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Abstract

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Velocities of Ultrasonic Longitudinal Waves in Oil-and-Gas-Bearing Reservoir Rocks of Azerbaijan at High Pressures

(Presented by Academician P. A. Rebinder, 10 XII 1964)

The study of the elastic properties of sedimentary rocks, especially those saturated with various fluids, is of great interest for the interpretation of continuous ultrasonic logging data ([1]), and also for the problem of direct prospecting for oil and gas by the seismic-exploration method. In connection with the fact that at present there has arisen the need to search for these minerals at great depths in Mesozoic deposits, whose depth in places reaches 10 km, it is important to consider the influence of high hydrostatic pressure on the elastic characteristics of rocks ([2]). The object of the present investigation was the sedimentary rocks of Azerbaijan, more precisely of the Caspian Lowland and the Baku Archipelago. As is known ([3], [4]), these geological regions are characterized by a thick sedimentary layer, reaching 8 km and possibly more. Therefore the tests of the rocks were carried out at pressures up to 4000 kg/cm^2.

The velocities of longitudinal waves in samples of sedimentary rocks were measured by the ultrasonic pulse method ([5]) with the aid of a somewhat modified IKL-5 radio-electronic instrument. Lead zirconate-titanate transducers with a natural frequency of 500 kHz were used as the piezoelectric emitter and receiver. During testing, the sample, wrapped in copper foil, together with the piezoelectric transducers was mounted in a high-pressure chamber ([6]), into which compressed nitrogen was supplied from a gas compressor. Samples of sedimentary rocks were prepared in the form of cylinders 3 cm in diameter and 3–15 cm long from cores taken from wells at various depths from 100 to 3500 m. Sedimentary rocks of different composition were tested: clays, siltstones, sandstones, limestones. For all rocks, a petrographic study was carried out, and the density and total porosity at atmospheric pressure were determined. The change in the velocity of longitudinal waves with increasing pressure was investigated in rock samples dried to constant weight, in samples saturated with kerosene or distilled water, and also in samples containing natural residual moisture. In all, 70 dry samples, 40 samples saturated with kerosene, and 30 moist samples were tested.

The experiments showed a rather significant increase in the velocities of longitudinal waves in the samples with increasing pressure, continuing up to the highest pressures, i.e., up to 4000 kg/cm^2. The greatest change in velocity, up to 200%, is observed in highly porous sandstones and clay. In limestones it is smaller and lies in the range 15-45%. This is explained by the fact that limestones, as denser, less porous rocks, have high velocities of longitudinal waves at atmospheric pressure. Increasing the hydrostatic pressure on a sample in limestones does not cause such a large relative increase in elasticity as in loose clays or porous sandstones. All these data refer to dry rocks. However, the presence of a fluid saturating a previously dried rock changes its properties. It was noted that

saturation of the specimen with kerosene leads to an increase in the velocity of longitudinal waves in all specimens of sedimentary rocks. At the same time, the relative change in velocity with pressure becomes smaller than in dry specimens.

Fig. 1. Dependence of the velocity of longitudinal waves on pressure in specimens of limestone (1) and clays (2).
a –dry, *b* –saturated with kerosene, *v* –moist

Kerosene penetrates well into the pores of the specimen and fills them completely. At the same time, being a nonpolar hydrocarbon, it does not interact with the substance of the rock, remaining neutral. Such a solid-liquid system possesses greater elasticity than a solid-gas system. In this case, with increasing pressure in a rock saturated with kerosene, the porosity decreases to a lesser extent than in dry rock. Unlike kerosene, water fills only part of the pore space. Therefore, it is natural that the velocity of longitudinal waves in specimens saturated with water is lower than in specimens saturated with kerosene at atmospheric pressure. With increasing pressure, the pore space contracts, and at some point the rock proves to be almost completely saturated with water. From this moment the velocity in such a specimen may become higher than in a specimen saturated with kerosene, in the event that the water does not interact with the substance of the rock. It often happens that when clay or sandstone with clayey cement is saturated with water, the specimen softens, swells, and sometimes is even completely destroyed (7). In such a case, the elastic properties of the rock decrease, and the velocity of longitudinal waves in such specimens becomes lower than in dry ones. This corresponds to P. A. Rebinder' s ideas (8) on the reduction in the strength of structures of moisture-saturated disperse systems. With increasing pressure, the process of softening may intensify, since water penetrates into deeper pores of the rock. Fig. 1 gives typical curves of the change in the velocity of longitudinal waves with pressure for specimens of limestone and clay that were tested in the dry state and when saturated with water and kerosene. The sandy-detrital limestone from a depth of 1550 m has a psammitic-clastic structure and consists of organic remains of fauna (40%), fragments of quartz (15%) and plagioclase (10%), and calcitopelitic cement (35%). The rock has cement

Fig. 2. Dependence of the velocity of longitudinal waves on the density of specimens of sedimentary rocks: *a* –clays, *b* –siltstones, *v* –sandstones, *g* –limestones.

1 –at atmospheric pressure, 2 –at a pressure of 4000 kg/cm^2

structure; it consists of a ferruginous pelitic mass (80%) with inclusions-

quartz and plagioclase (20%). The limestone has a density equal to 2.75 g/cm^2 and a porosity of 1.7%; the clay, respectively, 2.13 cm^2 and 15%.

It is of interest to investigate the dependence of elastic-wave velocities in samples of sedimentary rocks on their density for this region of Azerbaijan. When exploratory wells are drilled, samples are taken for which density and other reservoir properties are measured. Knowing the density of dry rocks at atmospheric pressure, one can determine the velocity of longitudinal waves in them at various depths, if, on the basis of experimental data, a relation between these characteristics is established. The graphs in Fig. 2 represent the dependences between the densities of sedimentary rocks and the velocities of longitudinal waves at atmospheric pressure and the velocities of longitudinal waves measured at a pressure of 4000 kg/cm^2. These graphs were constructed from laboratory measurements for all the rock samples from Azerbaijan that we tested. The results obtained once again confirm the proposition that the velocities of longitudinal waves in samples of less dense rocks change more strongly with pressure, and in samples of denser rocks more weakly.

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