

THE VERTICAL RANGE OF METALS DEPOSITED BY SECONDARY PROCESSES

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The theory of sulphide enrichment announced independently in 1900 by S. F. Emmons, W. H. Weed and C. R. Van Hise, has been successfully utilized in the exploration of so many mineral deposits that it has become an accepted tenet of applied geology. The processes involved are assumed to include, (1) solution of the valuable metals in an oxidizing acid environment in advance of the removal by erosion of the outcrop of the ore body; (2) transportation by descending meteoric waters of the metals dissolved; and (3) precipitation of the valuable metals in depth where the environment is reducing and perhaps alkaline.

Although our knowledge concerning the details of the chemistry of the processes is inadequate, the general nature of these chemical processes is fairly well understood. Few geological processes lend themselves more readily to experimental study. The mineral waters, as shown by study and comparison of numerous analyses of mine waters, may reasonably be assumed to be dilute solutions of sulphates and chlorides. The conditions of temperature and pressure which prevail are not very different from those obtaining in the laboratory. Hence the behaviour of the various minerals and ores in the presence of solutions like mine waters may easily be determined. By close correlation of field observations and laboratory experiments, it appears probable that in the near future we will know many of the details of the processes as well as we now know the nature of the general laws that operate in the weathering of a body of sulphide ore.

These processes are influenced by many factors. Among those of environment are temperature, rainfall, altitude and relief. An important physical factor is the permeability of the deposits. And so many geological events may affect, in one way or another, the operation of the processes of enrichment that the use of the theory is fraught with danger unless it is applied with an adequate knowledge of the geology of the region containing the deposits.

A review of the distribution of sulphide deposits having secondary zones shows that they are present at high and low latitudes, at high and low altitudes, in moist and in dry climates. They are present also in hot and in cold countries, although they are less numerous in high latitudes, especially in countries where Pleistocene glaciation has removed much of the surface.

On the other hand, many mining regions contain deposits with rich secondary zones, while other sulphide deposits that have weathered in the same region and under similar physiographic conditions, exhibit no evidence of appreciable enrichment. In general, such differences in the behavior of deposits, under approximately similar conditions have been attributed to differences in their permeability; and very correctly so, for in impermeable deposits the solutions cannot descend, and the valuable metals that may be dissolved in the upper portions of a deposit cannot be precipitated in the impermeable lower regions. Permeability is, however, a relative term and it is doubtful whether any deposits are altogether impermeable.

Another factor that influences the depth at which metals may be deposited is the chemical and mineralogical environment. If the conditions in the oxidizing zone

are favorable to solution, the metals will be dissolved; if they are unfavorable to solution the metals will remain to enrich the outcrop or to be carried away by processes of erosion. If the chemical environment in the lower unoxidized regions is favorable to rapid precipitation, the valuable metals will be precipitated before the downward moving solutions have migrated to great depths. The secondary zone may contain very rich ore, but the vertical extent of the latter will be less in consequence. On the other hand, if the minerals that compose the primary ore are those that react but slowly with the downward moving secondary solutions, precipitation of the metals will not be accomplished so readily, and the metals dissolved in the higher oxidizing environment may be carried downward to considerable depths. In deposits composed of such minerals the vertical extent of the secondary ores will be much greater than in deposits containing minerals that quickly precipitate the valuable metals.

If the behavior of solutions like mine waters containing gold, silver and copper in low concentration, toward each of the minerals of an ore and toward mineral associations were known, from experiment, and if the permeability of the deposit were ascertained, some estimate might be hazarded, perhaps in advance of extensive exploration, as to whether the secondary ores of a deposit would extend downward to considerable depths or whether they would be restricted vertically.

Examination and study of about fifty analyses of waters of gold, silver, and copper mines indicate that mine waters are fairly constant in composition. Near the surface they are acid sulphate and ferric sulphate waters. At greater depths they are acid ferrous sulphate waters, and deeper still they become alkaline ferrous sulphate waters. If the behaviour of such waters toward a given ore were known, and if the rate at which the solutions, under the several conditions of acidity and alkalinity, attack the primary ore were determined by experiment, much light might be thrown upon the superficial processes and upon the rate at which they operate under a known set of conditions.

Gold.—Gold, silver and copper are nearly related chemically and stand apart as metals in the concentration of which the processes of sulphide enrichment are most clearly expressed. They are dissolved in an oxidizing sulphate or chloride environment and are readily precipitated in a reducing, less acid, environment. Any one of them is readily precipitated by calcite, siderite, pyrrhotite, and probably by several sulphides. Under conditions that prevail in the oxidizing zones of ore deposits, gold is dissolved probably only in the presence of a chloride and oxidizing agent. The most important oxidizing agents in gold enrichment are doubtless manganese oxides, for these not only supply nascent chlorine by reaction with chlorides in solution, but inhibit the accumulation of ferrous sulphate that immediately precipitates gold from chloride solutions. In the deeper regions where oxides are reduced or acids are removed to form inert salts, gold is precipitated. Ferrous sulphate is doubtless an important precipitating agent, but many common ore and gangue minerals are also effective. As