The Kinetic Theory of the Origin of Mountain-Making Forces

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HARDLY a climber who has not sometimes wondered how mountain ranges came to be uplifted. An appreciation of their vast bulk—running far beyond trillions of tons of rock, and of their total uplift, two, three, five miles above sea level, makes this a peculiarly poignant question to a climber, weary and exhausted after having hauled his own mean mass, scarcely one-tenth of a ton, up their last few thousand feet—constituting to him a "great climb." To answer with a trite mention of geological processes is to beg the question, for whence came those forces that made possible these geological processes?

Introduction

The school-day theory of mountain origin compared the crust of the earth, as it cooled, to the wrinkling skin of an apple. Since those days many other theories have been proposed, generally based on a local expansion induced by one cause or another, within the sediments destined to be later themselves folded into mountains.

None of these theories have ever been satisfactorily shown to be capable of producing the great expansions of the earth's crust as recorded through folding and over-riding strata in amounts of hundreds of miles, in the Alps and elsewhere.

In seeking a more acceptable theory, the writer proposes the idea that those forces which compress sediments into mountain folds are primarily developed by the earth's own inertia. More exactly, by changes in the moments of inertia, as between adjacent sectors of the earth, the result of a slight shift in its axis. Such a shift could be produced by movements of sediments about its surface, or similar deformations of its surface, which would measurably alter the kinetic equilibrium of the several sectors of the earth, as it continued to rotate at a constant rate.

Illustration

For a simple illustration, take a flat wooden disc, on which some sand has been evenly sprinkled. Put this disc in a tub of water and spin it. If balanced, it will spin smoothly.

Now brush some of that sand over near one edge; spin it again; unbalanced, it will turn like an eccentric; it will also be obvious that the rim of the disc, immediately under the weight of sand, having a shorter "radius of gyration," is travelling at a smaller lineal velocity than its opposite side.

Then suppose we had two such discs, mounted parallel to each other on a single fixed axis—each disc likewise sprinkled evenly with sand. Now brush the sand on one disc over to one edge, and on the other disc over to the other edge, and give the double-decked disc a spin. It will spin about an axis which is inclined to its original construction. We would say that the "axis of gyration" has been tilted, with respect to the original axis.

Application to the Earth

Applying this principle to the earth, the brushing of sand to one spot on the one disc would represent accumulations of sediments in one sector of the Northern Hemisphere; and on the other disc, represent, of course, accumulations of sediments in an opposite sector in the Southern Hemisphere.

The result would be a tilting of the axis of the earth. It can be shown mathematically that a transfer of sediments involved in laying down Cretaceous rock throughout the world, would be capable of tilting the axis of the earth in the order of magnitude of 10 minutes ($1/6$ of a degree).

Transformation into Horizontal Forces

Two sets of forces would result in the crust of the earth from such a tilting: (a) North-South forces, and (b) East-West forces; as follows:

As to (a), we know that the equatorial diameter of the earth is 26 miles greater than the polar diameter, on account of the centrifugal force of the earth. If the axis of the earth is tilted, the plane of the equator must also be tilted to agree; and with this, the equatorial bulge will creep N. or S.; in so creeping it must produce N. or S. forces, as it compels the crust in its path to conform to its new position.

As to (b), recalling how, in either disc, a shift in their axis of gyration retarded the lineal velocity of one part of the rim, accelerated the other part—just so, in the earth, the crust on the side towards which its axis has shifted will be retarded, on the other side, accelerated.

With only a 10′ tilt of the axis, such forces may seem very slight; but the earth is a very massive object, and, rotating with a surface speed of 1000 miles an hour at the equator it does possess an immense inertia. Any attempt to retard any part of it is going to produce a lot of work, just as any attempt to speed any part of it up will require a lot of work.

Because the lineal velocity of any particle of the earth is East-West, such work—be it taken in, or given out—will involve East-West forces.

It must also be recognized that such changes in lineal velocity of one sector of the earth are local—sectors 90° removed are unaffected—forces must develop, therefore, *between* these sectors; and on account of the large area over which such forces must move to find complete equilibrium (up to 90°) forces developed by such kinetic principles are thus seen as uniquely competent to produce the great lineal displacements in the crust of the earth observed in mountain ranges.

Quantitative Calculation

It can be shown mathematically that the total work which can be done by both the North-South and the East-West forces, resulting from a 10′ tilt of the axis, would be theoretically equivalent to lifting 2,000,000 cubic miles of rock four miles vertically against gravity—provided no work was dissipated in friction, heat, or otherwise. As a matter of fact, losses by heat, etc., in any such a process would be very large, involving some two-thirds of all the work, such that at best some 600,000 cubic miles could be expected to be lifted up against gravity, four miles.

We thus have the picture of transfers of sediment such as were involved in laying down Cretaceous rock, as capable of developing kinetic forces in the surface of the earth, sufficient to lift up some 600,000 cubic miles of crust some four miles against gravity, in addition to having done even more work against friction, in the process of folding and faulting the crust.

While the above outlines the mechanical principles involved—and a quick calculation will show that, (a), the quantities of sediments required for transfer are comparable to known records of deposits of sedimentation; and, (b), the resulting available uplift is comparable to the uplift in major mountain systems—the reader may be interested in a little more specific data, without going into the several mathematical equations.

Additional Comments

(a) The axis may have been translated horizontally, instead of tilted—a translation of 3 miles is about equivalent to a tilt of 10′.

(b) North-South forces and East-West forces from *tilting* are, both, at their maximum at latitude 45° N. or S., and on the meridian toward which the axis has been shifted; tapering off to zero at the equator and poles, and tapering off away from that meridian.

(c) There are no appreciable North-South forces resulting from a *translated* axis.

(d) East-West forces from a *translated* axis are at their maximum at the equator, along the meridian toward which the axis has been shifted, and taper to zero at both poles, and also taper off away from that meridian.

(e) Calculation of the above quantitative figures indicates that the thickness of the completely rigid crust of the earth is only about 30 miles—meaning by completely rigid, the crust which will withstand, without any flowage, stresses that persist for millions of years—long term as opposed to daily tidal or, even shorter, earthquake stresses. (Against these *short term* stresses, experiments have shown even the centrosphere of the earth acts as "more rigid than steel.") Ultra-long term stresses are not to be confused with such near-instantaneous stresses in discussing the reactions of any very viscous substance. Even water is rigid to the unskilled bather who dives into it and hits it on his stomach!

Conditions Under Which Mountain-Making May Result From Such Kinetic Forces

This relatively slight thickness of the outer rigid crust leads on directly to the one process by which, alone, the above kinetic forces, on occasion, fold the crust into mountains, as follows:

As soft yielding sediments accumulate in some great hollow—a geosyncline in geology—they will tend to blanket the radiation of heat from beneath,[1] permitting the temperature of the underlying basement of normally resistant crystalline rock to rise, until

[1] This principle was first developed by Reade in his "Isogeotherm" theory of expansion of sediments into mountain folds.

finally, through long ages, that basement has become so heated and that it is more ready to yield to *long term* stresses. The overlying sediments are of course characteristically weak always.

The reader will realize at this point that these soft, yielding sediments, and now softened underlying basement rock, consitute a weak vertical "crevasse" cutting completely through the otherwise unyielding outer shell of the earth.

Such a "crevasse" of yieldable crust may lie dormant for many geological eras.

Resulting Uplift

If and when an accumulation of sediments somewhere else, by disturbing the earth's axis, starts to develop horizontal forces which happen to run transverse to, and through, this particular weak "crevasse," it is obvious that the yielding rock in this "crevasse" just cannot transmit the resulting horizontal forces as well as the resistant crystalline rocks of the normally rigid outer crust.

Superimposed on these horizontal forces may be additional intermittent seismic stresses, both of which combined may at first cause only small local displacements. Meanwhile, the attendant friction will heat the rock still more. Each such increase in heat will predispose the rock to yield still more easily the next time. The sediments in the crevasse (geosyncline) finally buckle and yield by folding and faulting. Much of the forces will be, of course, dissipated into heat in the process, further expediting "yieldability," but what survive of the forces will expend themselves in doing work against gravity in lifting up thousands of cubic miles of sediment, together, perhaps, with some of the underlying flowable crystalline basement, crumpling them all into folds.

It must be re-emphasized that only when, by chance, a previously prepared "crevasse" of sediments is presented to suitable forces—forces themselves developed and oriented by the chance location of other sedimentary deposits—only then is it possible for this process to carry through. If this combination does not take place, then the sediments in the geosyncline remain undisturbed and the forces generated elsewhere annul themselves in other ways, without producing mountains.

Possible Examples

Without any attempt at complete reconciliation with existing mountain ranges, for some minor ranges are no doubt due to one theory or another, we have the great range of the Alps-Caucasus-Himalayas, trending East-West, centered not far from latitude 45°, the latitude of maximum effect for North-South forces resulting from a tilt of the axis.

Also, the American Cordillera, running North-South, without a break at the equator, is reasonably the result of a horizontal translation of the axis.

Conclusion

This Kinetic Theory of mountain-making forces is thus offered as the reasonable reaction of the kinetic forces of a rotating body, whose specifications conform with our earth and where there is a priming agency such as erosion; reactions which, when conditions by chance are suitable, will result on occasion in a certain beautiful by-product which we climbers identify as a mountain range.

Postscript

The writer wishes to express his appreciation for the assistance given to him, in working up this Kinetic Theory, by his fellow-member, Professor Rollin T. Chamberlin, and by Professors Chester R. Longwell and Henry Margenau of Yale. Calculations supporting the statements made above will gladly be furnished by the writer to readers interested in a further study. They are not very complicated, and serve to emphasize the extraordinary beauty of balance between the physical characteristics of our own earth. If either its rotational velocity, its size, the density of its outer crust, the density of its centrosphere, or the intensity of solar radiation were changed to any moderate degree, it would appear probable that either terrestrial orogenic activity would be nearly non-existent (with our earth's surface mostly a flat sub-oceanic plain), or so extreme as to involve almost constant earthquakes and volcanic activity. In either case, terrestrial life today might still be in the Mesozoic state. Such is the meaning of our field, the Mountains.