DYNAMICS OF THE EARTH’ S CRUST IN ZONES OF TRANSITION FROM CONTINENTS TO OCEANS OF THE ATLANTIC TYPE

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DYNAMICS OF THE EARTH' S CRUST IN ZONES OF TRANSITION FROM CONTINENTS TO OCEANS OF THE ATLANTIC TYPE

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At present, a number of features of marginal zones of the Atlantic type are well known (^{1,2}):

1. Thick sequences of sediments accumulated either in the shelf zone or in the zone of coastal plains, and at present submerged along the periphery of the oceans to depths of up to 4–4.5 km.

2. Submarine canyons cutting across the shelf, the continental slope, and sometimes the continental rise, and representing continuations of large river valleys on land.

3. Discordant truncation of continental structures by the ocean shoreline.

These and other facts testify to an increase in the area of the oceans at the expense of the surrounding continents. According to V. V. Belousov (^{3}), they indicate the secondary character of the oceans, which arose as a result of the basification of crust of continental type. However, the hypothesis of basification of continental crust, as shown by V. A. Magnitskii (^{4}) and E. N. Lyustikh (^{5}), encounters insurmountable difficulties in explaining a number of facts.

A different explanation of the above-noted features of marginal zones of the Atlantic type was given by A. Wegener (^{6}), who spoke of the spreading of the edge of the continent. This idea was reflected in the work of F. F. Evison (^{7}). The latter considers the dynamics of the process of spreading of the continent' s edge relative to the ocean floor as analogous to the spreading of ice of a continental glaciation over the surface of the continent, according to the theory of S. E. Nye (^{8}).

In the light of modern data ($^{4,9–11}$), other features of the structure of marginal zones of the Atlantic type may be noted:

1. The continental slope and continental rise of the coastal zones of the Atlantic and Indian Oceans have a definite form, very similar in many parts of the marginal zone.*

2. The generalized relief of the continental slope and rise is a mirror image (with a certain coefficient) of the boundary M relative to the surface of the free mantle T. The magnitude of the coefficient is determined by the mean densities of water, crust, and mantle (^{4,10,11}), and also by the condition of isostasy, and is close to 0.2–0.3.

3. The wedging-out of the "granite" layer occurs at depths of 5–10 km.

The features listed above cannot be explained by the flow only of the upper layer of the Earth' s crust, located above the surface of a typical oceanic floor, as F. F. Evison assumes.

First, the surface of ice in the marginal zone of a continental glaciation differs fundamentally from the surface of the continental slope and rise. Second, the assumption that spreading occurs only in the layer of crust situated above oceanic depths contradicts the fact of similarity between the upper and lower boundaries of the Earth' s crust in the transition zone.

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* Exceptions are anomalous regions (the Caribbean Sea, island arcs) adjoining the Pacific marginal zone.

And third, it does not make it possible to explain the fact that the wedging-out of the "granitic" layer occurs at depths greater than the mean depth of the ocean.

It is known that, as a first approximation, the "floating" of the earth' s crust in the mantle may be likened to the floating of an iceberg in water. Therefore let us consider the forces arising in a block of viscous fluid immersed in an ideal, incompressible and denser fluid, under the condition that the system is in a gravitational field of constant magnitude and direction. Then, at the lower boundary of the immersed block, its weight will be balanced by the buoyant force of the fluid. At the lateral boundaries, because of the difference in densities of the viscous and ideal fluids, there will exist a horizontal force (Fig. 1) causing the viscous fluid to spread over the surface of the ideal fluid. On this surface the horizontal force reaches a maximum:

$$F_{\max} = \rho D,$$

where ρ is the density of the viscous fluid, and D is the height of the block of viscous fluid above the free surface of the ideal fluid.

Fig. 1. Forces acting on the boundary of a viscous body immersed in a heavier ideal fluid (a), and the forces causing the viscous body to spread over the surface of the ideal fluid (b)

Figure 1

Figure 1: Figure 1

To determine the character of spreading in our experiment, a block of viscous fluid (a mixture of bitumen with nigrol), whose density was $\rho = 0.9\text{-}0.95$ g/cm^3, was placed in water. It was found that the shape of the lateral boundaries of this block recorded during the process of spreading (Fig. 2) corresponds qualitatively to the shape of the surfaces of the earth' s crust in transition zones of the Atlantic type.*

For the case of the "floating" of a block of continental crust in the mantle, at a depth of the free surface of the substrate of 5-7 km, $F_{\max} \cong 10^6$ G/cm^2. Naturally, a lateral pressure of 500-1000 kG/cm^2, applied over $n \cdot 10^8$ years, is the cause—if not of viscous flow, then at least—of creep of the material of the earth' s crust. The process of creep to a considerable degree determines both the shape of the surfaces and many basic features of the structure of the earth' s crust in transition zones of the Atlantic type. The results of this process are: (a) the submergence of sediments accumulated in the shelf zone, (b) the shelves themselves, (c) canyons of the continental slope associated with continental valleys, (d) discordant truncation of continental structures by shorelines. As has already been noted, the wedging-out of the "granitic" layer (and consequently the level of the greatest horizontal velocities) is sometimes observed, although close to, somewhat below the level of the free surface of the mantle. This fact should probably be explained by changes in the rheological properties of the earth' s crust of transition zones with depth under the influence of temperature and pressure.

It may be considered that the earth' s crust has a creep threshold, for otherwise complete leveling of its relief would have occurred as a result of the spreading of the crust over the surface of the mantle. Because of the existence of a creep threshold, the process of creep of the material of the earth' s crust must occur in a layer of limited thickness, near the level of the free surfac— of the mantle substance T. Outside this layer, vertical leveling must occur under the action of gravity (above level T) and of the buoyant force (below T). The subsidence of the upper layer of the crust causes the formation of fractures, manifested as scarps on the continental slopes of the Atlantic (^{12}) and Indian (^{13}) Oceans.

Fig. 2. Example of spreading (creeping) under the action of gravity of a specimen made of a mixture of bitumen and nigrol, floating in water

* Owing to the small difference in the densities of the ideal and viscous fluids taken for the experiment, in Fig. 2 only a qualitative correspondence is clearly visible between the form of the relief of the lateral surface of boundary M and that below level T.

Fig. 2. Example of spreading (creeping) under the action of gravity of a specimen made of a mixture of bitumen and nigrol, floating in water

Figure 2: Fig. 2. Example of spreading (creeping) under the action of gravity of a specimen made of a mixture of bitumen and nigrol, floating in water

In light of the foregoing, it may be assumed that the well-known submergences of oceanic islands testify not so much to changes in ocean level (as was previously supposed (2)), but rather to the creeping of the "roots" of these islands. There is no doubt that the difference in the vertical thickness of blocks of the Earth's crust—both continental and oceanic—gives rise to significant horizontal forces, which reach a maximum near the level of the free surface of the mantle.

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