been bodily uplifted from far below sea-level to a height of many hundreds of feet in post-Tertiary times, as attested by the shell beaches that girdle their flanks, and when the present living mollusca were tenanted the present seas that wash their shores? Is it a rational induction or the reverse to argue that if such enormous movements in such tough rocks were the result of lateral thrusts caused by shrinkage of the earth's crust, which both induction and experiment combine to establish, that thrusts on this scale could hardly occur without the most serious breakages and fractures?

I have very little doubt, therefore, that the chalk dislocations of the Baltic were consequential on the uplift of the great hog-backed Scandinavian peninsula, and were almost certainly synchronous with the opening of the Baltic breach, which certainly dates from the human period.

(To be continued.)

V.—THE GENESIS OF TUNGSTEN ORES.

By R. H. RASTALL, M.A., F.G.S.

(Concluded from the July Number, p. 296.)

PART IV: SECONDARY TUNGSTEN DEPOSITS.

AT the present time a large proportion of the world's supply of tungsten ores comes from secondary (detrital) deposits of various kinds, formed by the normal denudation and redeposition of primary ores exposed at the surface to the agents of weathering and transport. It is impossible to form any idea of what fraction of the world's output actually comes from these sources, since the published statistics do not draw any distinctions in this respect, but the amount is undoubtedly large. Although of such great economic value, the secondary deposits do not show any features of special interest, and a lengthy description is unnecessary.

From this point of view the outstanding feature of the tungsten minerals is their great stability and resistance to any kind of chemical or mechanical alteration. Hence, like cassiterite and gold, they are particularly prone to occur in both residual and alluvial deposits. In many of the published descriptions, and especially in the technical journals, a good deal of confusion is found to exist between the residual deposits, where the material is still more or less in place, and the true alluvial or transported deposits. From their very stable character it follows that tungsten minerals must tend to remain unaltered in the gossan of lodes and other masses and also to concentrate in the shoad. Hence a kind of secondary enrichment is found on the weathered outcrops of lodes. This is, of course, not really an enrichment in tungsten ores, but rather a removal of other constituents of a less stable nature, leading to a concentration of the more resistant minerals of the weathered mass. From their stability and high density it also follows that the tungsten minerals are specially liable to occur as placers and other forms of transported deposits. The same properties also lead to a natural concentration in such deposits, especially in the lowermost layers, resting on the bed-rock, and in natural riffles. In this

respect both wolfram and scheelite behave like stream-tin, gold, and platinum. In fact, the properties of wolfram are so like those of cassiterite that their separation by mechanical processes is very difficult, and it was not till the introduction of magnetic separation that this difficulty was overcome.

Geologically the secondary tungsten deposits are so simple and straightforward that it seems unnecessary to describe any individual examples, while the practical details of their exploitation, concentration, and after-treatment do not fall within the scope of this paper. Essentially they consist mainly of breccias, gravels, and sands, formed to a large extent by water-action, and occasionally resulting from the effect of dry denudation in regions of small rainfall. The briefest possible reference may also be made to the "Head" of Bodmin Moor and other parts of Cornwall, so admirably described by Mr. Barrow.¹ In this connexion it may also be mentioned that of late years it has been found profitable in many instances to work over the old tin-dumps for wolfram, which was thrown away as worthless by the earlier miners.

PART V: CONCLUSIONS.

In the foregoing pages an attempt has been made to give a general account of the mode of occurrence and mineral paragenesis of the tungsten ores. Attention has been paid chiefly to the theoretical side of the subject, with a view to elucidating as far as is possible the genesis of the ores and their relation to the associated minerals and rocks.

Taking first the wolframite deposits, it is found that these occur most commonly along with cassiterite; other minerals also accompanying them in nearly all cases are arsenopyrite and molybdenite. The gangue minerals nearly always include some that are characteristic of the pegmatitic or pneumatolytic dykes or veins. Furthermore, it appears that this general association of tungsten, tin, molybdenum, and arsenic may be further subdivided on the basis of the rarer metallic elements present into subtypes or local metallogenetic provinces, such as the uranium province of Cornwall, the tantalum-molibium provinces of Burma and Dakota, and so forth. Another major subdivision is afforded by the tungsten-tin-silver-germanium group of Bolivia. From the evidence brought forward it may be regarded as established that the tungsten-tin deposits are derived in all cases from granitic magmas. Wolfram and cassiterite are found as original minerals in granite, being direct products of the crystallization of the magma; as constituents of pegmatite dykes within and in direct continuity with the granite, while wolfram is also found in quartz veins, so-called, which are continuations in space of pegmatite dykes. Hence there is no real distinction between a pegmatite dyke and a quartz vein, and the study of these lodes lends strong support to the idea that many of the larger quartz veins are in fact formed by crystallization of the last residues of an acid magma. The separation of these residues is, of course,

¹ Quart. Journ. Geol. Soc., vol. lxiv, p. 384, 1908.

essentially a process of differentiation, which may be described as fractional crystallization. Processes of this kind are generally described as pneumatolytic, but there does not seem to be any need for the use of the word in this connexion, since as commonly understood it seems to imply something unusual and out of the common order of events. This kind of differentiation is perfectly normal; its final results depend mainly on the extent to which highly volatile compounds and water were present in the original magma. The more of these are present the lower will be the freezing-point of the final product. The effect of alkaline tungstates in lowering the freezing-point of acid silicate melts, and thus enabling quartz and acid feldspars to crystallize, has long been known and used in petrological and mineralogical research. It appears that during the freezing of the residual magma cassiterite is formed first, then comes wolframite, while last of all quartz and fluorite are formed, resulting in veins of quartz and fluorite without metallic minerals, or even of fluorite alone.

The evidence afforded by the wolframite lodes without tinstone is entirely in conformity with the foregoing considerations. There is a continuous gradation between the two types by diminution of tinstone; the series passes through the wolfram-quartz lodes, in which molybdenum and arsenic tend to disappear, whereas other sulphides tend to increase. As the final member of the series we have the association of wolfram with siliceous gold ores, as in Colorado, and of scheelite with gold ores in California. This relationship of tungsten to siliceous gold ores is of much interest in connexion with the classification of ore-deposits proposed by Spurr.¹ This author regards all ore-deposits as due to differentiation of igneous magmas, the variations depending on the amount of water and rarer elements originally present in the magma. According to this scheme, the bulk of the tungsten deposits belong to the first or pegmatitic type, which is characterized by tin, tungsten, molybdenum, with tourmaline and topaz as gangue minerals. Some of the tungsten ores, however, both wolfram and scheelite, extend into the second group, "the free-gold pyrite zone with quartz."

Spurr correlates these differences mainly with depth, since he regards all ores as deposited by ascending solutions. Although this idea is highly probable, it cannot yet be regarded as demonstrated that the tin-tungsten lodes were formed at a greater depth from the surface than the gold lodes or the cupriferous pyrite deposits. This point, however, is not of very great importance. It is a fact, however, that the occurrence of tungsten ores when studied in detail lends strong support to the idea of a definite sequence of differentiation of the rarer metallic contents of the granitic magmas.

The tungsten ores are definitely oxidic in character, and in many ways afford a strong contrast to the behaviour of the sulphidic ores. They appear to belong characteristically to acid magmas, whereas most of the great masses of sulphides are connected with basic intrusions. There is also a strong contrast between the two classes

¹ Spurr, *Economic Geology*, vol. ii, p. 781, 1907.

in the elements which act as "carriers". In the case of the tungsten ores the most important of these is undoubtedly fluorine; boron is a very common associate, but it is not known whether it plays any actual part in the formation of wolframite or scheelite. A detailed study of the literature does not lend any support to the statement sometimes found in textbooks that apatite is a common associate of this group. In fact, minerals containing phosphorus or chlorine seem to be conspicuously absent.

Another point of interest is that the tungsten minerals are all characterized by a high degree of stability and consequent resistance to chemical action of any sort. Hence they do not undergo any alteration in the zone of oxidation and are not carried down in solution into the zone of cementation. This is equivalent to saying that they do not undergo secondary enrichment. It follows from this that tungsten lodes are always primary in the narrowest sense of the term, and this is a fact which should be taken into consideration in the valuation of such deposits. The behaviour of tungsten lodes in this respect is on the whole very similar to that of the tin lodes, and shows no resemblance to the characters of the copper lodes, for example.

To sum up, it may be said that the tungsten ore-deposits are of magmatic origin, being formed by the natural and normal concentration in certain fractions of the magma of a group of constituents, metallic and otherwise, which tend to occur together owing to the similarity of their chemical and physical properties under the conditions that prevail during the later stages of magmatic consolidation. Of these constituents the most important are tungsten, tin, molybdenum, arsenic, fluorine, and boron. These constitute the general paragenesis, while certain regional subtypes can be distinguished, characterized by uranium, niobium, tantalum, and possibly others not yet specifically distinguished. In certain cases transitions can be traced to other groups of ore-deposits containing gold, silver, copper, zinc, and lead. Some of these mixed deposits may be explainable by deposition of metals in the same locality at two or more distinct periods, while in other instances the differentiation of the original magma may have been incomplete and ill-defined. At any rate, it is clear that in the typical cases the prime factor at work has been differentiation of igneous magmas, and the study of the genesis of the tungsten ores lends the strongest support to modern views as to the origin of ore-deposits in general. It is now becoming increasingly manifest that the study of the characters and origin of the metalliferous rocks is an extraordinarily interesting and important branch of the science of petrology, and that in the past this branch has been unduly neglected by workers on the purely scientific and theoretical side. A detailed investigation of the chemical and physical laws governing the formation of the oxides and sulphides of the igneous rocks, on the same lines as already applied by many workers to the silicates, could not fail to yield results of the highest scientific interest and of the utmost practical value.