

GRAVITATIONAL ASSEMBLAGE IN GRANITE*

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INTRODUCTION

In the higher parts of the Sierra Nevada the dominant rock is granite. By reason of Pleistocene glaciation the exposures are exceptionally fine. Over broad areas glacial erosion has removed the products of decay, laying bare the unaltered rock, and large portions of these areas are free from glacial débris. On most of the drift-free surfaces postglacial decay has made little progress and vegetation has as yet no foothold. In many places one can walk for miles on firm granite, and tracts of ideally perfect exposure are often many acres in extent. Taking account of the further fact that the summer climate is usually dry, I regard the region as one of the finest in the world for the study of problems associated with large bodies of granite.

My acquaintance with the Sierra granites is superficial and fragmentary. While engaged in physiographic and glacial studies I have traversed them on several lines, and finding my attention attracted by some of their conspicuous features have made a desultory record with notebook and camera. As I am not versed in either the methods or the lore of the petrographer, it has not seemed best that I attempt either to round out my field observations or to supplement them by office study, and this publication is undertaken chiefly for the purpose of directing attention to what I regard as a superb field for the study of the mechanics and physics of large plutonic

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bodies. The publication does not cover all my observations, but selects those in reference to certain assemblages of crystals and inclusions. The word "granite" is used in its broadest sense, including rocks to which the discriminating petrographer would give several different names.

FELDSPAR

One of the broadly developed granite types of the Sierra is of pale color, being composed chiefly of feldspar and quartz, with moderate amounts of mica and hornblende. It is characterized by very large phenocrysts of feldspar, the crystals ranging in diameter from one inch to four inches. Ordinarily these are scattered through the rock at intervals ranging from two to four or five diameters of the phenocryst, but there are many spots where they are so closely aggregated as to be in actual contact. Such aggregations are usually from a few feet to a few yards in extent. Their boundaries may be definite or indefinite. They are more abundant in regions where the phenocrysts are comparatively large. The one represented in the illustration is composed of crystals from $2\frac{1}{2}$ to 4 inches in greatest diameter. The crystals of an aggregation, although in contact, do not interfere one with another. Their interstices are occupied by smaller crystals, like those of the general mass of granite. These characteristics seem to me to indicate that the crystals were not formed in juxtaposition, but were in some way assembled after completion; and the hypothesis I suggest is that they were assembled by gravity, being either lighter or heavier than the magma from which they had crystallized. Their great size is favorable to the hypothesis that they were propelled through the magma, for the propelling force, differential weight, is proportional to the cube of the diameter, while the resistance of the magma is proportional to the square of the diameter.

Localities at which the phenomena have been observed are the uplands about Tuolumne meadows, and the vicinity of Cooper meadow on the headwaters of Yuba river. The locality of the illustration, plate 43, is one mile and a half east by south of McGee lake, in latitude $37^{\circ} 53'.8$, longitude $119^{\circ} 24'.3$.

HORNBLLENDE

Granites of light gray color, but somewhat darker than the last mentioned, exhibited in places a similar assemblage of hornblende. The hornblende crystals range in length from three-eighths to three-fourths of an inch. The largest assemblages seen are 6 or 7 yards wide and their limits are indefinite. In one instance there is a definite limit on one side. The hornblende crystals are not so closely packed as are the feldspar

crystals mentioned above. Here again the hypothesis offered is that of gravitational assemblage. At ordinary temperatures hornblende is 20 per cent denser than quartz and feldspar, the dominant minerals of the rock. If the same ratio obtains at the temperatures at which the magma congealed, the phenocrysts of hornblende might sink through the viscous magma without requiring such advantage of size as the feldspars possessed.

The locality represented in the illustration, plate 43, is on the east base of mount Silliman, in latitude $36^{\circ} 39'$, longitude $118^{\circ} 41'$. Another locality is on the north slope of the dome called Liberty Cap, at the head of Yosemite valley.

BANDING

A third phenomenon with which I am disposed, though less confidently, to associate gravity is a banding of granite. About one mile south of Cooper meadow, just to the left of the trail leading to Upper Relief valley (in latitude $38^{\circ} 13'$, longitude $119^{\circ} 49'.3$), there is a body of granite, some scores of feet in thickness and some hundreds of yards in length, which is conspicuously banded throughout. The rock is of rather fine texture and composed of quartz, feldspar, mica, and hornblende. The bands are alternately dark and pale, the color of dark bands being given by the dominance of hornblende and mica, that of the pale bands by the dominance of feldspar and quartz. They range in width from one inch to nearly or quite one foot. Some of the dark bands are darker than others; some of the pale bands are paler than others. The transition from a pale band to a dark may take place in a quarter of an inch or be diffused through an inch. The more abrupt transitions are from a pale band below to a dark band above. Within both dark and pale bands the attitudes of minerals seem to be wholly irregular. There is no parallelism of orientation and nothing about the rock suggests schistosity.

Several instances of unconformity were observed, as though the various bands had been successively deposited and the history of deposition had been interrupted by temporary erosion. Such a plane of unconformity appears in plate 44, opposite the man's wrist. At another locality, the southeast base of Goat mountain, in the Kings River basin (latitude $36^{\circ} 51'.3$, longitude $118^{\circ} 34'.2$), unconformity is associated with a discordance of dip of more than 20 degrees. I did not there see the rock *in situ*, but the banding is fully and characteristically displayed in a large boulder. Figure 1, based on a diagrammatic field sketch, represents a portion of the boulder.

I think that these bands are not only apparently but actually the result of deposition, and that the unconformities have been caused by erosion

and subsequent deposition. When the phenomena of the boulder (which happened to be first observed) stood alone, I entertained as an alternative the hypothesis that the unconformity was occasioned by the fortuitous juxtaposition of parts of a dislocated body of banded rock; but the unconformities of the Cooper Meadow locality do not admit of that explanation. In each example the bands of the body below the plane of unconformity are obliquely transected, while the bands of the body above the unconformity are continuous.

In each unconformity the lowest band of the upper series, that which rests directly on the eroded surface of the lower series, is one of the dark bands. This fact, taken in connection with the fact that the dark bands

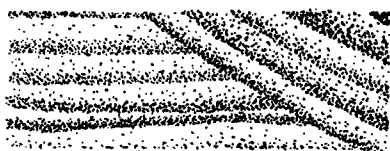


FIGURE 1.—*Banding and Unconformity in Granite.*

are more sharply separated from the pale bands below them than from the pale bands above them, suggests the hypothesis that a pair of bands—dark below and pale above—constitute the unit of deposition.

As to the general nature of the deposition, two ideas have occurred to me: (1) that the granite is metamorphic and the dark and pale bands were originally aqueous sediment; (2) that the granite is igneous and the bands were deposited from and partly eroded by liquid magma in motion. The first of these is opposed by the absence of schistosity, by the fact that the bands seem to lie in their original positions without distortion, and by the fact that the less siliceous bands, instead of the more siliceous, lie next to the planes of unconformity, thus reversing the normal order for aqueous deposition. The second suggestion, of deposition from a liquid magma, is too little developed for critical consideration. To constitute a useful working hypothesis it should be supplemented by the suggestion of conditions determining deposition and erosion.

If deposition was from a magma, and if the unit of deposition was a double layer, with dominance in its lower part of the heavy minerals, mica and hornblende, and dominance in its upper part of the relatively light minerals, quartz and feldspar, then gravity may have played a rôle in the process of deposition.

INCLUSIONS

Some of the Sierra granites are practically devoid of inclusions. Others show inclusions at all exposures. A body of light gray granite in the Kings River country, occupying a territory of unknown extent but not

less than 20 miles across, was nowhere observed without inclusions. The inclusions are all of one type, being composed of the same minerals as the matrix but with a larger percentage of mica and hornblende. They are somewhat finer grained than the including rock and they contain small phenocrysts of white feldspar. Similar phenocrysts occur in the matrix, but are less conspicuous because the general color of the rock is paler. A further characteristic of the inclusions is their small size. Ordinarily they range from two or three inches to about a foot in greatest diameter, and the largest seen is only three feet across. In a general way they constitute the tenth or twentieth part of the mass (plate 45, figure 1), but there are many belts and limited tracts where they are much more abundant, and in some places they form more than half the rock (plate 45, figure 2). When closely aggregated they do not touch one another, but are always separated by selvages or interstitial fillets of the matrix. In form they range from oval to angular, the angular individuals having rounded corners. Where they are closely assembled they indent one another in such manner as to indicate plasticity. Their boundaries are definite in the sense that there is not a gradual transition from inclusion to matrix, but are not sharply drawn like those of a pebble in a conglomerate. The inclusions do not separate from the matrix in weathering. While the inclusions are all of one type, they differ in size of grain and also to some extent in shade. Where they are closely aggregated, individuals of different shade and texture may be seen side by side. The assemblages may be only a few feet or a few yards across or may be several hundred feet in extent. Often they constitute belts traversing the ordinary granite, and sometimes the belts show evidence of flowage, all inclusions being elongated parallel to the general direction of the belt (plate 46). In extreme cases this elongation is carried so far that the individual inclusions become difficult to trace and the general appearance is that of banding, but there is no development of schistosity.

Somewhat similar inclusions observed a little farther south by Knopf and Thelen* are regarded by them as concretions. A concretionary explanation of the inclusions of the Kings River region would account for their omnipresence, for their uniformly small size, and for the frequent recurrence of the oval outline. It seems to be opposed by the dominance of subangular outlines and by the uniformity in texture of each individual in all its parts. There is no suggestion of concentric structure. While I gave some consideration in the field to the possibility of concretionary origin, the hypothesis more prominently in mind was that of fragmental

*A. Knopf and P. Thelen, *Sketch of the geology of Mineral King, California*: Univ. Cal. Pubs., Geology, vol. 4, pp. 236-239.

derivation from an older plutonic body. This hypothesis still seems to me the more available, but is held lightly, partly because it does not readily explain the small size of the inclusions and partly because it has been compared with macroscopic data only. Using it as a working hypothesis in the field, I interpreted the subangular forms of the bodies as fracture forms modified by partial solution in the enveloping magma.

Assuming the inclusions to be of fragmental origin, it seems evident that they experienced partial refusion while in the including magma. A plastic condition is implied by their deformation through interference where they are crowded close together, and also by the fact that they yielded to squeezing with the same facility as the surrounding magma. Had they been more rigid than their matrix, they would have been forced into contact before suffering elongation (see plate 46).

Assuming them to be fragmental, it is an open question whether their close aggregations are best explained as features of original distribution or as the result of gravitational assemblage. The first explanation accounts best for the long belts of closely grouped inclusions separating tracts in which they are sparse. The second accords best with the mingling of inclusions of diverse texture and also with the rounding of angles. A mass of angular fragments associated with little more matrix than was required to fill the interstices would have small opportunity for surface modification by solution.

In the vicinity of Cooper meadow, on the upper Yuba river, a very different granite, a pale variety with large feldspar phenocrysts, contains an abundance of small inclusions, and these also are in places closely assembled. In this case the inclusions vary through a much wider petrographic range and their history is more complex.

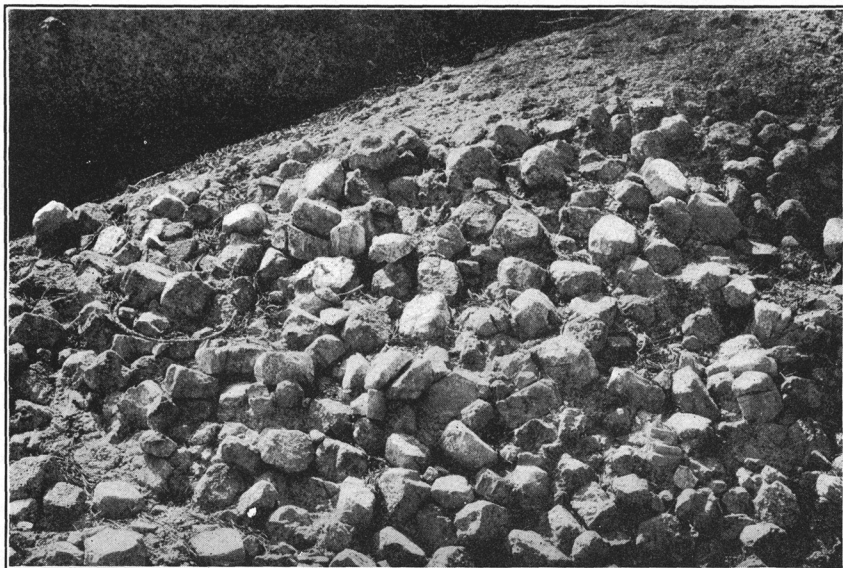
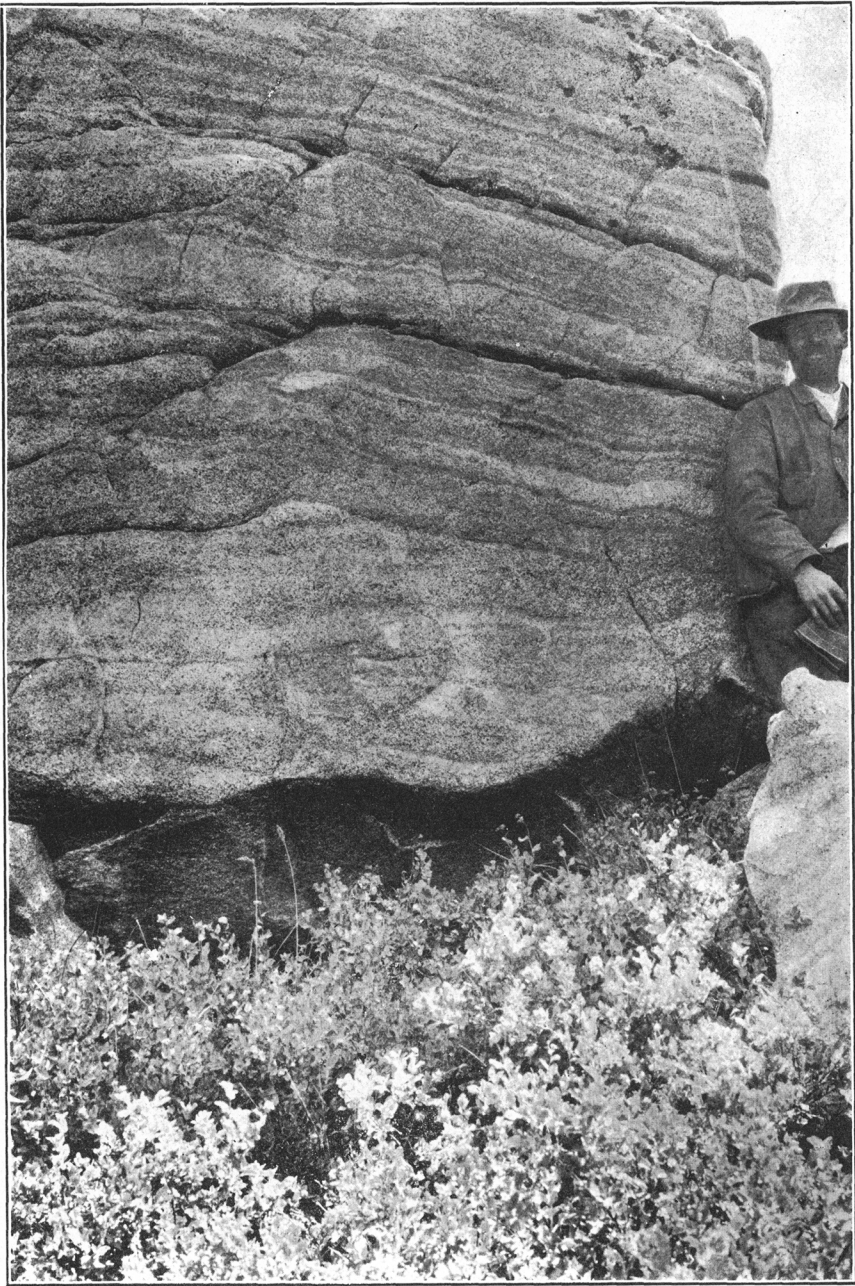


FIGURE 1.—FELDSPAR



FIGURE 2.—HORNBLENDE

ASSEMBLAGES OF PHENOCRYSTS IN GRANITE



BANDED GRANITE



FIGURE 1.—NORMAL DISTRIBUTION

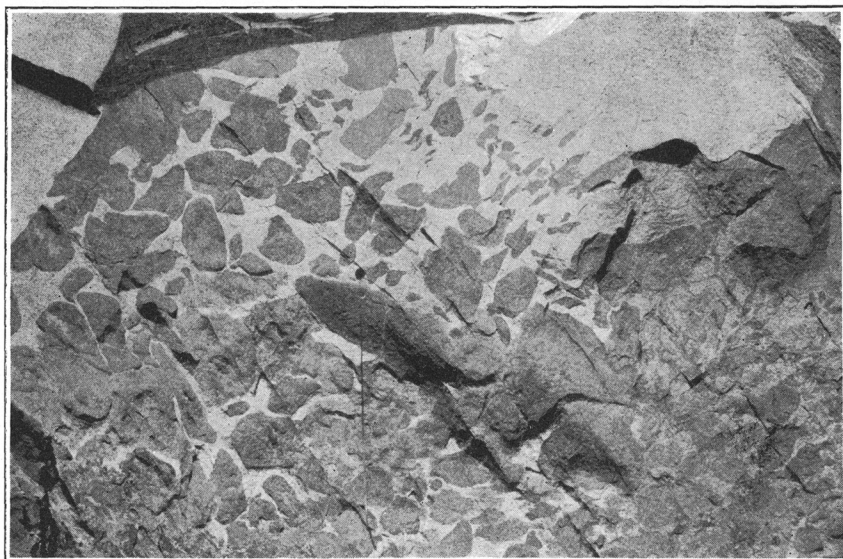
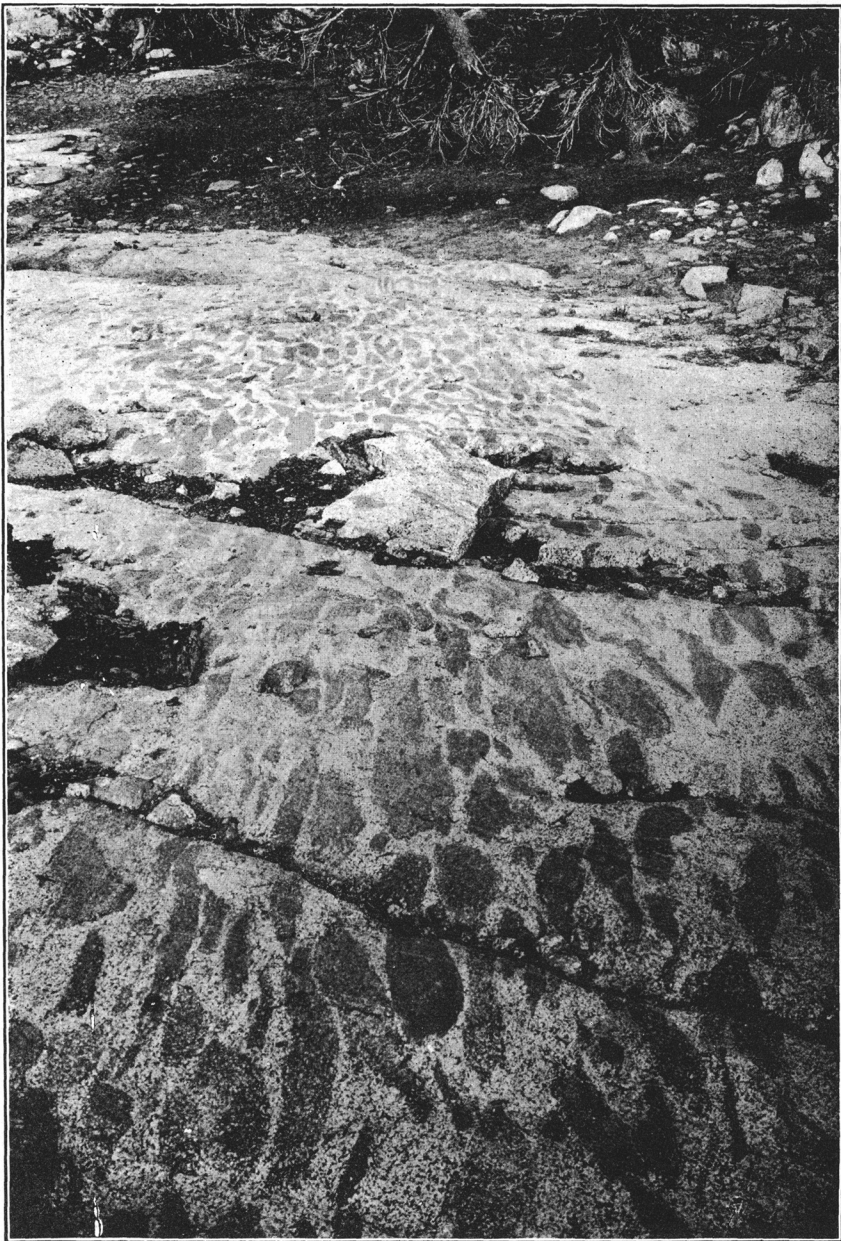


FIGURE 2.—AN ASSEMBLAGE

INCLUSIONS IN GRANITE OF KINGS RIVER REGION



COMPRESSED INCLUSIONS

EXPLANATION OF PLATES

PLATE 43.—*Assemblages of Phenocrysts in Granite*

FIGURE 1.—Feldspar.

The locality is on the north slope of a granite dome, between Tuolumne meadows and McGee lake, Sierra Nevada. The crystals are *in situ*, being brought into relief by the weathering of the granite. The upper limit of the assemblage appears in the view, and above it some of the ordinary granite. The view covers a width of three feet.

FIGURE 2.—Hornblende.

The locality is at the base of mount Silliman, near a branch of Sugarloaf creek, Sierra Nevada. The view shows the upper part of an assemblage. The granite immediately above is nearly normal, but has a slight excess of hornblende. The white patches at right are of aplite. The hammer handle, giving scale, is 15 inches long.

PLATE 44.—*Banded Granite*

The locality is one mile south of Cooper meadow, in the upper basin of the South fork of Stanislaus river, Sierra Nevada, near the middle of the Dardanelles quadrangle of the U. S. Geological Survey Atlas. An unconformity is shown to the left of the man's wrist.

PLATE 45.—*Inclusions in Granite of Kings River Region*

FIGURE 1.—Normal distribution.

The locality is on the northeastern slope of mount Silliman, Sierra Nevada, near its base. The inclusions are distinguished from various patches of surface discoloration by their compact forms and simple outlines. The largest inclusion has a diameter of about one foot.

FIGURE 2.—An assemblage.

Face of a boulder lying near the main trail through Kings canyon, Sierra Nevada. Scale is given by a steel tape, three feet long, near the middle of the view.

PLATE 46.—*Compressed Inclusions*

The locality is on the middle fork of Dougherty creek, Sierra Nevada, in the northeast part of the Tehipite quadrangle, U. S. Geological Survey, and approximately in latitude $36^{\circ} 54'$, longitude $118^{\circ} 36\frac{1}{2}'$. An assemblage of inclusions having the form of a belt is shown in perspective, some of the normal granite appearing on each side. All the inclusions are elongated in the direction of the belt and compressed laterally. The inclusions show differences in shade and texture.