Even more interesting than pain is the problem of its relief. Intractable pain is fortunately rare but does occur in some diseases. Opium and its derivatives, though of great value, are not altogether satisfactory, especially when the pain is lasting; and they have other drawbacks. Section of afferent nerves, extirpation of ganglia and other destructive procedures, have been used in intractable pain. All such methods are attempts to prevent

the passage of pain-producing impulses by the afferent nerves to the central nervous system. Mr. Todd described a method of alleviation by the intrathecal injection of alcohol. This paralyses the afferent fibres in the spinal canal, and has proved valuable in cases suffering from pain in the pelvis and lower limbs. There is still room for some drug which will possess the ideal properties.

METAMORPHISM AND IGNEOUS ACTION*

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A PART from the question of the time-continuity of the progressive series represented by, say, the Barrovian zones, there is the chemical continuity to be considered. How far do the zones of Barrow represent an isochemical series of pelitic rocks? The degree to which such processes as metamorphic differentiation and diffusion have operated obviously affects the compositions of members of the series at any stage. Such possible departures from the isochemical series arise through processes inherent in the rock. There is, however, another aspect of this topic which, though usually ignored in Great Britain, must in my opinion be carefully considered. The possibility of the introduction of material of so-called magmatic origin is one that certainly cannot be dismissed in the higher grades, and one that might apply even to the lower grades of regional metamorphism. It will be convenient for the development of my argument, however, if we transfer ourselves to the domain of ultra-metamorphism, and I discuss the reality of granitization, for, if granitization is real, certain consequences seem to follow.

In a paper which has appeared during the writing of this address, granitization is defined by Malcolm MacGregor and Gilbert Wilson as "the process by which solid rocks are converted to rocks of granitic character". It includes all such operations as palingenesis, syntexis, transfusion, permeation, metasomatism, migmatization, injection, assimilation, contamination, and the like. These authors conclude that exchanges take place between the country-rocks and their pore-fluids—whether these are entirely indigenous or reinforced by accessions from magmatic sources—and that these exchanges are selective so that there is a convergence, both chemical and mineralogical, of rocks originally different. They consider two processes to be concerned in granitization; first,

a metasomatism under the influence of "permeating highly energized fluids—emanations—ahead of advancing magma", and second, a mechanical penetration by magma. I consider that no reasonable objection can be raised to these conclusions, notwithstanding the uncompromising attitude of Rosenbusch and others.

The question of room in migmatization is one that has caused difficulties to many observers. This room-question was answered by Hugh Miller fifty years ago, and has been answered many times since. Replacement is the essential process in the formation of the migmatites. It is unfortunate that the term injection-complex, used in Great Britain, emphasizes injection, since permeation, imbibition and metasomatism are more widespread phenomena. As I have pointed out elsewhere, the formation of banded gneisses and lity-par-lit complexes is best explained by a process of replacement to different degrees along layers of different permeabilities. The many examples of the tracing of the regional country-rock structure through granitic masses, the existence of thin plane screens of country-rock in them, the great extension of minute *lits* of quartzo-felspathic material in migmatites, and the detailed heterogeneity of many granites are all readily explicable by a replacement origin for these rocks.

Replacement in sedimentary rocks will be controlled by the original structures of such rocks. Permeation by the emanations or ichors will take place preferentially along certain layers depending upon both the chemical and physical nature of these layers. Original platy minerals lying in the bedding planes will become enlarged if they suit the new chemical environment, and new-formed minerals will grow so that their direction of greatest crystallization-velocity agrees with the old planes of weakness. The original sedimentary structure may thus become preserved until a high

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degree of granitization has been reached, and the bulk composition of the rock has been greatly changed. I consider the foliation of granitic gneisses, for example, as essentially controlled by previously existing sedimentary structures, and not by any process of dynamic metamorphism or piezo-crystallization.

Whether the granitizing solutions are thought of as emanations of no specified ancestry, or as ichors from a granitic magma-body, opinion is agreed amongst workers in this subject that they are highly mobile and capable of great chemical action. Working in conjunction with the pore-fluids of the country-rock, they can transform vast portions of the crust. In connexion with direct granitic invasion, gases may be of great importance; when they have condensed to solutions and have received assistance from the true liquid residuals and from the pore-solutions, they must be capable of gigantic results. I wish to emphasize, therefore, that granitization and feldspathization are valid processes, and that they are essentially based upon replacement.

In regions of granitization there has been an afflux of material, either from a 'magmatic' body or from some unspecified source. It is reasonable to believe that during the resulting replacement there occurs an emigration of material. Holmes has put the whole matter graphically—"the 'granite' is the balance of what was there originally, *plus* what has migrated in, *minus* what has been driven out". The emigrating material moves into the country-rocks adjacent to the theatre of granitization.

The material thus moving through the country-rocks is of several origins and qualities. It consists of (i) the material expelled from the region of granitization; (ii) the direct emanations from the granitizing agent; and (iii) the pore-fluids of the country-rocks. Its diverse constituents must move with different speeds, perhaps depending, as Backlund has ingeniously suggested, upon the ionic radii of the participating elements. Various overlapping belts of precipitation may come into being, and from each a further expulsion may take place. By some such processes zones of various characters arise about the granitization or migmatite core.

Wegmann has elaborated a magnesia-metasomatism dependent upon the expulsion mechanism in granitization; he expects to find a zone characterized by cordierite in close proximity to the migmatite area, whilst farther away would be found lower-temperature minerals like andalusite, kyanite, garnet, etc., and farther still tourmaline. The formation of 'fronts' of more or less marked chemical individuality can be exemplified by the soda-fronts of Stavanger, Sutherland, and Cromar,

Aberdeenshire, by the potash-front of Hango, Finland, and by the magnesia-front of Orijärvi; there is no need to elaborate these examples.

One of the most firmly established facts of metamorphic geology is the close association in the field of highest grade metamorphic rocks and migmatites. The significance of this coincidence has been differently interpreted. I adopt the view of the company familiar with migmatites and see with them a direct causal relation between the highest grade of regional metamorphism and migmatization.

In my opinion, therefore, the cordierite and sillimanite zones are genetically related to granitization. But these zones are the final stages of the apparently continuous progressive series of Barrovian zones which as a whole supply the common types of regionally metamorphosed rocks. It seems reasonable to me, therefore, to believe that regional metamorphism as a whole is genetically related to 'igneous' activity of some kind.

Out from the central theatre of granitization there pass waves of metasomatizing solutions, changing in composition and in temperature as they become more distant from the core and promoting thereby the formation of zones of metamorphism about it. Very often a spurious depth control appears to have operated, since the flow of solutions must be largely towards higher parts of the crust. Such a metasomatic metamorphism accounts for the superposition occasionally observed of high-grade zones on lower-grade, and does away with the infelicities attending the alleged inversion of metamorphic zones. Further, the difficulties that the idea of static or load metamorphism fails to meet are surmounted. Deeply buried sediments remain unmetamorphosed unless igneous material gets access to them. In metasomatic metamorphism, original sedimentary textures can be reasonably preserved, mimetic crystallization can prevail, schistosity and bedding, even in violently folded strata, can coincide. Finally, all those phenomena which Daly felt to be "truly inexplicable by pure dynamic metamorphism", are satisfactorily explained.

A continuous series of changes in composition from low-grade regionally metamorphosed rocks to migmatites has been established by many investigations. Even in the low-grade rocks changes are perceptible, and all must be ascribed to the activity of material from a granitization centre. To move this material and to promote the recrystallizations and replacements that occur in cubic miles of rock, great quantities of solvents are required. It seems to me unlikely that the solvents in action are indigenous to the country-rocks—they are more reasonably to be derived from a granitic source. When the enormous

extent of migmatite granites is considered, it is clear that sufficient water is available to promote the changes seen in the regionally metamorphosed rocks.

Are there any indications in low- to medium-grade rocks, not visibly associated with igneous activity in the field, which point to solutions from magmatic sources having travelled so far from the locus of migmatization? In my opinion, we see such indications in the presence of tourmaline in rocks of all grades. Admittedly, this opinion is one not generally accepted in Great Britain, but on balance I prefer to regard most tourmaline in metamorphic rocks as due to impregnations from granitization fluids. Tourmaline occurs not only in pelitic derivatives but also in rocks of other compositions. In many examples of high- and medium grade rocks it is clearly introduced, as shown by its relation to the other minerals present. I believe that the ubiquitous tourmaline in regionally metamorphosed rocks is an indicator of the action of 'emanations' throughout all grades.

Whilst I have belittled the role of the dynamic factor in regional metamorphism, it is of course

true that in the lower grades it must be of considerable importance. How can this be reconciled with the view that migmatization is the prime cause of regional metamorphism? The reconciliation may be sought, I suggest, in the stresses set up by the increase of volume consequent upon the invasion of the crust by the migmatite front. Relief is obtained in the outer and cooler zones by shearing; in the inner and hotter zones by internal reconstructions. The unity of the zonal series may thus be preserved.

I have shown my predilection for dividing all rock transformations into two groups, one those of dislocation-metamorphism associated with dislocations of the crust, and the other those of regional and thermal metamorphism associated with igneous activity. My remarks, I trust, will receive thorough criticism. I am prepared for this, for, just as things too absurd to be said can yet be sung with perfect propriety, so views too tenuous, unsubstantiated and generalized for ordinary scientific papers can yet appear with some measure of dignity in presidential addresses.

POWDERED FUEL: PROGRESS AND PROSPECTS

THE necessity imposed by the demands of war to make use of any available materials in order to eke out inadequate supplies of the usual commodities is frequently the means of bringing to practical use ideas and inventions which might otherwise languish for years. An example is the introduction in the Napoleonic era of the present method of making soap in consequence of France being cut off from the usual supplies of kelp. The use of powdered fuel in aero-engines may, owing to Germany having difficulty in getting adequate supplies of petrol, be one of the results of the present hostilities; that the Germans have been working in this direction is evidenced by patents covering the use of powdered fuel. Patent literature shows that two distinct methods of operation have been envisaged. One consists in mixing the fuel with air and introducing the mixture into the combustion chamber, thus following the cycle used in petrol engines. The other adopts Diesel practice in injecting the fuel directly into the combustion chamber, though obviously with a fuel in the form of a powder some important modifications at the injection stage would be necessary.

Powdered coal cannot be described as a tractable material for the purpose of being metered out in small quantities for injection into the combustion chambers of a high-speed engine. Freshly

pulverized, it is light and fluffy but, in the presence of moisture it readily tends to change its physical characteristics and to pack itself into a dense and rather inert mass. It is necessary, therefore, that it should be well dried before the final pulverization, and it is desirable also that it should not be kept in storage but rather used at once. After a long period of trial, it has now become well established as a boiler fuel, and a brief statement of its history in this connexion may indicate its possibilities.

In 1831, a patent was granted to John Dawes, ironmaster, for a method of introducing fuel into the blast of furnaces. Later patentees include the name of Mushet who, it will be noted, was also interested in steel furnaces. The first to advocate pulverized fuel seems to have been John Bourne, in whose "Treatise on the Steam Engine" of 1861 it is stated that "the fuel and air must be fed in simultaneously and the most feasible way of accomplishing this object seems to be in reducing the coal to dust and blowing it into a chamber lined with firebrick so that the coal dust may be ignited by coming into contact with the red hot surfaces". In 1868, T. R. Crampton experimented on the use of pulverized coal in steam boilers and puddling furnaces, and the views he put forward in a paper read before the Iron and Steel Institute