

A NOTE ON THE PROBABILITY OF ASSIMILATION OF ROCKS
INTRUDED BY THE CENTRAL ARIZONA DIABASE

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Speculation as to the reasons for locally missing volumes of Precambrian rocks in the stratigraphic section occupied by the extensive Arizona diabase can benefit from some fundamental concepts clearly set forth by N. L. Bowen (1929) in his discussion of the reaction principle. Arguments have been presented for and against large scale assimilation by the diabase of two widespread units, the Troy quartzite and the Mescal limestone. Certainly protagonists of large-scale assimilation would find in this process a satisfactory explanation to a perplexing fact, viz., the absence of volumes of Precambrian to Cambrian rocks whose normal stratigraphic position is now occupied by the intruded diabase.

James Sell in the preceding paper has presented arguments against the concept of wholesale assimilation of Troy quartzite through comparison of chemical analyses of rocks on either side of contacts between diabase and the Troy formation. It is the purpose of this note to point out some pertinent general considerations which also argue against large scale assimilation by such a magma intruding rocks of the kind under consideration.

In developing this concept, reference will be made to the phase equilibrium diagram of a simple, well known binary silicate system in which complete solid solution occurs--the system $\text{NaAlSi}_3\text{O}_8$ - $\text{CaAl}_2\text{Si}_2\text{O}_8$. (N. L. Bowen, Am. Jour. Sci., 4th Series, Vol. 40, 1915). The complexities of a magma of the kind from which the diabase crystallized obviously must have been considerably greater. The fundamental principles elucidated by Bowen should nevertheless apply. The principles reviewed here are taken from Bowen (1928).

Referring to the diagram (Fig. 1), let us assume a liquid of composition "X" ($\text{Ab}_{50}\text{An}_{50}$) of such temperature (1450°C) as to be just on the liquidus, i. e., just saturated and having no superheat. This liquid is in equilibrium with calcic crystals of composition $\text{Ab}_{20}\text{An}_{80}$ (point Y on diagram). With decreasing temperature the plagioclase crystals being precipitated, in order to stay in equilibrium with the liquid, will react with the liquid by ionic diffusion and change composition along the solidus, becoming progressively more sodic until the final composition of the solid phase is that of the initial bulk composition. The composition of the liquid must change accordingly, and does this by moving along the liquidus from point X toward point Z, which represents the composition of the last drop of liquid in the system.

The only effect produced by the addition to the system of crystals of the same composition $\text{Ab}_{20}\text{An}_{80}$ as those in equilibrium with the originally assumed liquid would be to achieve the completely solid state at a somewhat higher temperature. That is, the added crystals would react with the liquid in exactly the same manner as the crystals initially precipitated from the liquid.

If, however, we were to add to a melt of the composition assumed, plagioclase crystals of composition more calcic than those with which the melt at 1450°C . is in equilibrium, say, $\text{Ab}_{10}\text{An}_{90}$, (C, Fig. 1) which are at the same temperature as the liquid, the system will be in disequilibrium. The liquid cannot melt the crystals because their melting point is higher than the temperature of the liquid. A reaction will take place, however, between the initial liquid of composition $\text{Ab}_{50}\text{An}_{50}$, and foreign crystals of composition $\text{Ab}_{10}\text{An}_{90}$ in an attempt to reestablish equilibrium. If the reaction is assumed to be adiabatic, there will be a temperature rise as crystals precipitate, liberating their latent heat of crystallization. These crystals, which are in equilibrium with the liquid, will become progressively more calcic as their composition moves

toward the new bulk composition (about $Ab_{17}An_{83}$, or Ab_1An_5 , point D, Fig. 1). The composition of the liquid will change sympathetically and move up the liquidus until equilibrium is established. The reaction is exothermic. The composition of the introduced crystals will be changed by reaction with the liquid to become more sodic.

If the reaction progresses isothermally, equilibrium will be attained only when the introduced crystals have reacted with the liquid until they are in equilibrium with it. The compositions of crystals and liquid in equilibrium with the new bulk composition are shown at about E and F, Fig. 1, when crystallization is completed. Equilibrium will theoretically be attained at a temperature somewhat above point E.

Assume that we add to a melt of composition $Ab_{33}An_{67}$ (Ab_1An_2), crystals of composition $Ab_{67}An_{33}$ (Ab_2An_1) at a temperature sufficiently low so that the latter are solid.

Again, the system is out of equilibrium and the composition of the liquid must change to be in equilibrium with crystals at a new bulk composition. The composition of the introduced crystals is now toward the low melting point end of the albite-anorthite series so that the more calcic liquid has the capacity to melt them. The temperature of the melt will be lowered by this action, necessitating the crystallization of plagioclase. Latent heat of crystallization is thus made available to heat up the "foreign" feldspar crystals to their melting point and to melt them. The amount of heat given off on crystallization is very large compared to the specific heats of silicates, so that relatively small amounts of crystals need be formed to supply the heat necessary to warm up the foreign crystals. The quantity of heat necessary to melt the introduced crystals will require that an amount of plagioclase be precipitated that is approximately equal to the amount melted, because latent heats of fusion and crystallization of the two silicates are approximately equal. This process would bring about the rapid crystallization of plagioclase of composition more calcic than the foreign crystals; the system would rapidly run out of energy, and the reaction is endothermic. Naturally the composition of the crystals forming is affected by the progressive change in composition of the liquid as foreign crystals are melted.

The principles developed by Bowen with respect to this simple system are general and may be extended to more complex, multicomponent systems. Further, theoretical considerations born out by field observations, many examples of which are in the literature, corroborate them. As a consequence, we may generalize and make the following statements with respect to the kinds of reactions expected when a magma intrudes country rock, and note some effects one might expect to observe at and near the contacts between the two.

1. If a magma were to invade a rock which has a more mafic(basic) bulk composition than itself, the reaction between the two would be exothermic. One might expect to observe profound effects of corrosion at the margins of the invaded rock together with signs of reduction or breaking up of the rock as if some constituents had reacted with the melt and been eaten away. Reversed zoning of silicates would be expected if reactions were not complete. If assimilation of the wall rock by the magma were extensive, and diffusion and convection within the magma limited, one might expect that there would be rather gradual graduations between the "uncontaminated" rock crystallized from the magma and the unaffected invaded rock. The extent to which the magma could react with the wall rock would depend, in large part, on the degree of facility with which it could become insinuated into the wall rock. Thus, the degree of fracturing of the wall rock would be an important factor dictating the extent of digestion.

Recall that in the simple situation discussed we assumed no superheat, i. e., the initial liquid was just saturated with respect to the phase with which it was in equilibrium and, in the case of adding more calcic crystals to the melt, the introduced crystals had been pre-heated to the temperature of the liquid. Additional heat would be required of a magma, of course, to warm up the invaded

rocks, so that the natural situation would impose more energy requirements on the magma than were demanded of the liquid discussed here.

2. If the rock were invaded by a magma whose bulk composition was more mafic than itself, the reaction would be endothermic. Melting of constituents of the country rock would ensue. The process would tend to run down rapidly and there would be few marginal effects. Indications of melting and chill zones might be present. Chill zones are commonly observed at the selvages of mafic dikes which have been injected into rocks of less mafic composition than themselves. The powerful corrosive effects which often mark the intrusion of a basaltic rock by a granitic magma are not typical of the reversed situation. These sometimes profound reactions are not due to melting but rather to reactions in the solid state between minerals in the more mafic invaded rock which are higher in the appropriate reaction series than similar crystals with which the magma liquid is presumably in equilibrium.

The composition of a diabasic magma approximates that of a basalt (Daly, 1933). The bulk composition of such a magma, relative to a rock as siliceous as the Troy quartzite, is decidedly mafic. The system would be in an extreme state of dis-equilibrium. We would expect, then, in accord with the foregoing, that reactions during the intrusion of the magma into such a highly siliceous rock would be endothermic in nature. Some melting would be expected, but reactions would not be of such a kind as to digest and disintegrate the quartzite. Precipitation of crystals from the magma would be hastened as their latent heat of crystallization was supplied to the magma to supply energy to melt the quartzite in order to bring it into equilibrium with the invading magma. Chill zones of finer crystalline textures would be expected at and near the contacts. Barth (1952) observes that most diabases exhibit chilled borders and that "usually no assimilation of the country rock has taken place."

At first thought one might consider that the Mescal limestone would be ultramafic with respect to a diabasic magma, and this would be true if the limestone had been previously subjected to intense metamorphism so that a lime and/or magnesian metamorphic mineral assemblage such as olivine, pyroxenes, spinel, and wollastonite had formed. One would expect under these circumstances to observe at the contacts evidences of exothermic reaction--signs of digestion, perhaps reversed zoning, etc.

Limestone, however, contains carbonate radical; thus a large quantity of heat is required of the magma to drive off CO_2 , so that the initial reaction upon intrusion would be endothermic and "self-damping." If the carbon dioxide evolved during any dissociation of the limestone, in excess of the amount soluble in the magma, could not find egress from the system, the pressure build-up would also oppose dissociation of the carbonate rock. One would not expect, then, important reactions between a diabasic magma and a limestone. Surface effects would be present, together with a limited amount of melting.

Because the heat necessary to perpetuate the magma's attack on the limestone in the face of the ensuing endothermic reactions is supplied by latent heat of crystallization of the normally crystallizing minerals of the diabasic magma, and as the volume of the diabase may be locally restricted in its sill-like environment, this reaction should not be expected to progress to any appreciable extent.

If extensive assimilation of limestone had taken place, the residual liquid developing while the normal crystallization sequence progressed should contain excessive carbon dioxide as the residual magma became progressively enriched in carbon dioxide. Indications of this, either in the presence of abundant calcite or carbonate-bearing minerals such as scapolite, should be observed in or closely associated with the diabase or from the appearance of carbonate-bearing rocks formed from late stage differentiated magma. These have not been reported (E. D. Wilson, personal communication). Calcite seams intimately associated with asbestos deposits related to the diabase are common, but are regarded as being hydrothermal in origin.

To summarize, consideration of some basic petrologic principles suggests that, owing to the relative compositions of the rocks and magma involved, one should not expect extensive assimilation of sedimentary units such as the Troy quartzite and Mescal limestone by the magma which formed the Central Arizona diabase.

REFERENCES

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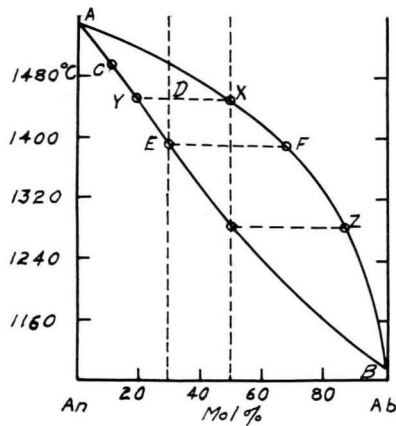


Fig. 1. Modified from Bowen