ART. XXIX.—*The Phenomenon of Rifting in Granite*; by
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IN the granite at Cape Ann and elsewhere it is noticed that the rock splits most easily in certain fixed directions; and it is by taking advantage of these lines of weakness, that large regular blocks are easily split from their bed in the quarry. An expert quarryman knows full well just what may be expected of the granite and in making his calculation, the prime factor is the direction and strength of the "rift." In many places there are other lines of weakness along which the

granite easily splits; but these lines rarely exceed three and they are termed respectively "rift," "cut off" and "lift." The latter is generally more or less horizontal; the "rift" is the stronger and the "cut off" the weaker of the two nearly vertical lines of splitting.

During the summer of 1887, as an assistant to Professor N. S. Shaler,* I made a careful study of the jointing and other phenomena exhibited in the granite quarries at Cape Ann,† and in the course of these studies became interested in the phenomenon of "rifting." Later some slides were cut with the idea of determining if possible the nature and cause of this phenomenon.

The Cape Ann quarries exhibit "rifting" in every form of variation. There are no two quarries in which the "rift" has the same peculiarities and in which it has exactly the same direction. In fact in the same quarry as in the case of the Rockport Granite Company quarry, the rift changes completely in different portions of the large pit. Furthermore, in one case, the "rift" becomes weak and the "cut-off" changes to "rift" in the same quarry. The reason for giving these facts is to show that there is such decided variation that the idea of attempting to explain the phenomena on the theory of widespread and uniform disturbance is out of the question, at least since the granite came into anywhere near its present position. That there has been much faulting in the granite is plain upon the most cursory examination. It might be reasonable therefore to suppose that the phenomenon of rifting was produced early in the history of the granite, and that the present variation is chiefly due to faulting and contortion.

The so-called granite of Cape Ann is a hornblendic granite containing orthoclase and some plagioclase feldspar, quartz, hornblende, a very little biotite and some magnetite. Under the microscope it is found that the quartz and feldspar show signs of much strain. There are tiny irregular faults and fault breccias (figs. 1, 2 and 3) both in the quartz and feldspar. With the naked eye the rift can be plainly seen, when it is strongly developed, to be a slightly irregular break cutting the rock and crossing quartz and feldspar alike. With the petrographical microscope, the crack appears quite irregular, and it can be frequently traced around quartz grains rather than directly across them. The line of breaking will often turn to one side in order to take such an easy path, and when crossing the feldspar it generally, in fact as far as my observations extend, always follows cleavage lines. Macroscopically

* While much of the detailed work was done by the writer, the general scheme and most of the conclusion must be credited to Prof. N. S. Shaler.

† See Ninth Annual Report U. S. Geol. Survey.

the line does not appear as a fault but simply a crack; but microscopically extremely minute faults can be detected, and the universally present fault breccia proves actual dislocation.

The fault breccia is in reality a breccia, not as I at one time suspected a secondary development, for in several places I found pieces of feldspar only partially removed from the main crystal in such a way as to show the continuation of cleavage lines from the main piece into the dislocated portion. Along the fault lines in the margin of the feldspar, cleavage lines are frequently developed, and these tend to hide the fact that dislocation has actually occurred (fig. 4).

Rifting is, then, dependent upon the thousands of minute dislocations which occur in every cubic inch of rock. The strains which produced these dislocations were of such a nature that three distinct sets were produced. I refer to Professor Shaler's article on Cape Ann in the Ninth Annual Report of the U. S. Geological Survey for 1887, for a full statement of the joint planes in the Cape Ann quarries. In this statement one of the most striking facts brought out, especially in the diagrams is that the joint planes follow distinct systems. There are three of these systems, one nearly horizontal and two vertical. The horizontal system is probably a contraction jointing formed during the cooling of the granite. These joints are irregular both in position and dip, are usually more or less dome-shaped, and lie one beneath another in concentric layers. The vertical sets of joints are much more regular, and are frequently perfectly straight cracks for several hundred feet horizontally and more than fifty feet vertically. They form with each other an angle several degrees less than a right angle. In almost any quarry these systems of jointing may be readily detected. Other joints occur, striking in almost every direction; but they are clearly accidental being most commonly diagonal across a block formed by the main joint planes, while the two main sets of vertical joints are the

result of one general cause, and in consequence follow a general law. In different portions of the Cape, the joints extend in different directions, but these variations may be readily explained on the supposition of faulting which has clearly been extremely common in this granite mass. In a number of cases the rift is found to follow the same general direction as the principal set of joints. This is particularly the case where the rift is well developed, as for instance in the quarries at Bay View.

In regard to the age of the rift, I can say very little that is definite. A careful study of 70 slides, cut from specimens of rock taken from the diabase dikes of Cape Ann, failed to show any sign of rift. From this it would appear that the rifting tendency was induced before the dikes were injected into the granite, but as the dikes mainly follow the joint planes, this is of little value in placing the age of the disturbance. There are some ragged dikes of quartz porphyry which were intruded before the jointing, but these show no signs of rifting. The evidence furnished by the dikes, however, is of little value for fine-grained rocks would not be likely to show evidence of microscopic faults. This fact is particularly well seen in the Cape Ann granite, in places where there are fine grained basic segregations. These segregations are as old as the granite, yet they show no rifting, although the surrounding granite has a very strong rift. The older dikes of quartz porphyries, and ragged diorite are very much faulted macroscopically, and very much changed in mineralogical composition microscopically, showing that there has been much motion and consequent alteration.

I suspect, although no evidence that I have been able to find conclusively proves it, that rifting and jointing are closely associated phenomena, and that the cause which produced one caused the other. What this cause was I shall not attempt to say, though plainly it was one of great extent and vast force. Between the almost microscopic rift and the joint plane hundreds of feet in linear extension, I have been unable to find any satisfactory gradation. Even the similarity in direction is not as striking as could be desired, to prove the connection. At Bay View, however, where the rift is remarkably strong, in some exposed places it has developed into many small parallel joints. These joints are about six inches apart; but if the rock is struck with a hammer it cleaves into many pieces parallel to these rift joints. Certain so-called "green seams" have been observed to pass out into rift-like breaks. These "green seams" are imperfect joints, lined with a thin layer of chloritic matter, which are not generally noticed by the quarrymen; but along which the rock is liable to split if

it is allowed to fall or is otherwise jarred. In one of these breaks I could plainly trace the passage from a distinct "green seam" to a rift-like break and then into unbroken granite.

From these facts I have been led to the supposition that before the injection of the dikes, the granite was subjected to contortion and pressure, which finally resulted in the production of rifting. Contortion would, it seems to me, produce just such a weakness in a hard, brittle, quartz-bearing rock. If, now, along some line of weakness in this partially rifted rock, the cohesion is overcome by the strength of the force which is compressing the mass, a joint plane would be formed. The probabilities are that the joint would be nearly parallel to the general rifted weakness, or else along the other line of weakness approximately at right angles to this. The third or horizontal set of "rift" planes, the so-called "lift" may have been a weakness inherent in the granite on account of the contraction of the mass during cooling. Subsequent faulting has displaced the granite, and broken it into such a number of pieces that we can no longer trace the general cause of rifting any better than we can that of jointing.

There is another possible explanation of rifting. There are in Cape Ann several hundred dikes, in many cases extending no doubt completely across the island (see Ninth Annual Rep. U. S. G. S., 1887—Shaler). The injection of this matter has expanded the bed rock several per cent more than its original bulk. This expansion must have been accompanied by a condition of great strain, perhaps enough to account for the breaking of the granite into its present rifted form. As the dikes for the most part follow the prevalent joint planes, these must have existed before the dikes were injected. This fact that the dikes follow the joints would explain the apparent similarity in direction of the joint and rift planes; and the absence of rift planes in certain places could be explained, either by the absence of dikes in that vicinity, or by some local peculiarity which relieved the pressure. The one fact which militates against this hypothesis is that there are no signs of rifting, and very little sign of strain in any of the earlier dikes which follow the joint planes, although they must have been subjected to great pressure during the injection of the later dikes. Altogether it seems to me more reasonable to suppose that the joints and rift phenomena are due to the same general cause, especially since there is a certain parallelism in direction between the two.

The inquiry then stands in rather an unsettled condition. The phenomenon of rifting is dependent upon certain microscopic breaks and even faults. There is a certain though not very definite parallelism between joints and rift and in some

cases the rift has actually developed into a joint. These facts indicate, though rather indefinitely, a common origin for the two phenomena though it is not impossible that the rifting phenomenon is subsequent in origin to the time of formation of the joint planes and possibly the result of the intrusion of the great number of dikes which cut the granite base of Cape Ann, and which must have brought about a condition of intense strain in the mass. A careful study both in the field and the laboratory fails to bring about a definite and satisfactory explanation of the cause of the phenomenon; and its settlement must await studies in other regions where dikes are less abundant.

Aside from the economic value of the rifting tendency there is a geologic effect of considerable importance dependent upon it. It was noticed in the study of the Cape Ann region that certain of the boulders in the morainic drift had a tendency to crumble while others had no such tendency. This crumbling has gone so far that glacial boulders which at the time of their transportation must have been solid and in a measure fresh, have, since the end of the glacial period, completely decayed to a crumbling mass of gravel. All stages in this decay may be seen on the island of Cape Ann. At first it was thought that this was the result of some chemical weakness in the rock, but a microscopic examination proved that the weakness was not chemical but mechanical. Whenever the rift is strongly developed the rock has the tendency to decay along the rift breaks; and at places, notably at the Bay View Quarry along the line of the railway in a fresh cut not more than fifteen years old, the decay along the line of the rift has not only developed well marked joint-planes but has begun to crumble the granite into gravel. A better case than this even is illustrated in the photograph (Plate LI, 9th Annual U. S. G. S.), where several large boulders of degradation have resulted through the agency of the weather acting along the rift planes in post-glacial times. Thus the phenomenon of rifting is, in the Cape Ann region at least, an important geological agent because of the aid which the lines of mechanical weakness furnish the agents of disintegration. Prior to our investigations, so far as I know, no notice has ever been taken of the phenomenon of the rift, yet I have no doubt it will be found to be of equal importance in many other localities than the one studied.