

in the inner part of the laterite are present in considerable number, but in these slices of laterite they do not appear as abundantly in the outer crust as they do in the inner one; this, however, may be due to differences in the distribution of micropegmatite in the original rock.

The microscopical studies have afforded important corroboratory evidence to that supplied by the chemical examinations. Like the latter they indicate that, at any rate in the case of a diabasic rock, the changes which result in the production of a laterite are exceedingly simple, and are such as would result from the mass-action of percolating rain and soil waters through very long periods of time. In the case of the felspar I cannot trace any production of hydrated micas or of kaolinite as intermediate between the plagioclase and the gibbsite. In that of the augite the change appears to be nearly but not quite as simple; in its case talc appears to be in part an intermediary product directly from the pyroxene, whilst a ferruginous mica seems to be a temporary product from the possible interaction of some of the constituents of the augite and of the orthoclase fraction of the felspars. The fact of the deposition of part of the silica set free by the weathering of the silicates in the form of more or less irregular granules of quartz is fully corroborated.

The comparisons of the inner and the outer parts of the lateritic crusts indicate that subsequent to the changes which gave rise to the laterite there were changes in the state of aggregation and of the hydration of the oxide of iron due doubtless to its solution and redeposition, whilst indications are not wanting that the gibbsite is subject, but to a lesser extent, to similar changes.

The examinations have thrown little light on the production of the masses of bauxitic laterite, in which much of the hydrate of alumina appears to be in a colloidal state.

V.—WHAT IS A METAMORPHIC ROCK?

By Professor E. H. L. SCHWARZ, A.R.C.S., F.G.S., Rhodes University College, Grahamstown, South Africa.

THE latest book on metamorphism, Dr. V. Grubenmann's *Kristallinen Schiefer*, still leaves it an open question what a metamorphic rock is. Generally speaking there is no doubt about the matter; every geologist has a more or less precise idea of what he means by the term, but no one has yet been able to propound a definition which is perfectly satisfactory, and which will enable one to distinguish a metamorphic rock from all other kinds and at the same time convey an expression of the characteristic peculiarities inherent in such a rock. The need of a definition is very necessary. The want of it has led Dr. Grubenmann to include some rocks among the crystalline schists which one ordinarily would not refer to that class, and on the other hand there are some rocks frequently referred to that class which are not included. In the first case, the masses of emery form the twelfth group of Dr. Grubenmann's classification, yet the analysis of the Naxos emery, which reveals traces of boric oxide (1.15 per cent. in one case) would seem to place these lenses among the ore-bodies deposited by pneumatolitic action. In the second case, the granulites

appear to be genetically related to the eclogites and should find a place in a systematic classification of crystalline schists if the eclogites are included, whereas Dr. Grubenmann leaves them out though the eclogites are one of the rock-types included in his fourth group.

Van Hise logically defines a metamorphic rock as one that has been altered, and hence, as agents of metamorphism, we find listed plants, worms, burrowing animals, and man. One's dinner plate thus could be classed as a metamorphic rock, but it would be an unusual use of the term. There are conventional restrictions to such general terms, just as in the use of the word 'geology', which means the science of the world. If we were to apply Van Hise's logical use of terms, then we should mean by geology the science of everything on the earth and the *Encyclopædia Britannica* would be all too meagre a textbook. But while the old-fashioned expression 'mineral kingdom' usefully defines the subject-matter of geology, what are the restrictions that are to be observed in the use of the term 'metamorphic rock'? what is the subject-matter to be treated under metamorphism?

There is no doubt that the general usage is to exclude from metamorphism the change in rocks produced by weathering and also the change brought about by igneous fusion, whatever that expression means, so that we obtain an upper and a lower limit.

In the case of the upper limit, what amount of change is necessary in a rock for it to be taken from one of the other classes and placed in the metamorphic class? Certainly not the ordinary compacting of sediments, nor even the simple cementing of the grains by deposit from solution of silica, iron oxide or sulphide, calcite, etc., will make a sedimentary rock a metamorphic one; nor will the development of pegmatitic structure take an igneous rock out of its own particular class.

The development of secondary crystals in sedimentary or igneous rocks is again not sufficient to make a rock a metamorphic one. In the Carboniferous sandstones about Grahamstown the shaly laminæ are profusely scattered with scales of secondary mica (sericite), and these lie on perfectly unaltered Devonian shales; the sandstones have undergone a process of change precisely similar to that which produces a mica-schist, yet the micaceous sandstones are not metamorphic rocks. In the case of igneous rocks in the same way, diabases and melaphyres in which the augites, for instance, are entirely altered to urallite, are still igneous rocks, yet the process of alteration is the same as that which produces a hornblende-schist.

Dr. Grubenmann defines metamorphism as a process of rock-forming which is quite as characteristic as that which produces igneous or sedimentary rocks; it impresses on the crystalline schists their peculiar character and invests them with an independence as a class in contrast to other rocks. But what the 'stempel' or peculiar character is which, impressed on a rock, at once allows one to class it as a crystalline schist, Dr. Grubenmann does not say.

The crystalline schists, the same author says, are rocks which may have originated from igneous or sedimentary rocks, or mixtures of the two, in which the chemical composition has remained essentially

unaltered. Consequently rocks of the same composition, no matter what their origin, under the same conditions of metamorphism, yield the same variety of crystalline schist. That is to say, a sandy dolomite with a layer of salt on top to render sodium to the mass, will, under the action of metamorphism, produce a diorite gneiss just as readily as an original diorite of approximately the same composition. Still, the amount of alteration necessary to change the sedimentary or igneous rock into a metamorphic one is left unexpressed.

If we take Dr. Grubenmann's three types of metamorphic rocks we seem to be near the possibility of a definition; there are, according to this author, rocks of three types, those belonging to the uppermost, middle, and lowermost zones of metamorphism, the first being represented by the phyllites and chlorite schists, the second by the schists proper (mica-, hornblende-schists), and the third by the gneisses and eclogites. The zones are marked off by the action of pressure. In the uppermost zone the pressure is stress (mass \times motion) or, as we might call it, dynamical pressure; in the lowermost zone the pressure approximates to hydrostatic pressure, or pressure acting equally in all directions, which we can call static pressure. Under the action of these forces hydro-chemical processes have gone on in the sense that in the uppermost zone the compounds formed obey the volume law, that is to say, are those with the smallest molecular volume; in the lowermost zone the activity of the molecules is such that they are enabled to overcome the pressure from without and form compounds independently of the volume law. Thus, an impure dolomite might yield in the respective zones—

<i>Uppermost zone.</i>		<i>Lowermost zone.</i>	
Garnet and quartz.	Molecular volume.	Augite and anorthite.	Molecular volume.
$\text{Ca}_2 \text{Mg Al}_2 \text{Si}_3 \text{O}_{12}$	123	$\text{Ca Mg Si}_2 \text{O}_6$	68.0
SiO_2	22.8	$\text{Ca Al}_2 \text{Si}_2 \text{O}_8$	101.1
	<hr/> 145.8		<hr/> 169.1

Under extreme pressure, where static pressure is alone active, the crystals will form without any reference to direction, which is produced by dynamical pressure, hence the minerals in the crystalline schist will crystallize as in an igneous rock. Here we come to the difficulty in defining the lower limit of crystalline schists; for if it be true that an increasing disregard of the volume law is characteristic of the lower zones, then the igneous rocks become simply metamorphic rocks in one stage lower than Dr. Grubenmann's lowest zone, thus:—

<i>Lowermost metamorphic zone.</i>		<i>Igneous rock.</i>	
Eclogite.	Molecular volume.	Gabbro.	Molecular volume.
Garnet, $3 \text{R}_3 \text{Al}_2 \text{Si}_3 \text{O}_{12}$	369	Augite $(2 \text{Ca Mg Si}_2 \text{O}_6)$	204.0
Omphacite, $\text{Na Al Si}_2 \text{O}_6$	64.8	$(\text{Mg Al}_2 \text{SiO}_6)$	
Quartz, 2SiO_2	45.6	Olivine, $\text{Mg}_2 \text{SiO}_4$	43.9
		Anorthite, $2 \text{Ca Al}_2 \text{Si}_2 \text{O}_8$	202.2
		Albite, $\text{Na Al Si}_3 \text{O}_8$	100.3
	<hr/> 479.4		<hr/> 550.4

It is very generally held now that igneous fusion of rocks is accomplished with the help of water; whatever rock we examine, whether it belongs to the acid series with micas which contain combined water, or to the basic rocks (perhaps with the exception of some of the ultra-basic rocks), there is always evidence that a part of the peculiarities exhibited by it must be explained by aqueous solution. Quartz is readily soluble in water at 200° C., and becomes a powerful acid like nitric or sulphuric acid; the solution becomes a solvent in which bases can be dissolved, and on cooling or super-saturation these would combine with the silica to form the various minerals of igneous rocks. The pegmatites and quartz veins which come from granite masses can be regarded as the end products of a series of crystallizations which began by the formation of the normal granite and which were accomplished by hydro-chemical processes. There is the old experiment of Fouqué and Michel-Lévy of fusing microcline and biotite; the melt on crystallizing gave leucite, olivine, and magnetite. If it be objected that the pressure on the earth's crust was the only thing needful to keep the chemical combination represented by microcline and biotite, we have Oetling's experiments to contradict such an assumption. Oetling,¹ on fusing the rock-forming minerals under pressure, found that the melt solidified as a glass, whereas under ordinary pressure they crystallized, sometimes as the original minerals, sometimes, as in Fouqué and Michel-Lévy's experiment, in other forms. Whichever way we attack the question we find that solvent water is the agent active in forming the characteristic minerals and structures of igneous rocks: a discussion of the whole question, with references, is given in *Natural History of Igneous Rocks*, by A. Harker, pp. 294 et seq.

If this be so, then where are the dividing peculiarities between, say, a graphic granite and an eclogite? Both form dyke-like masses which may be in both cases in gneiss; both are holocrystalline with the crystals formed without reference to any leading direction, and more than one mineral may be common to both (quartz, feldspar, hornblende, etc.), and yet the one is unquestionably a rock belonging to the so-called igneous class and the other to the metamorphic class. The answer seems to me to lie in a recognition that in the igneous rock some law of chemical combination has been carried out under circumstances which have allowed complete freedom of molecular action, whereas in the metamorphic rocks there have been restrictions. Using the fact that the sum of the molecular volumes of the minerals in an igneous rock are greater than the sum of the molecular volumes of corresponding minerals in a metamorphic rock of the same chemical composition, it is perhaps possible to define the differences in the two as due, in the one case, to the internal pressure (i.e. molecular activity) having been greater than the external pressure, and in the other that the reverse has obtained. In other words, if a rock magma is under sufficient pressure to allow the solid particles to move freely into the solvent water, the chemical affinities of the substances in the

¹ A. Oetling, "Vergleichende Experimente über Verfestigung geschmolzener Gesteinmassen unter erhöhtem und normalem Druck": *Tscher. Mitt.*, xvii, 1898.

magma are allowed to satisfy themselves without reference to any disturbing factor, and an igneous rock will result. If on the other hand the pressure is not sufficient to produce a complete fluidal phase, in Riecke's sense, but the whole rock remains solid except at the boundaries of the constituent grains where interchange of substance can take place, then the law of least molecular volume comes into play; the small amount of dissolved substance is restricted in its molecular activity, and a metamorphic rock is produced.¹ As the pressure approaches the static condition the mineral arrangement will tend to become massive like that of igneous rocks, and as the pressure decreases the lateral stress will produce more and more pronounced schistose structures.

If we accept some such definition of a metamorphic rock in terms of molecular energy we can apply it to separate such a rock at its upper limit, as well as at its lower limit, from other varieties. That is to say, a metamorphic rock must be one in which dynamical pressure has acted, and the term cannot be applied to one in which, owing to peculiar circumstances, a mineral usually associated with metamorphism has crystallized, as in the micaceous sandstones referred to above.

A metamorphic rock under this conception could not arise between two sedimentary rocks, or in the midst of an igneous mass, because the metamorphism, being due to hydro-chemical reactions under dynamical pressure, will be a measure of the 'head' or pressure on the water which permits the chemical activity to proceed. Water under such a pressure will permeate all the surrounding rocks irrespective of their texture or composition, and therefore there can be no selective action on particular zones of the rock-complex, but there will be a progressive intensity of metamorphism from above downwards. Mere accession of heat will not produce a metamorphic rock; for example, the anorthosites of Canada are traversed by bands of brecciation in which the rock is reduced to a 'Rutschmehl'; in Madras, in the charnockite gneisses, similar bands or 'trap-shotten' are produced in which the temperature has risen sufficiently to partially fuse the rock,² but these mylonites are entirely different from metamorphic rocks.

In the case of contact metamorphism the same explanation will simplify considerably the interpretation of the phenomena. Along the course of the dyke, or in the neighbourhood of the intruding boss or laccolite, the water pressure will be temporarily increased to such a degree that metamorphic action can proceed. If the 'head' of the water is maintained either by fresh supplies from the invading magma or by the closeness of the texture of the rock suddenly subjected to the increased water pressure, then metamorphic action will go on vigorously; if, however, the surrounding rocks are not sufficiently compact, or the invading rock is not pumping up sufficient water to

¹ E. Riecke, "Über das Gleichgewicht zwischen einem festen, homogen deformierten Körper und einer flüssigen Phase, insbesondere über die Depression des Schmelzpunktes durch Spannung": *Nachr. Ges. Wiss. Göttingen*, iv, p. 278, 1894.

² T. H. H. Holland, *Mem. Geol. Surv. India*, vol. xxviii, pt. ii, p. 198, 1900.

maintain the pressure, then the metamorphic action will not take place and a granite or dolerite may come to rest against a slate without showing the least sign of alteration at the contact.

The purpose of this note, however, is not to discuss the whole subject of metamorphism but to draw attention to the want of definitiveness in the terms used by authors in describing the metamorphic rocks. It seems to me to be impossible to attain any definitiveness unless we use molecular energy as a basis: the mischief of this is that it makes it necessary for geologists to add to their already overburdened subject the additional trouble of physical chemistry.

ADDENDUM.—Since writing the above I have received *Recherches sur l'exhalaison volcanique*, by A. Brun, in which it is recorded that certain of the metamorphic minerals, kyanite, epidote, vesuvianite, etc., have their crystalline structure destroyed at temperatures in many cases much below the fusion-point. Epidote, for instance, loses its crystalline structure at 900° C. and fuses at 1250° C.

Epidote = $2 \text{ H Ca}_2 (\text{Al Fe})_3 \text{ Si}_3 \text{ O}_{13}$, molecular volume 296

Anorthite = $3 \text{ Ca Al}_2 \text{ Si}_2 \text{ O}_8$, „ „ 303.3

So that, in spite of its having within its molecular structure water, iron, and a surplus of lime, epidote has a far smaller bulk than the igneous mineral anorthite. The destruction of the crystalline structure by heat long before fusion seems to point, therefore, to expansion of the molecule. All the metamorphic minerals do not show this character, garnet and spinel for instance, but the presence in a rock of one mineral that does might be taken as an indication that the rock belongs to the metamorphic class.

VI.—ON A LARGE FORM OF *ANTHRAPALÆMON* FROM THE CLAY-IRONSTONE NODULES OF THE MIDDLE COAL-MEASURES, SPARTH BOTTOMS, ROCHDALE.

By HENRY WOODWARD, LL.D., F.R.S.

AS long ago as 1836 Prestwich published his historical paper “On the Geology of Coalbrook Dale”,¹ and in it he figured a Crustacean carapace under the name of *Apus dubuis*.

In 1861² J. W. Salter figured and described some new Coal-measure forms of Crustacea which he referred to the genus *Anthrapalæmon*, gen. nov., and included therein Prestwich’s *Apus dubuis*.

In my second year’s Presidential Address to the Geological Society, in 1896, I dealt with the “Life-history of the Crustacea in Later Palæozoic and in Neozoic Times”, and, under the Decapoda Macrura, I referred to those of the Coal-measures (Proc. Quart. Journ. Geol. Soc., 1896, vol. lii). “Eight species of *Anthrapalæmon* from the Coal-measures of Scotland and England, one from Illinois, U.S.A., and one from Nova Scotia, illustrate the abundance of these small Crustacea in the Carboniferous period. They have many points in common, but probably deserve more than specific differentiation.

¹ See Trans. Geol. Soc., 1840, vol. v.

² See Quart. Journ. Geol. Soc., vol. xvii, p. 530, 1861.