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DOMES AND DOME STRUCTURE OF THE HIGH SIERRA

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CONTENTS

GENERAL CHARACTER OF THE DOMES

In the granite areas of the Sierra Nevada are many hills and other summits having the form of domes. A few of the domes are symmetric, with approximately circular or oval bases, but the majority are somewhat one-sided or irregular. Associated with these domelike forms are closely related structures. The granite is divided into curved plates or sheets which wrap around the topographic forms. The removal of one discloses another, and the domes seem at the surface to be composed, like an onion, of enwrapping layers.

THEORIES OF RELATION BETWEEN STRUCTURE AND FORM

In explanation of these peculiar forms and structures two general theories have been advanced.* According to one theory the separation of the granite into curved plates is an original structure, antedating the sculpture of the country and determining the peculiarities of form.

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*H. W. Turner gives a digest of opinions, with references, in Proc. Cal. Acad. Sci., 3d ser., Geology, vol. 1, pp. 312-315. To his enumeration may be added Muir (Am. Assoc. Adv. Sci. Proc., vol. 23, pp. 61-62) and Le Conte (Elements of Geology, 4th ed., pp. 283-284), both on the side of original structure.

According to the other theory the structure originated subsequently to the form, and was caused by some reaction from the surface. Visiting the Sierra in the summer of 1903, I had these two theories in mind, and sought for characters by which they might be tested.

The dome structure appears not to extend downward and inward indefinitely, but to be limited to a somewhat shallow zone. The opportunities for observing this fact of distribution are not numerous, and, so far as I am aware, are found only on what are called half domes—that is, domes that have been pared away on one side so as to exhibit the structure in section. The Half dome at the head of Yosemite valley, which has been described by several writers, has been undercut in the development of the glacial trough of Tenaya creek, so that its northwestern part has fallen away. The curved plates are there seen (figure 1) to occupy a very moderate depth, probably not more than 50 feet, while beneath them the rock is massive, except as vertical shear planes or joints have developed parallel to the flat face. In another instance the estimated depth of the zone of dome structure is about the same, and in a third instance about 100 feet. This downward limitation of the zone appears to me favorable to the second theory. If the structure were original, one would expect to find it continuing indefinitely downward and inward.

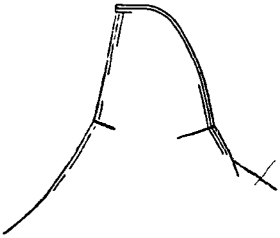


FIGURE 1.—*Section of the Half Dome, showing the relation of the dome structure to the surface and to joints.*

The section is at right angles to the side shown in plate 2.

The structure is not restricted to domes. In some districts the walls of canyons, the sides of ridges, and the bottoms of trough valleys are characterized by partings approximately parallel to the surface. (See plate 3, figures 1 and 2.) These partings are not ordinary joints, but are distinguished by curvature, and their forms of curvature are always adjusted to the general shapes of the topography. In the last respect they differ greatly from the structures produced by folding of strata. The curves of folded strata are diversely related to topographic features. A syncline may be found in a valley or on a hilltop, and an anticline may have either of these positions; but in dome structure each anticline coincides with a summit and each syncline with a valley. If the dome structure were original, we should expect that it would often be traversed discordantly by superposed drainage and dissection, and the fact of its accordance with features of dissection is therefore unfavorable to the theory that it is an original structure.

Where the granite is divided by a solitary joint into distinct masses, the dome structure of each mass is independent of the structure developed in its neighbor (figure 1). The curves of the dome structure do not cross the joint plane, and are thus shown to be newer than the joint. This phenomenon is not favorable to the view that the structure is original.

These considerations, as they were developed gradually in the field, led me to abandon altogether the hypothesis that the structure was developed either in the original constitution of the granite or at some early stage in its history, and to adopt the alternative view that it followed the production of the principal topographic features and was in some way conditioned by the surface forms.

RELATION OF DOME STRUCTURE TO PLANE JOINTING

The dome structure appears to have been developed only in massive rock; that is to say, it is not found in rock which is divided by systems of parallel plane joints. Through large areas the granite is divided by such joint systems into angular blocks (plate 4, figure 1), and in these areas the peculiar domes do not appear. I thought at one time that the two types of partings might be correlated with certain rock types, but this tentative generalization was afterward completely disproved. There are at least three prominent and broadly exposed types of granite in the Sierra which exhibit dome structure, and each of these is also characterized in some different locality by plane joints. It is easy to understand that the existence of either system of partings within the rock might, by facilitating the relief of strain, prevent the development of the other system, so that their mutual exclusiveness gives no indication of their relative age. But there is independent reason for assigning a greater age to the plane joint systems. The dome structure, being conditioned by surface forms, is in each locality more recent than the topographic features; but the topographic sculpture is superposed on the systems of plane joints. Minor details of form show the influence of joint structure, but features of the rank of hill and valley are notably independent, their trends making all angles with the strikes of joint systems.

Joints and other division planes are aids to erosion, whether the process be subaerial or glacial. When in ordinary jointing several sets of division planes intersect and the rock is separated into blocks, weathering and transportation are both facilitated. In dome structure there is but a single set of division planes, and the broad rock plates are almost as resistant as a continuous mass. It results that the granite masses divided only by dome structure tend to survive general degradation, and often to stand forth as prominent hills.

The Question of Cause

In the effort to pass from the general phenomena of dome structure to its cause, I have found instruction in a comparison of the disrupting effects of expansion and contraction. When a forest fire sweeps over a rocky hillside the surfaces of rocks are rapidly heated and thereby expanded. The result is a sort of exfoliation. Flakes of rock, broad in comparison with their thickness, break loose and fall away (plate 4, figure 2). Thus the effect of surface expansion is to develop partings approximately parallel to the original exterior. The effect of contraction is illustrated by the cooling of a lava stream or dike. The cooling and contraction begin at the surface, and there develop a plexus of cracks, which are propagated downward or inward as cooling proceeds. These cracks are normal to the surface, and they separate the rock into normal columns. Comparing dome structure with these familiar types, it seems evident that it should be ascribed to expansion rather than to contraction, and we are led to inquire what natural process or processes may have expanded the Sierra granite at the surface.

Heating is naturally the first to suggest itself. Diurnal and annual changes of temperature may be dismissed at once, because their influence penetrates but a small distance. Secular changes penetrate farther, and may be quantitatively adequate. Secular warming after glaciation may have been a *vera causa*, but its discussion is complicated by the fact that the dome structure, or at least its principal part, antedated a large amount of glacial erosion. If the structure originated with Pleistocene climatic changes, the changes must have pertained to an early epoch of glaciation.

A second process developing expansive force is weathering, and here again future investigation may discover a true cause; but to cursory and inexpert observation the granites of the Sierra in the glaciated district appear to be unaltered.

A third process—one as to which we have no direct knowledge—is dilatation from unloading. When the granite came into existence by the cooling of the parent magma it was buried under a deep cover of older rock. Because of that cover it was subject to compressive stress, and that compressive stress was of course balanced by internal expansive stress competent to cause actual expansion if the external pressure were removed. As in course of time the load was in fact gradually removed, the compressive stress was diminished and the expansive stress became operative. *Pari passu* with this release of expansive stress there was cooling, and the effect of the cooling was to diminish expansive stress; and the result may have been complicated by other stress factors. So long as the pressure of superjacent material was great, the equilibrium of stresses was approximately adjusted by flowage; but as the descending surface of degradation approached the granite, flowage diminished, and it ultimately ceased. The final adjustment was by change of volume, the change being contraction if lowering of temperature was a more important factor than relief from load, and expansion if relief from load was the more important factor. In the latter case (which I regard as the more probable) the parts of the granite successively exposed at the surface were in a condition of potential expansion, or tensile strain, and that strain would be relieved by the separation of layers through the development of division planes approximately parallel to the surface.

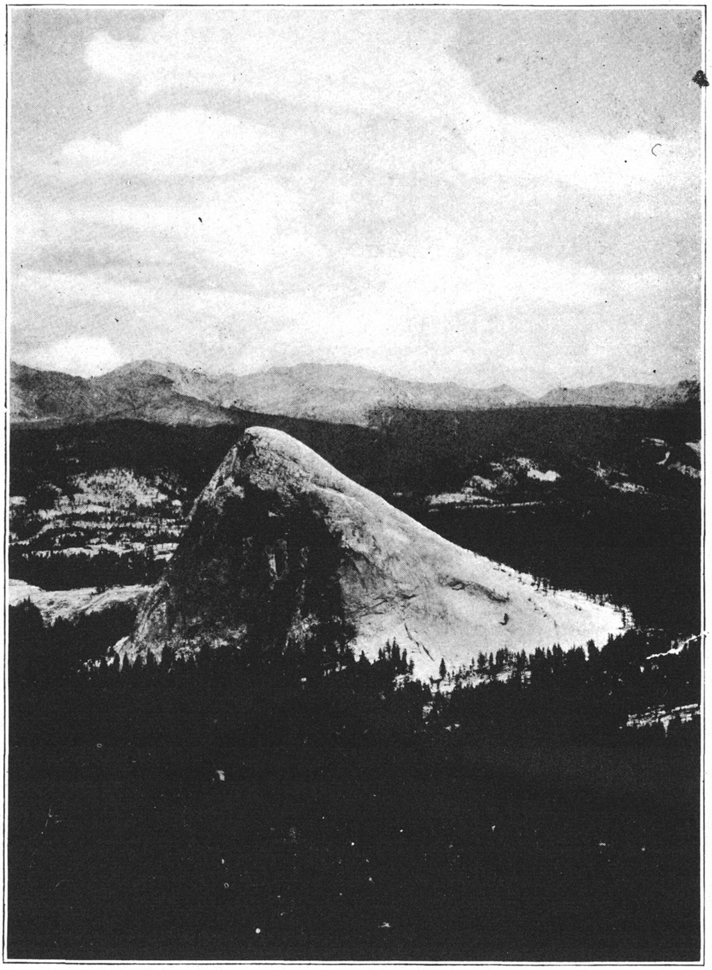
While it is possible that all these processes are concerned in the production of the structure, I regard it as more probable that some one cause is dominant. The data at hand seem to me not to warrant a confident selection from the three suggested, but if the truth lies among them, there should be little difficulty in obtaining additional facts of crucial character. Certain domes, some of which I saw at a distance, are supposed to be outside the area of Pleistocene glaciation. If they exhibit the characteristic structure, and are really extraglacial, their characters can not plausibly be ascribed to secular changes of climate. It should be possible to determine the relation of weathering to the structure by petrographic study of outer and inner layers at such a locality as that shown in plate 3, figure 1, where glacial erosion has exposed a fresh section.

EXPLANATION OF ROUNDING

The view in plate 3, figure 1, was selected as an illustration of dome structure because the plates and partings of the structure are there shown in natural section. In the making of that section the dominant erosional process was glacial attrition or grinding. While this process has been of great importance in the sculpture of the higher parts of the Sierra, it is probably second in rank to glacial plucking or quarrying; and glacial degradation as a whole has been small in comparison with subaerial degradation. In glacial plucking and in most phases of subaerial erosion the most active attack on rock traversed by dome structure is by way of the partings, and the broad outer faces of the granite plates are comparatively unaffected. The removal of the rock is essentially through a process of peeling. One layer at a time is carried away, and the surface at each stage coincides approximately with one of the partings.

Whatever the cause of the dilatation producing the partings, they are formed in succession from without inward. For each one the determining strains are themselves conditioned not only by the form of the outer surface, but by the form of the last made parting. Parallelism is not perfect but approximate, and the departures from strict parallelism are of such nature as to reduce or omit angles and other features of irregularity. The inner partings reflect only the general features of the external sculpture. As peeling progresses and the zone of competent strain moves inward, the outer surfaces are successively more and more simple in contour, and the newly developed partings are endowed with still greater simplicity.

Opposed to the rounding process is corrasion. The attrition of a detritus-armed stream or glacier saws through the rock plates with little regard for the presence or absence of partings. By so doing it creates discordant elements of topography and modifies the conditions under which the expansive strains are developed. In the Sierra the effects of glacial corrasion are at present conspicuous. By the corrasion of the Tenaya trough the base of Half dome was sapped, so that a part was sheared off by gravity, producing a vertical flat face (figure 1), in which the structureless nucleus was exposed. In this face the "dome structure" was developed, but, being conditioned by a plane outer surface, the new partings are plane (except at the edges), and thus simulate ordinary plane joints.



FAIRVIEW DOME

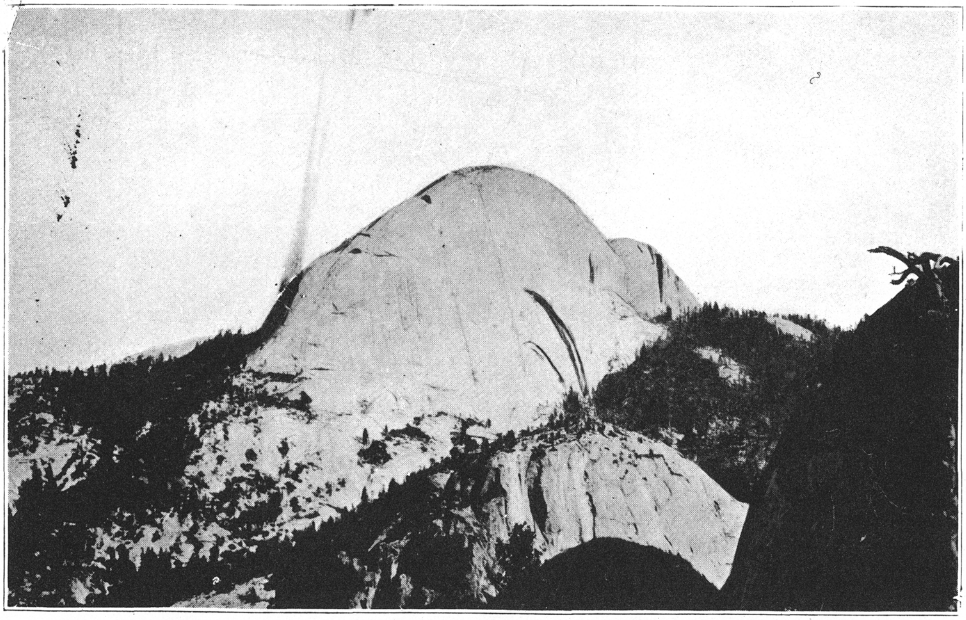


FIGURE 1.—HALF DOME AT EAST END OF YOSEMITE VALLEY, SEEN FROM THE SOUTH

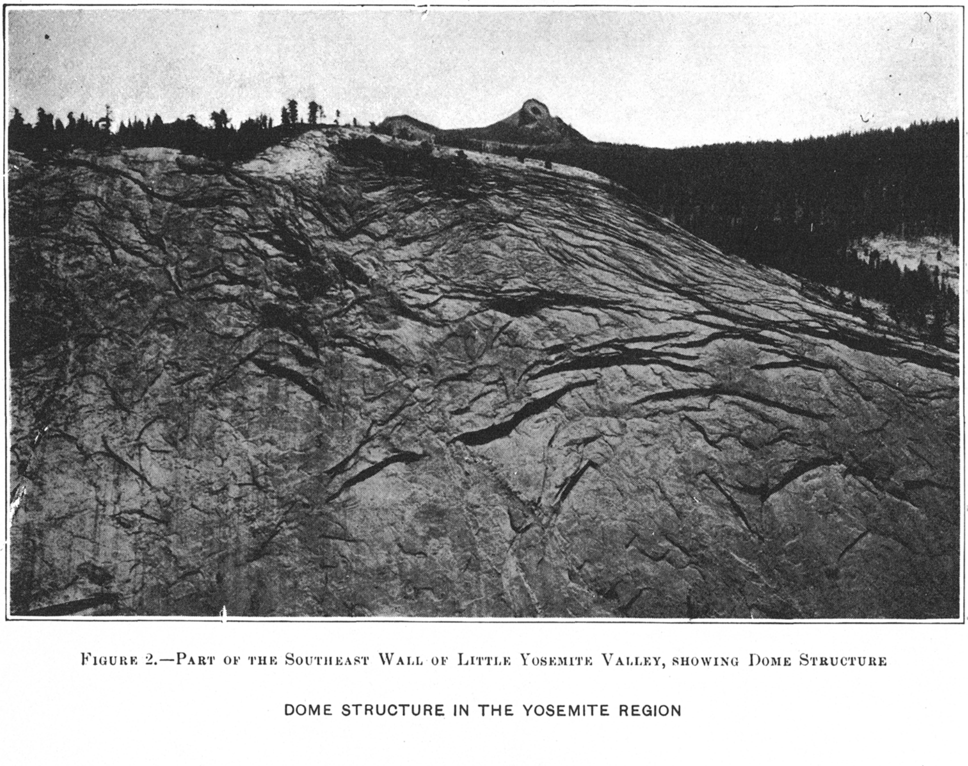


FIGURE 2.—PART OF THE SOUTHEAST WALL OF LITTLE YOSEMITE VALLEY, SHOWING DOME STRUCTURE

DOME STRUCTURE IN THE YOSEMITE REGION

Explanation of Plates

Plate 1.—*Fairview Dome*

This dome, sometimes called Tuolumne monument, is in the Sierra Nevada, west of Tuolumne meadows. In common with the surrounding country, it is of granite. It stands at the edge of a plateau, its summit being 800 feet above one base and 1,300 feet above the other; it is not above timberline, but is bare of trees, because in the absence of joints they get no foothold. Pleistocene ice covered it, flowing from right to left and from distance to foreground.

Plate 2.—*Dome Structure in the Yosemite Region*

Figure 1.—Half Dome, at east end of Yosemite Valley, seen from the south; from a photograph by C. D. Walcott.

The view shows the convex side of the dome, in which the structure closely parallels the surface. The height above the nearer base is about 1,500 feet; above the farther base at right 900 feet. The dome was covered by Pleistocene ice, which moved from the right and from the distance. The surface is treeless, because devoid of joints. No rock but granite is visible in the view.

The text contains a cross-profile of the dome.

Figure 2.—Part of the southeast wall of Little Yosemite Valley, showing dome structure.

The rock is granite. The valley is deeply incised in a plateau of relatively mature topography. Pleistocene ice covered everything shown in the view except the distant crest, but the glacial degradation of the upland was slight.

In the upper parts of the cliff the dome structure parallels the surfaces of the upland topography; lower down it parallels the cliff face.

PLATE 3.—*Dome Structure near Emerick Lake*

FIGURE 1.—Hill southeast of Emerick Lake, Upper Merced Basin, Sierra Nevada.

The hill, which is about 250 feet high, is the terminal and culminating point of a long ridge of granite. The dome structure in the ridge is anticlinal, changing in the hill to the inverted canoe form. At the extreme right the convex or anticlinal curvature is seen to merge into a concave or synclinal curvature, better shown in figure 2. The hill was deeply buried by a glacier moving from left to right. Glacial erosion made the rock basin occupied by the lake and excavated the hillside so as to expose the dome structure in partial section.

FIGURE 2.—A Syncline in dome structure.

Emerick lake (figure 1) lies out of sight, just beyond the granite slope at right. Its outlet, crossing the sill without notable incision, descends to the foreground at left. Structure and topographic configuration are in harmony. A syncline pitches toward the foreground and also (slightly) toward the lake. At the lip of the lake basin the cross-section is synclinal and the longitudinal section anticlinal.

PLATE 4.—*Joint Structure and Fire Spalling*

FIGURE 1.—Jointed granite in Kuna Crest, Sierra Nevada.

The granite is traversed by four systems of parallel plane joints. The cliff is at the head of a glacial cirque, and the sloping plain above it belongs to preglacial topography. The general forms of cirque and plain are independent of the attitudes of the joint systems. Compare with plate 3 and observe the contrast between joint structure and dome structure.

FIGURE 2.—Granite boulder from which spalls or flakes have been riven by the heat of forest or meadow fires.

The spall at the left, still standing in position, illustrates the approximate parallelism of fractures thus produced to the exterior surface. Probably in this case the strong heating was at the side and local—as the heating would be, for example, if the log at the right should be burned—and the small size of the spall was determined by the localization of the heat.

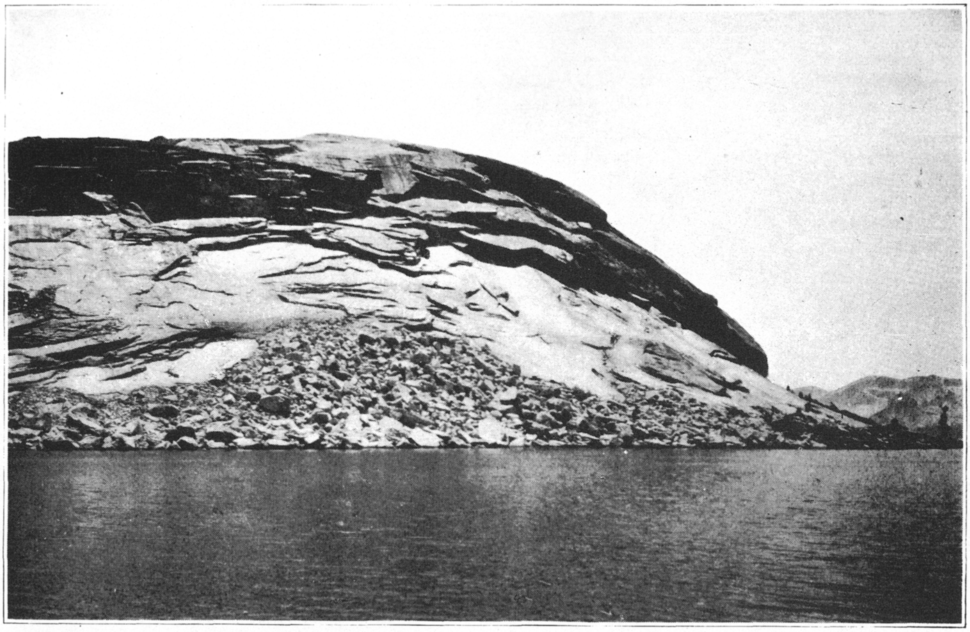


FIGURE 1.—HILL SOUTHEAST OF EMERICK LAKE, UPPER MERCED BASIN, SIERRA NEVADA

FIGURE 2.—A SYNCLINE IN DOME STRUCTURE

DOME STRUCTURE NEAR EMERICK LAKE

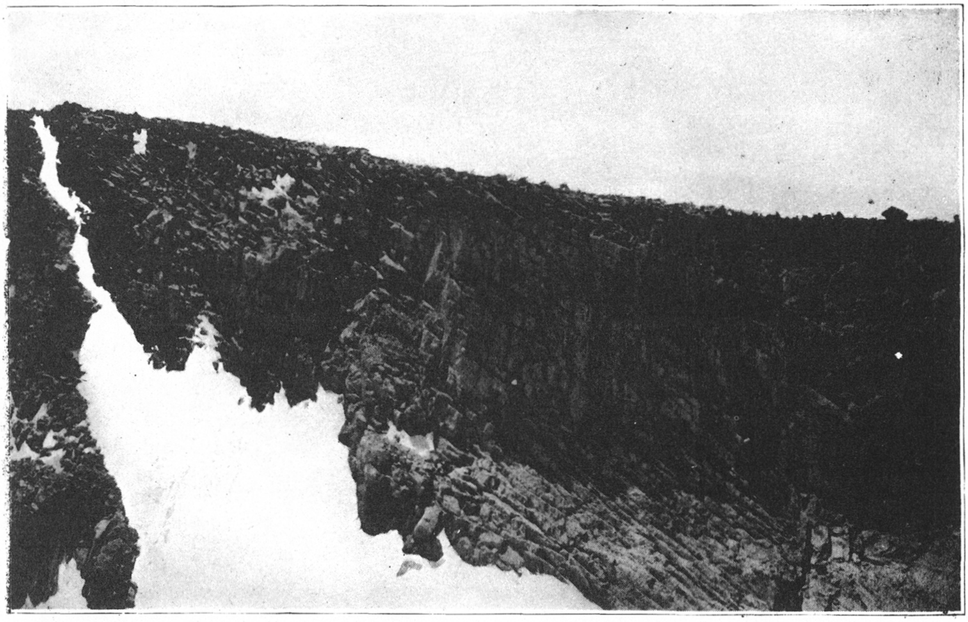
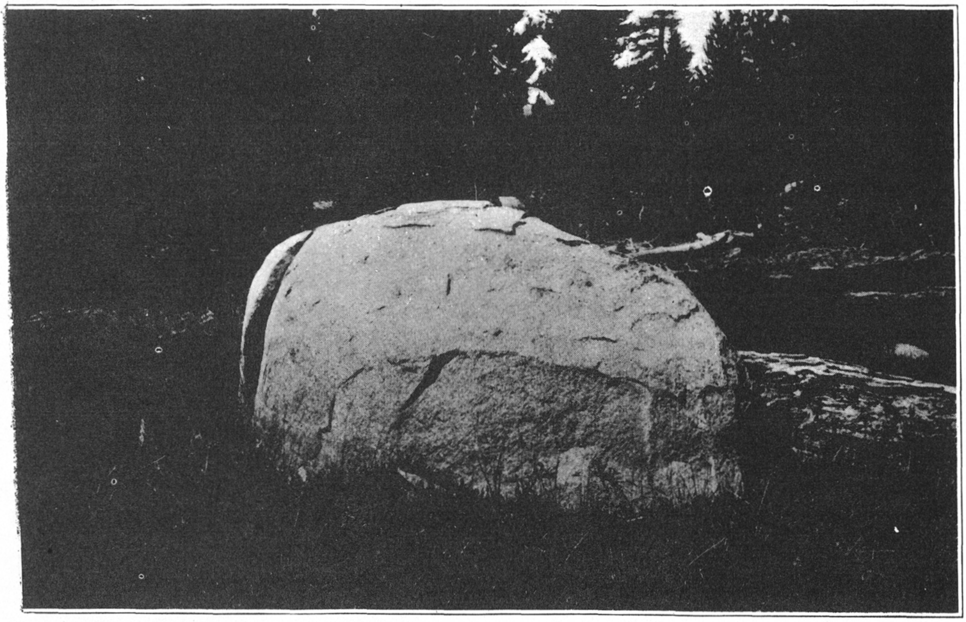


Figure 1.—Jointed Granite in Kuna Crest, Sierra Nevada



GURE 2.—Granite Boulder from which Spalls or Flakes have been Riven by the Heat of Forest or Meadow Fires

JOINT STRUCTURE AND FIRE SPALLING

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