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DISCUSSION

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

MAGMATIC DIFFERENTIATION A FACTOR IN THE OCCURRENCE OF ORE-SHOOTS.

While engaged in the examination of various mines, in the Pachuca (including Real del Monte) district, Hidalgo, Mexico, it appeared to the writer that the occurrence of the ore-shoots was closely associated with certain phases of the country rock and that these phases were the result of magmatic differentiation.

It is the purpose of this paper to give in a general way the data upon which this opinion is based. As the mines were examined while under professional engagement I do not, at the present time, feel at liberty to go into any detail concerning them.

Briefly the geological sequence of the district may be outlined as follows:

1. The most recent sedimentary rocks in the district belong to the Cretaceous period.

2. The Cretaceous rocks were penetrated by large intrusions closely related to andesites. These intrusions occur as large elliptical dome-shaped masses striking northwest-southeast. Their exposures are from ten to eighteen miles long, from eight to twelve miles wide and they probably have a much larger extent.

The ore-bodies of the Pachuca and of the Real del Monte districts occur within one of these dome-shaped masses. A consideration of the macroscopic and microscopic characteristics of this intrusion and the association of the known ore-bodies of the district with certain phases of the intrusion will constitute the essential features of this communication.

3. A period of erosion during which the contour of the andesite porphyry was changed.

4. The introduction of a later andesite (very acidic) which occurs as flows and rests uncomfortably on the earlier andesite. Inasmuch as these later andesites are in no way associated with the ore-bodies of the district they will not be further considered.

5. A second period of erosion during which large areas of the later andesite were eroded again exposing areas of the andesite porphyry domes.

6. The introduction of a series of rhyolite flows which partially covered both the later andesite flows and the primary andesite masses. These rhyolites are in no way related to the ore-bodies of the districts and will not be considered further.

7. A third period of erosion which exposed large areas of the andesite flows and of the primary andesite domes. During this period there were many intrusions of quartz-porphyry dikes which cut both the andesites.

8. A period of areal faulting when the veins of the district were formed. This faulting was probably due to subsidence and adjustment caused by the large primary andesite-porphyry intrusion cooling at depth. During this period fissures were formed, rock between the walls was brecciated and there was a heavy silicification but practically no economic values were brought into the veins. It was essentially a period of fissuring, brecciation and silicification.

9. A second period of faulting with movements, relatively, much less than during the former period. It was during and immediately subsequent to this secondary faulting that the veins received their commercial values. During the period the economic values were being deposited; there was some silicification but, relatively to the primary silicification following the primary faulting, it was slight.

10. Erosion and a few minor faults.

As studied in the field the andesitic dome-shaped mass, in which the ore-bodies occur, is not homogeneous. For the most part the color is a light grayish-green, the rock is porphyritic and breaks irregularly. Here and there within it there are variations. These variations in the extreme cases have a dark reddish-brown to a dark-greenish color, break with a conchoidal fracture, are porphyritic and very tough. Whereas the predominant, or lighter hued types average approximately 65.0 per cent. of silica, the dark-colored variations are more basic, averaging only a few tenths more than 60.0 per cent. of silica. Where observed over the surface and in the various workings, between the two types, there is no definite dividing line—the one imperceptibly graduates into the other. Within the predominating or acidic phase the basic occurs in the most irregular manner. In many cases its occurrences are roughly lenticular; strike in any direction and dip at any angle. In extent these somewhat lenticular masses vary from a foot in diameter up to masses several thousands of feet long, several hundreds of feet wide and two have been proven to a continuous depth of eighteen hundred feet. In some places the two phases irregularly alternate, both horizontally and vertically, with each other. In these particular instances either type may predominate.

Operations in the Pachuca district have demonstrated that the tough basic phases are not favorable for the formation of ore and that all the large ore-bodies are found in the acidic types. Thus from an economic standpoint it was necessary to determine whether these variations belong to a single mass with many differentiation facies, or, whether on the other hand, they are each separate units of structure occurring as dikes, sheets or flows. In the field, the most careful scrutiny failed to find more than one recognizable division and all observations indicated that the two phases are simply differentiations of a common magma. For petrographic study a series of specimens illustrating the range of field appearances were submitted to Dr. Charles P. Berkey, of Columbia University, who has communicated with me regarding them as follows:

The acid type is plainly a porphyritic rock with a groundmass of somewhat trachytic habit composed chiefly of medium plagioclase. The groundmass is never coarse and the fluxion structure, which is rarely present, is never strongly developed. The phenocrysts are also chiefly medium plagioclase, with an occasional chloritic area representing original ferro-magnesian minerals while rarely a very badly corroded quartz is to be seen. These last are always mere skeletal remnants indicating severe attack upon them in the final magmatic changes. The usual accessory constituents are present.

Secondary products are abundant chief among which are carbonates (probably calcite), chlorite, epidote and secondary quartz. There is no complicated history indicated except the small traces of fissuring represented by minute crevices and a chemical attack represented by the greenish and uniformly distributed secondary products. There is a little pyrite mineralization in rather large grains.

The basic type is also plainly porphyritic in habit and both groundmass and phenocrysts are chiefly plagioclase of medium composition. In this type, however, the ferro-magnesian constituents are noticeably more abundant. Derivatives from hornblende, augite and possibly biotite and olivine are present. Much more rarely than in the acid type a skeletal remnant of quartz may be found. Some specimens show fluxion structure but in most cases this is obscure.

Secondary products are abundant, the most common being carbonates and chlorite. There is very little epidote and quartz. Very minute crevices rehealed with calcite occur as in the other type.

This rock has had the same history as the more acid variety.

The two types differ most on the following points. The acid rock has more original hornblende, less pyroxene and less secondary chlorite. These differences are consistent with the known chemical difference of 5.0 per cent. of silica. There are no strikingly unlike varieties. The great similarity of composition, texture and alteration in each type leads readily to the belief that they are all representatives of a single parent magma and that they probably represent a single parent mass. Even the extreme acidic and basic types have no differences of large consequence and are consistent enough with the differentiation of a single mass.

The most inconsistent features for so large an intrusive mass are texture, the persistent porphyritic habit and the occasional fluxion structure. In spite of these, however, there is no reliable ground for regarding the whole series as anything other than a magmatic differentiation. While the extremes of the series are noticeably unlike, any two adjacent ones are almost identical in all essential respects.

Regarding the rocks therefore as intrusive, the term andesite is not strictly appropriate for their classification. Nor is diorite very suitable for a porphyritic rock of this character. In order to indicate as fully as possible the field relation and the slight mineralogic differences, the acid type may be called a quartz andesite porphyry or a dacitic porphyrite and the basic type may be called a medium andesite porphyry or a hornblende pyroxene porphyrite.

CHARACTER OF THE VEINS.

The veins are not simply fissures filled with silica and economic minerals but in a general way may be described as crushed zones varying from a few feet up to forty or fifty feet in width. In some instances both footwall and hanging-wall are clearly defined. In many places there is no observable dividing line between the ore-body and the wall-rock and the limits of economic ore can be determined only by sampling.

During the period of vein formation there were at least two distinct movements.

1. A primary movement which crushed and brecciated the rock along the zone of faulting. This primary movement was followed by the introduction of solutions which were highly silicious. The silica formed vein material in two ways: (*a*) It attacked the crushed and brecciated rock replacing it metasomatically. (*b*) It deposited in the openings around the breccia and more or less cemented them together. Little, if any, economic values were associated with this primary movement. It was essentially a movement of crushing and silicification.

2. A secondary movement for the most part within the zone of the primary crushing. There was, relatively, far less displacement during this secondary movement than during the first. The rock broken by the primary movement and more or less cemented by silicification was again broken—silicious solutions again permeated the breaks but, relatively to the primary, this secondary silicification was very slight. It was during this secondary silicification that argentite, the principal economic mineral, was brought into the veins and deposited.

Since the deposition of economic values was subsequent to the secondary fracturing, it is patent that the occurrence of ore is closely associated with the character and the intensity of the secondary fracturing. Where the primary fault broke through a basic phase of the rock, the crushing was not as intense as within the acidic—the brecciation units were larger. Further, the basic phase was not so susceptible to metasomatic silicification as the acidic. The replacement did not penetrate the breccia units so deeply nor was the metasomatism nearly so complete—the altered portion being a tough, so called, bony-quartz rather than a typical friable quartz which latter type characterizes the metasomatic product of the acidic phase of the rock. This tough bony-quartz when cemented by further additions of silica rendered this portion of the vein firmer and tougher than the country rock so that when the secondary movement occurred, instead of a distributive crushing movement over the entire breadth of the vein which would reopen the original zone of fracturing for its whole width, there was more or less of a gliding movement over a very narrow width. In many places where the original fracturing passed through a basic phase of the rock the secondary movement did not maintain within the vein *per se,* since, the movement left the vein and closely followed either the hanging or the foot-wall, the residual effects being now manifested in a narrow gouge streak with practically no values. In other instances the secondary movement did pass through this tough tightly cemented portion of the vein but always as a very narrow irregular fracture. For the most part these narrow fractures are well mineralized with argentite but the width is by far too small to even approximate pay ore. Thus, where the vein passes through a basic phase of the rock, it is as wide and the quartz is as pronounced as where it passes through the acidic phase but economic values are not found.

The acidic phase of the rock on the other hand was more amenable to crushing than the basic and with the primary movement freely brecciated leaving many and in some instances large cavities. It was more susceptible to silicification than the basic. Large brecciation units were completely replaced and the metasomatism was for the most part very pronounced, the final product being a friable quartz. In many places there was insufficient silica to completely fill the spaces between the brecciation units.

Thus where the vein passed through the acidic phase of the rock, the primary crushing and silicification did not leave it as tight and tough as where it passed through a basic phase, consequently, when the second movement occurred this portion of the vein was not in a condition to resist fracturing but moved and crushed throughout its entire width and opened up so as to afford passages for the introduction and deposition of economic values.'

Thus it would appear that for this particular district the occurrence of the ore-shoots is closely associated with a certain differentiation phase of the original magma. In this particular instance the favorable phase is the more acidic facies. The difference in the amenability of the two phases of the rock, where all general conditions are the same, for the formation of economic ore (ore-shoots) is due to the fact that the one phase is more easily fractured than the other and also that the same phase is more susceptible to silicification. The occurrence of the ore-bodies is essentially the resultant of two variable factors—the one physical—the other chemical and thus it is probable that in other districts ore-shoots may be found associated with a basic phase of the country rock while the acid facies is found to be unfavorable.

In the district under consideration there were two periods of movement and silicification and the primary silicification was one of the most important features which determined the limits of pay ore. In a great many districts, however, there has been for all practical considerations only one period during which there was movement and mineralization. In many such cases, although the line of fracturing maintains for considerable distances, yet, economic ore-bodies or shoots are restricted to one or more, relatively, quite short distances. In many such occurrences the writer has observed that along the strike of the fracturing the country rock varies—that within certain phases the movement was restricted to a narrow impervious gouge streak—that within other phases the movement was distributive over a more or less considerable width—that within this width the rock was brecciated leaving spaces for the introduction and deposition of mineralizing solutions and that the occurrence of the ore-shoots is closely associated with a certain differentiation phase of the country rock.

That the final products of magmatic cooling are rarely homogeneous but present, even within quite restricted areas, marked differentiation is recognized by all field-workers. Thus with granites we may have a feldspar—a hornblende—a quartz—or even a mica facie forming a differentiation within the more normal and predominating type. Similarly in other igneous rocks we frequently find one of the essential minerals so abnormally abundant as to form a facie which differs more or less from the predominating phase. In most instances where there has been segregation during cooling the differentiation facies, because of pronounced differences in the color or size of the essential minerals, are readily distinguished in the field. On the other hand, there are instances of differentiation which are not so readily identified since the essential minerals are of approximately the same appearance and the differentiation phases can be appreciated only by a petrographic examination of a representative series of specimens.

That an appreciation of magmatic differentiation as a factor in the occurrence of ore-shoots can be of economic importance was recently demonstrated by the writer in Arizona. At the locality under consideration the predominating rock in the field presents a greenish to light-green groundmass containing numerous whitish feldspar phenocrysts. Inclosed in this greenish portion, the one imperciptibly graduating into the other, are irregular dark bodies with a dark groundmass containing somewhat glassy feldspar phenocrysts. The light-green variety was found to contain 44.5 per cent. of silica and the dark 54.5 per cent. A petrographic study of representative specimens of the two varieties was made by Dr. Berkey. A summary of his conclusions is as follows: The specimens are both to be regarded as andesites. There is not a sufficient difference in their mineralogical composition or habit to separate them as distinct types and there is nothing to indicate that they are not differentiation phases of the same magma.

Inasmuch as the dark-hued acidic variety is the less abundant it may be regarded as a differentiation phase from the more predominant, more basic, light-green variety.

At the property, where the above observations were made, the developed ore occurred in a well-defined shoot and this shoot was found to maintain within the vein where the faulting crosses a dark acidic differentiation phase of the andesite. So pronounced is the differentiation that locally it is referred to as a dike and the vein is said to make ore where it crosses the dike. Along the vein, south from the ore-shoot, the rock within a distance of twenty feet changes from a pronounced phase of the acidic type to the basic and within this distance values lessen from good pay ore to practically nothing. Going north from the recognized ore-shoot for several hundred feet the two facies irregularly alternate—the basic phase predominating. Within this distance development showed a few small widely separated bodies of ore. Beginning at a point about 700 feet north of the ore-shoot and extending for many hundreds of feet further the extension of the vein is covered with wash. Some little distance north of where the wash begins to cover the vein and about 100 feet west of the axis of the strike, there is a prominent exposure of the acidic (ore-bearing) phase of the andesite. The boundaries of this differentiation mass are ill-defined but it appeared that it would extend across the vein. Having already recognized the association between the developed ore-shoot and the acidic phase of the andesite the writer expressed the opinion that this portion of the vein, although covered with wash and far beyond demonstrated ore, would be found to carry pay values. Subsequent work corroborated the opinion.

Ore-bodies have been described as "the resultant of a number of fortuitous circumstances" and it is the opinion of the writer that magmatic differentiation, perhaps more than has been appreciated, is one of the factors which frequently plays an important rôle in the formation of ore-shoots.

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