IGNEOUS ASSIMILATION AND ASSOCIATED CONTACT METAMORPHISM IN THE VIRGINIA MINING DISTRICT, NEW MEXICO*

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ABSTRACT

The rocks of the Virginia mining district consist chiefly of basalt of Comanche (?) age intruded by late Cretaceous or early Tertiary granodiorite. The granodiorite generally has a dark border, as much as 20 feet thick, that contains much augite as well as a more calcic plagioclase and a great deal more magnetite than the main mass. The differences are interpreted as being the results of partial assimilation of the adjacent basalt, in accordance with Bowen's reaction principle. In addition, the basalt adjacent to the contact, in a zone as much as 15 feet thick, is metamorphosed to a rock that mineralogically is similar to the invading granodiorite. The metamorphism is believed to have taken place at a period slightly later than the stage of magmatic assimilation and to have been in general accord with the reaction principle.

INTRODUCTION

The Virginia mining district is in Hidalgo County, southwestern New Mexico, and occupies the northern part of the Pyramid Mountains, one of the isolated desert ranges typical of the Mexican Highland of the Basin and Range province. (See figure 1.) An investigation of the geology and ore deposits of this district was made by the writer during parts of 1931 and 1933 for the United States Geological Survey in cooperation with the New Mexico Bureau of Mines and Mineral Resources, and this paper describes some of the features observed. A detailed report on the district is in preparation.

The rocks of the Virginia district consist chiefly of basalt flows and associated intrusive plugs of volcanic breccia and of rhyolite, of Comanche (?) age, all intruded by a stock of porphyritic granodiorite. Figure 2 shows the areal distribution of the different rocks. The basalt occupies most of the area and extends southward under the Tertiary volcanic rocks that form the main part of the Pyramid Mountains. The base of the basalt is nowhere exposed, though the workings of one mine penetrate it vertically over 2,000 feet. The granodiorite is an irregular, horseshoe-shaped mass that has an exposed area of about 10 square miles. Outliers, generally close to

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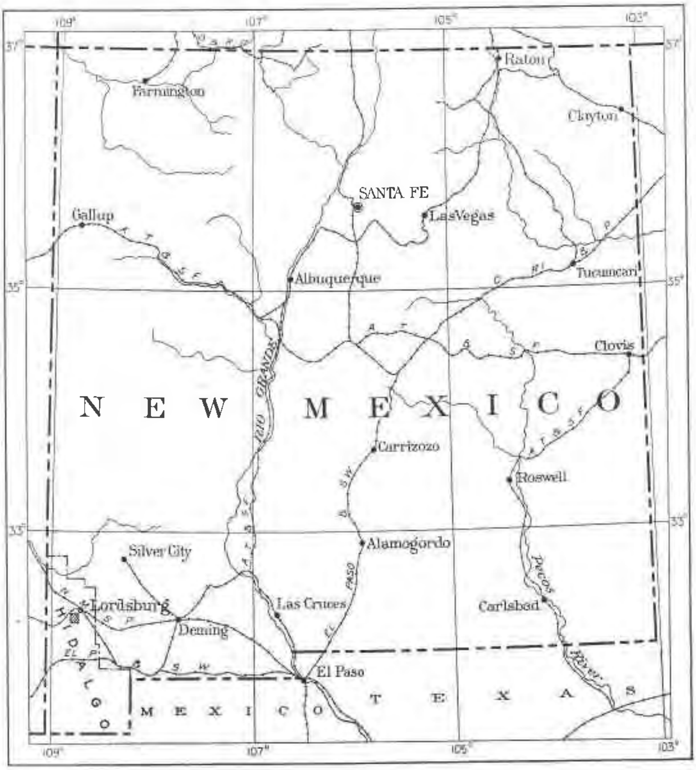

FIG. 1. Map of New Mexico. Shaded area shows location of the Virginia mining district, in Hidalgo County.

the main mass, are common and suggest that the stock may be appreciably larger at no great depth. The cover has been barely removed from the northern part of the stock, and the present topography in that part is very much like the original upper surface of the intrusion.

PETROGRAPHY

NORMAL ROCKS

Basalt.—The basalt is a soft, easily eroded rock that breaks into small angular pieces. It tends to be greenish in surface exposures but is dark gray to black as viewed underground. It is commonly aphanitic to faintly crystalline and contains a few phenocrysts of colorless augite, generally less than a millimeter long, in a groundmass that consists of a felt of labradorite laths (about An_{60}) among

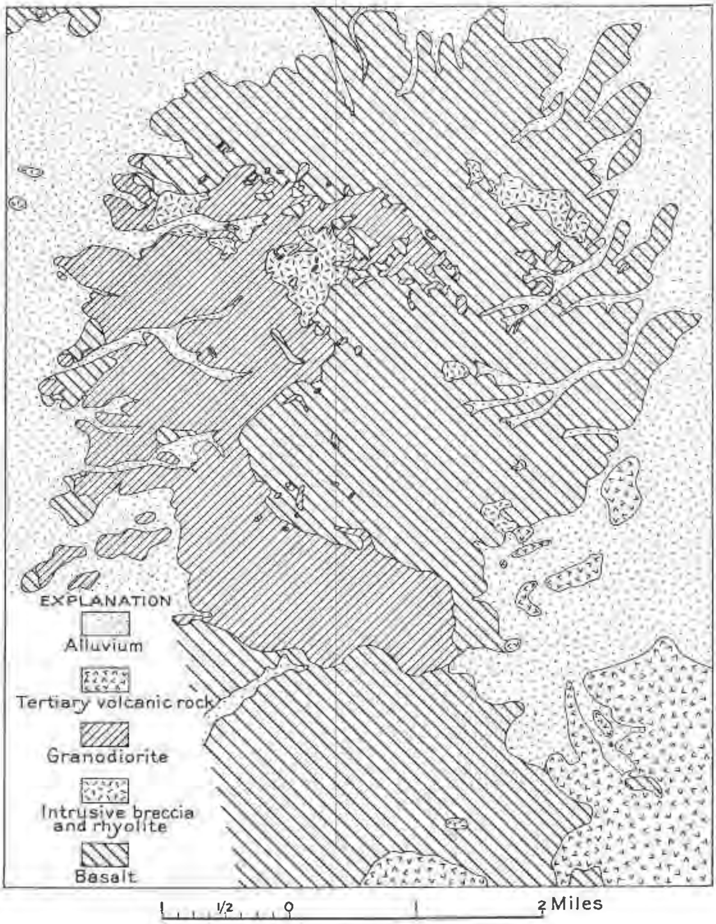

FIG. 2. Map showing areal distribution of major rock formations of the Virginia mining district, New Mexico.

which are scattered minute grains of augite and subordinate magnetite. The average composition is estimated to be about 50 per cent of feldspar, 35 per cent of augite, and nearly equal amounts of glass and magnetite.

Granodiorite.—The granodiorite is fairly uniform in texture and appearance throughout the main part of the mass. It is decidedly pink and contains as much as 40 per cent of plagioclase phenocrysts (about An_{30}), ranging from 1 to over 5 millimeters in length, a few phenocrysts of orthoclase, and several per cent of hornblende and biotite in a granitic intergrowth of quartz and pink orthoclase, which are present in nearly equal amounts. Magnetite, titanite, apatite, and zircon are the accessory minerals. The magnetite is derived in part from resorbed and altered biotite and hornblende. The rock appears more porphyritic in thin section than would be supposed from the hand specimen.

Border-zone Rocks

Granodiorite.—Locally at the borders of the stock, in a zone that ranges from a fraction of an inch to 20 feet in thickness, the granodiorite is much darker and is finer-grained than the normal rock. It is generally porphyritic, containing small phenocrysts of plagioclase and locally of ferromagnesian minerals. Quartz and orthoclase, one or both, are prominent at some places but scarce at others. Augite is present, ranging from a trace to about 15 per cent, as well as much more magnetite than characterizes the pink granodiorite. The augite seemingly is in two generations (as phenocrysts and in the groundmass), as in the basalt, and some of it is partly replaced by hornblende. The feldspars in some specimens

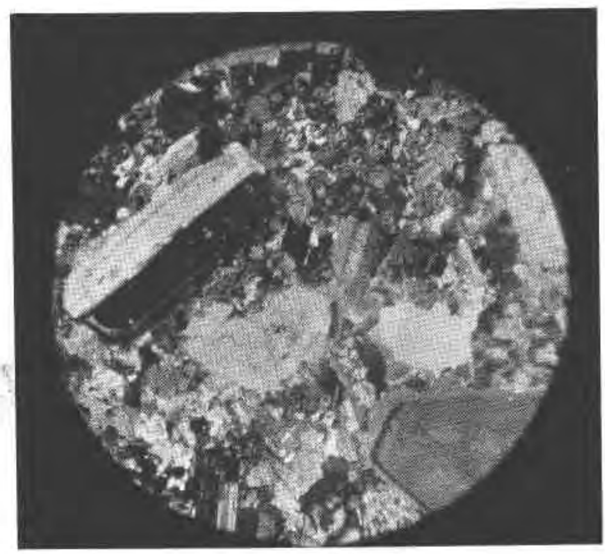

Fig. 3. Photomicrograph of dark granodiorite adjacent to included fragment of basalt. Nicols crossed. Shows zoning of the plagioclase in a single narrow band near the periphery of the crystals. Magnified 28 diameters.

contain included grains of augite, and in all specimens examined the plagioclase is about 10 per cent more anorthitic than in the main part of the stock. This basic border has been observed only where the granodiorite is in contact with basalt.

One specimen of granodiorite was collected that contained small inclusions of basalt only an inch or two across. The granodiorite adjacent to the inclusions, the contacts of which range from sharp to gradational, contains 5 to 10 per cent of augite, seemingly in two generations, as in the border rock and as in the basalt, and the plagioclase is zoned, the zoning in most crystals consisting of a single narrow calcic band near the edge of the crystal. (See figure 3.) The core and the periphery seem to be of about the same composition (An_{29}) as the plagioclase in the normal granodiorite; the calcic band is about An_{40}, the same as the plagioclase in the border facies.

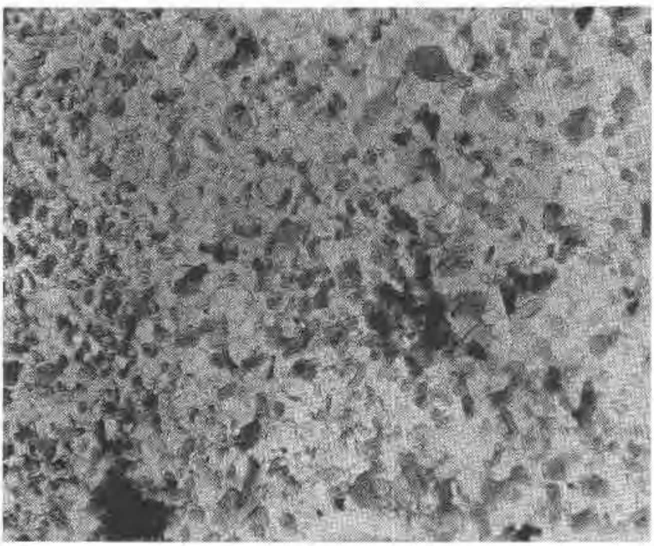

FIG. 4. Photomicrograph of metamorphosed basalt. Plain transmitted light. This rock originally was the same as that shown in figure 5. The abundant small dark crystals are crystalloblasts of biotite. The rest of the rock consists of a very fine-grained aggregate of orthoclase, plagioclase, and quartz. Magnified 56 diameters.

Basalt.—At those places where the granodiorite is marked by the dark border, the adjacent basalt for a distance of about 15 feet or less differs considerably from the average rock. It is more coarsely crystalline and contains as much as 30 per cent of minute idiomorphic crystals of biotite and a few cumulophyric aggregates of the same mineral in a very fine-grained mosaic of orthoclase, oligoclase (An_{28}), and subordinate quartz. The original augite of the rock is represented by fibrous uralite, with which is usually associated a little magnetite. Figures 4 and 5 show the contrast between the original basalt and the metamorphosed rock. Other parts of the rock in the narrow alteration zone show an intermediate stage of modification; the augite is converted to an aggregate of pale-greenish fibrous amphibole, and the surrounding feldspathic groundmass contains patches and grains of orthoclase and quartz that appear to corrode the original material. The altered rock in this zone contains indistinct veinlets of orthoclase, quartz, and biotite and also larger irregular patches of the same material as much as an inch in diameter, and specimens of basalt containing metasomatic crystals of orthoclase and clusters of orthoclase and quartz have been collected 90 feet from any visible granodiorite contact.

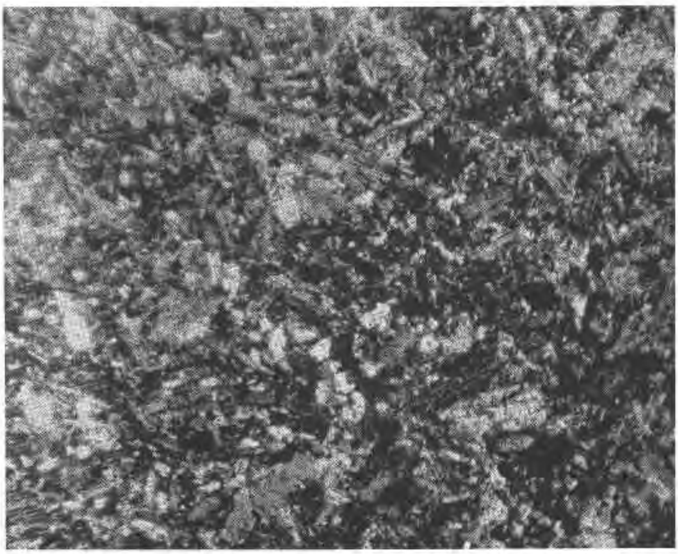

FIG. 5. Photomicrograph of the average basalt of the Virginia district. Nicols crossed. This photograph is in focus and shows the indistinctly crystalline felted intergrowth of the feldspar laths. Magnified 56 diameters.

At many places the weathered border-zone basalt is hardly distinguishable from the adjacent border-zone granodiorite.

DISCUSSION AND CONCLUSIONS

Changes in the Granodiorite

Three hypotheses have been advanced by petrologists to explain basic borders—that they originate (1) as the result of differentiation in place; (2) as a frozen sample of the original magma; and (3) as the result of assimilation of adjacent rock. The first two hypotheses seem to have nothing to recommend them in the Virginia district. On the contrary, they are actually opposed by some of the evidence. The basic borders have been observed only where the granodiorite is in contact with basalt, yet there would seem to be no reason why, under either of the first two hypotheses, there should not be a similar border against the intrusive rhyolite as well. Furthermore, there are thin basic borders against inclusions only an inch or two across, yet such small inclusions would hardly be expected to exert the degree of thermodynamic control required by both hypotheses. On the other hand, the differences between the basic border and the main mass seem to conform nicely with what would be expected from a partial assimilation of the adjacent basalt in accordance with Bowen's reaction principle.[1] According to this principle, foreign inclusions of augite and labradorite dropped into a magma from which hornblende and oligoclase were being precipitated would react with the liquid of the magma and would be converted into the minerals with which the liquid was saturated—the augite into hornblende, the labradorite into oligoclase. On casual consideration there seems to be a discrepancy between this expected ideal and the fact that the new plagioclase in the hybrid granodiorite of the Virginia district is more calcic than the plagioclase of the original granodiorite magma. But this discrepancy is apparent only. The composition of the plagioclase that is formed after equilibrium is reached depends upon the temperature, and the more calcic nature of the new plagioclase implies, therefore, a temperature increase in the border zone. Normally this may not be expected, but Bowen stresses the fact that reactions such as the conversion of labradorite to oligoclase and of augite to hornblende would yield heat

[1] Bowen, N. L., The evolution of igneous rocks, pp. 54–62; 173–223, Princeton Univ. Press, **1928.**

to the system, and that if the withdrawal of heat were very slow these reactions "might result in actual rise in temperature and the establishment of equilibrium at a higher temperature where the plagioclase crystals would be more calcic."[2] The presence of plagioclase of composition An_{28} in the adjacent metamorphosed basalt would seem to indicate that the temperature there was close to that in the granodiorite—a condition that would have delayed withdrawal of heat from the assimilation zone.

Where only small inclusions of basalt were assimilated, the change in the composition of the new plagioclase was only temporary. In the specimen described above, which contained the zoned feldspar, the pieces of basalt were engulfed after crystallization of the normal plagioclase (An_{30}) had started. When assimilation began, a calcic border (An_{40}) was built upon the sodic nuclei. As the foreign lime was consumed the plagioclase gradually became more sodic, and the final material consisted again of the plagioclase characteristic of the unmodified granodiorite magma. The evidence verifies Bowen's prediction that the addition of foreign inclusions more calcic than the material in equilibrium with the liquid might result in a reversal of zoning.[3]

A second interesting feature is the complete assimilation of the plagioclase of the basalt as contrasted with only partial destruction of the augite. A fundamental part of the reaction principle is the idea that minerals early in the reaction series can be converted to minerals later in the series only by precipitation of large quantities of those minerals with which the reacting liquid is saturated, and that the degree of conversion, or "assimilation," depends upon the amount of liquid available. Bowen stresses this idea strongly, and in illustration he discusses in detail situations in which forsterite is added to the system anorthite-forsterite-silica,[4] a system analogous to the natural system under discussion. In some situations the forsterite is assimilated completely, being converted to clinoenstatite as the liquid cools, but in others the liquid is exhausted before the forsterite is consumed, and the final mass consists of clinoenstatite, forsterite, and anorthite, the forsterite being "strewn about," to use Bowen's words, just as the partly assimilated augite grains are strewn about in the granodiorite of the

[2] Idem, pp. 187–188, 196.
[3] Idem, p. 188.
[4] Idem, pp. 194–195.

Virginia district. Assimilation of the augite and labradorite of the basalt could have taken place only if accompanied by precipitation of large amounts of plagioclase and hornblende, with which the reacting liquid was saturated, and we need conclude simply that the liquid was exhausted as the result of this precipitation before the augite was assimilated completely but not before the labradorite was. Many individual grains of augite could have been assimilated fully, and there would be nothing to indicate the fact. The small amount of augite in the hybrid granodiorite as compared with that in the basalt supports this suggestion.

Metamorphism of the Basalt

The crystalloblastic biotite-bearing rock is presumably a contact-metamorphosed basalt to which soda, potash, and silica were added. The changes that took place were evidently in general accord with the principle of reaction and were similar to those that occurred in the assimilation zone of the granodiorite, the tendency having been to convert the basalt into a rock like the granodiorite. The pyroxene was changed to amphibole, the plagioclase to less calcic plagioclase, and in addition biotite, orthoclase, and quartz were formed. The reactions are not considered as having been necessarily a continuation of those in the granodiorite, for it seems hazardous to assume that a reaction series can be carried from the complex but closed system of the magma into the independent and more complex open system of escaping emanations. As stated by Fenner,[5]

> According to a simple principle of thermodynamics, in a system consisting of solid, liquid, and gas, if the solid and liquid are in equilibrium, also the liquid and gas, then the solid and gas must be in equilibrium. It follows directly from this that if we have a fluid magma through which gases are rising, and if these gases form volatile compounds with the mineral matter of the magma or bring it into the gaseous condition in any manner, then (provided that there is equilibrium) any minerals crystallizing in the liquid portions of the magma will have their counterpart in minerals depositing from the gases at the contact. . . .
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> With reference to actual magmas and the minerals formed by gases escaping from them, these principles have important applications. It is apparent that modifications of the ideal system are required, but there should be a strong tendency to reproduce in the contact rocks the same minerals that are crystallizing in the magma

[5] Fenner, C. N., Ore deposits of western United States: *Am. Inst. Min. and Met. Eng.*, pp. 80–81, **1933.**

Geologists do not agree on whether metamorphism is produced by gases or by liquids, but Fenner's conclusions would apply equally well for either.

The addition of soda, potash, and silica to the basalt suggests that the metamorphism occurred after the granodiorite had passed the plagioclase stage of pyrogenic crystallization—that is, at a period slightly later than the stage of magmatic assimilation of the basalt. If albite had been formed, or if there were any albitization of the oligoclase or of the original labradorite, there would be little reason to hesitate in accepting this suggestion and concluding that the metamorphism had taken place at a very early hydrothermal stage. That conclusion seems to be the most plausible for the general situation, regardless of the calcic nature of the new plagioclase, which may well be the result of a temperature control. It is necessary to assume only that the narrow zone in which metamorphism occurred had been heated to the approximate temperature of the adjacent magma before the altering emanations escaped.

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