THE EARTH'S CRUST

Have the nature and pattern of continents and ocean basins been essentially the same since the origin of the earth — or are they constantly undergoing change?

by A. E. J. ENGEL

A SOMEWHAT CRUDE but useful analogy of man's span of time on earth has been offered by Sir James Jeans. He pointed out that if we took the height of the Woolworth Building as representative of the total age of the earth (some 2-1/3 billions of years), the period of man's occupancy here could be represented by the thickness of a nickel placed upon the top of the building. Obviously we've come late to the party. Our limited impressions are probably highly tainted, and our data of the past extremely fragmentary.

Even in our short tenure on the earth, however, we are able to watch rivers, wind, and ice erode segments of the continents and carry the detritus to the sea, where sediments are formed. Volcanoes are born, flourish, and die; and earthquakes and related crustal movements suggest some ways in which mountains may grow. We may infer readily that the present is a key to much in the past, and use this concept as a philosophical basis in our geologic reconstructions.

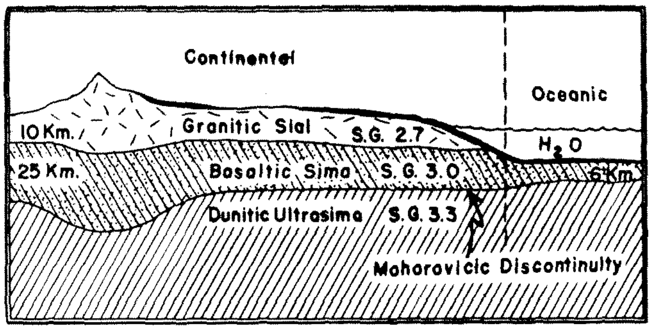
It is apparent, however, that these sequences of irregular but *somewhat repetitive* events *cannot* be extrapolated backward forever. Some gross processes and resulting features are bound to seem more or less unique to our short-lived earthly point of view. For example, to an earthling, the origin of our solar system, and of the earth, was a cataclysmic sort of thing. But even in this instance, though the labor may have been awful, the period of birth seems to have been extremely short in terms of the earth's after life.

Are there features of the earth itself—formed in the many tens or hundreds or millions of years after its birth —which are unique, or special, in their origin? Very possibly because of the time and scale factor, or perhaps because the material record is so fragmentary, such features would not be perceived readily.

We may confine our speculations to the crust of the earth, which is most readily examined, and—in the earth, as well as in pies—is worth inspection. Actually, the upper crust in the continental areas is about the only part of the earth subject to detailed geological observation and study. From geological data we can readily infer earth features in some places to a depth of at least several kilometers, and possibly locally to 10 kilometers. Geophysical data are invaluable in filling out our information of the deeper parts of the crust.

The earth's crust is frequently thought of in terms of its response to deformation—that is, in terms of its strength. Strengthwise, geophysicists find that at depths of about 80 kilometers in the earth there is a marked change in the strength of the material, although probably no change in composition. At this depth the resistance to plastic flow is presumably less than 1/100 of that near the surface. This susceptibility of the lower crust to plastic flow has special significance in conjunction with any movements of parts or all of the crust, relative to the earth's interior.

Let us first, however, think of a crust in terms of composition, or rock types. So considered, we find that the crust under continents is quite different from that under oceanic basins. The general relations of continental to



Vertical section through earth's crust shows inferred compositions of continental and oceanic segments.

oceanic segments of the earth's crust, as inferred from geological and geophysical data, are shown in the diagram above.

These data indicate unequivocally that in the continental areas the patchy deposits of sedimentary rocks are underlain by granitic rock (called sial because of the preponderance of silica, alumina and alkalis). The sial layer under the continents averages perhaps 10 kilometers in thickness. Interestingly enough, the sial thins or terminates abruptly at the continental margins and is very thin or absent in the oceanic basins.

Below this granitic zone of the continents the velocities of elastic waves (earthquake shock waves) suggest a zone of basalt—possibly grading downward into olivine basalt—with a total thickness of 20 to 25 kilometers.

Variations in the earth's crust

This so-called sima also thins abruptly in the oceanic basins. There it is apparently 5 to 8 kilometers thick, and is overlain only by patchy sediments and perhaps by minor sial and basaltic lava flows.

The base of the basaltic layer or sima in both continental and oceanic areas is marked by a sharp discontinuity in wave velocities (the so-called Mohorovicic discontinuity). This discontinuity is arbitrarily taken as the base of the compositionally unique rind or crust of the earth.

Immediately below, we may infer that there is material presumably kindred to the olivine rich rock dunite, and it is in this inferred dunitic rock, some 80 kilometers below the surface, that the marked change in resistance to plastic flow is found.

On the whole it is reasonable to think of the crustal masses composing the continents as lighter, thicker bodies of distinctive sial buoyed up above the heavier simatic ocean floors.

Along the belts of great mountain ranges such as the Sierra Nevada, or the Alps, the sial and/or sima are especially thickened. These and most other major mountain chains seem to have roots extending downward and depressing the Mohorovicic discontinuity.

The question may be asked, have these lighter, upstanding continental masses of the crust persisted through geologic time, essentially unique in form, in geographic distribution and structure, as contrasted with ocean basins—or have there been various modifications in the space and character of the major crustal features of the globe? An unequivocal answer to this question may be a long way off.

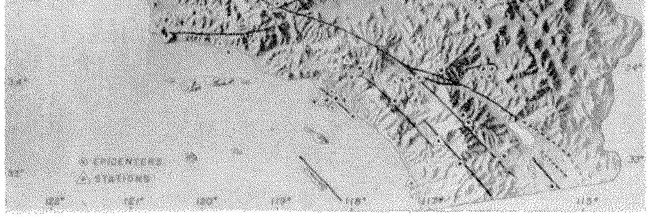
But let's very briefly explore the possibilities that these continental masses may have led a somewhat nomadic life on earth—not at all settled or quiescent.

Southern California residents need no assurance that the boundary area between this continent and the Pacific is in a state of unrest. On the map below, Dr. Gutenberg has plotted the epicenters of numerous earthquakes—many of which are clearly concentrated along and directly associated with the major faults in California. Relative motions of opposite blocks of the crust along the San Andreas fault alone are believed to total 25 miles. The same motion pattern appears to exist on many other subparallel faults of this area; much of the displacement is horizontal, with the west side of each fault moving northwest, relative to the east side.

Had our earlier politicians known about these faults and their movement patterns, they wouldn't have had to argue with Mexico about boundaries. We can just settle down and wait, and in a few geologic periods much of Mexico will be within the latitudes of the U. S. A.

True, these motions are not large in terms of the face of the earth—but they represent movements in a minute part of the crust, in only a minute fraction of geologic time.

Major vertical oscillations of the continents are forcefully displayed by their present relief. Obviously, if no major elevation of continents relative to oceans took place, erosion would have reduced all parts of the earth's crust to a featureless plane in a short space of geologic time. Marine fossils impressed the ancients with the fact that the floors of shallow seas had been elevated to the tops of mountains.

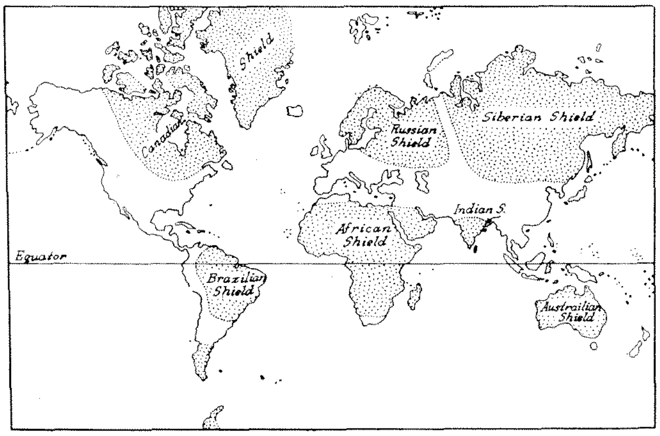


Relief map of part of California shows close association of major faults and earthquake epicenters as plotted by Gutenberg. San Andreas fault is long line passing into ocean near San Francisco.

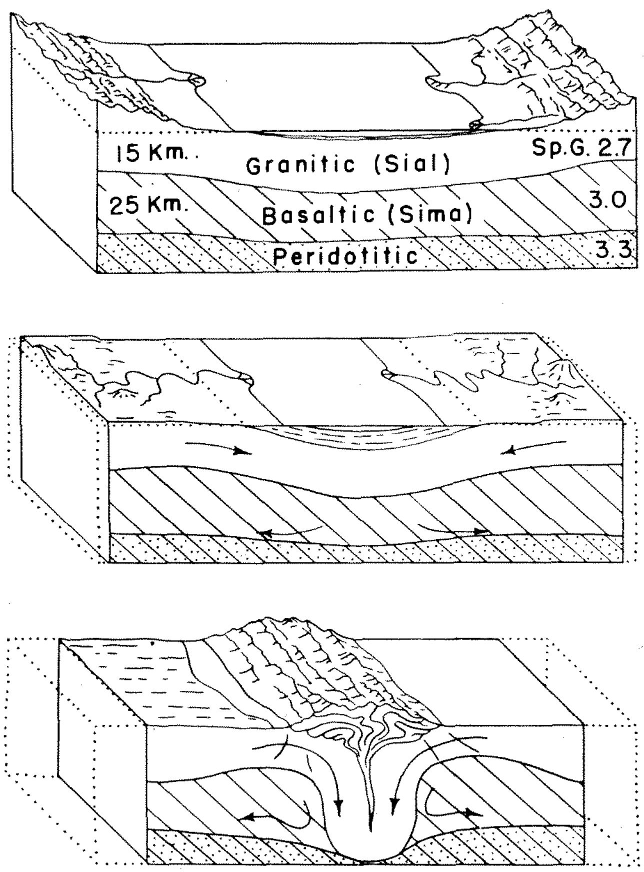
The patterns and history of such continental oscillations are in themselves peculiar and interesting. We find on each continent two general types of areas—shown on the right. One is commonly called a shield area or stable shield since the geologic evidence indicates that it has been remarkably stable, relative to sea level, since the Cambrian period—or for about the last 500 million years. These shield areas are bordered by so-called shelf seas and geosynclinal belts which are elongate zones along which transgressions of seas have occurred repeatedly since Cambrian time. The geosynclinal belts are major sites of deposition of sediments in these last 500 million years. The history of these geosynclines is that of lineaments on the earth along which the crust has been appreciably depressed, filled with great prisms of sediments, and then constricted and elevated into the great mountain chains of the world.

Curiously enough, the features of the stable shield show that prior to the Cambrian period, these now-stable shield areas had histories comparable to the present areas of shelf seas and geosynclinal belts. Consequently we know of no continental area that has remained stable and quiescent throughout geologic time.

Studies of the crudely cyclical evolution of downwarped segments of the crust into mountain ranges offer perhaps the most conclusive evidence of appreciable *lateral* as well as vertical movement of at least large segments of continental blocks. Almost invariably the dominant features along the mountain belts of the world suggest constriction and lateral migration as well as elevation of the earth's crust.



The world in Mercator's projection, showing the distribution of continental shield areas which have remained stable relative to sea level during last 500 million years.



Schematic block diagrams represent stages in the hypothetical evolution of a mountain belt from a geosyncline in the earth's crust.

The various geological and geophysical data derived along such mountain belts suggest the following sequence, as shown on the left.

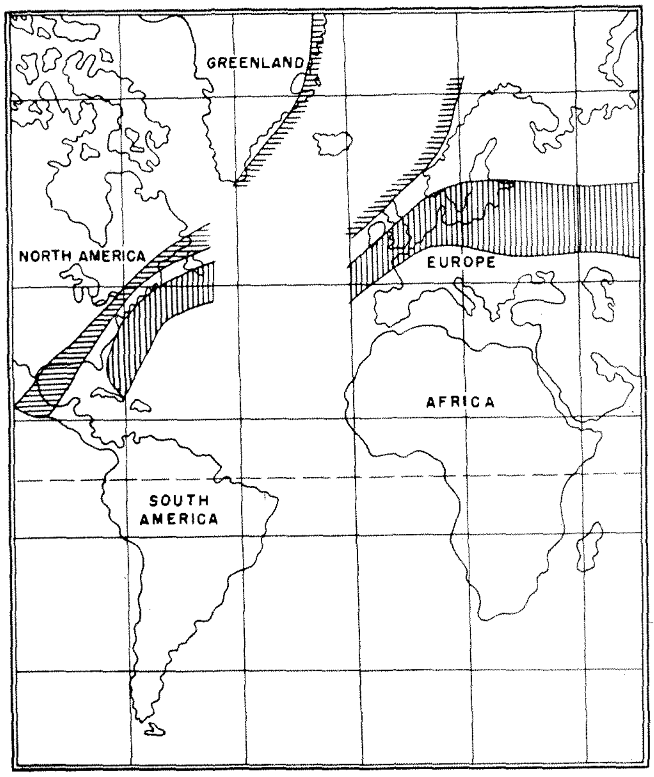
1. Successive downwarping of at least the sial or granitic part of the crust—actually in some examples the sial and underlying basaltic layer may both act as a unit in this downwarping. This is the geosynclinal stage, with detritus from adjacent continental highs contributing sediments to the trough.

2. With increased downbuckling and constriction of the crust the soft sediments and commonly imbricate slices of the granitic sial are forced upward and laterally to form a positive mountain belt. This is accompanied by a downward depression or buckling of the sial into the earth and by profound plastic flow in the subcrustal layers.

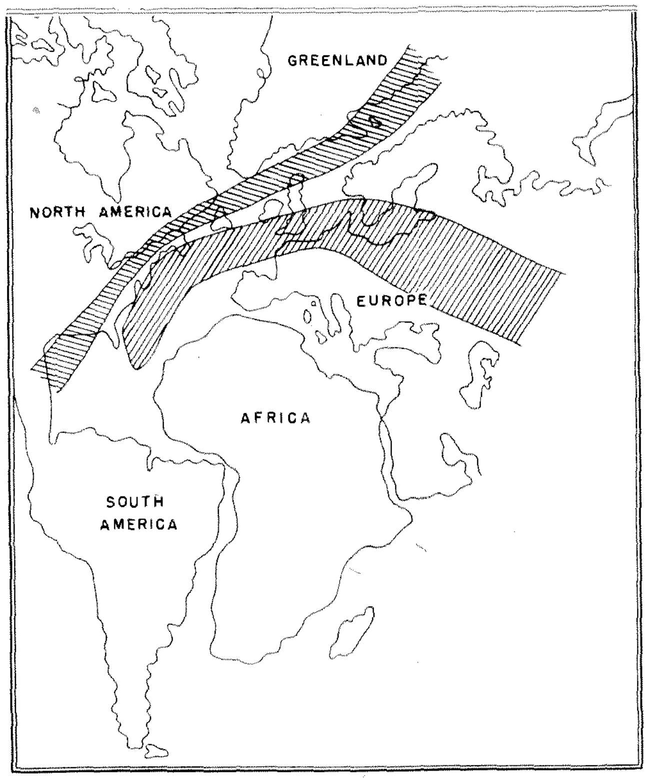
The sequence outlined briefly above, and shown in diagrammatic form, left, fits most known mountain ranges of the world. A classic example is the Alpine Himalayan type of mountain belt, which stretches from at least Gibraltar eastward through the northern Mediterranean into Asia as the Himalayan Range.

Most of the great island arcs of the world—the Japanese island arc, Java, the Philippines, Formosa, and the West Indies—appear to represent intermediate steps in what may be a somewhat analogous orogenic cycle.

If we consider any one of the great mountain chains on the crust of the earth we do find ample evidence of crustal shortening of appreciable dimensions. For example, in the Alpine Himalayan belt geological features seem to indicate that the Eurasian continental segment on the north and the African-Indian segments on the south have moved relatively much closer together. Certainly in the vicinity of the Alps a horizontal constriction of 200 miles or much more is possible, if not probable.



Map shows distribution of several mountain ranges formed during the upper Paleozoic Era of earth's history.



Possible relationship between continental masses at the time of evolution of the upper Paleozoic mountains.

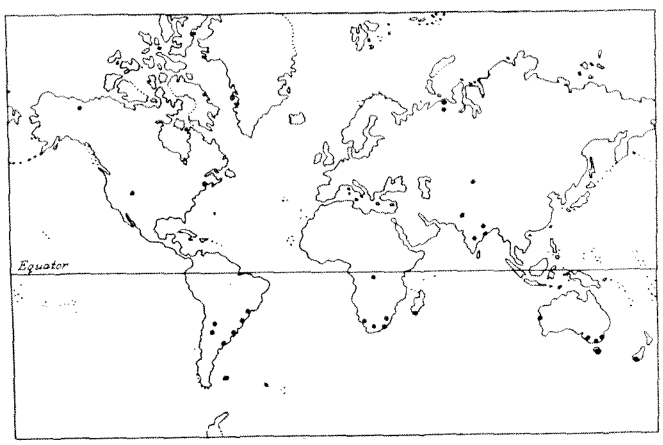
In view of the great frequency of such orogenic cycles in the crust throughout geologic time, the amount of lateral migration of parts or all of the continental blocks may be very great. We may ask, have the crustal motions in these orogenic cycles been localized or taken such directions as to cancel out each other; or do the numerous orogenic belts of the world represent evidence of crustal crumpling as the continental blocks have migrated rather extensively in some systematic way over a yielding substratum?

The fact is that we are too short on good data to provide an unequivocal answer. Certainly some orogenic patterns do suggest a common direction sense for continental sliding and close genetic relationships between now widely separated continents. In the diagram above, for example, are plotted several of the mountain belts of Carboniferous and Permian age, which may be of possible kinship. The diagram beside it is a reconstruction of a possible initial relationship between these mountain belts. Their many similar features suggest that during their evolution these ranges were contiguous units. To make them so, we have moved North and South America into the arms of Europe and Africa on the diagram.

The willingness of some geophysicists and geologists to consider such extensive travels of some of our continental masses is not prompted by data from orogenic belts alone.

For example, the projection of the world on the right shows the distribution of glacial deposits of the Carboniferous period—some 250 million years ago. One striking thing about these glacial deposits is that some of them lie within 25 degrees of the equator, in areas clearly not elevated at the time of glaciation. We do not know the source of the ice but if it is near the equator, a remarkable change in the near-equatorial climates is necessary. Alternatives are, of course, to assume a quite distant source area for the ice. One expedient is to postulate migration of the continents relative to the Pole, into their present position after the Carboniferous glaciation.

More than a few workers have been struck by the fact



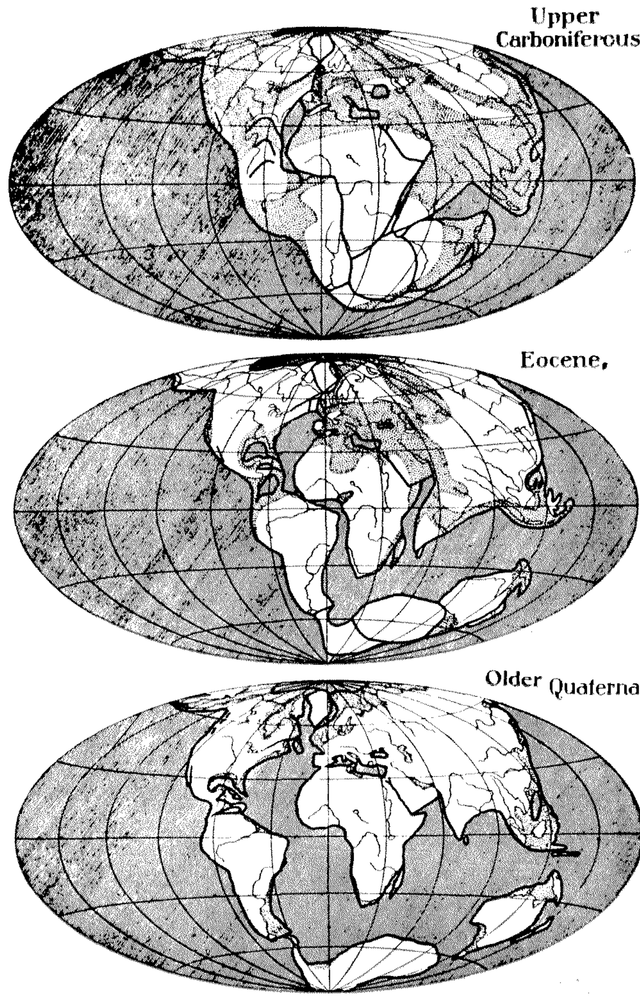
World map showing the distribution of deposits laid down by upper Paleozoic glaciers.

that the same reunion of the continents that tends to bring together the loose ends of possible kindred mountain ranges also brings these glacial deposits into areas of the globe where the climate is more consistent with great snow fields and ice sheets.

There are other data which may be explained by the assumption of continental displacements. For example, if we plot for any period in geologic time the distribution of certain closely related fossil organisms, or of some quite distinctive types of sedimentary rocks, patterns emerge which also suggest a hypothesis of continental displacement or scattering from a more common point.

The critical problem is of course to acquire reliable data on earth features and climates at successive geological dates, and then to see if these are consistent with a path or paths of continental drift.

This has been attempted by several courageous workers. One of the earliest and best known attempts at such reconstruction, made by the geophysicist Wegener, is shown on the right.



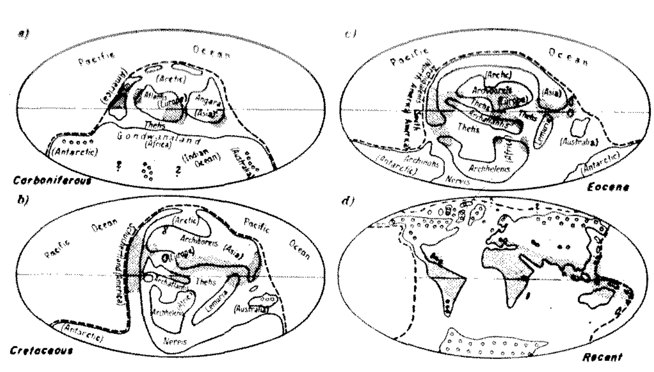
World maps showing successive stages in the migration of continents from a common nucleus, as postulated by Wegener.

Wegener's hypothesis

Wegener postulated a single large granitic cluster from which North America, South America, Antarctica, and Australia seceded in about Eocene time (let's say 50 million years ago—only yesterday in geologic time). Historically speaking, the secession movement, you see, is quite an old one.

Wegener's hypothesis got into grave troubles in large part because he employed as a cause of drift the tidal forces—which seem quite inadequate to move large segments of sial, or sial and sima, across a plastically yielding subcrust.

Subsequently many modifications of Wegener's hypothesis of continental drift have been proposed. Gutenberg has offered the suggestion that the continents flowed apart in the manner shown in the drawing below. Gutenberg suggests that the movements of the continents was accomplished by plastic flow in both the continents and the substratum. In the continental flow thin connections of continental material were left in the Atlantic and Indian Oceans—this suggestion to account for certain fundamental differences in the structure of these basins from that of the Pacific. Subcrustal currents, possible convection currents in the earth's interior, have been invoked as a possible mechanism to induce flow.



Pattern of continental spreading suggested by Gutenberg.

A problem for all the sciences

Clearly these proposals are highly speculative. To deal with them in a serious way demands a comprehensive knowledge of the history of the earth and its inhabitants. This can be had only with a thorough mapping of the face of the earth and a study of geological features and fossils of all ages. In addition, of course, the problems require the attention of all branches of science—physical, chemical, biological, astronomical, and mathematical, if they are to be solved.

To the geologist and geophysicist they are problems of compelling interest. Inasmuch as all of us must live here until death, or until space travel is accomplished, these problems have a common interest. There is undoubtedly here to be answered a question as fascinating as any in all science.