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Abstract

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Results of Seismic Investigations in the Black Sea in the Region of the City of Anapa

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M. V. Muratov came to the conclusion that in the Black Sea depression a transformation of the earth' s crust from the continental type to the oceanic type is taking place ([1]). Beneath the waters of the Black Sea lie hidden parts of the structures of the Caucasus, Crimea, and the Balkans, regarding whose interrelations—as well as, in general, the deep structure of the Black Sea depression—it is still possible to speak only hypothetically ([2]). Geophysical methods of investigation should help resolve these questions, which are important for geology.

The work described in the present article was carried out by the Black Sea Experimental Research Station of the Institute of Oceanology of the Academy of Sciences of the USSR in the summer of 1957 in the region of the city of Anapa and constitutes the first stage of systematic seismic investigations of the structure of the bottom of the Black Sea. In addition to the author, M. F. Mikhno and G. N. Shchipletsov took part in the marine work, and A. F. Neprochnova in the processing of the materials. The work was conducted from the expedition vessel *Akademik Shirshov* by the refracted-wave method. Explosive charges weighing from 0.4 to 15 kg were detonated from a launch. The time mark of the explosion was transmitted to the recording vessel by radio. Preliminary experiments were made to determine the optimal depth of explosions when recording refracted waves. The optimal explosion depth varies depending on the frequency spectrum of the refracted wave and the magnitude of the charge.

For recording seismic waves, apparatus was used consisting of three principal components: a hydrophone, amplifiers, and a POB-14 14-channel oscillograph. A compact hydrophone was used, with a body made of organic glass; inside it were placed a piezoelectric battery of Rochelle salt and a preamplifier. The signals arising in the hydrophone during the passage of seismic waves in the water were fed by cable to the inputs of the amplifiers, where they were filtered and amplified, and were then recorded on photographic paper in the oscillograph. For recording refracted waves, an amplifier was used whose frequency-response maxima lay in the range 5-15 Hz. For recording reflected waves, a medium-frequency amplifier was used (pass band 10-50 Hz). Waves propagating from the explosion to the receiver through the water (water waves) were recorded with the aid of an amplifier with the maximum of its frequency response in the

Fig. 1. Layout of the seismic profiles. a—seismic profiles, b—isobaths

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Fig. 2. Hodographs and seismic section along profile I

Figure 2: Fig. 2. Hodographs and seismic section along profile I

range 50–500 Hz.

To facilitate the identification of useful waves on the seismograms, recording at each point was carried out simultaneously by two hydrophones through two independent amplifier channels. When working in shallow-water areas (sea depth up to 50 m), the hydrophones were lowered to the bottom. The recording vessel stood at anchor at this time. When recording at great depths, the vessel drifted, and the hydrophones were lowered to a depth of about 50 m, which approximately corresponds to 1/4 of the length of the recorded refracted—

waves in water. Such submergence of the hydrophone creates the most favorable conditions for recording these waves. To reduce interference from swell, current, drift, and other mechanical oscillations transmitted along the cable, 20 m of the hydrophone line (starting from the hydrophone) was given neutral buoyancy in the water. (This method of suspending hydrophones was developed on the expedition vessel *Vityaz*.)

Fig. 1. Layout of the seismic profiles. *a*—seismic profiles, *b*—isobaths

In the Anapa area, two mutually perpendicular profiles 30 and 40 km long were worked (Fig. 1). The recording points were located successively at the ends of each profile, while the launch carried out explosions along the line of the profile. Thus, each profile was shot twice, which ensured the acquisition of reciprocal hodographs of refracted waves, necessary for unambiguous interpretation. The intervals between explosions were 2–3 km, and sometimes 4–5 km. On the seismograms, a large number of refracted waves, direct water waves, and multiple reflections within the water column (in deep-water sections), as well as reflections from underlying layers, were recorded. To monitor the gain of the apparatus, a calibration signal from a generator was recorded on each seismogram after the explosion. The distances to the shot points were determined from the travel time of direct water waves. The speed of sound in water was refined from the results of hydrological observations.

Fig. 2. Hodographs and seismic section along profile *I*

From the obtained materials, hodographs of refracted waves were constructed (Figs. 2 and 3). Because of the large intervals between explosions, a sufficiently reliable correlation of refracted waves along the profiles could be carried out only in the region of the first arrivals. In the correlation, the kinematic and dynamic characteristics of the waves were used.

Fig. 3. Hodographs and seismic section along profile II

Figure 3: Fig. 3. Hodographs and seismic section along profile II

On profile I, two refracted waves, t_1 and t_2, are distinguished. Wave t_1 has an apparent velocity $V^* = 3500$ m/sec and is observed only when recording at the western end of the profile. Wave t_2 is traced both in the forward and in opposite directions; its form is well maintained from explosion to explosion. The reciprocal hodographs of this wave are tied at mutual points. It should be noted that sufficiently intense records of wave t_2 were obtained for explosions of comparatively small charges (2.5 kg) at distances of up to 30 km from the recording point.

Wave t_2 is also distinguished on profile II. It was possible to trace it confidently to a distance of 25 km from the northern end of the profile. Reciprocal hodographs on this profile were not obtained because of poor meteorological conditions.

From the hodographs of wave t_2, seismic sections were constructed, which are given in the lower parts of Figs. 2 and 3. To construct the boundary corresponding to wave t_2, the average propagation velocity of seismic waves in the overlying layer was taken as $V = 2400$ m/sec, determined from the point of intersection of the hodographs of waves t_1 and t_2. The method used for the determination, as is known, has low accuracy ($\pm 10\%$). However, we note that a similar value of the average velocity for the upper rock sequence of the region under study was also obtained in work (^{3}) by interpolation of seismic logging data.

Fig. 3. Hodographs and seismic section along profile II

The section along profile I was constructed by the method of time fields (^{4}). Boundary R is characterized by a boundary velocity V_r equal to about 5000 m/sec. The dashed line shows parts of the refracting boundary constructed from nonoverlapping segments of the hodographs $\vec{t}_2$ and $\overleftarrow{t}_2$, under the assumption that the boundary velocity remains unchanged in these intervals. Boundary R dips to the west; its apparent angle of dip is approximately 7° and increases at the bend in the boundary to 15°. There are insufficient data to construct the boundary corresponding to wave t_1.

The seismic section along profile II was also constructed by the method of time fields; moreover, on the basis of kinematic and dynamic features it was assumed that wave t_2 corresponds to the same boundary R. The value of the average velocity was also taken as $\overline{V} = 2400$ m/sec. As the initial point in the construction, the depth of boundary R at the place where the profiles intersect, determined from profile I, was adopted. It is assumed that V_r is constant and equal to 5000 m/sec and that the penetration phenomenon is absent. In view of all the assumptions indicated, the section along profile II, naturally, is less reliable than the section along profile I, and the position of the refracting boundary is shown by a dashed line.

The boundary R along the second profile dips to the south; the dip angle reaches 10–15°.

In the geological interpretation of the seismic sections, we proceeded from the obtained values of the boundary and average velocities of propagation of seismic waves, which characterize the physical properties of the refracting bed and of the rocks overlying it. Data were used on the elastic properties of rocks in the region of the foredeeps of the Alpine geosynclinal area of the southern USSR, given in work ([3]), and the facies schemes of M. V. Muratov for the Black Sea ([5]). On the basis of these data, the boundary R may tentatively be assigned to the top of thick Middle Eocene limestones (seismic-wave propagation velocity about 5000 m/sec). Above, apparently, occur clayey and sandy-clayey deposits of the Upper Paleogene, Neogene, and Quaternary, having an average seismic-wave propagation velocity of about 2400 m/sec. The boundary corresponding to wave t_1 on profile I is probably associated with one of the sandstone beds of this sequence.

The dip of boundary R observed on profile I reflects the westward plunge of the meganticlinorium of the Greater Caucasus. From the second section (profile II) one may judge the behavior of the corresponding bedding of the southern limb of this meganticlinorium in the Anapa region.

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