

FORMATION OF DIKES AND VEINS

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INTRODUCTION

Although few writers appear to have concerned themselves, in any careful way, with the question as to the conditions which determine the formation of the fissures in which dikes and veins are deposited, they commonly assume that these seats of the accumulations of igneous or aqueous deposited materials existed before the intrusive matter which has entered the rocks found its resting place. The aim of this paper is to present certain facts and considerations which serve to make the steps by which these structures were formed clearer than they now are. In

this inquiry the phenomena of dikes will first be considered ; after that, those of veins.

DIKE FISSURES

CLASSES OF DIKES

Even a cursory examination of dike phenomena will show the observer that so far as the fissures which these structures occupy are concerned they are divisible into three groups: Those which clearly follow the planes of preexisting joints, those which are developed along the bedding planes of stratified rocks, and those which more or less deviously burrow their way through the country-rock without availing themselves of either of the kinds of incipient cracks which may exist in the rocks they traverse.

MODES OF OCCURRENCE

Not infrequently there may occur in the same field of dike action two of these types of fissures. More rarely all three of them may be found associated within a small area, sometimes in such close juxtaposition that a single hand specimen may exhibit the several types of penetration. It not infrequently occurs that the dike which forces its way upward by developing the joint planes here and there extends laterally through the bedding planes for great distances, and this when the beds are horizontal and the intruding sheets of exceeding tenuity; they may, indeed, not exceed a few millimeters in thickness. Under certain rarely occurring conditions a dike intruded between layers of sedimentation may, as Gilbert has shown, cease to move onward as a sheet of even thickness. When this process of development is arrested before the thrust from below ceases to operate, the relief is accomplished by the process of uplifting the overlying masses forming a local vertical enlargement of the intruded lava in the form well termed "laccolite." Such upward movement of the overlying beds most likely occurs in the intrusion of all the greater sills, though some of them of smaller size may be formed without any uprising of the surface, the space being won through the compression of the rocks, due to the in-wedging action of the dike. This is probably the commonest form of relief in the case of the ordinary vertical or joint-following dikes.

EFFECT OF HEAT ON WALLS

It is noticeable that in nearly all dikes save those of exceptionally great width the effect of the heat of the material on the walls of country rock has been but slight. It is rarely sufficient to produce any fusion

of that rock, even where the constitution of the material is such as to favor melting at anything like the temperature which must have existed in the mass of the lava. It is otherwise where the dike has burrowed its way through the deposits it has penetrated without following distinct joints or bed planes. In these instances there is, so far as I have been able to observe, always abundant evidence that the igneous matter has absorbed or fused a large part of the country rock which occupied the position of the intruded mass. This difference in the effect of the dike materials in the rifting and the burrowing dikes—that is, those which follow the planes of distinct beds or joints and those which do not do so—is, as we shall see, a matter of much importance. With these features of dike fissures in mind, let us proceed to consider the conditions under which these fissures are riven.

INFLUENCE OF STRATIFICATION

It is commonly though tacitly assumed that there is some distinct injecting action which drives the liquid rock into the fissures of the solid overlying strata, but I am not aware that any effort has been made to show exactly how such an action is effected. Let us imagine a fluid mass, however developed, lying beneath the deep covering of overlying solid material. Are we to conceive that the dikes are formed as the result of a disruptive action, such as that which rends a bursting shell or steam boiler? Clearly such is not the fact, for in that work the whole of the covering would be rent and the escaping lava would attain the surface. This point is made the clearer by the fact that in the formation of laccolites the overlying strata, which by their extension should give passage for the lava of the congested sill, are not often the seat of numerous upward going dikes leading from the main mass. Even when these overlying rocks are apparently normally jointed, there appears to be some reason why these incipient fractures are not readily opened to the molten rock. It seems, indeed, that in certain cases a section of stratified rock may present conditions which favor the formation of sills extending for great distances in approximately horizontal directions, in directions in which no diminution of pressure is obtained, while a vertical course of the injected materials is to a great extent hindered by the conditions mentioned.

INFLUENCE OF JOINTING

In other instances, the greater number of those in which dikes penetrate stratified rocks, the path of the dike materials is along the joints, a preference being given to those which lie nearest the vertical position.

In these cases, although the bedding planes may be extremely well developed, so that the layers may be separated with the greatest ease, while the joints are very closely adpressed, the intrusions persistently follow the paths of these close fissures, entirely neglecting the opportunity to extend between the beds.

COMBINATION DIKES

In yet other and exceptional occurrences a dike may be formed which has burrowed its way upward without the advantage afforded it by following distinct joint planes, while from point to point it has given off sills which have entered readily between the strata, extending it may be into very thin sheets. Excellent examples of such combinations of dikes, in which great opportunity of vertical extension through layers of rock is combined with exceeding ease in the development of sills, may be observed in the highly metamorphosed slates along the Missouri river, near Helena, Montana, especially in the boulders at the abandoned placers on the banks of that stream.

CAUSES OF DIVERSITY IN DIKES

EFFECT OF ROCK STRUCTURE

The wide differences in the behavior of injected lavas when they cover stratified deposits appear to indicate some conditions serving to determine their path other than those afforded by the force which forces them upward or the extent to which the walls of the joint or bedding planes adhere. The facts seem to indicate that in certain cases these joint fissures readily open and give passage to the fluid rock, while in others, in no evident manner different, they resist the entrance of the dike matter in an obstinate way. The question is as to the cause or causes of these variations.

The first suggestion that may be made as to the cause of the diversity which we note in the paths of dikes through stratified rock is that it is due to the relative ease with which the fluid rock forced its way toward the zone of diminished pressure at or near the surface. This view is, however, not reconcilable with observations which may be made in any region where sills abound. It may be there seen how improbable it is that the igneous matter gained in nearness to the surface by extending into the sills.

In certain cases where the beds are tilted the extension along the upward inclined bedding planes may have furnished a way toward the air; but such conditions are rare.

In the greatest number of instances the opening of the space occupied by the sill must have been accomplished by the bodily uplifting of the overlying mass of strata; yet the inducement of lessened pressure could not apparently have been the only action which led to the formation of the far-extending and often relatively very thin sheet of dike matter.

In some examples the sills may be observed to deflect somewhat downward from their original pathway, when the extended overlying beds should have afforded an easier passage by way of the joints.

EFFECT OF WATER

Unable to find any other working hypothesis concerning the development of the paths of dike injections which aids us in understanding the curious conditions of their movements, I have ventured on the conjecture that their course is in part at least determined by the presence or absence of water in the incipient crevices—that is, the joints or bedding planes—or in the relative quantity of that material in those planes. Let us suppose that the molten rock comes in contact with such an incipient fissure containing water, either free or in connection with the rock on either side of the crevice. The effect would be to vaporize this water, or, if the pressure at the given depth were too great to permit vaporization, at least to bring about an expansive strain, which would help to open the space to the entrance of the lava. Should the pressure engendered by this process of vaporizing be less than that which impelled the igneous matter from below, as would doubtless usually be the case, this matter would begin to enter the rent. If the pressure due to the vapor were by chance greater than that impelling the lava it would for the time be debarred from that path. It is perhaps not to be supposed that in ordinary conditions the pressure due to the expansion of water vapor, even in the high temperature which the presence of the fluid rock would occasion, would of itself bring about the opening of the crevice, but this action might cooperate with that of the diking material in determining the course it would follow.

At first sight there appears to be a fundamental difficulty in this hypothesis, in that it does not provide a way by which the vapor of the water generated in the fissure could be disposed of. On consideration, however, it seems eminently probable that relief might be found in either or both of two ways. The stratified rocks would be, it may be assumed, more permeable to vapor than they are to the injected fluid, so that there might be some, though most likely a slow, escape provided in that manner; it is even more likely that the vapor would be absorbed into the molten rock either mechanically or in connection with chemical changes, or these actions, resulting in the removal of the vapor, may be combined.

It must be acknowledged that these processes, though essential to the hypothesis, are somewhat conjectural, but they appear to be in the field of legitimate supposition.

VARIATION IN MOISTURE OF ROCK STRUCTURES

Reviewing the phenomena of dikes in the light of the above noted working hypothesis, we see that they become more intelligible than they now are. Thus, as those who have studied in deep mines have learned, there is a great difference in the extent to which joints and bedding planes contain water. Some are quite dry, others not. It is not unlikely that this difference continues to a much greater depth than our observations extend. The difference is even greater in the case of bedding planes where the water spaces are likely to be more extensive and where the layers of rock may be charged with the fluid. The variations in this feature are obviously great, some sections of strata having the separate members loosely united, while in others they are firmly knit together. Considering these differences, we may conceive that when dike materials seek to force their way upward they may be guided in this movement by the aid which they receive in opening their paths through the action of the expanding vapors. Where the vapors are readily generated in the bedding planes and not in the joints, the lava will be deposited as sills. Where the joints tend to be opened by the steam while there is no like action in the bed planes, no sills will be formed. Where, as is not infrequently the case, the dike has evidently encountered difficulties in breaking its path upward, being forced to make its way without much, if any, assistance from the joint fissures, either because they are not well developed or because they are very tight, we should expect to find, as we do in fact often find, that the sills are well developed. In the case of the dikes of the above-mentioned district near Helena, Montana, this feature of burrowing dikes evidently formed with difficulty, from which extend slender sills, which appear to have been developed with relative ease, is very apparent.

CONDITION OF SILLS

So far as my observations extend, the history of diking in every well stratified section shows that when sills are formed they are commonly produced in the first invasions of the igneous rocks, the later injections tending to follow the first planes. This is the order which we should expect if the contact of water with the heated injections was of importance in developing the fissures, for where the layers are so related to one another that there is a storage of water between them, the quantity thus

contained is usually much larger than is held in joints; whereas it is usually the case in dikes which follow joint planes that we find one plane or set of planes evidently affording a freer way than others, and the selection of the path may be explained by the fact that the amount of water in different sets of joints varied greatly.

It is to be noted in this connection that in the greater number of dikes the effect of the heated matter on the country rock is, as often remarked, surprisingly small considering the temperatures at which we must suppose the diking matter entered the fissure. If, however, we assume that the fluid rock comes in contact with considerable amounts of water the effect would be to lower its temperature. It is true that so far as this vaporized water afterward combined with the molten rock this effect would be diminished; yet the evidence in general goes to show a lessening of the action of heat, which can best be explained by the supposition that it is taken up in part by the vaporizing process. On the other hand, those dikes of relatively rare occurrence, which have made their way through rocks without following definite rifts, and therefore may be presumed not to have come in contact with other than crevice water, often—indeed we may say quite generally—melt or absorb their walls, as is shown by the absence of parallelism of the walls and also by other evidence.

It can not be assumed that the considerations which have been adduced in the foregoing pages effectively verify the hypothesis above set forth, but they point to the conclusion that further study of the matter may bring about this result.

VEIN FISSURES

DISSIMILARITY BETWEEN DIKES AND VEINS

Although the early geologists were inclined to regard dikes and veins as species of one genus, it is evident that they have no other common feature than those dependent on the fact that they alike occupy spaces which they have won in rocks in which they did not originally belong.

UNTENABILITY OF THEORY OF OPEN FISSURES

As regards the formation of the fissures in which veins are contained—the point with which we are here concerned—the original view was to the effect that these rents were freely open at the time when the deposits were laid on their walls. This view has been generally abandoned—at least, in its unqualified form—though it is perpetuated in many of our text books. The evidence concerning the formation of vein fissures goes to show that only rarely could veins have been deposited in

widely open fissures; such rents have occasionally been observed in mines at considerable depth beneath the surface, but within the zone where the greater part of the vein building takes place we may fairly presume that the pressure is such as would prevent the development of freely open crevices. Such, indeed, could not be maintained at the depth of even 3 miles below the surface, except they were filled with water which had no chance to escape upwardly as fluid or vapor. The only kind of fissure which could, except for the presence of water, be maintained at any great depth would be such as were formed by faults, the walls of which were not perfectly parallel—a condition of all faults—so that when slipped apart one from another, though closely adpressed, a winding cavity would be formed by the contact of the warped surfaces; but it is doubtful if even such openings could be maintained at the depths where most veins are deposited. The well known fact that veins usually contain here and there masses of the country rock which have been forced out of position laterally by the formation of the vein matter, but have not fallen downward, and that in no case within my observation has a mass of the country rock disappeared in a way to suggest such down-falling, shows pretty clearly that the deposition in wide veins rarely if ever occurs in previously open fissures; that is, those in which there is a cavity having an area anything like that occupied by the completed vein. It therefore becomes a question as to the mode in which the vein material finds its way to the place of deposition.

ILLUSTRATION OF VEIN-FORMING FROM GEODES

Some light on the foregoing question appears to be afforded by observations which may be readily made on the formation of geodes. As is well known, these bodies in their typical form are spheroidal masses, usually of quartz, which are formed essentially in the manner of veins. They may, indeed, be termed globular deposits in this class; in fact, by extending the inquiry over a large field I have been able to trace a tolerably complete series of forms from spherical geodes to ordinary fissure veins, a series sufficiently without breaks to warrant the assumption that all these bodies belong in one category. A study of these geodes as they occur in Kentucky and elsewhere, especially in the shales of the sub-Carboniferous rock, has afforded me some interesting and instructive suggestions concerning the process of vein-making which I will now briefly set forth.

Normal geodes are hollow spheroids and are generally found in shales. They clearly represent in most cases a segregation of silica, which has evidently taken place under conditions of no very great heat, brought

about by deep burial beneath sediments or other sources of temperature. It is difficult in all cases to observe the circumstances of their origin, but in certain instructive instances this can be traced. It is there as follows: Where in a bed in which the conditions have permitted the formation of geodes the calyx of a crinoid occurs, the planes of junction of the several plates of which it is composed may become the seat of vein-building. As the process advances these plates are pushed apart and in course of time enwrapped by the silica until the original sphere may attain many times its original diameter and all trace of its origin lost to view, though it may be more or less clearly revealed by breaking the mass.

In the process of enlargement which the geodes undergo they evidently provide the space for their storage by compressing the rock in which they are formed. In the rare instances where I have been able clearly to observe them in their original position they were evidently cramped against the country rock, the layers of which they had condensed and more or less deformed. Although when found upon the talus slopes or the soil these spheres usually contain no water in their central cavities, these spaces are filled with the fluid while they are forming and so long as they are deeply buried. There can be no doubt that this water is under a considerable though variable pressure.

The conditions of formation of spheroidal veins or geodes clearly indicate that an apparently solid mass of crystalline structure may be in effect easily permeated by vein-building waters, and this when the temperatures and pressures could not have been great. It is readily seen that the walls of these hollow spheres grow interstitially while at the same time the crystals projecting from the inner side of the shell grow toward the center. We therefore have to recognize the fact that the siliceous water penetrated through the dense wall. In many of these spherical veins we may note that the process of growth in the interior of the spheres has been from time to time interrupted and again resumed. These changes may be due to the variations in pressure to which the water in the cavities is necessarily subjected as the conditions of its passage through the geode-bearing zone are altered.

The most important information we obtain from the study of spherical veins or geodes is that no distinct fissures or rifts are required for the passage of vein-building waters through existing masses of lodes. It is true that the distances they traverse in these spherical lodes is limited to, at most, a few inches; but there is in these cases no other impulse than diffusive action to bring about the movement, while in an ordinary tabulate vein we may generally assume, in addition to the influence operating in bringing the dissolved materials into the geode, a pressure which impels the fluid upward. Thus, while it is not to be denied that many

veins are prepared for by the formation of somewhat gaping fissures, and that these rents, after being more or less completely closed, are reopened by faulting on the plane of the deposit, such original or secondary spaces are not required for the development of a vein. The other point is that the pressure of the growing vein, which in the case of the geode is able so to condense the rock matter about it as to win room for the deposit, is likely to be even more effective in the group of tabulate deposits in forcing the walls asunder.

CONDENSING AND DEFORMING EFFECTS OF VEIN AND DIKE MATERIALS

In this connection it may be well to note that the introduction of large amounts of vein and dike material brought from lower to higher levels of the rocks is likely to prove an important source of condensation and deformation of the beds in which the deposits are formed. I have elsewhere referred in some detail to the importance of this action. It clearly deserves more attention than it has yet received.