than otherwise. None of the other constituents of the rock are at all vulnerable to the attacks of the acid atmosphere of cities.

Examination of buildings confirms the evidence of chemical analysis and thin section, and in this connection a very fortunate chance presents itself—up the dip of the rock from the Bothwell Park Quarries, and about 300 yards distant, the face of an old quarry is exposed. This is Bell's Quarry, which was opened two hundred years ago, so that here we have the actual stone at present worked in the neighbourhood exposed for a known time. Such an exposure is much more useful for the present

purpose than the fine exposures along the banks of the Clyde at Bothwell Castle, for there the rock is on a higher horizon, being nearer the centre of the basin, and it is a different type. Further, it has been exposed for an indefinite period, is an inferior weather stone, and has not been worked for many years. To return to the two-hundred-years-old exposure, examination shows this old face still bearing the pick marks of the quarrymen, still plane and regular, and weathering excellently in spite of the fact that it is situated in a district ringed by coal mines and steelworks, which render the atmosphere scarcely less hurtful than that of a city. To good weather qualities the stone adds facility in quarrying, and therefore cheapness, another very desirable quality.

The main disadvantage of the stone is its colour. The cementing hæmatite is present as little botryoidal aggregates, and this gives the rock a dull uncertain tint, neither so bright nor so uniform as the sandstones of the Permian and Trias. Again, the presence of kaolinite cement and fairly numerous pores detract from the mechanical strength of the rock, so that it would not give an exceptionally high crushing test. This is not of vital importance for ordinary building purposes, however, for there the strains involved are usually well within the limit that the stone can bear. The sandstone is subject to various irregularities, which will be dealt with later. These, however, are easily seen, and have simply to be avoided in the stone selected for building purposes. Quarrymasters in this area, as in others, deplore the modern practice of building on "cant," which has been extensively adopted for cheapness. All freestones should be built on their natural bed, but building on "cant" removes the stone from its natural bedding position, thus seriously impairing its weather qualities, shortening its life, and detracting from its reputation as a building stone.

Flaggy Bands in the Sandstone.—Between the White Top Rock and the Liver Rock bands of very micaceous, flaggy sandstone occur. They are present elsewhere, but are more persistent at this horizon. In the Bothwell Park Quarry they are only a few inches thick, and differ from the rest of the rock only by having a much larger proportion of mica, but when followed for a few hundred yards to Bell's Quarry they have

thickened out to about 10 feet of very fine, incoherent red shale. Rapid lateral variation in the type of sediment such as this seems common in the area. Thin sections of these flaggy sandstones are most fascinating, and a casual examination might easily lead one to believe that the slide had been made from a Dalradian quartz-mica schist. There is a marked parallel orientation of all constituents. Quartz makes up the bulk of the slide, fresh feldspars are not uncommon, and mica occurs in large plates, muscovite and biotite intergrown and bending round the other constituents in true schist fashion. The particles are cemented in the usual manner of the sandstones, so that here the pseudo-schist aspect is lost. In places the quartz and feldspar grains become so reduced as to leave bands composed mainly of layer after layer of mica in large plates, ranging up to 2 or 3 mm. across, just as if they had been blown into a temporarily isolated pool, and allowed to settle there. The presence of these micaceous bands and minor stratifications seriously affects the weathering of the stone in which they occur, and an excess of this fine material, together with occasional aggregates of it, produce a kind of honeycomb weathering well seen in the exposures along the Clyde at Bothwell Castle and Priory. Building stone quarried from this horizon is a very poor weather stone, the Castle, the Priory, and Bothwell Parish Church being outstanding monuments to its inefficiency.

IRREGULARITIES IN THE ROCK.

Clay Galls.—Throughout the whole depth of the sandstone clay galls are occasionally met with. These are most commonly about 1 inch in diameter, but are got varying in size up to several feet, when they become lenticular in shape. The clay is very fine, usually purplish red, but occasionally light green. They are scarce, quite irregularly distributed, and of all sizes, so that their presence there seems best accounted for by considering them samples of late Carboniferous soil dropped there from the roots of drifting snags.

Whinnyboles.—The most frequent and conspicuous irregularity in the sandstone is what the quarrymen term "whin"

These whinnyboles are very common in the White Top Rock at a certain horizon, and become scarcer and smaller deeper down. They quite unaccountably assume a variety of sizes and shapes, ranging from small nodules weighing ounces to large masses weighing tons, and from perfect spheres to weird masses which assume an infinite variety of fantastic shapes. The colour is a deep red or purple, and the rock is much harder, more compact, and more uniform than the ordinary sandstone. When chipped with the hammer it sometimes breaks along plane, glistening surfaces, as if all the varied material of which it is composed were optically enclosed in calcite, although calcite is not present in any appreciable quantity. A thin section (Fig. 2) shows the whin to be composed of grains averaging $\cdot 4$ mm. in diameter, and of very varied shape, set in a plentiful and continuous cement showing deep red in reflected light, so that a large percentage of hæmatite might be expected. However, an analysis shows the whin to have the following composition:—

Free SiO_2	-	-	-	-	-	49·61
Silicates	-	-	-	-	-	11·38
Al_2O_3	-	-	-	-	-	1·27
MnO	-	-	-	-	-	10·70
Fe_2O_3	-	-	-	-	-	7·15
CaO	-	-	-	-	-	13·35
MgO	-	-	-	-	-	5·11
Loss	-	-	-	-	-	2·32
						<hr/>
						100·89

Jointing.—The sandstone is traversed by a series of plane joints or “backs” running in a north and south direction. Another series, less often present, cut the first at an angle of 60° , running, roughly, N.W. The fine material of the overlying boulder clay has been washed down these joints, forming a quite appreciable coating. Occasionally huge masses of the rock are found possessing a spherulitic jointing. This is the most imposing structure met with, and is quite inexplicable, for there is no whinnybole nucleus, nor is there any appreciable difference in the strength of the cement of the different layers. The plate shows the structure well (Fig. 4).

MINERALOGICAL CONSTITUTION.

The sandstone has yielded a rich series of minerals which are not only interesting in themselves, but are valuable, as indicators of the source of the material and as reconstructors of late Carboniferous topography. The minerals have been recognised mainly by the thin section and by heavy liquid separation. Thin sections of a friable sandstone such as this give infinite trouble to prepare, requiring the chip to be well boiled in balsam before grinding. The sections, however, have been found most useful in this case, though the contrary has often been stated. The cement, the grains, and the inclusions can all be studied much better than is possible with loose grains.

Heavy Liquid Separation.—The majority of the minerals found were got in heavy residues. The method employed was as follows:—A weighed quantity (about 40 grams.) of the sandstone was disintegrated carefully so as to detach the grains without fracturing them. The sand was treated with strong HCl to clean the grains, the clay substance being poured off, dried, and examined. When the grains were free from colouring matter the sand was dried and passed through bromoform (sp. gr. 2·85), Smeeth's separator being used. Bromoform has been objected to on the ground that it gives imperfect separations owing to the facility with which convection currents are set up. In all the separations carried out this difficulty was only encountered twice, once when the sand was added before it was quite cool, and a second time when the apparatus was at a window under a strong sun. Otherwise the bromoform served excellently, but required almost continual stirring. After the separation the heavy residue was weighed and mounted. Some of the light residue was mounted also to be used for examining the size, shape, and inclusions of the grains. At first an attempt was made to use the percentages of heavy residues, from specimens collected from different localities, to give the direction of the currents and an indication of the source of the material, the argument being that the heavy minerals would be more plentiful as the source was approached. Samples collected from most of the

exposures in the area were treated, and in the main these showed higher percentages towards the north and west, affording, apparently, good evidence in support of the other indications pointing to that source. However, Professor Gregory cast doubts on the value of this evidence, quoting the case of the irregular distribution of fine gold in placers, and advising further investigation. To this end a series of samples were collected over a vertical range of 90 feet from a suitable face in the Bothwell Park Quarries, specimens being taken every 10 feet. The residues were found to vary from .04 per cent. to .81 per cent., and that, too, quite irregularly, there being no regular vertical increase or decrease. This alone, without considering lateral variation, renders percentages valueless in this case, for the sandstones occupy the centre of a basin, and, in the few exposures available, the horizon could not be determined to within much more than 10 feet. This complete failure of percentages does not detract from the value of the heavy minerals themselves, and since it entailed the mounting of many heavy residues, many minerals were available for examination. The same suite of minerals was present in all the residues, though the relative proportions varied.

Cubic System.

Iron Pyrites.

Tetragonal System.

Zircon.

Rutile.

Anatase.

Orthorhombic System.

None.

Hexagonal System.

Quartz.

Tourmaline.

Hæmatite.

Ilmenite.

Calcite.

Monoclinic System.

Muscovite.

Biotite.

Orthoclase.

Kaolinite.

Chlorite.

Triclinic System.

Microcline.

Plagioclase Felspars.

The above list of minerals includes only those continually present or of special importance, and does not profess to be

exhaustive. Other minerals are present, *e.g.*, apatite and sillimanite, as very occasional inclusions in quartz grains; monazite and xenotime are suspected, but would require more detailed investigation to confirm.

Some of the minerals require special note. (See Fig. 1.)

Iron Pyrites.—This mineral occurs occasionally as cement, but only in small patches seldom more than half an inch across. These are more resistant than the rest of the rock and weather into prominences. Well-formed pentagonal dodecahedra were once observed.

Zircon.—The plate shows the forms in which zircon occurs. These are quite usual, and along with the typical inclusions have been frequently described. One peculiar and noteworthy point, however, is the high degree of rounding attained by the zircons. This will be dealt with later when considering the origin of the material.

Rutile.—This occurs as angular fragments, and less commonly as rounded particles. Both acicular and squat crystals are present, the former scarce, and usually golden yellow, the latter very plentiful, and with colour ranging from a rich red to a deep dark red almost opaque. Occasional geniculate twins as figured have been observed. The rutile seems to alter readily, showing every stage of alteration into apparently opaque ilmenite.

Anatase.—This is by far the most beautifully formed mineral present, and both its mode of occurrence and perfection of form indicate that most of it must have been formed *in situ*. It usually occurs growing out of spongy ilmenite, but detached crystals are common. It is usually pale green in colour, but is sometimes colourless and blotched. Single crystals seldom exceed .1 mm. in size, but exhibit the faces perfectly. The form most frequently met with is that figured in the plate showing large basal planes (001) and small pyramids (111). Crystals showing (001), (111), and (101) are common, and combinations of (001), (111), and (110) have occasionally been observed. All the above are tabular, and none of the blue pyramidal varieties have been definitely met with.

Tourmaline.—This mineral occurs in well-rounded grains, more often in angular fragments, and occasionally in good

crystals with rhombohedral terminations, as shown in the plate. Crystals with both ends well terminated are accounted somewhat rare among Scottish tourmalines. The predominant colour is light brown, but the colour ranges from this to almost colourless, and in all varieties the pleochroism is most intense. Inclusions are numerous, and often strangely pleochroic.

Ilmenite.—Fresh ilmenite is scarce. It occurs in rounded grains, and many of these are in a state of alteration to leucoxene, which, in incident light, is seen to form a buff-coloured incrustation.

Muscovite.—This mineral is fairly plentiful throughout the sandstone, but in some of the very fine flaggy bands it becomes the chief constituent. It is present as large irregular plates with frequent inclusions of rounded zircons.

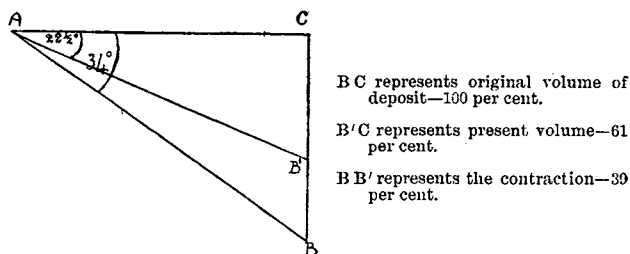
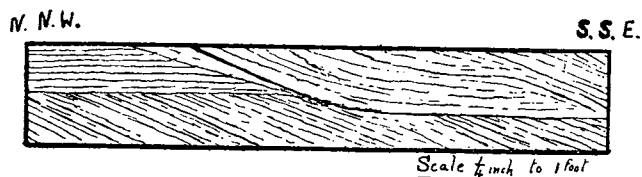
Biotite.—This is less plentiful, but is occasionally met with, sometimes intergrown with muscovite, often perfectly fresh and strongly pleochroic, and often altered to chlorite.

Felspars.—These form less than 10 per cent. of the sandstone, and are remarkable for their freshness. The cross-hatching of microcline and the simple twinning of orthoclase are frequently seen. Albite and oligoclase have been recognised, but the majority of the plagioclase felspars are not identifiable. Many perfectly fresh cleaved grains show no twinning, have a refractive index less than that of quartz, and are probably albite.

Kaolinite.—This mineral serves as cement in the sandstone, being present as low-polarising aggregates. It is separated by washing the sand and pouring off the fine material. Good hexagonal plates are got, some perfect, but the majority lacking in parts which have been split off along the cleavages. It is a primary constituent of the sandstone, and from its occurrence in irregular patches, with sometimes an unaltered felspar fragment in the centre, it is clear that its existence is due to originally kaolinised felspars which subsequent pressure has squeezed between the sand grains so that the kaolinite now acts as cement. The presence of perfectly fresh felspar in the sandstone negatives the possibility of the kaolinisation having taken place subsequently to deposition.

CHANGES IN THE SANDSTONE SINCE DEPOSITION.

The changes that have taken place in the sandstone have been investigated on the lines laid down by Dr. Sorby.² In the White Top Rock the particles average .25 mm. diameter. The angle of repose for sand composed of such grains is 34° . The angle of drift bedding in the sandstone is now only $22\frac{1}{2}^{\circ}$. The diagram shows a 12-feet block of the sandstone, with well-marked drift bedding as distinguished from the oft-figured current or false bedding. The lower half of the block shows



Angle $CAB = 34^{\circ}$ = Angle of repose of sand.

Angle $CAB' = 22\frac{1}{2}^{\circ}$ = Angle of drift bedding.

it most regularly, giving exactly the appearance one would expect in a section through a tip-heap. These angles are all very near to $22\frac{1}{2}^{\circ}$. Here the current has been from the N.N.W., and a section at right angles to this shows typical false bedding. Drawing the angles as shown indicates fairly accurately the contraction, which in this case has been 39 per cent.

² Q. J. G. S., 1908. H. C. Sorby. "On the application of Quantitative Methods to the Study of the Structure and History of Rocks."

This shrinkage is due in part to removal of material by solution and to the filling of interspaces by kaolinised felspars. Now, the sand derived by disintegrating the sandstone is found to possess 47·08 per cent. of interspaces. By reducing 100 volumes of this sand to 61 volumes, and supposing none of the solid material removed, there would remain 8·08 volumes of interspaces and the original 52·92 volumes of solid material. These interspaces would now represent 13·25 per cent. of the whole. In the present sandstone the average of a number of determinations of interspaces is 20·35 per cent. Collecting these results:—

Interspaces in derived sand,	-	-	-	47·08 per cent.
Ideal Interspaces on shrinking, 39 per cent.,				13·25 „
Actual Interspaces in present sandstone,	-			20·35 „

This indicates that an appreciable amount of material must have been removed in solution, not only to account for the difference between 20·35 per cent. and 13·25 per cent., but also to counterbalance anything which may have been added by solutions. Much of the removal by solution may have been nothing more than migration of the material to another part of the sandstone, for the White Top Rock contains much “whin” in which the interspaces are only 5 per cent. of the bulk.

The above evidence, coupled with the fact that the sandstone now contains practically nothing but the most stable minerals, points to the conclusion that very little material could have been added to the deposit by subsequent infiltration. The only doubtful mineral in this respect is the universally present hæmatite, the irregularly distributed and scanty calcite being neglected. This ferric oxide could not have been deposited *pari passu* with the accumulation of the sand, for, as will be shown later, deposition was not in a region of inland drainage, neither was decaying vegetable matter absent.³ The sandstone at present does not contain ferro-magnesian minerals in any appreciable quantity, and magnetite is absent. Thus, it is possible that the 2 or 3 per cent. of hæmatite at present colouring the sandstone may have been derived mainly from

³ *Trans., Edin. G.S.*, vol. 7. J. G. Goodchild. “Desert Conditions in Britain.”

minerals initially present. The way in which the ilmenite is altering into anatase and necessarily setting free the iron may be typical of the whole process.

THE SOURCE OF THE MATERIAL.

The only reliable evidence available for determination of the source of the material is that got from a study of the individual particles. All other means have proved futile in this case. Taking percentages of the heavy minerals, as has already been shown, was quite unsatisfactory. Increasing or diminishing size of particle is likewise valueless owing to like reasons, viz., uncertainty of horizon and irregular and rapid change in the sediment. Bedding and channel cutting are of some value, but interference by local currents is apt to obscure the evidence for the main current. Being thus forced to rely on the grains of the constituent minerals it is fortunate that their evidence is unequivocal. The state of wear of the grains, the inclusions, and the minerals present, all bear witness to the one origin. The shapes of the grains vary from perfect millet seed types to quite unworn angular fragments. Even some of the largest grains, which would round rapidly with travel, are got showing sharp angles and a glassy fresh appearance, as if coming from no great distance, so that such grains might be taken as representing the contribution of the nearest part of the parent mass, and thus roughly fix its position. The inclusions contained in the grains have been studied after the method advised by Dr. Mackie.⁴ He states the following general law:—"Acicular and irregular inclusions abound in the quartz of granite. Regular inclusions are to be found in various proportions, but always in relatively large numbers in the quartz of gneiss and schist." The regular inclusions in this case are the same minerals as occur in the heavy residues, *i.e.*, mainly zircon, tourmaline, rutile, and ilmenite. These, occurring more often as rounded grains than well-formed crystals, are found to be present in between 40 and 50 per cent. of the quartz grains, while typical acicular inclusions are found in no more than 6 per cent. of the grains. The quartz grain shown in the plate (Fig.

⁴ *Trans., Edin. G. S.*, vol. 7. W. Mackie. "The Sands and Sandstones of Eastern Moray."

1, D) is an excellent example of a grain containing regular inclusions. In this grain the inclusions are exceptionally large and numerous, but otherwise it is quite typical. The high percentage of such grains clearly indicates that the bulk of the material was derived from an area of crystalline schists and gneisses. Unfortunately the sandstone does not contain a single rock fragment, unless a compound quartz grain can be considered a fragment of quartzite, or an intergrowth of muscovite and biotite a fragment of mica-schist. The absence of fragments of recognisable rocks prevents the correlation with well-known rocks, and renders exact localising of the parent mass somewhat speculative. Further, when the vast amount of denudation since Carboniferous times is considered, it would be unwise to suppose that exact counterparts of the rocks now exposed were then being denuded. While enumerating the difficulties here it might be well to voice again the universal wail of all workers in sedimentary rocks, viz., insufficient knowledge of the rocks which probably contributed the material. "To trace the parent rocks we must be armed with microscopic sections of all rocks in the neighbourhood."

Having bedding showing currents from directions more or less N.W., and having evidence pointing to an area of crystalline schists as the parent mass, and that at no great distance either, a glance at the map shows that the W. or N.W. is the direction of the source. The Highlands probably remained above water throughout Carboniferous times, for even the Carboniferous Limestone Series is not wholly marine, and from this land extending to some distance south of the boundary fault, the material must have come. Still bearing in mind the difficulties and uncertainty of exact localising, it is nevertheless interesting to see what degree of correspondence exists between the minerals of the sandstone and those in any special area. It is found that the Cowal district answers excellently in this respect. Eliminate the authigenous minerals of the sandstone, and eliminate the unstable minerals in the Cowal schists, and practically the same list of minerals is got. Many of the minerals, of course, are such as would be got in any sandstone, and might be furnished by any metamorphic area; but, considering a mineral such as tourmaline, which can be got in an infinite variety of shades, it is found that the

few varieties got in the sandstone can be exactly matched in Cowal. Again, apatite is seldom met with in the Cowal district, and in the sandstone it has not been observed except for an occasional doubtful inclusion. Mineral for mineral this correspondence continues till a quite inexplicable anomaly appears. Cowal is teeming with garnets, yet careful search of numerous heavy residues has not revealed a single scrap of garnet in the sandstone. Explanations of this might be attempted in three ways—(1) It might be merely postulated that, in late Carboniferous times, the rocks undergoing denudation were barren of garnets. This does not seem likely in the face of a suite of minerals pointing to rocks similar in essentials to those at present exposed. (2) We might suppose the distribution of garnets in Cowal the same in Carboniferous times as at present. Going on this assumption it would be possible for a river coming from the west to avoid the region rich in garnets, since south of Newton, on Loch Fyne, garnets are very scarce. The most that can be said for this theory is that it is a possibility, but it is unlikely that the garnet rich area would not be tapped by some tributary, even if it were missed by the main stream. (3) The third theory would explain the difficulty by putting garnet among the minerals not stable enough to persist in the sandstone. Several facts render this unlikely—(a) The garnets in the schists weather out as hard parts. (b) They can withstand the wear of travel, for they abound in the sand brought down by the streams flowing through the area. (c) They are plentiful in other sandstones.⁵ (d) When a mineral, such as biotite, is got still fresh in the sandstone there is no reason for supposing special circumstances or agents of weathering to have attacked this sandstone. In short, there seems to be no good reason why garnets should not be present.⁶

Before leaving the question of the rocks which supplied the material, reference must be made to the peculiar condition of the zircons in the sandstone and the light they throw on the

⁵ *Q. J. G. S.*, 1909. H. H. Thomas. "A Contribution to the Petrography of the New Red Sandstone in the West of England."

⁶ Since the reading of this paper, a continuation of the work among the thin sandstones in the lower half of the Red Measures has revealed the presence of garnets in addition to the other minerals. This makes the case for explanation (2) much stronger.

problem. Zircon is by far the most plentiful of the heavy minerals, and the grains are rounded in a most striking fashion, so much so that, for comparison, an analysis of the grains of zircon, tourmaline, and rutile was made, since these three compose the bulk of the heavy residues. Three degrees were used— α =angular; r =rounded, and R =perfectly rounded, wind polished. From an examination of several hundreds of grains taken from all localities the following percentage results were got:—

			α	r	R
Tourmaline,	-	-	67	28	5
Rutile,	-	-	73	23	4
Zircon,	-	-	19	37	44

The tourmaline and rutile show practically the same amount of rounding as the rest of the minerals present in the sandstone, and the degree of rounding is normal for water carriage, but the zircons show no less than 44 per cent. of beautifully rounded grains, with surfaces like ground glass. Many of these grains are less than .1 mm. in diameter, and this is the limit at which Daubr  e says the power of water to round grains ceases. Wind action, on the other hand, can round almost any size of particle. The natural inference is that these are wind-blown particles. Now, older pal  ozoic rocks, especially the Old Red Sandstone, must have contributed material to this deposit, but we cannot attribute the rounded zircons to such, for there would be a like proportion of rounded grains among the other constituent minerals. Neither can the state of the zircons be explained by the fact that zircon is more readily rounded than quartz, for in the table of relative "psephicities" or "coefficients of roundability" given by Dr. Mackie,⁷ the following order holds;—Quartz, .23; tourmaline, .3; zircon, .45; rutile, .51. These values are calculated for the rounding of a cube of each mineral, so that commencing with a squat crystal of tourmaline it would be rounded much faster than its place in the table would indicate. [See plate, Fig. 1, B, Tourmaline.] This would account for the tourmalines being slightly better rounded than the rutiles. No explanation of this kind can account for the very high degree of rounding attained by the zircons. While

⁷ *Trans., Edin. G. S.*, vol. 7. W. Mackie. "On the Laws that Govern the Rounding of Particles."

admitting the possibility of chemical change being responsible, considering the susceptibility of zircon to pneumatolytic action, still the most probable and straightforward explanation is that the grains are wind worn, and they might be accounted for in the following way:—Zircon is one of the most stable minerals, remaining unaltered even when rocks have been recrystallised. Many of the zircons in the sandstone have been derived from crystalline rocks, say, quartzites, which have originally been laid down as wind deposits. Recrystallisation would obliterate the forms of the other grains, but leave the stable zircons unaltered. This is the only explanation the evidence permits, even in the teeth of the fact that there is no evidence of wind action in Dalradian times. If we grant this history of the zircons, and consider that the Clyde is at present cutting down the sandstone and carrying off these same zircon grains once again, it brings home the full meaning of Dr. Sorby's dictum—"In the first place, it is important to distinguish between the age of the grains and the age of the deposit. A very ancient sand may be made up of grains practically new and unworn, whilst, on the contrary, the grains of a modern sea beach may be of vast antiquity, may have passed through the greatest vicissitudes, may have successively formed a part of several different geological formations, and may be greatly altered and worn."⁸

CONDITIONS UNDER WHICH DEPOSITION OCCURRED.

In the majority of cases the most reliable evidence bearing on the conditions of deposition is got from the fossils present. In the Upper Red Barren Measures the absence of such evidence makes it necessary to depend on less reliable criteria. Even the very fact that signs of former life are almost wholly wanting does not make it certain that the conditions were unfavourable to life, but rather that the deposit has proved unsuitable for preserving evidence. The coarse and porous nature of the sandstone and the working of solutions through it would afford little chance of preservation to delicate organisms entombed in it. This fact being recognised, the fine-grained

⁸ *Q. J. G. S.*, 1880. H. C. Sorby. "Anniversary Address of the President."

purple shale in Bell's Quarry was searched, and fairly numerous plant remains were discovered. They were in a very poor state of preservation, and Dr. Kidston, who very kindly examined them, pronounced them unidentifiable, with the exception of one or two which may have been fragments of *Calamites*. Although these uncertain fossils give no aid in fixing the exact stratigraphical position of these Red Measures, they at least show that life was neither absent nor scarce; besides, they indicate possibilities in this old exposure in Bell's Quarry. It may have been here that the silent workers of 1840 got the data which enabled them to remove these sandstones from the Old Red Sandstone to the Carboniferous.

Climatic Conditions.—Dr. Mackie⁹ has shown how the feldspars present in sedimentary rocks can indicate the climate prevailing at the time of deposition, and although, in many cases, the method becomes unreliable, in this case complications are fortunately scarce, and the evidence is correspondingly more convincing. Stated as briefly as possible the principle is that fresh feldspars indicate the operation of mechanical agents of weathering, thus pointing to a cold or a very warm and dry climate, while kaolinised feldspars indicate chemical agencies, and therefore a temperate and humid climate. In the sandstone under consideration practically all the feldspars would be classed as fresh, while the kaolinite cement must represent what would originally be kaolinised feldspar grains. Complications arise when the feldspars in the sediment represent a concentrate composed only of the more stable potash feldspars, but this gives no trouble in the present case, because (1) although microcline is most abundant, it occurs universally in the metamorphic parent rocks often to the exclusion of other feldspars; and (2) although plagioclase feldspars are less plentiful they do occur, and are perfectly fresh, showing good twinning and polarisation colours. Lastly, they are often sharply angular, the sure sign of original freshness, so that kaolinisation of feldspar fragments subsequently to deposition may be neglected. Thus, roughly speaking, it may be said that in the original sand the feldspar grains were laid down in two con-

⁹ *Trans., Edin. G. S.*, vol. 7. W. Mackie. "On the Feldspars present in Sedimentary Rocks as Indicators of the Conditions of Contemporaneous Climate."

ditions, the majority as perfectly fresh fragments, and the rest as soft kaolinised grains. Keeping in view the possibility of the evidence being to some extent falsified by many of these grains being derived from earlier palæozoic sediments, it still seems possible to submit the country to the same rough division to correspond with the felspars. A fringe of land enjoying a humid climate would account at once for the plant remains and the kaolinised felspars, while the abundant fresh felspars could be explained by a more elevated hinterland stretching far inland and enjoying a warm climate more free from moisture.

The Productive Coal Measures, and even the lower half of the Upper Red Barren Measures, with their thin coals and fire-clays, indicate terrestrial and lagoon conditions, but the massive sandstones in the upper half have the appearance of a deposit laid down in the tidal flats of an expansive estuary. The Liver Rock below, with its regular bedding, indicates deeper water with a strong current above raining in the larger particles among the material brought by the slower bottom current, while the White Top Rock exhibits all the phenomena of a shallower water deposit within the influence of the tide. Local variations of current, channel cutting, pockets of mica, and fine silt settled in the flat, shallow pools isolated by the retreating tide, badly preserved rain-marks—all signs indicate the sand flats of an estuary with differential subsidence keeping pace with the rate of deposition. The absence of indications of the life which must have existed both here and on the land hard by has already been explained.

Investigation¹⁰ of palæozoic sediments in general has shown that a vast quantity of pre-Cambrian material has gone to form them. This is explained by the proximity of the ancient continent of Arctis which linked the Scottish Highlands with the Scandinavian Peninsula, and stretched far to the N.W. with a gentle slope to the S.E. The material composing the sandstones of the Upper Red Barren Measures must have been transported from this continent by an immense river coming from the W. or N.W., and, at the embouchure of this long, low

¹⁰ B. A. Report, 1886, p. 601. Prof. T. G. Bonney. "The Application of Microscope Analysis to discovering the Physical Geography of Bye-gone Ages."

river, the travel-worn grains from the country beyond were deposited, covered, and finally re-exposed as the Red Sandstone now occupying the centre of the Glasgow basin.

In conclusion, it only remains for me to thank the many friends who have assisted me in this work. I am indebted to Mr. Fleck for his help with the camera and his company in the field; to Mr. Scott for chemical analyses; and to Mr. Skilling's truthful pen for the plate of the heavy minerals. For affording me every facility for study I am indebted to Mr. King, managing director of the Bothwell Park Quarries. Lastly, to Professor Gregory and Mr. Tyrrell I owe most, having received not only the encouragement and moral support necessary in a first work of this kind, but also frequent practical assistance.

EXPLANATION OF PLATES.

FIG. 1—A. Rutile, (1) geniculate twin \times about 50.

„ (2) acicular crystal \times about 50.

„ (3) typical angular fragment \times about 50.

B. Tourmaline, (1) crystal with perfect rhombohedral termination \times about 50.

(2) and (3) different stages of rounding \times about 50.

C. Anatase, (1) small crystals growing out of spongy ilmenite \times about 20.

„ (2) commonest form showing (001) and (111) \times about 200.

„ (3) crystal showing (001), (111) and (101) \times about 200.

D. Zircon, (1)–(5) crystals showing stages in rounding \times about 50.

„ (6) quartz grain specially rich in typical inclusions which are rounded zircons, tourmalines and ilmenites \times about 50.

FIG. 2—“Whin” from whinnybole in White Top Rock, Fallside \times 24.

FIG. 3—White Top Rock, Fallside \times 24.

FIG. 4—Spherulitic jointing in Sandstone, Bothwell Park Quarries, Fallside.

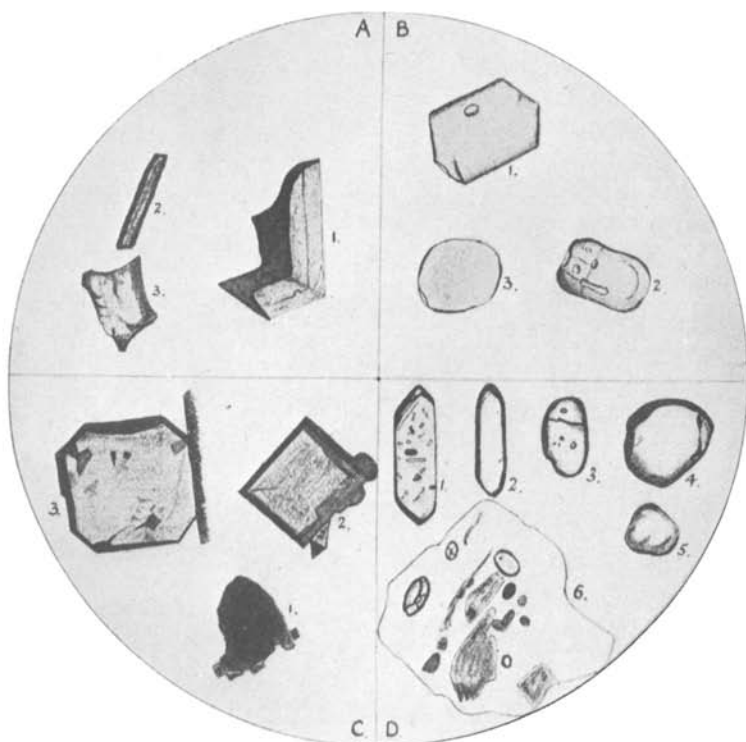


Fig. 1.
 Photo-micrograph of Heavy Minerals from the Sandstone.

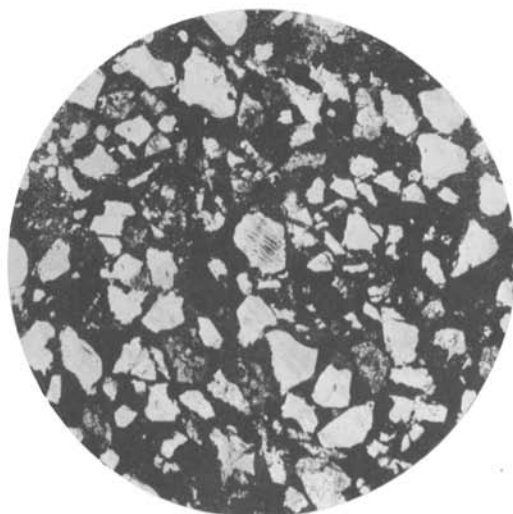


Fig. 2.
 Photo-micrograph of thin section of "Whin."

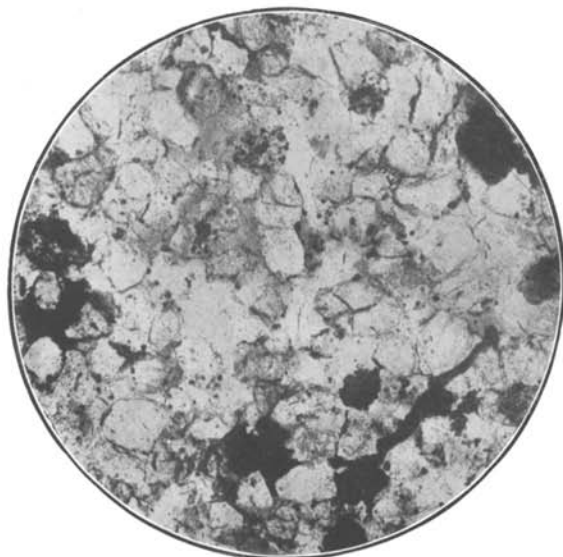


Fig. 3.

Photo-micrograph of thin section of Sandstone (White Top Rock), Fallside.



Fig. 4.

Spherulitic Jointing in Sandstone, Bothwell Park Quarries, Fallside.