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Abstract

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GEOPHYSICS

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ON CERTAIN FACTORS AFFECTING THE MAGNITUDE OF THE VELOCITY OF PROPAGATION OF ELASTIC OSCILLATIONS IN ROCKS

(Presented by Academician V. V. Shuleikin on 25 IX 1956)

Data from seismic measurements in boreholes ([1,7–9]) indicate that the magnitudes of the formation velocity of propagation of longitudinal elastic oscillations depend on many causes (the static load of the overlying rocks, metamorphism, the lithological composition of the rocks, etc.), whose influence on the magnitude of the formation velocity in different rocks and in different regions is usually not the same. In the present article one of the principal factors affecting the change in formation velocity is considered—the static load of the overlying rocks.

It is known that one and the same sedimentary rocks occurring at different depths are characterized by velocities that differ in magnitude; moreover, the greater the depth of occurrence of the deposits under consideration, the greater the formation velocity in them.

In order to study the regular relationship between the magnitude of the velocity and the static load, we carried out measurements of velocity in rock samples subjected to different pressures.

In the laboratory investigations, to measure the velocity of propagation of longitudinal elastic oscillations, a pulsed ultrasonic seismoscope was used, constructed according to the design of Yu. V. Riznichenko, B. N. Ivakin, and V. R. Bugrov ([5]). Crystals of Rochelle salt of cut X—45°, with a natural frequency of 140 kHz, were used as transducers. The investigations were carried out on cubic rock samples with sides of 8-10 cm, which were subjected to uniaxial compression in a hydraulic press with load intervals of 20 kg/cm^2. The method adopted by us is analogous to that used in the seismic laboratory of the Geophysical

Fig. 1

Figure 1: Fig. 1

Institute of the Academy of Sciences of the USSR in similar investigations ([6]). Samples of sandstones and limestones, 24 in number, were tested.

During experiments with samples of one and the same rock, the operating mode of the seismoscope remained strictly constant. The reproducibility of the data obtained was checked by repeated measurement of the velocity of elastic waves before the start of testing under pressure.

From the laboratory data, graphs $v_{\parallel} = f(P)$ were constructed, where $v_{\parallel}$ is the velocity of propagation of longitudinal elastic oscillations in m/sec, measured parallel to the applied load, and P is the load in kg/cm^2. Typical curves of the dependence of velocity on the applied load are shown in Fig. 1 (curve 1 for sandstones, curve 2 for limestones).

Curve 1 is characterized by the following features: when the load changes from 0 to 120 kg/cm^2, the velocity of passage of ultrasonic waves increases intensively from 3200 to 3900 m/sec. When the load is increased from 120 to 420 kg/cm^2, the increase in velocity slows down and amounts to only 200 m/sec (4100 m/sec). A further increase in load already leads

to a decrease in velocity, after which destruction of the specimen occurs (at a pressure of 610–620 kg/cm^2).

Curve 2 shows the same regularity in the change of velocity with pressure as curve 1; the only difference is in the absolute values of the velocities and pressures.

The nature of the curves obtained can be explained physically as follows: a rock specimen in the unloaded state is characterized by a certain velocity of propagation of elastic vibrations. When a load is applied to the specimen, the porosity of the rock decreases, the small particles adhere more closely to one another and, naturally, the velocity of passage of elastic waves increases.

The increase in velocity continues up to a certain point, when the porosity of the rock is reduced to a limit and the compaction process sharply slows down. A further increase in load apparently affects the compaction and redistribution of the elementary particles themselves. There may be cases in which the velocity remains practically constant. The period of decreasing velocity with a further increase in load apparently corresponds to the appearance of micro-, and then macrocracking, which ends in complete destruction of the rock specimen. Such a phenomenon is observed under uniaxial compression of a specimen. Under all-round pressure, as D. N. Balashov ([2]) showed, in the first stage of loading the picture will be analogous to that given above, but with a considerable increase in pressure the velocity of propagation of elastic waves remains approximately constant.

Fig. 2

Figure 2: Fig. 2

Fig. 1

Under natural conditions, in the process of sediment accumulation, rock beds, depending on their depth of occurrence, find themselves under different loading conditions. Consequently, the degree of compaction of the same rocks at different depths will not be the same, and therefore the dependence of the increase in velocity on load at different depths will be different. For example, in the Sarmatian and Upper Tortonian deposits of the Ciscarpathian trough, at a depth of 250–750 m the vertical gradient is 60 m/sec per 100 m of depth, while for depths of 1500–2000 m it is only 30 m/sec. In the area of the Prikuban depression, in the Maykop deposits, for depths of 250–270 m the gradient is 30–40 m/sec per 100 m, and in the interval 1500–2000 m it is 20 m/sec.

In addition to the laboratory experiments described above, studies were carried out on a number of specimens to determine the dependence of the velocity of elastic waves on pressure under repeated loading and unloading of the specimen. For these purposes the rock specimen was loaded to 40–50% of the destructive load, in steps of 20 kg/cm^2, then unloaded in the same steps and loaded again. At all stages of loading and unloading the velocities of longitudinal elastic waves were measured.

In Fig. 2 the solid line shows the change in velocity during the first loading cycle, the dashed line characterizes the decrease in velocity during unloading, and, finally, the dash-dotted line characterizes the change in velocity in the specimen during repeated loading.

Curve 1, obtained in testing a sandstone specimen, shows that the changes in the magnitude of the velocity during loading, unloading, and repeated loading are very similar. This indicates that the specimen under study, in its behavior, approaches an ideal elastic medium, i.e., no residual deformation is observed.

Curve 2 (for the looser sandstone) has a somewhat different character. During the first cycle—loading—the velocity increases. During unloading the velocity in the specimen decreases, according to a different regularity than in the first cycle. The absolute values of the velocity during unloading are somewhat greater than during loading. Consequently, in this case the phenomenon of residual deformation in the specimen takes place. Repeated loading causes an increase in velocity in the specimen, and the character of the change in the latter remains approximately the same as in the first cycle, but the absolute velocity values are considerably greater.

Fig. 2

The data of the investigations show that in rocks, alongside phenomena of sharply expressed residual deformation, there may also be an almost complete absence of it, even in specimens of one and the same lithological composition. Apparently, the phenomenon of residual deformation depends on the structural features of the specimens studied.

Let us compare our laboratory investigations with certain processes occurring in the sedimentary deposits of the earth' s crust. The formation of the sediments of one region or another is a rather complex process, consisting of numerous cycles of sediment accumulation and denudation. In analyzing a series of successive cycles, one may arrive at the conclusion that one and the same stratum of rock, in the process of formation of the region, underwent repeated cycles of loading and unloading. During the period of sediment accumulation, when the thickness of the overlying deposits increased, the stratum experienced a continuous increase in load, and its bed velocity changed in the direction of increase. During the period of denudation this stratum was unloaded as a result of the removal of the overlying deposits, and the velocity in it decreased. These processes were repeated more than once, since after processes of erosion there could arise processes of sediment accumulation, and so on.

From all that has been said it is clear that the laboratory studies we have carried out, with loading of a rock sample, unloading, and its repeated loading, may, with certain reservations (without taking the phenomenon of relaxation into account), be compared with the processes occurring during the geological history of one region or another (tectonic processes, as has already been indicated, are not considered).

Thus, the characteristics of the elastic properties of rocks and, in particular, the velocity of propagation of longitudinal vibrations in them depend in many respects on the geological history of the region under consideration and on the properties of the rock itself.

For a rock to which the properties of an ideally elastic medium are, as it were, inherent, the velocity does not depend on the number of recurring processes of sediment accumulation and erosion of the overlying rocks, but depends only on the present depth of occurrence of the rock (factors of lithology and dynamometamorphism are not taken into account in this case).

In the case where a rock, in its properties, differs noticeably from an ideally elastic body, the magnitude of the velocity of propagation of elastic vibrations in it will depend not only on the depth of occurrence of the latter, but also on the geological history of the region under consideration. In this case residual elastic deformation will play a role, and the greater the number of cycles of sediment accumulation and denudation that took place, the more noticeable will be the difference in the regularity of the change of velocity with depth in different regions.

From the laboratory studies presented and the results of seismic observations in boreholes, the following conclusions may be drawn.

1. The static load of the overlying strata has a significant influence on the

elastic properties of particular deposits; namely, the greater the indicated load, the greater the value of the velocity of propagation of elastic vibrations in rocks of the same type.

2. In the case where a rock approaches an ideally elastic body, the velocity in it depends only on the static load and does not depend on the geological processes (sediment accumulation and denudation) that occurred in the region under consideration.

3. Rocks that differ from ideally elastic bodies have residual deformation, as a result of which the currently observed velocity of propagation of elastic waves in them depends not only on the depth of occurrence, but also on the geological processes that took place in the region studied. Therefore, rocks of the same age in different regions may differ in velocity even when they occur at one and the same depth.

4. A detailed analysis of the magnitudes of formation velocities in rocks may provide certain data for judging the formation of the region under study and for identifying major breaks in sediment accumulation.

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Note: Figure translations are in progress. See original paper for figures.