ART. VI.—*On the Origin of Jointed Structure;* by G. K. GILBERT.

IN the March number of this Journal, President LeConte proposes to explain the jointed structure of the Quaternary clays of the Great Salt Lake Desert by referring it to the same category with certain shrinkage cracks observed in recent Californian alluvial deposits. The cracks he describes form by their intersection "more or less rude approximations to quadrangular or hexagonal prismatic blocks,"—and these words seem to imply the irregular arrangement characteristic of sun cracks. The joints dividing the clays of the Desert have, on the contrary, a regular arrangement. In describing them in the January number of the Journal, I spoke of a drainage system to which they give rise, and said that the blocks marked out by that system are "rudely rectangular," but the adjective *rude* could not with propriety be applied to the blocks cut out by the joints, for these are well-defined parallelograms. The joints are definitely divided into two systems, one nearly at right angles to the other, and within each system they are parallel. For this reason I am led to regard the proposed explanation as insufficient.

When a moist clay stratum shrinks by drying, its fracture is resisted, first, by its internal cohesion, and second, by its adhesion to that on which it rests. The average size of the blocks into which it divides is determined by these two conditions—the cohesion tending to make them large, the adhesion to make them small. The forms of the blocks are determined primarily by the fact that the contraction is equal in all directions, and we may conceive that each block tends to be circular about its center of adhesion—becoming actually polygonal, with as many sides as there are contiguous blocks. The arrangement of the centers of adhesion follows no law, but is conditioned in part by slight inequalities of adhesion or cohesion, and is irregular. There is always some inequality in the size of the blocks and the number of their sides ranges ordinarily from 4 to 7. It is a general characteristic of the cracks thus formed that they meet but do not cross each other. If four come together in such way as to include equal angles it is purely a matter of accident. Ordinarily only three meet in a point and neither of the three is, properly speaking, the continuation of one of the others.

The features characteristic of sun cracks in clay are repeated wherever a superficial layer of any material shrinks so rapidly as to crack. They are illustrated by a great variety of cooling and drying processes in the arts, and conspicuously by the cooling of lava beds. The system of cracks formed on the surface of a congealing lava stream are carried downward as solidification and contraction progress, and cause the rock to be divided into a system of polygonal, prismatic blocks.

Cracks of this type are included by some writers under the head of joints, but it will be convenient here to call them distinctively *shrinkage cracks* and follow Professor Dana in giving to the word *joints* a more restricted meaning. The joints which occur so generally in indurated rocks are characterized primarily by parallelism. By means of parallelism they are grouped in systems, and most rock-bodies are traversed by two or more of these systems. Their tracings at the surface constitute a lattice of straight lines or of lines nearly straight. The lines of two systems cross each other without interference. From each point of intersection lines go in four directions, and the alternate lines are prolongations of each other. Exceptional points can be found in which three lines meet, but the meeting always makes a letter T and never a letter Y—that is to say, two of the three meeting lines always agree in direction so as to constitute a continuous line, against which the third terminates. Usually the hammer will reveal an inchoate joint in the prolongation of the third line. In each of these respects joints differ from shrinkage cracks.

Joints of the same system are parallel; shrinkage cracks are not parallel. Joints of different systems cross each other; shrinkage cracks do not cross each other. In jointed structure the joint is the leading feature, the block is incidental, and the wide-spread evidence of system everywhere observed shows that the causative force either is diffused or is extraneous. In shrinkage-crack structure the causative force is localized in the shrinking block, and the crack is incidental.

Yet other points of difference could be enumerated, but enough have been adduced to show that the two series of phenomena are not closely parallel. Perhaps the shrinkage hypothesis for joints should not be set aside as absolutely untenable, but it certainly cannot be adopted until division planes demonstrably due to shrinkage are in some instance shown to have the peculiar characters of joints.

If we turn, now, to the relation between jointed structure and slaty cleavage, we find, to say the least, a close analogy. They agree in the parallelism of division planes. Just as one system of joints intersects another, so a system of joints is found to intersect a system of cleavage planes; and it is probable, though perhaps not certainly known, that two or more systems of slaty cleavage may exist in the same rock mass. The most striking difference between the two structures may possibly be one of degree merely:—in the case of joints the parting planes are separated by wide interspaces, while in the case of slaty cleavage the interspaces are small. Another difference is exhibited by the internal structures of the blocks separated by the division planes. In slaty structure the blocks are themselves cleavable in the direction parallel to the planes of division, while in typical jointed structure the blocks are not thus cleavable. These two differences are perfectly evident when typical samples are considered, but it may be doubted if they are universal and diagnostic. Many examples are difficult to class with one type or the other, and there appears to be a gradation of character alike in regard to the thickness of the parted blocks and in regard to their cleavability. It is practically impossible to draw a hard and fast line between the two structures, and the geologists who regard jointed structure as identical with slaty cleavage certainly have much to say in support of their opinion.

When however we come to the question of cause, serious doubts arise. We have a well-sustained theory that slaty cleavage is due to compression, the direction of the compressing force being normal to the planes of cleavage. If this theory is true, and if joints are essentially identical with cleavage planes, then joints too are caused by pressure and compression. Should we grant this we must accept joints in every instance as evidence of compression, and we must conclude that all or nearly all level-lying strata have been subjected to coercive pressure from one or more directions. Two systems of joints must indicate pressure from two directions at two different times, for coincident pressures could only induce jointing planes normal to the direction of their mechanical resultant. The occurrence in the same rock-mass of a number of systems of joints, theoretically indicates the successive, and not the coincident, existence of the same number of mechanical stresses. The application of this rule to the Quaternary strata of the Salt Lake Desert imposes a severe strain upon the imagination, for it requires us to believe that a broad sheet of freshly-formed sediments—so fresh that the shore-trace of the formative lake has scarcely been impaired by the weather—has been compressed by forces acting first in one direction and afterward in a direction nearly at right angles. There are, indeed, evidences of Post-Quaternary orographic movements in the region, but those movements were small and vertical, and the type of structure exhibited by all the surrounding mountains is one implying vertical displacement and no lateral contraction.

If the theory of lateral compression were valid, and if each epoch of compression left its record in a system of joints, it would be reasonable to expect that the older strata would be found to contain a greater number of joint systems than the newer, and that, *cæteris paribus*, there would be found a more or less gradual increase in the complexity of joint division from new rocks to old. Such, however, is not the case. Restricting our attention to those rocks which lie nearly level, we find that Paleozoic rocks rarely exhibit more than three or four joint-systems and frequently only two, while the same remark applies to Secondary and Tertiary rocks, and while the Quaternary clays of the Salt Lake Basin have two systems. In the range of my own experience the rocks freest from joints are the massive, cross-laminated, Triassic and Jurassic sandstones of the Colorado Plateaus, and these strata afford the only localities in which I have ever observed a *single* joint system. Indeed, the record of single systems of joints is so rare that I am disposed to question my own observation and suspect that the minimum number of coincident joint systems is two. However this may be, it is certainly an objection to the compression theory that, while the number of joint-systems in level-lying formations of all ages is frequently no more than two, it is rarely or never one.

Now, unless we include the suggestion that joints have a magnetic cause, or the absolutely baseless hypothesis that they are due to shearing force, there seem to be only the two hypotheses above discussed to account for them. The most competent writers who have treated of them have classed them either with shrinkage cracks or with slaty cleavage, ascribing them on one theory to mechanical pulling and on the other to mechanical pushing. If the considerations here adduced have weight, then neither hypothesis is satisfactory, and the problem is an open one. It is certainly hard to correlate the parallelopipedons into which the clays of the Salt Lake Desert are divided with the polygonal prisms normally arising from shrinkage; and it is equally hard to admit that the clays have been subjected since their deposition to coercive pressure from two independent directions.

In my judgment it is proper to conclude, first, that joints are not due to shrinkage, and second, that the theory which regards them as identical with slaty cleavage and ascribes both to compression is untenable. If pressure and compression suffice for the explanation of slaty cleavage, then jointed structure is something distinct from cleavage and needs an independent explanation. If joints and cleavage are merely diverse examples of the same general structure, then the theory of slaty cleavage which has been so widely received fails to comprehend all the facts and needs to be revised.