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ART. XXXVII.—*On the Origin of Normal Faults and of the Structure of the Basin region*; by JOSEPH LECONTE.

I HAVE already, in a previous paper (Am. Geol., vol. iv, p. 38), given reasons for thinking that the general structure of the earth is that of *a solid nucleus* constituting nearly its whole mass, a solid crust of inconsiderable comparative thickness, and a subcrust liquid layer, either universal or over large areas, separating the one from the other. In this paper I assume such a general constitution. I assume also that the crust rests upon the subcrust liquid as a *floating body*. We may well assume this because, broken as we know the crust to be, if it were not so it would long ago have sunk into the subcrust liquid. I have also, in the previous article already alluded to, shown that this condition of flotation would be the necessary result of the increasing density of the earth as we go down. I now wish to apply these two assumptions to the explanation of Normal Faults and of the origin of the Structure of the Basin region.

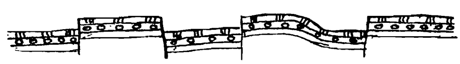
Crust-fissures and great faults.—Leaving aside the small fractures called joints which affect rocks of all kinds and in all places, the crust of the earth, as is well known, is everywhere traversed by great fissures more or less parallel to one another in the same region, often hundreds of miles in length, and passing entirely through the crust into the subcrust liquid beneath, by which the crust is broken into great oblong crust-blocks many miles in extent and through which the subcrust liquid is often outpoured on the surface in the form of lava sheets. The walls of such fissures do not remain in their original position but are always slipped, one side being heaved and the other dropped.

Such displacements are called *faults*. The amount of vertical displacement is often enormous, especially in the Basin and Plateau regions. The vertical displacement on the north side of the Uinta Mountains according to Powell is 20,000 ft., that on the west side of the Wahsatch according to King is 40,000 ft. In the Plateau region according to Dutton there are faults extending for 200 miles with a vertical displacement of 2000 to 12,000 feet. It seems impossible to account for such faults, unless there be a subcrust liquid.

The displacement of these enormous crust-blocks did not take place all at once, nor by uniform motion, but by a succession of slight slippings, each doubtless attended by an earthquake. This is by far the most common cause of earthquakes. If it were not for erosion, of course every fault would be marked by a great cliff of height equal to the displacement. But in every case the resulting cliff has been greatly lessened, and in many cases entirely destroyed by erosion. If, however, the rate of slipping has been greater than the rate of erosion a cliff will be formed; and if the time since the displacement was finished be not too great, the cliff will still remain. The faults of the Basin and Plateau region are on an enormous scale and are of comparatively recent origin, in fact are still growing. For this reason fault-scarps form a very conspicuous feature of this region.

Law of Faults.—If fissures be vertical so that the crust-blocks are rectangular prisms, then one block may sink bodily lower and another float bodily higher, giving rise to level tables

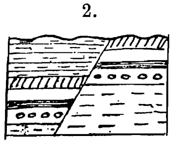
1.



Ideal section showing the general structure of the Plateau region.

separated by fault-cliffs (fig. 1). This structure is so common in the Plateau region that it may well be called Plateau-region structure. In such cases the fissures being vertical we can have no distinctive names for the two walls. But in nearly all cases the fractures are more or less *inclined*, and therefore we have

2.



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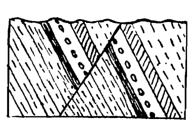

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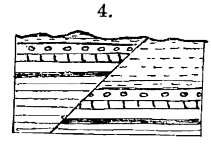
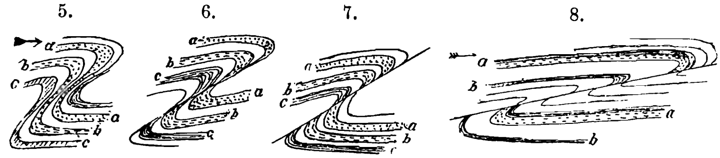


Normal Faults. Reverse Fault.

an upper or *hanging* wall and a lower or *foot wall*. Now in by far the larger number of faults we find that the *foot wall* has gone up and the hanging wall dropped down. These therefore are called *normal faults* (figs. 2 and 3). In many cases however, especially in strongly folded and crumpled strata whether in existing mountains or in the places of extinct mountains, we find faults in which the hanging wall has slidden upward and forward over the foot wall. These therefore are called *reverse* faults (fig. 4).

Theory of Faults.—The explanation of the *reverse* faults seems obvious enough. They occur, as we have already said, mostly in strongly folded regions. Such folds can only be produced by lateral pressure. The pressure when extreme often produces overfolds. If such overfolds break, the dip of the fissure will be toward the direction from which the pressure came and the hanging wall be *pushed* forward and upward over the footwall by the sheer force of the lateral thrust (figs. 5, 6

5. 6. 7. 8.



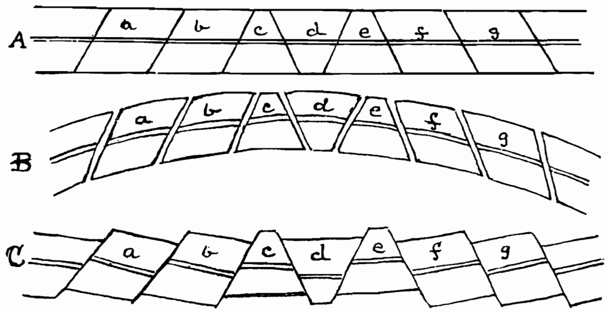
Diagrams showing made of formation of reverse faults.
(After DeMargerie and Heim.)

and 7). Extreme examples of this are found in the Scottish highlands in which the plane of displacement is nearly or quite horizontal. These are called by Geikie *thrust-planes* (fig. 8).

But the explanation of normal faults which are by far the most common is not so obvious. I will give very briefly what seems to me the simplest explanation—an explanation which I have used in my class lectures for many years.

Suppose then the earth-crust in any place to be *not crowded together* by lateral pressure, as in the formation of mountains of the Appalachian type, but *uplifted into an arch* by intumescence of the subcrust liquid. Such local intumescence of the subcrust liquid may be the result (*a*) of elastic force of steam incorporated in the magma in more than usual quantity by the access of water from above, or (*b*) of hydrostatic pressure transferred from a subsiding area in some other perhaps distant place. Such an arch being put upon a stretch would be broken by long fissures more or less parallel to one another and to the axis of uplift into oblong prismatic crust-blocks many miles in extent. After the outpouring of liquid lava or the escape of elastic vapors had relieved the tension, these crust-blocks would again be re-adjusted by gravity. If the blocks are *rectangular* prisms, some may float bodily higher and some sink bodily lower, giving rise to level tables separated by fault cliffs as in the Plateau region already explained. But if the fissures are more or less *inclined*, as is more commonly the case, then it is evident that the crust-blocks will be either rhomboidal (*a*, *b*, *f*, *g*,)

9.



A. Crust broken into blocks. B. Crust arched and blocks separated. C. Crust re-adjusted by gravity.

or wedge shaped (*c*, *d*, *e*, fig. 9 A). These in the arching of the crust would be separated from one another, fig. 9 B. But after the relief of tension by outpouring of lava or by the escape of steam, they would of course readjust themselves by gravity in new positions. Now by the laws of flotation how would such blocks adjust themselves? It is quite evident that every rhomboidal block would tip over on the *overhanging side* and heave up on the obtuse angle side producing in every case *normal* faults, and every wedged-shaped block would sink bodily lower or float bodily higher according as the base of the wedge were upward or downward, producing again in every case *normal* faults (fig. 9 C). A thick board sawn in the manner represented in fig. 9 A and the separated blocks placed together and floated on water would take exactly the positions represented in fig. 9 C. The explanation is complete. Of course erosion will modify the fault-scarps thus formed, by sculpturing their faces and by reducing their heights and slopes or even in some cases effacing them altogether. But if the fracturing and faulting have been geologically recent and on a large enough scale they may still remain and give rise to very conspicuous orographic features.

It is in this way that the orographic features of the Basin region have been formed; and the scale has been so grand and the features are so conspicuous that the resulting structure has been appropriately called *Basin structure.* The Basin region, according to the researches of King, Gilbert and Russell, is traversed by numerous north and south ridges several thousand feet high, with intervening valleys which are now or have been occupied by lakes. Although greatly modified by contemporaneous igneous ejections and subsequent erosion, these mountains consist essentially of gentle monoclinal slopes terminated by fault-scarps. They are in fact a succession of tilted and displaced crust blocks (fig. 10). The simplest and

Fig. 10. Basin structure, (after Gilbert.)

most beautiful illustration of this structure is found in the northern part of the Basin region in S. E. Oregon. In this region, as Russell has shown, the country rock consists of level sheets of lava outpoured during the later Tertiary period. These have been subsequently broken by parallel N. and S. fissures into rhomboidal and wedge-shaped blocks, which, readjusting themselves by gravity, have tilted or else sunk bodily lower, or floated bodily higher, so as to make a succession of normal faults. Moreover, the event has been so recent and the scale so grand that the uptilted side of each block forms a mountain ridge and the down dropped side a valley, on which has often accumulated a lake (fig. 11). Where the

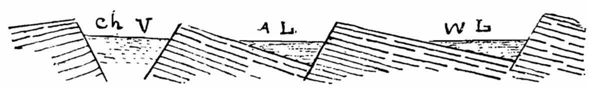


Fig. 11. Sketch section showing structure of S. E. Oregon, (after Russell.) W. L.—Warner Lake. A. L.—Albert Lake. Ch. V.—Chewaukan Valley.

inclination of contiguous fissures are in opposite directions, so as to form wedge-shaped blocks, these, as already explained, will drop down or heave up bodily. Some of the most conspicuous valleys are formed in this way—as for example Chewaukan Valley in Oregon, and Surprise Valley in N. E. California.

Geological age of these events.—I have already shown in a previous article (this Journal, vol. xxxii, p. 167, 1886), that the Sierra Nevada is a great crust-block 300 miles long and 50–60 miles wide heaved and slipped on the eastern side, forming there a great fault of 15,000–20,000 feet vertical displacement, and that this took place at the end of the Tertiary, accompanied with floods of lava. The evidence of this is found in the relation of the new to the old river-beds. The rivers displaced from their old beds by the lava have since that time cut far deeper than before, although cutting far less time.* Now,

* There is another evidence of the comparative recency of the origin of the Sierra in its present form, to which attention is now drawn for the first time. It is well known that *slates* overlying the axial granite are found forming the very crests of the Sierra. Furthermore, the deepest biting into the granite is found twenty miles westward of the crests in the region of the domes about the margin of the Upper Yosemite. This would be impossible if the crest had been in its present position ever since Jurassic times. When these mountains were first formed at the end of the Jurassic, the crest was probably about the region of the Domes. The tilting of the Sierra crust-block transferred it eastward to, or a little beyond, its present position Since that time it has been migrating westward by erosion. But the recency of this event is shown by the fact that these once flanking slates now forming the crest have not yet been removed.

this event seems, as shown by Russell to have been coincident with the formation of the Basin ridges, and both of these with the formation of the great fault-scarp on the western side of the Wahsatch range.

How the Basin system was formed.—Now regarding the Sierra and Wahsatch as belonging to the Basin system, we may imagine how the whole system was formed. At the end of the Tertiary the whole region from the Wahsatch to the Sierra, inclusive, was lifted by intumescent lava into a great arch, the abutments of which were the Sierra on the one side and the Wahsatch on the other as shown in the dotted line

Fig. 12. Ideal section, showing mode of formation of Basin system.

(fig. 12). The arch broke down and the broken parts readjusted themselves by gravity into the ridges and valleys of the Basin region, leaving the raw faces of the abutments overlooking the Basin and toward one another. It must not be supposed, however, that this took place at once, but *gradually;* the lifting, the breaking down and the readjustment going on together *pari passu;* each readjustment probably giving rise to an earthquake.

Process still going on.—There are many evidences that the process of adjustment of these crust-blocks is still going on. In the Sierra we find evidence in the still deepening channels of the rivers and especially in the occasional readjustment of the walls of the eastern fault of the Sierra block. The Inyo earthquake of 1872 was undoubtedly produced in this way. Gilbert also finds evidences of recent movement of the Wahsatch block in the faulted terraces of Lake Bonneville; and in this fact foresees the probability of destructive earthquakes here in the future. In the Basin region, both in Nevada and in S. E. Oregon, Russell finds evidences of the same in faulted lake terraces. Finally, during a camp of two or three weeks in 1887 in Warner Mountains, where the structure described by Russell is finely displayed, I found abundant evidences of local subsidence still in progress. Many small lakes in that region, probably of the type produced by block-tilting, have apparently been formed during the present century. In Blue Lake, for example, I found stumps of pines standing in water fifty or more feet deep, rotted off level with the surface, *but perfectly sound below.*

Two kinds of mountains.—I must not be understood as maintaining that the Sierra, the Wahsatch and the Basin ranges were entirely formed at the end of the Tertiary. Some of the

Basin ranges, for example those of S. E. Oregon, were indeed wholly formed at that time and in the manner already explained. But the Sierra, the Wahsatch and many of the Basin ranges existed before that time. The Sierra was born from the sea by the folding and upswelling of thick sediments at *the end of the Jurassic.* Many ranges in the Basin region were formed at the same time and in the same way. The Wahsatch was similarly formed, probably about the end of the Cretaceous. But at the end of the Tertiary the greatly eroded land surface previously formed in this region was arched and broken and readjusted, forming these ranges *in their present condition*, as already explained.

In an article published in 1872,* entitled "Theory of the formation of the greater features of the earth's surface." I showed that mountain ranges were formed by lateral pressure acting upon thick sediments folding and swelling up the mass along the line of yielding. In another article published in 1878,† I further developed the same views and tried to show that even the Basin ranges—claimed by Gilbert as belonging to a different type and formed in a different way—were no exception; that *they also* were formed by lateral pressure; only that in this case the crust of the earth being rigid would not yield by mashing, but only by arching—the blocks of the broken arch readjusting themselves to form the orographic features already described; and therefore that mountain ranges are all of one type and formed in one way, viz: by lateral pressure. I now feel compelled to modify this statement. It is evident from the *character of the faults* i. e. normal instead of reverse faults, that the arch was not formed by lateral *pressure* but by *tension of lifting.* Therefore, I now believe that mountain ranges are of two types: (1.) Those formed by lateral crushing and folding, and (2.) those formed by adjustment of crust-blocks. The one produces reverse faults, the other normal faults. The best types of the one are the Appalachian, the Alps, and the Coast ranges of California; the best types of the other are the Basin ranges. Very often the two types are mixed, or one is superposed on the other—the one or the other predominating. This is the case with the Sierra, the Wahsatch, and to some extent with many of the Basin ranges.

Note.—Since writing the above my attention has been called to the fact that Hopkins, in his "Researches in Physical Geology" (Phil. Trans. for 1842, p. 53), gives a similar explanation of normal faults in the case of *wedge-shaped blocks,* but he says nothing of the far more common case of rhomboidal blocks.

* This Journal, vol. iv, p. 345–460.
† This Journal, vol. xvi, p. 95.