

THE FLOTATION PRINCIPLE IN ORE FORMATION

BY

JOHN STANSFIELD

Urbana, Illinois.

In connection with the formation of metallic ore deposits of igneous origin, the following six important processes may be recognized:

(1) Separation of the ores from the magmas; (2) Segregation of the ores; (3) Injection of segregated ore magmas; (4) Transport of ore materials as vapours, with subsequent deposition in veins, etc.; (5) Transport of ore materials in solution, with subsequent deposition in veins, etc.; and (6) Transport of ore particles by flotation, with subsequent deposition in veins, etc.

The importance of the first two of these has long been recognized, and discussion of them has formed a part of formal treatment of the subject of ore formation in the standard text-books and reference works dealing with ores of igneous origin.

The injection of ore magmas has been demonstrated, but it has been reserved to Spurr to give us the most masterly presentation of the "injection principle" in his book on *Ore Magmas* (1923). Although part of his terminology has not received general acceptance, our deepest thanks are due to him for his treatment of this interesting topic.

The efficacy of the process of transport of ore materials in the form of vapour has long been recognized in connection with ores of pneumatolytic origin.

The transport of ore materials in hydrothermal solution, and their subsequent deposition in ore bodies, has received its most complete treatment at the hands of Lindgren in his book on *Mineral Deposits* (1913 and subsequent editions).

The principle of flotation in connection with the segregation of ore minerals from magmas, on a small experimental scale, has been demonstrated by the writer, who has applied it to the explanation of certain details of ore formation processes.¹

It is the purpose of the present paper to develop a little farther the application of the principle of flotation to the processes of ore formation.

¹ *Assimilation and Petrogenesis: Separation of ores from magmas.* Valley Publishing Co., Urbana, Ill., 1928.

With falling temperature sulphide, oxide, or metal particles may separate from a magma as minute globules. Previous to this, at higher temperatures, they may be regarded as having formed a part of the magma and to have been evenly distributed throughout it. After the ore particles have been separated from the magma, they may be regarded as remaining liquid for a more or less prolonged period. We may regard the condition of the magma as that of a colloidal emulsion of minute liquid ore particles suspended in a dispersion medium of silicate magma. The constant motion of such colloidal particles tends to keep a uniform distribution of them in all parts of the magma. But with the passage of time the forces of gravity, of surface tension, and of cohesion tend to cause the segregation of these ore particles into larger masses. Cohesion causes particles to come together and coalesce. Surface tension relations tend to cause the segregation of ores at the walls (including floor and roof) of the magma reservoir. Sinking under gravity tends to collect ore masses near the base of the magma reservoir. Flotation helps to keep the ore particles in suspension so that the forces of surface tension mentioned above may have play, and also by its own strong action causes the collection of ore masses at or near the roof of the magma reservoir. These forces have been discussed in my work mentioned above.

I wish to add, here, some ideas upon the flotation principle as it may be applied to igneous magmas, and to carry through the application of the principle to the transport of ore particles in the processes of ore formation.

At greater depths, the gases which form a part of magmas remain within the magmas, by reason of the great pressures existing at those depths. But, as the magmas approach the earth's surface, gases may separate from the previously homogeneous fluids, and again we may regard such a magma as a colloidal emulsion of minute gas bubbles in a dispersion medium of silicate magma. The minute bubbles are in constant motion and tend to remain in uniform distribution, in consequence of this motion. Contact between bubbles and the action of cohesion causes their enlargement, so that the Brownian movement which governs the even distribution of the minute bubbles becomes subordinate to the movement under gravity, and as a result the enlarged bubbles begin to rise in the magma. In these rising gas bubbles we may recognize a very potent force which may bring about the phenomena of flotation which we are considering. Daly has given us a wonderful picture of the efficacy of this gaseous force in bringing to the earth's surface a

constant stream of frothed magma in the lava lake of Halemaumau at Kilauea.

For our present study we have to take note of the chance that ore globules may become attached to gas bubbles and that they may then ride upward with them toward the roof of the magma reservoir, where they may be collected into masses by the dispersal of the gases, and kept from sinking by the cooling and congelation of the magma. We may thus account for marginal ore-bodies at the roof of a magma reservoir, and a further step will account for the common occurrence of ore bodies in "roof pendants" which extend downward from the country rock into those parts of the magma reservoir where the floated ores tend to collect.

Many kinds of gases may be liberated from magmas and so ore particles may be transported upon gas bubbles which may differ widely in their chemical natures. By the same token, the ore particles may be of many different kinds, and it may be a matter of chance that more silver values may be collected in one place, more copper values at another place, more gold values at a third location, and so on. We shall see later, that such a separation may not always be entirely governed by chance.

As the gases pass outward from the magma into the surrounding country rocks, eventually condensing, in part, to aqueous solutions, they may carry with them part, at least, of their metallic load. Hence, we may draw for ourselves a picture of hot, aqueous, magmatic solutions passing along cracks in the country rock and carrying with them a gaseous froth, in part laden with ore particles, liquid at first, and becoming solid ore particles at lower temperatures. These particles may be dropped, here and there, en passant, along with other materials which may have been carried in solution.

This addition to the available methods of transport of ore materials will help us to comprehend more readily the "spotty" distribution of values, which is a condition well known to mining men.

It is possible that the idea of *selective flotation* may be useful in helping to account for *zonal distribution* of ores around igneous intrusions. In my experiments lead sulphide was found to lend itself to the action of flotation to a more marked degree than the other sulphides used (pyrite, pyrrhotite, pentlandite, chalcocite, bornite, chalcopyrite and zinc blende). Under conditions of nature, it may be that this tendency causes lead sulphide to be transported to greater distances from the igneous source than other sulphides. The frequent association

of zinc sulphide with lead sulphide in ore bodies may have its basis in some chemical force, which may cause the zinc and lead sulphides to stick together and be transported together.

It is possible to apply this principle of selective flotation to account for the details of the distribution of ore minerals into copper zone, silver zone, lead-zinc zone, etc., in the many cases of zonal arrangement of ores which are known in different parts of the world. Discussion and investigation of this principle will doubtless throw light on these problems in the future.

It seems probable that by use of the principle of flotation we may be helped to combine our ideas on the formation of ore deposits into a harmonious whole, each process being utilized in its proper perspective. In this connection it must be borne in mind constantly that hydrothermal solutions can have play only at temperatures lower than the critical temperature of water.