ALTERATION STUDIES*

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Mineralogy is rich in the lore of pure science. Lately, this heritage has been called upon for substantial aid in the service of the nation. In the years to come it seems likely that mineralogy will be asked to furnish even greater contributions. The purpose of this discussion is to outline but one of the major opportunities for further service which is now emerging on the post war horizon.

Mineral industry finds itself in somewhat of a dilemma. On the one hand, new mineral deposits are becoming more difficult to find. On the other, known deposits continue to be depleted ever more rapidly. The alternatives are simple. Either the rate of discovery must increase, or metals necessary to modern civilization will become economically unavailable.

Leaders are becoming aware of this situation, and increased emphasis is being placed upon the search for new methods of exploration. The techniques of engineering, physics, chemistry, geophysics, geology, and mineralogy are being scanned as never before to discover fundamental phenomena which may be applied in finding mineral deposits. A product of this survey of special interest to mineralogists, which has received particular impetus of late, is the study of rock alteration associated with ore deposition.

The term "alteration study" has been applied to the investigation of clays and other fine mineral aggregates often found within or near mineral deposits. Most frequently, the deposits considered contain copper, zinc, lead, silver, or other metals. Localities are found in and around many of the igneous intrusives of the western United States.

Areas of alteration which contain clay vary widely in their dimensions. Some may form an envelope a few feet in thickness along the walls of a vein. Others may comprise areas traceable for thousands of feet or even miles. Alteration phenomena occur in various rock types, but are perhaps most effectively studied when found in igneous masses. Stocks, flows, sills and dikes often provide the locale in which progressive clay-mineral alteration may be observed.

Suites of alteration minerals contain a variety of species, but delineation of zones or stages appears best established when attention is directed to a comparatively small number of the most significant species. The common clay minerals, sericite, jarosite, alunite, limonite, pyrite, various carbonates, and fine quartz are among the most significant.

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Where alteration is a weathering effect, or is entirely supergene, these studies have little application. On the other hand, where recognizable processes are hypogene the relationship of alteration to the formation of the ore minerals may be particularly significant. It is with the latter that we are most concerned.

The technique of alteration study is one of combined field and laboratory investigation. Field study includes careful geologic mapping with instrumental control and in sufficient detail to delineate significant alteration zones. Among the laboratory techniques employed, the two which are probably most useful are microscopic and *x*-ray examination. These two methods may be supplemented on occasion by chemical analysis, hydration study and frequently by differential thermal analysis. In some instances photographs with the electron microscope are desirable. For example, electron micrographs of halloysite are particularly significant.

Clay mineral techniques have been improving constantly since Ross and Shannon (1926) published their classic paper on the montmorillonite group. With the stimulus provided by early work numerous scientists in mineralogy and allied fields became active in furthering clay mineral studies. Due to the cumulative efforts of these investigators, the principal clay mineral groups have been established and much has been learned about their relationships and fundamental nature. As a result of modern studies the nomenclature of the clay minerals has been greatly clarified and many obscure and invalid species eliminated. The kaolin group has been established. Montmorillonite has become known as a group and has become better understood. The hydromica group, or as some say, the "illite" group, has received recognition. The relationships of subsidiary clay minerals to the chief groups and related species are becoming better established. Such progress in 21 years indicates that the clay minerals may now be said to be of age.

Although the clay minerals may have but recently become of age, the application of clay mineral technique to alteration studies has been in progress for several years. The need for coordinated field and laboratory investigation was emphasized by Mr. Reno Sales in an address delivered in 1938. He especially stressed the desirability of more research covering chemical changes in wall rocks associated with ore deposits. Mr. Sales has not only recognized a need but has taken active steps to work out a solution. Under his direction, Mr. Charles Meyers of the staff of the Anaconda Copper Co. has carried on studies of wall rock alteration associated with the veins at Butte, Montana. The laboratory at Butte has also contributed to alteration studies through the development of an improved technique in the cutting of thin sections of alteration materials, as described by Mr. Meyers. Large slices not much greater in thickness than a standard thin section are cut by a saw in a single operation.

Schroter and Campbell (1940) called attention to a clay deposit of hydrothermal origin. It consists of a large mass of halloysite which occurs in the workings of the Dragon Consolidated mine, in the Tintic district near Eureka, Utah. The writer visited the Dragon Consolidated mine during the summer of 1945 with Mr. Dudley Davis of the International Smelting and Refining Company. The deposit was originally mined for gold, but in recent years a considerable number of carloads of high grade halloysite have been shipped. The halloysite body occurs along the contact between a monzonite intrusive and Paleozoic sediments, where it marks a zone of hydrothermal alteration. Some distance away, lead-zinc ore bodies have been mined from the sediments along the same channel of mineralization.

One of the most active students of alteration has been Dr. T. S. Lovering. His earlier work in the Boulder, Colorado, tungsten district and more recent studies in the East Tintic district of Utah are of particular interest. Compared to some of the large zones of alteration in the copper districts of the west the alteration zones at Boulder are minor features. On the other hand, the symmetry of the alteration envelopes and the zonal grouping of the clay minerals provide criteria of more than local significance.

In the East Tintic district the alteration which has resulted in clay zones has long attracted attention. In places clay zones are so prominent that exploration ventures have been based in part at least on their existence. As a result of the work of Mr. Paul Billingsley, Dr. M. B. Kildale and others, important ore bodies have been found.

For several years Dr. Lovering and his associates have sought to apply alteration study techniques to geologic mapping in the East Tintic district. Through Dr. Lovering's kindness, the writer had an opportunity to spend several days with the East Tintic field party in the summer of 1945. The East Tintic studies have been directed in particular toward the observation of alteration in the Packard rhyolite together with a study of changes with depth or lateral changes at a given depth. Rhyolite forms a blanket lying uncomformably above a considerable portion of the Paleozoic sediments in which ore bodies at times occur. Study of zones of alteration in both the rhyolite and sedimentary formations has been carried on to define centers of mineralization possibly worthy of exploration.

Two stages of alteration are recognized in the East Tintic studies:(1) an earlier barren stage and (2) a later productive stage. The barren stage developed first, accompanied by hydrothermal dolomitization of limestone, and chloritization of the rhyolite. This was followed by argillic or clay mineral alteration and subsequent silicification. The productive stage was marked by the formation of hydromica and sericite.

Another area of interest from the standpoint of alteration study is the San Manuel district in Arizona. Here a large ore body was found during the war. The locality lies near the Mammoth mine where a copper stained area of only a few hundred square feet was exposed. Copper ores occur in the midst of a large altered area which has been studied in detail by Dr. G. M. Schwartz for the U. S. Geological Survey. According to a preliminary report a close relationship is indicated between the rock alteration and the primary sulfide mineralization. The effects of this alteration decrease outward from a center of greatest intensity. Several types of alteration have been recognized and a considerable number of clay minerals observed. The ore body appears to occupy a definite position in the pattern of hydrothermal alteration of the surrounding rocks.

In association with J. L. Kulp, C. M. Patterson and R. J. Wright and through the cooperation of several mining companies, the speaker has recently had an opportunity to study the relationship of alteration to ore deposition in the vicinity of Santa Rita, near Silver City, New Mexico.

The general geological relationships of the Santa Rita area are well known through the works of a number of excellent contributors. Topographic maps on a scale of 100 and 200 feet to the inch were furnished by the Kennecott Copper Corporation, the Empire Zinc Co., and the American Smelting and Refining Co. Many thousands of feet of diamond drill cores were available for inspection.

Field studies show that the alteration at Santa Rita followed the intrusive stock, was contemporaneous with some of the intrusive dikes and continued into later Tertiary time. Clay minerals are widely distributed through the various intrusive rocks of the district. They occur in dikes which accompany zinc ore bodies, in more or less horizontal intrusive sheets which are widely distributed, and in parts of a granodiorite porphyry intrusive. To date the relationship between the clay alteration and copper deposition is best understood. Certain of the alteration zones in the porphyry stock, correlate with reasonable accuracy with ore zones in the open pit copper mine at Santa Rita. This correlation has been of considerable interest and has provided stimulation to laboratory studies which are now in progress.

At Gilman, Colorado, the geological staff of the Empire Zinc Co., under the direction of Mr. S. E. Jerome, has been engaged for some time in the examination of the clay minerals and other alteration effects which occur in the Gilman porphyry. The bulk of this work has been carried on by Mr. Richard Bogue of the local staff. The Gilman porphyry forms a sill some fifty feet thick which extends for a goodly number of miles laterally. In places zinc ore bodies have been found in the limestone below the sill. As a result of the alteration studies it seems clear that the clay minerals of the sill are hydrothermal in origin even under near surface conditions. In general, the intensity of alteration may be shown to be greatest in the vicinity of known ore bodies. In a mineral suite which comprises at least a dozen species, sericite, hydromica, kaolinite and dickite have been selected as furnishing the best index to the progress of alteration. These minerals are found in both the groundmass and the oligoclase phenocrysts of the porphyry, but most consistent results have been obtained where the progress of alteration has been interpreted from the destruction of the phenocrysts. The altered phenocrysts when studied statistically appear to indicate zones which in general are related to ore deposition. The Gilman studies although incomplete provide further confirmation of the significance of clay mineral alteration in connection with ore deposition.

The time has not arrived when one may correctly evaluate the implications of alteration studies. To date the results have more than justified the effort they have entailed and one may predict that the future will witness a much more intensive study of rock alteration than the past.

A most important aspect of these studies will be a closer coordination between field and laboratory than has previously existed. Although no one can foresee the ultimate outcome, it is clear that at least one better illuminated avenue has been found along which to approach the problem of replenishing mineral reserves. The same science of mineralogy which has yielded its scientific lore so generously in the years just past, bids fair to continue to do so.

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