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Abstract

Full Text

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GEOPHYSICS

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ON THE NATURE OF THE LAYERING OF THE EARTH' S CRUST AND UPPER MANTLE

The numerous sections of the Earth' s crust obtained in recent years in various regions of the USSR (¹⁻⁴) and abroad vividly illustrate two principal points.

The first is the block character of the structure of the crust, and often also of the upper mantle, with blocks of different orders of magnitude: from different blocks beneath continents and oceans, plains and mountains, down to the block structure of the consolidated basement of individual regions.

The second is the nearly horizontal layering of the crust and upper mantle, preserved at least within large blocks and uniting smaller blocks. This layering is also of different orders: from the large-scale, crude division into crust and mantle to their subdivision into individual, increasingly finer layers.

At one time there was a tendency to contrast the concept of a structurally heterogeneous, as it were "granular," but macroscopically homogeneous crust with that of a layered crust. The layering of the consolidated continental crust was generally called into question. However, in the last several years (beginning in 1957, when continuous profiling was first applied in deep seismic sounding) more and more direct evidence and concrete examples have accumulated for the existence of a number of "seismic boundaries" and, correspondingly, layers in the consolidated crust and upper mantle. The Moho boundary is only one of them.

But if both these apparently mutually exclusive tendencies—the block character ("granularity") and the layering of the crust and upper mantle—really coexist, then the question arises as to the nature of this phenomenon and its causes: are deep seismic boundaries connected with changes in rock composition, or do they represent the result of changes of state under the influence of temperature and pressure, or, finally, are these boundaries similar to stratigraphic boundaries in a sedimentary sequence and do they represent the result of the successive deposition of individual layers of the Earth' s crust one upon another (⁵)?

All the possibilities listed are currently being discussed, but, given the still very scant factual material, it is impossible to arrive at fully definite conclusions. Nevertheless, some of the proposed explanations can already be rejected as untenable. First of all, one should reject a general explanation of deep seismic boundaries in the crust (and still more so in the mantle) by the successive deposition of layers. It is hardly worthwhile to dwell here on the possibility of layered fallout of heterogeneous material onto the Earth from space. It is sufficient to consider only internal factors. Although examples are known of the local accumulation of rather considerable parts of the Earth's crust as a result of volcanic extrusions and layered intrusions, such formations nevertheless have a comparatively local distribution. Most important is the existence of an approximately horizontal deep-seated differentiation in physical properties of complexly dislocated rock complexes, folded into complicated folds, cut by faults, with contacting heterogeneous blocks—over enormous areas of ancient shields and in the consolidated basements of platforms of very different ages. If layered formation of the crust in ancient times did occur in some places, then in

subsequent time these “layers” were evidently repeatedly disturbed by tectonic movements. And only upon the already formed blocky, “granular” structure of the medium were the modern smooth seismic boundaries, which smooth out the details, superimposed. Let us also note that in modern volcanic regions, on the contrary, a reduced layering of the crust and mantle is observed—a “crust-mantle mixture” (6, 7).

Nor can one agree with the universal formation of layers in the crust and upper mantle, in particular with the formation of the Moho boundary, under the influence solely of the modern distribution of pressure and temperature in the macroscopic medium of the crust and upper mantle. For the crust this was clearly demonstrated in the USA by Birch, whose considerations are well confirmed also by Soviet observations. This is also indicated by the large differences in the thickness of the Earth's crust as a whole and of its individual layers in different regions, with approximately the same average density and velocity composition, at least in the upper parts of the consolidated crust.

Until now, the literature has discussed, from geophysical, geochemical, and petrological points of view, essentially only the possible nature of the Moho boundary (6-9). The possibility is not excluded of explaining this boundary mainly by the presence of a solid phase transition of rock-forming minerals under the conditions of a thick continental crust (the gabbro—eclogite transition). But this explanation is obviously untenable for the thin oceanic crust, where at the Moho boundary a change in composition clearly has to be assumed. However, the typically continental and the typically oceanic crust are only the extreme members of a continuous sequence of different types of crustal structure. Moreover, the task is to explain not only the Moho boundary, but also other boundaries, in particular boundaries within the crust, where the modern magnitudes and gradients of pressure and temperature may prove insufficient

for substantial phase transitions.

Finally, the assumption also seems improbable that all known deep seismic boundaries are boundaries between layers of different composition, formed, say, as a result of the successive melting out from the mantle material first of acidic and then of increasingly basic rocks, which then took their places on the corresponding “floors” of the Earth’ s crust. This is contradicted by the same well-known complex block structure of the basement, where rocks of different composition may occur at the same level, while horizontal layering continues to show through this structural heterogeneity.

As a result, it appears that deep seismic boundaries and, correspondingly, layers are the consequence of the combined influence of changes both in the composition and in the state of matter under conditions of a changing regime of pressures and temperature and of the displacement of matter in the Earth’ s interior. They represent, in our opinion, certain **fronts of metamorphism**, characteristic of definite, rather narrow depth intervals, at least under stable platform conditions. These boundaries have an essentially different nature from the stratigraphic boundaries customary for geologists, or, on the other hand, from boundaries of a disjunctive character between heterogeneous complexes of metamorphic and other rocks, or between magmatic massifs of different composition and time of formation. If these geological structural features of the medium are regarded as primary, then the seismic boundaries should be recognized as secondary, superimposed upon these “details” of the structure of the medium.

It also seems clear that the modern position of deep boundaries bears traces of past conditions of formation, the action of which is only gradually erased with time. True, the relaxation time of these past influences on the geological scale is not very great—less than one era, as is evidenced by the approximately identical modern deep layering of the basements of platforms of different ages. Therefore, the position and form of deep boundaries in comparison with structures in

sedimentary layers reflect the character of crustal movements in the recent geological past, up to the present time.

Thus, despite the “non-geological” character of these “geophysical” boundaries, their study should be of paramount interest for solving a number of the most important geological problems connected with the formation and development of the Earth’ s crust and the upper mantle.

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