THE GEODYNAMICS PROJECT

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RESUMEN

Se presenta un bosquejo histórico del desarrollo de las ideas sobre dinámica de la tierra, y sobre los procesos que originan su constitución exterior. Este desarrollo culmina con el Proyecto de Geodinámica, una empresa científica internacional auspiciada por los organismos mundiales especializados en el campo de la geología y la geofísica. Se hace hincapié sobre las oportunidades de investigación en la región de México, Centroamérica y el Caribe.

ABSTRACT

The historical development of the study of the dynamics of the earth, and of the processes that produce its surface features, is outlined. This development leads up to the Geodynamics Project, an international venture sponsored by the world scientific organizations in the field of geology and geophysics. The opportunities for research in Mexico, Central America and the Caribbean region are stressed.

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The Geodynamics Project was formally inaugurated by the International Council of Scientific Unions (ICSU) in 1970 at the urging of the International Union of Geodesy and Geophysics (IUGG) and the International Union of Geological Sciences (IUGS). The purpose of the Project is to study the dynamics and the dynamic history of the earth and the processes that produce its surface features. ICSU invited member countries to participate and some have responded including, of course, our hosts at the first major geodynamics symposium, held in conjunction with the meetings of the American Association for the Advancement of Science in Mexico City. Although the purpose of the project is scientific –to determine how the earth functions as a system– thepractical aspects are obvious, particularly in regard to energy and mineral resources and in prediction, or perhaps even prevention, of natural disasters.

The Geodynamics Project had its immediate origins in the Upper Mantle Project (UMP), ably led by Professor V. V. Beloussov, during which the group of ideas that led to the plate tectonics model of the earth's outer shell were developed. It owes a debt to UMP, to the International Geophysical Year and to other experiments in cooperative international science, but it owes its existence to ideas –some good, others flawed; some inspired, others outrageous– generated by individuals working alone or in small groups. The plate tectonics model has a long and checkered history and a pattern of development in some ways similar to that of relativity theory in physics where parallel lines of development in mechanics and electromagnetism led to an unifying concept.

Some like to think that Francis Bacon (1620) was the first proponent of continental drift because of his speculations on the similarities of coastlines of Africa and South America. This is somewhat hard to defend since he was comparing the west coasts of each continent (Carozzi, 1970). Others note the work of Placet (1668) although the proposed that he separation of the continents was caused by sinking of the Atlantic Ocean basin. One can also make cases for Carl Ludwig Willdenow, Benjamin Franklin, Alexander von Humboldt and others, but it appears likely that the first man with sufficient confidence in the idea of drifting continents to publish maps was A. Snider (1858) who showed the continents first in juxtaposition and then in their present positions (see Holmes, 1965, p. 1197). His purpose was to explain the similarities of the coal measures of Europe to those of North America and the juxtaposition of the coastlines on the two sides of the Atlantic. He did not consider a mechanism or a cause of the continental movements. Baker (1911, 1932) went beyond the kinematics of the system and speculated about the dynamics. He suggested that tidal forces caused by eccentricities in the orbits of the earth and Venus ripped the crust off the Pacific and, following the idea of George Darwin, formed the moon from it. The remaining protocontinent broke up, the pieces drifted apart and the waters of the resulting oceans were captured from the breakup of the hypothetical planet now represented by the asteroids. This model did not gain wide acceptance.

At about the same time F. B. Taylor (1910) related the young mountain systems surrounding the Pacific to the opening of the Atlantic. Because his emphasis was on the splendors of Tertiary mountain building, the magnitude of the proposed continental movements tends to be obscured. His mechanism is a little vague and probably too weak. He invokes tidal action and hints in a later paper (Taylor, 1928) that capture of the moon during Cretaceous time might have increased tidal action sufficiently to cause the continents to start sliding around.

In January 1912, Alfred Wegener presented his ideas at an annual meeting of the geological society in Frankfort. This was subsequently published in monograph form in 1915 (Wegener, 1915). Wegener, a meteorologist, made the first detailed analysis of continental drift taking into account as much of the existing information from all branches of science as he could. He rejected the idea of permanence of ocean basins and pointed out that the oceans were qualitatively different from the continents, with basic rather than acidic rocks being dominant. He pictured a protocontinent as breaking up at the end of Paleozoic time with the fragments drifting slowly to their present positions, and, in a later edition, called upon convection in the earth's interior as the driving mechanism. This was significant since the process is continuous rather than catastrophic.

The idea of convection as a driving force was further developed by Arthur Holmes in two papers published in 1928-29 (Holmes, 1928, 1929). He pursued the idea that radioactivity within the earth produced the heat and the resulting convection produced the drift. His picture of a 50-100 km thick lithosphere being moved about is not too different from present ideas and was an improvement on what Wegener was usually credited as thinking-continents plowing through oceans.

Vening Meinesz (1952), who invented the submarine gravity pendulum apparatus, also favored convection. The large negative gravity anomalies he found associated with deep-sea trenches in the East Indies could not be explained by the water depth alone and he concluded that they must be due to down-buckling of the "crust". He is sometimes taken to task on the grounds that the crust under the continents is thicker than that beneath the oceans, but careful review will reveal that his "crust", refers to what is termed "lithosphere" today, the upper 50 kilometers or so of the earth's outer shell.

Kuenen (1936) built a model to demonstrate this downbuckling consisting of a "crust" of finite strength over a fluid substratum. With a slight initial depression to localize the deformation, he was able to produce a downbuckle similar to that proposed by Vening Meinesz. Usually it was a single downbuckle, but sometimes it sheared as buckling proceeded and underthrusting was initiated. Hess (1938) superimposed Alpine mountain structures on this downbuckle or "Tectogene" and suggested that features of this type underlay the major mountain systems as well as island arcs and were the reason for their existence. Griggs (1939) found some objections to the dynamical similarity of the Kuenen model and suggested instead a convection model that did not require such a large difference in apparent viscosity between the lithosphere and the underlying substratum. He constructed a model with which a downbuckle could be produced by rotation of two small cranks in opposing directions.

Meanwhile, other ideas about the development of the earth's surface features had sprung up. Helgenburg (1933) suggested that separation of the continents was caused by expansion of the earth. His concept was not taken seriously because it included an *ad hoc* hypothesis that the interior of the earth increased in mass as well as in volume, a concept repellent to most physicists. This deficiency was corrected by J. K. E. Halm, (1935) a South African astronomer who approached the problem in the light of current thoughts about the evolution of stars, and the idea was further revived by Egyed (1956), Heezen (1959), Carey (1958) and others. Although there are difficulties with the amount of expansion required to explain the apparent relative movements of the continents and with the rates at which it occurred, the possibility of some expansion of the earth through geologic time cannot at this time be denied. Elie de Beaumont (1829) advanced the converse hypothesis, that the earth is thermally contracting, to account for the folding, thrusting and apparent crustal shortening found in the Alps and other mountain ranges. As the inside cooled and shrank, the already cool and solid exterior would be too large to fit the shrunken interior, hence it would become wrinkled like the skin of a dehydrated apple. This concept had many supporters and the physical arguments in favor of contraction were well developed by Jeffreys (1952) who noted that "thermal contraction predicts the correct order of magnitude of the total crustal shortening indicated by mountain systems; it also explains the intermittence of mountain formation in time. . ."

Father Francois Placet (1668) prior of the Abbey of Bellosanne, near Rouen, France suggested that the separation of the continents on the two sides of the Atlantic was caused by sinking, or subsidence, accompanied by the uplift of the Americas. The concept of creation of ocean basins by vertical movements was supported by Suess (1904) who viewed them as evidence of collapse of the earth's crust and by Haug (1907) who spoke of submerged continents. The idea has been further espoused by Beloussov (1968) who suggests a mechanism of basification to transform continental crust into oceans. There is no question of the importance of vertical movements and it is difficult to explain the geological features of continental margins and marginal seas such as the Mediterranean without invoking some sort of oceanization process.

Each of the above ideas had its defenders and it was difficult to choose among them on the basis of solid data rather than emotion. Holmes (1953) commented "I should confess that despite appearances to the contrary, I have never succeeded in freeing myself from a nagging prejudice against continental drift; in my geological bones, so to speak, I feel the hypothesis to be a fantastic one. But this is not science. . . While so many contradictory voices confuse judgment, one cannot do better that commend Dunbar's wise dictum that 'it is unsafe to reject, a priori, either continental drift or foundering of broad land bridges' ".

The currently favored plate tectonics mode did not spring suddenly into prominence but grew as a result of new data. There have been many contributions, but three, in particular, served to make the model acceptable to a majority of the earth sciences community. The first, chronologically, was the concept of the asthenosphere (Barrel, 1914; Fisher, 1889) that beneath a relatively strong lithosphere there exists a layer of small strength that permits gradual movements to approach a hydrostatic equilibrium. This was discussed by Daly (1940) and pursued by Gutenberg (1926, 1953) in his investigation of a low-velocity channel in the upper mantle. Benioff (1955) noted the difference in the strain release characteristics between shallow (0-70 km) and deep (70-700 km) earthquake sequences and concluded that they are tectonically isolated from each other. He also suggested that the great earthquakes might form a single tectonic system. Thus, it might have been inferred that the earth's outer shell is decoupled to some degree from the interior and that it is being subjected to forces of a global scale.

The second was the identification of the pattern of magnetic stripes in the oceans with the time-scale of magnetic reversals (Vine and Matthews, 1963; Vine, 1966). It had been known for some time

(Rothé, 1954) that seismicity in the ocean basins was mostly rather narrowly confined to the axis of the mid-ocean ridges. This indicated that tectonic processes were most active there and the correlation of the magnetic stripes with time led to the concept that new crust was being formed at the ridge axis and that the lithosphere was moving away from these axis at rates of the order of centimeters per year.

The third resulted from studies of deep focus earthquakes. Such earthquakes had long been recognized (Turner, 1922) and their distribution in a dipping zone had been pointed out for Japan (Wadati, 1935) and for the circum-Pacific belt (Benioff, 1954). Studies of the deep focus earthquakes in the Tonga-Kermadec region (Isacks, Oliver and Sykes, 1968) revealed that the properties of the rock material in the earthquake zone, dipping from the surface to 700 km, were more like those of the lithosphere than those of the underlying asthenosphere. Thus it was reasonable to conclude that in the regions where deep-focus earthquakes are found the lithosphere was being underthrust to depths at least as great as those to which earthquakes occurred.

These basic observations led through the concept of Hess (1960) called sea-floor spreading by Dietz (1961), and new global tectonics by Isacks et al (1968), to the commonly accepted term, plate tectonics (McKenzie and Parker, 1967; Morgan, 1968). On a global scale, plate tectonics considers the earth's outer shell as made up of a small number of very large plates moving relative to each other –converging in the deep earthquake zones, diverging along the world rift system (Drake, 1964) and sliding along each other in areas of major transverse faulting such as the San Andreas system of western North America. The plates are of the order of 100 km in thickness and while the major tectonic activity occurs on their margins, their interiors are not entirely quiescent, being subjected to vertical movements of considerable magnitude and to volcanism.

This basic model has brought new vigor into the earth sciences since the observations from all parts of the field can be related to it. It has great promise not only in explaining the nature and history of the earth and the processes that have created its surface features, but in providing the fundamental knowledge necessary for predicting or preventing natural disasters and for the discovery and utilization of earth resources. Since the plate tectonics model is of global scale, full understanding requires international cooperation and investigations of the same magnitude. It is the purpose of the Geodynamics Project to promote and encourage these activities and to provide a communication mechanism through which ideas and data can be exchanged. To date 52 countries have announced their intention to participate in the Geodynamics Project. Several have specific investigations underway. Some countries have not attempted to organize special new programs, but a number have indicated their intention to undertake ambitious new efforts over a period of six years.

In conclusion, and in recognition of the locale of the AAAS Symposium to which this paper is a contribution, it should be noted that the opportunities for significant geodynamic research in Mexico, Central America, the Cocos plate and the Caribbean are very great. The history of this region is the key to the history of the opening of the Atlantic Ocean and the separation of the continents around it. Active subduction is taking place in part of the area, active divergence is occurring in other parts, and major strike-slip movements are found in several areas. Measurable vertical movements are found in many areas –both short and long term, and the processes that produce economic concentrations of minerals are active. The geological history of this region places definite constraints on the global plate tectonics model. There are many challenging questions whose answers can be found in this critical area and the contributions of geoscientists from the region can extend far beyond its borders.

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