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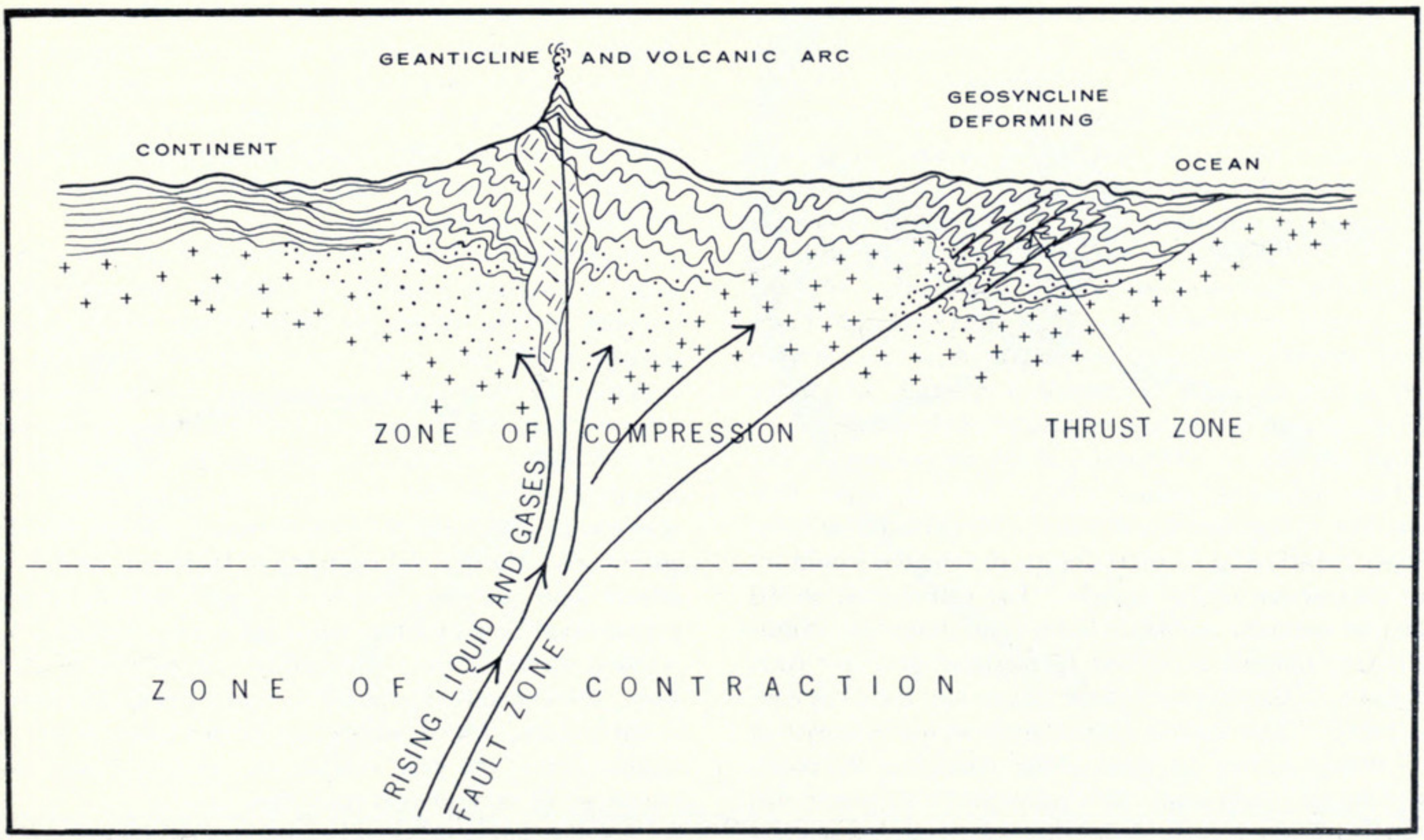
plex folds, led to the idea of horizontal compression in the crust as the operating force which caused the crumpling. A French geologist, Elie de Beaumont, in 1829 proposed that the compression originated through the contraction of the earth as it cooled. The hypothesis received much support about the turn of the century when it was recognized that in the Alps large slices of the earth's crust had been folded, dislocated, and thrust over others for distances up to tens of miles. Such overthrusting of masses thousands of feet thick was interpreted as proof of considerable crustal shortening by compression as a result of contraction. The fact that the folded zones occurred in restricted parts of the crust was explained by the crust's heterogeneity, certain sections behaving more plastically than the rest, which acted as rigid blocks. The geosynclines, in which large thicknesses of sediment accumulated prior to their conversion to folded mountain belts, were also believed to have formed as large crustal downbuckles produced by lateral compressive forces in the crust.

Contraction of the earth by cooling was an attractive idea as the earth was believed to have originated by condensation from hot nebular gases. It would have passed through a completely molten stage and on further cooling its mantle would have gradually solidified. An earthquake wave discontinuity at a depth of about 1,800 miles has been interpreted as the boundary between the solid mantle and the still liquid core of iron-nickel which is supposed to have settled inward under the influence of gravity. The crust formed as an early crystallized layer, likened to the slag floating on the iron in a blast furnace. The zone of cooling in the upper mantle is a region of contraction, while above this layer the already cooled crust and uppermost mantle are under compressional forces as they adjust to a smaller area.



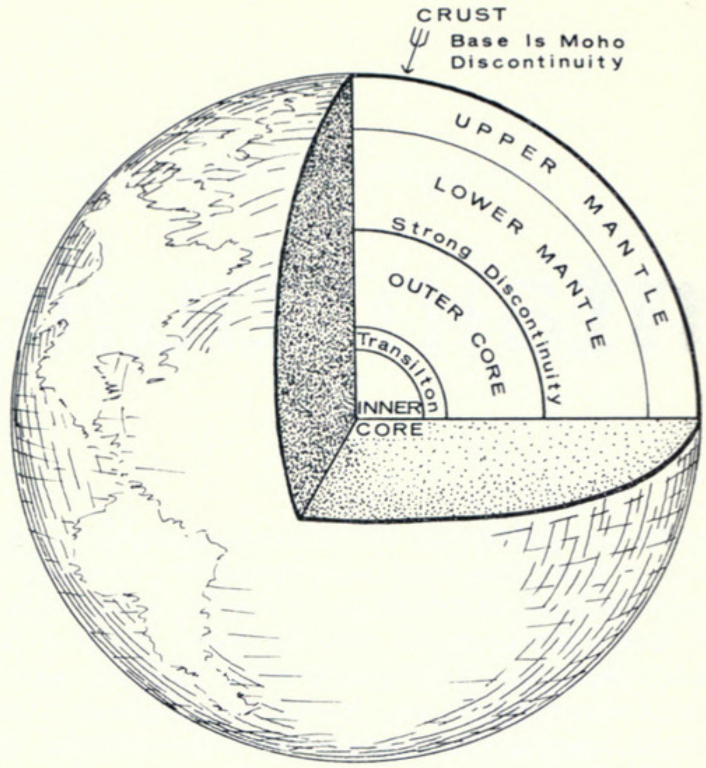
Vertical section of the crust and upper mantle at right angles to an orogenic belt according to the contraction theory.

One version of the mechanism of orogenesis suggests that the crust is pulled down to form a trough which becomes a geosyncline and is filled with sediment. Further compression of the crust leads to deformation of the thick deposits, metamorphism of the deep roots, production of magma and intrusion of granitic material; concomitant uplift is produced by the compressional thickening of the crust and isostatic response.

Another version attempts to relate the operation of the forces arising from contraction more directly to the large scale structures of the present active belts and their associated volcanic and seismic activity. Thus, continental margins with their thick load of sediment constitute a 'weak' zone which serves to focus rupture in both the contracting and the crustal compressional zones. Failure by faulting would take place along inclined planes which intersect the earth's surface as arcs. The inclined fault planes are equated with the inclined zones of earthquake origin which dip from the oceanic trenches toward and under the neighboring continents. Arcuate volcanic islands are formed by magma produced along the fault zone. The fault zone within the zone of compression is manifested by thrusting, which eventually affects the folded and altered sediments of the trough. Uplift of these transforms the trough into a geanticline, a new deep trough forms on the oceanward side, and the process is repeated.

There are a number of strong objections to the contraction theory. Today, the evolution of the earth from a hot gas cloud through a completely molten stage is not considered likely. Instead, it is believed the earth evolved by the agglomeration of many small cold bodies that formed in an orbit around the sun. The earth would gradually become heated, however, as a consequence of the great pressures developed internally and also from the energy released by the breakdown of radioactive elements. There is dispute about how much heat would be developed. Some hold that it would have been sufficient to largely melt the earth at an early stage and so aid the formation of the metallic core and sialic crust. Solidification of the mantle and further cooling would have ensued, allowing the application of the contraction hypothesis for mountain building as outlined above. Others consider that the rise in temperature has never been enough to bring about anything like complete melting and, further, that the earth may still be warming up rather than cooling. These different interpretations arise because, as yet, we do not have enough criteria on which to establish a generally acceptable set of calculations of the thermal history of the earth.

There are three modifications of the contraction theory that do not depend on cooling as the underlying cause. One suggests that the production of magma by partial melting of the upper mantle and its extrusion to the surface would result in contraction of the mantle. The contraction would provide the forces for mountain building as described. Additionally, the magma produced throughout geologic time would form the basaltic crust of the oceans and the sialic continental crust. The magma for the latter would originate at greater depths and be extruded at the margins of the continents (volcanic island arcs); the continents thus grow in size marginally. There is no evidence that volcanism is quantitatively adequate to produce contractional forces in the mantle and, as mentioned earlier, calculations suggest it is also inadequate to explain continental accretion in the time available.



Section of the earth showing internal structure.

The other variants of the contraction theory postulate that the core of the earth has been increasing in size throughout the earth's history. Generally, it is considered that the core is composed of iron-nickel; this is in accord with the overall density of the earth and with the iron-nickel meteorites that are presumed to have formed deep within a now fragmented planet. In contrast to the mantle, the greater part of the core behaves as a liquid with respect to the transmission of seismic waves. (A smaller inner core with a radius of about 750 miles is believed to be solid.)

Some earth scientists believe the core has grown continuously by gravitative settling of iron after radioactive heating had warmed the mantle sufficiently to aid the process. The growth of the core would cause contraction because of increase in the volume of the denser material, but it would also release gravitational energy in the form of heat at the mantle-core boundary. The heat would raise the temperature of the mantle and cause thermal expansion and changes in mineralogical constitution to less dense forms. These would only partly offset the general contraction by core growth. If the effects were periodic, however, it may explain periods of greater heat flow and tension in the crust (produced by expansion in the mantle) alternating with periods of contraction. Additionally, the heat may cause circulation of matter in the mantle, but we will return to this aspect later. Ultimately, when the core reaches its maximum size, cooling would set in as a general condition.

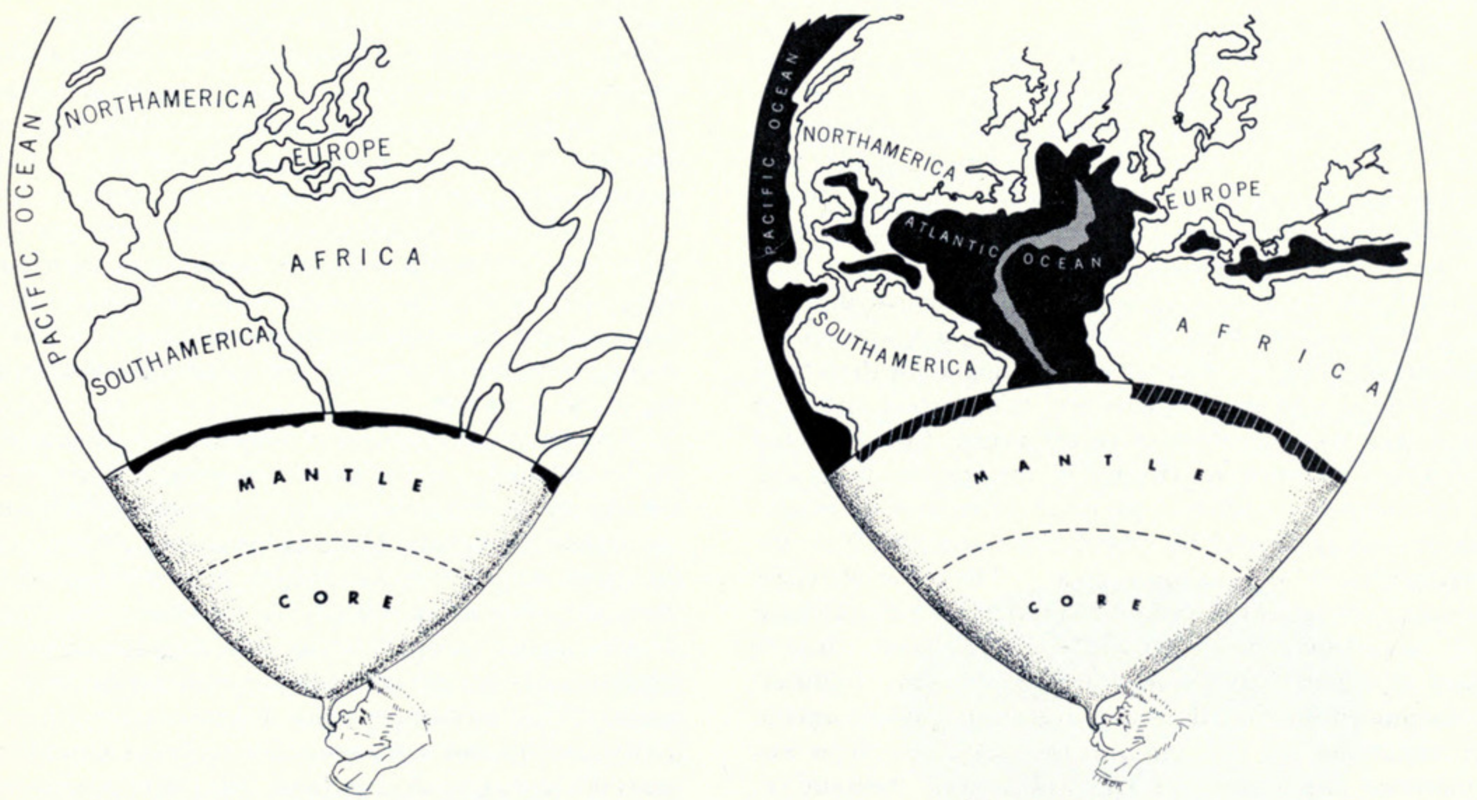
An alternative but highly controversial theory postulates core growth by an entirely different mechanism. Instead of being composed of iron-nickel, the core is considered to have the same chemical composition as the mantle but to be changed in physical state by the very high pressures and temperatures that exist deep in the earth. The minerals have broken down into simpler constituents and the atoms have been *ionized*, that is, electrons have been stripped off the outer shells that surround the atomic nucleii. The electrons are free to wander and the material is then in a metallic state (i.e., a good conductor of electricity). The breakdown of the crystalline state would mean also that the core behaves as a liquid. Thus, flow in this metallic-state core could equally well generate the earth's magnetic field as it would in a liquid iron-nickel core. Continuing increase in size of such a core would again lead to shrinkage of the earth's radius and also to release of gravitational energy as heat, with the attendant effects described above.

The major difficulties that have been placed in the way of the acceptance of any contraction hypothesis are the extensive system of mid-ocean ridges with their median rifts and transcurrent faults with evidence of large horizontal movements such as the San Andreas of California and the Alpine fault of South Island, New Zealand. The median rifts and their extension in the Red Sea and East African rift valleys imply major tensional forces pulling the crust apart. This is contrary to the state of compression which should reign in the crust if the earth is contracting. Likewise, it is difficult to explain large horizontal crustal shifts and also the movements and crustal tension deduced for many earthquakes of the circum-Pacific region if the crust is subject to compression.

However, it may be argued that there is another internal process to explain the crustal rifting, while orogenesis may still arise mainly through contraction, particularly if the two effects should operate more or less alternatively and periodically as noted above. Some geologists maintain that the earth is not contracting and is, in fact, expanding and that major earth structures can be better understood in an earth of gradually increasing radius. So we shall now turn to an examination of these ideas.

Expanding Earth Hypotheses

The concept of an expanding earth was first suggested about the turn of the century but has received more attention during the last ten years. It was put forward by some as an explanation of the theory of continental drift, i.e., the separation of the Americas from Europe and Africa was brought about by the expansion of the mantle and the rupturing of the crust and its separation to form the Atlantic Ocean. Carried to the extreme, some even advocate that the area of the present sialic crust (area of the continents plus the area of the surrounding seas down to an arbitrary depth) equals the area of the earth at the time when the crust was largely formed. This means the surface area was then a little under a third of what it is at present and the radius would have been only just over half of that of today's earth. The mantle and core would have expanded while the cooled thin sialic crust remained about the same in size; the crust was thus rent into pieces and dispersed into the pattern of the existing continents. The great system of median rifts along the mid-ocean ridges has been cited as evidence for expansion of the earth with the rifts representing the tearing apart of the crust and the development of new oceanic crust by extrusion of magma



Diagrammatic representation of an expanding earth; the continents are nearly coalesced at an early stage—LEFT, but have spread apart as the earth expanded—RIGHT. The continents remain essentially the same size but new oceans have formed.

from the mantle. Rifting of the continental crust would be marked by the African and Red Sea rifts, with the formation of a new ocean in the case of the latter.

Theoretical considerations of the evolution of the earth's interior have led some to postulate expansion. Thus, heat produced by decay of radioactive elements has been suggested as a source of thermal expansion; in general, calculations indicate, however, that this source is insufficient to explain any notable increase in volume. Another idea is that the earth's core is composed of matter in a very dense state and that this is unstable and changing slowly but continually into a less dense form. The volume increases, but in addition the energy released would cause thermal expansion and further mineralogic changes in the mantle. Contrary to this is the hypothesis of gradual core growth, during which the release of gravitational energy may suffice to cause enough expansion of the mantle to more than compensate for the contraction inherent in the increase of the dense core. Lastly, there is the very interesting postulate that the value of the universal gravitational constant is decreasing with time; this is related to the theory of the expanding universe. If gravity is decreasing, then the pressures within the earth are decreasing; this would cause expansion and also changes in the mineral structures to less dense forms and perhaps change of dense core material to less dense mantle material (assuming a non-iron core).

Geological data on the extent of the seas that have periodically inundated the continents during the last 600 million years have been interpreted as showing that the area of the incursions has steadily diminished to the present. This is taken to indicate earth expansion on the assumption that the continental sial area has remained much the same while the oceanic areas have increased.

Expansion has been utilized not only as the underlying force for continental drift but also for mountain building. The crust ruptures along the median rifts of the mid-oceanic ridges, and new crust is formed from the upper mantle. According to one view, deep sea trenches are formed by tension associated with deep mantle fractures (deep earthquake zones) which occur at the boundary of oceans and continents. Filling of the trenches produces geosynclines and hot volatile material, differentiated from the deep mantle, migrates up the fractures resulting in volcanism and melting of the deep crust and production of granite; increased temperature and deep burial cause metamorphism of the sediments. Compressional folding and thrusting are effected by the granite masses and by the increase in radius of the crust consequent on expansion, as well as possibly by crustal rotation arising from the development of new oceanic areas. Thus, the Pyrenees Mountains between France and Spain were supposed to have been formed by compression as the present North Coast of Spain separated from France forming the Bay of Biscay. Spain rotated southward around a pivot at the west end of the mountains and the region to the east of the pivot was compressed and folded forming the Pyrenees. Isostatic response to the thickened and granite-intruded crust causes emergence accompanied by sliding and folding of sediments from the uplifted mass. In these ways expansion forces are used to explain the process of mountain building and all the attendant phenomena which traditionally had been explained as caused by a regime of contraction in the earth. Previously we have seen that the contraction theories have problems, particularly in the existence of the world-wide oceanic ridge-rift system. How then can the expansion theories be assessed?

Compression of mountain range during twisting movement of a crustal block during earth expansion and formation of the Bay of Biscay.

There is little concrete evidence available on which to base estimates of possible earth expansion independent of geological interpretations. Calculations based on the postulated decrease of the gravitational constant suggest that the earth may have increased its area by some 5.5 to 6% during its total history (this means an increase in radius of only 0.002 of an inch per year). Estimates of radius increase over the last 200 million years based on paleomagnetic measurements on rocks of that age from widely separated localities on the same continent are not yet good enough to be used with confidence; it is suggested, however, that they do indicate a slow increase of between about 0.01 and 0.07 of an inch per year, depending on the data used.

Another possible source of information depends on the earth's rotation. If the earth was smaller in the past, it would have rotated more rapidly and there would have been more days in the year. Study of the growth pattern of corals that lived some 350 to 400 million years ago indicates that there were then about 400 days in the year. Assuming that the increase in the length of day since then is entirely due to expansion, the earth's radius has been increasing at a rate of about 0.026 of an inch per year. Unfortunately, tides caused by the moon's and sun's gravitational fields also affect the speed of rotation, rendering it very difficult to disentangle the various effects. Calculations have been made that attempt to separate the lunar tide component, and these still support a very slow expansion, rather than contraction, of the earth.

Expansion on a scale large enough to explain the drift of continents and the production of the Atlantic and Indian Oceans during the last 200 million years (amounting to an increase of about 36% of the present surface area, or an increase in radius of 0.2 of an inch per year) is apparently unexplainable by any possible means. Slow expansion over 3½ to 4 billion years, assuming the present sialic crust area was once the total surface area and requiring an increase of 70% of the present surface area and of 0.03 of an inch per year in radius, remains a possibility on the basis of existing data. It is regarded as unlikely by some and certainly there is no evidence that the sial ever completely covered the earth.

The suggestion has also been made that the area of the mid-ocean ridges represents new crust formed during expansion. The ridges cover about 12% of the total area and, if this is averaged over the greater part of the earth's history, the necessary expansion (a radius increase of only 0.004 of an inch per year) is very reasonable. However, the data available about the ridges indicate that they are geologically young features. If it is assumed they developed during the last 200 million years, then the amount of expansion becomes excessive.

It thus seems possible that the earth may have slowly expanded, but probably not at the rate some theories demand. Other causes are needed to explain features such as mid-ocean ridges and complex mountain ranges. While crustal rifting may be plausibly explained by an expanding earth, it does not seem possible to explain the totality of effects which are involved in the development of an orogenic belt, particularly the early subsiding geosynclinal stage.

This article will be continued in a subsequent issue of the BULLETIN.

ANTON BRUUN *(continued from page 4)*

The deepest dive was along the base of the spectacular pinnacle pictured on page 3, named Peterborough Cathedral. The water was quite clear. The bottom consisted of huge rounded boulders piled together, black and bare or gray-green when covered with algae and encrusting invertebrates. Long-spined sea urchins were scattered everywhere on the rocks and not together in clumps as is so often the case on a coral reef. The largest fishes here were moray eels but there were also bright red scorpion fishes, a brilliant pink sea bass, and a beautiful yellow butterfly fish boldly marked with black transverse bands. Most of the fishes were red, green or black and had to be searched out in the crevices or under the kelps.

Mas a Tierra, the island of the Juan Fernandez Islands nearest the mainland, is strikingly different from San Felix. Mas a Tierra has 3,000-foot ridges, sufficiently high for clouds to gather. This produces abundant rainfall on at least part of the island so the valleys have trees and most of the slopes dark green shrubbery. There are also barren ridges where the soil is thin; even these usually have some grass. About 600 people, mostly Chilean fishermen, live in one village; their main occupation is tending spring-lobster traps. The lobsters are kept alive in floats and once a week a seaplane calls to carry them to the Chilean market.

The water around Mas a Tierra was several degrees colder than at San Felix. The pine-cone and butterfly fishes were absent but otherwise the varieties of fishes at these two isolated, widely-separated localities were very much alike.

Perhaps half of the species of shore fishes around these islands are the same as those found on the mainland. Most of the remainder appear to be endemic species. Some of these, such as the pine-cone fish and deep-bodied snipe-fish, have their nearest relatives in New Zealand, Southern Australia or South Africa. The nearest relative of the strange butterfly fish has not been determined, but certainly it is very different from any American species.

The specimens have been sent to the Smithsonian Sorting Center and to Scripps Institute of Oceanography where they will be sorted and labeled. Certain groups are to be sent to specialists for study and eventual publication. The remainder will be available in institutions like Chicago Natural History Museum, for study by staff, visitors and students. The *Anton Bruun*, returned to its labors, still criss-crosses the sea, gathering the evidence which will in the years to come contribute to a fuller portrait of the Pacific.

The Anton Bruun