MOHO DEPTH DETERMINATION BY CONVERTED PS-WAVE METHOD FOR THE TERRITORY OF THE GREAT CAUCASUS

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Introduction

The first definitions of the depth of the surface of Mokhorovich in Azerbaijan were made on the basis of seismological data. Using the data from the DSS in compiling the gravitational model of the Earth's crust, the depth and accuracy of research have sharply increased. The DSS data provided the uniqueness of the solution of the inverse problem of gravimetry - the calculation of the depth density distribution. Most of the known methods of the automated approach involve obtaining a density section; the effect of which would coincide with the observed gravitational field.

The methodology of the reflected waves, or as it is commonly called, the “Receiver function” method, is well known and widely used throughout the world to study the deep structure of the Earth up to 800 km. The method is based on the registration, isolation, and interpretation of Ps-exchange waves. These studies were conducted as part of the International Seismotomographic Laboratory using a software package developed at the University of Missouri (USA). Studies in many countries of the world have shown the effectiveness of the method of reflected waves in studying the structure of the lithosphere within one or more seismic stations.

In the method of exchange reflected waves, the exchange waves propagate from the source as longitudinal, and at the boundaries in the area of the seismic station are transformed into transverse. To distinguish the phases of the reflected waves against random noise, it is necessary to know the properties of the converted waves and use them in the processing algorithm of the initial seismograms [6].

Passing the path from the exchange boundary to the surface at a lower speed compared to the refracted longitudinal wave P, the exchange waves Ps enter the records with some delay with respect to the wave P generating them. The delay time depends on the distance between the source and the station and the depth of the boundary at which the exchange took place. At a fixed exchange depth, the delay time of the exchange wave Ps decreases with increasing epicentral distance and increases with its decrease [6].

There are a number of criteria for recognition of exchange waves in seismograms. However, in practice, not all of them are kept. In particular, the sign of polarization is quite often not observed, that is, intense horizontal components of the “SH” components (perpendicular to the direction to the epicenter), often shifted in phase relative to the x “SV” components, are recorded [1, 3-5]. Since the transverse wave Ps in an isotropic medium is polarized as SV, the desired wave is emitted in the source – receiver plane in the direction perpendicular to the direction of polarization in the P wave (Fig. 1). Since the amplitude of the exchange wave Ps is much smaller than the amplitude of the P wave, the most critical moment of processing is the extraction of the signal of the exchange wave against the background of various waves and interference [6].

Data processing methods

Data processing consists of five main tasks: frequency filtering of input seismic records in the “SAC” format, rotation of the Z, N, E axes to the source, standardization of the L, Q, T components, obtaining individual receiving functions for each earthquake, summing traces from all earthquakes. Seismograms of selected earthquakes are processed using the Seismic Analysis Code (SAC) software package (developed by the University of Missouri (USA)) under the MacOs operating system.

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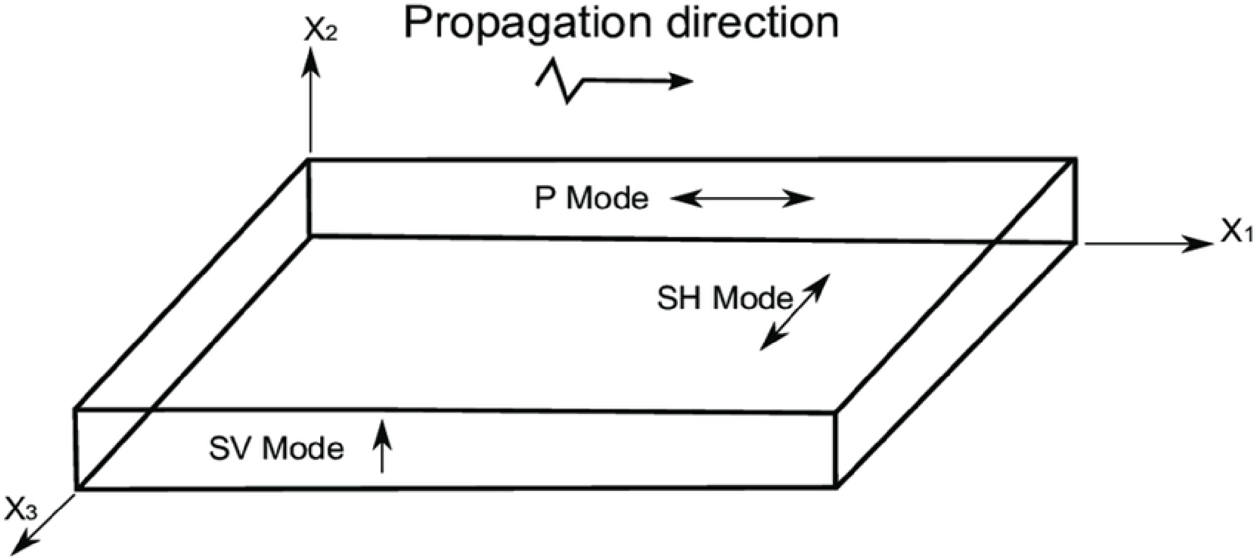

Figure 1. Three-dimensional coordinate system and polarization directions of waves P, SV and SH.

At the first stage, frequency filtering is carried out in order to eliminate oscillations that are too high, containing the effects of random scattering by in homogeneities, and too low frequencies that reduce the resolution [6]. The working range of periods is from 2 to 10 seconds.

Next, two-dimensional and three-dimensional rotation of the axes. Mathematically, this transformation consists in finding the eigenvectors of the covariance matrix obtained by calculating the covariances of the vertical and radial components. Two-dimensional rotation of the axes can be represented in the form of a matrix [10]:

$$M_{2D} = \begin{bmatrix} \cos a & \sin a \\ -\sin a & \cos a \end{bmatrix} \quad \begin{bmatrix} R \\ T \end{bmatrix} = M_{2D} \begin{bmatrix} N \\ E \end{bmatrix}$$

where N and E represent the original (horizontal) axis; R and T represent the radial and tangential components; α is the azimuth measured clockwise from the north.

Three-dimensional rotation of the axes is expressed as the following matrix [10]:

$$M_{3D} = \begin{bmatrix} \cos i & -\sin i \sin ba & -\sin i \cos ba \\ \sin i & \cos i \sin ba & \cos i \cos ba \\ 0 & -\cos ba & \sin ba \end{bmatrix}$$

$$\begin{bmatrix} L \\ Q \\ T \end{bmatrix} = M_{3D} \begin{bmatrix} Z \\ E \\ N \end{bmatrix}$$

where *i* is the angle of incidence, measured vertically; Z, E and N are the original (horizontal and vertical) axes; L, Q, and T are transformed axes: L corresponds to the direction of polarization of the P wave, Q is perpendicular to the axis of L and corresponds to the direction of polarization of the SV wave, T corresponds to the direction of polarization of the SH wave (Fig. 2).

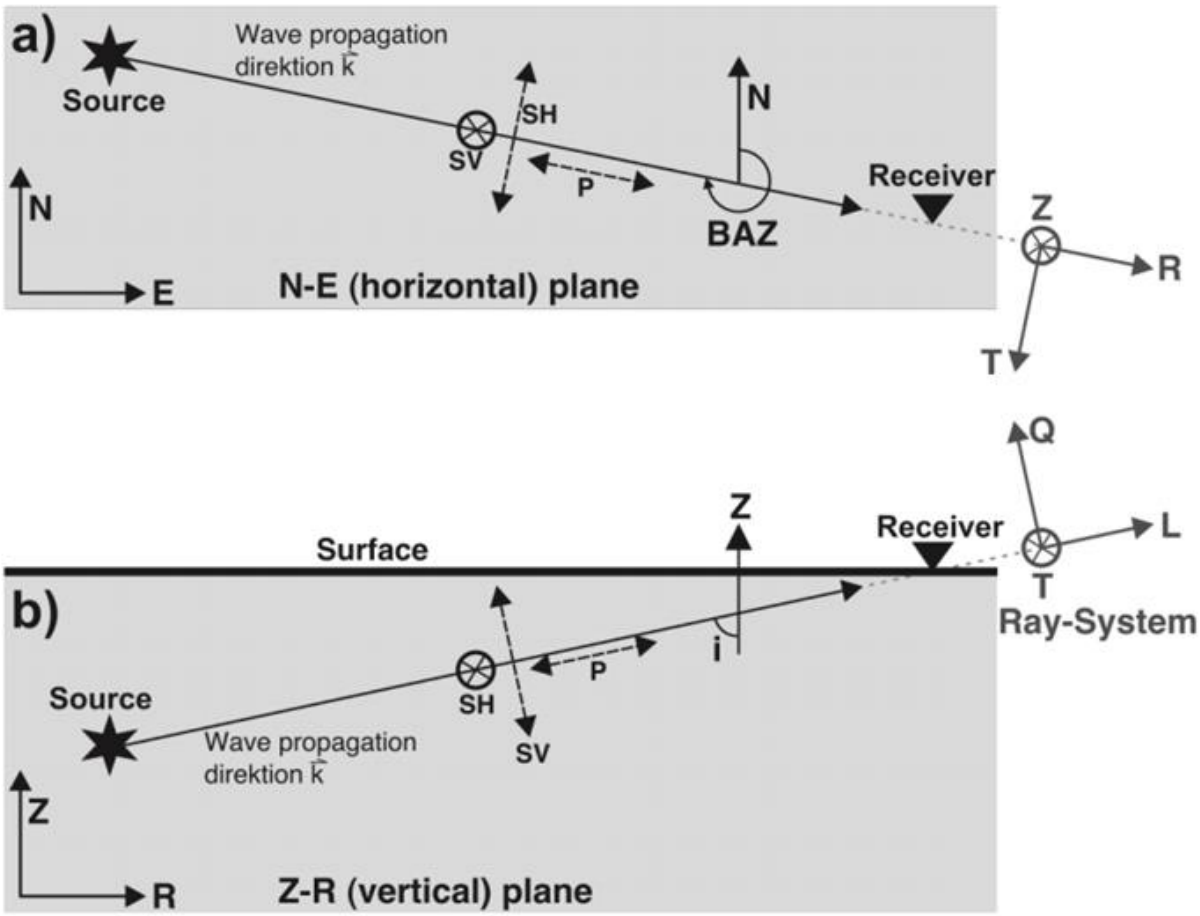

Figure 2. The motion of particles for waves P and S along the direction of wave propagation a) in the horizontal plane and b) in the vertical plane.

Application of the method of exchange reflected waves for the territory of the Greater Caucasus

One of the best regions for studying the early stages of mountain building is the Greater Caucasus, where most of the volcanism and mountain building is represented 5 million years. Of particular interest is the immersion zone of the Kura Depression under the Greater Caucasus, the so-called subduction zone, which has not been sufficiently studied up to date [8, 9]. To this end, we began our studies of the depth of the Moho border from this region. At the present stage, there is a dense network of highly sensitive digital seismic stations, which allows recording all seismic events with a magnitude of ml>0.1 within Azerbaijan, as well as remote telemetric seismic events around the world with ml>5.0. The study examined seismological data recorded by a network of telemetric stations (N=20) for 2009-2019 (Fig. 3). In total, 2428 earthquakes recorded at an epicenter distance of 35 to 90 degrees were analyzed. Remote earthquakes were taken to the "Earthquake Research Bureau" of the RSSC ANAS.

Thus, after filtering and rotating the seismic waves, the final components L, Q, T were standardized using a deconvolution filter formed on the section of the final seismogram containing the incident P-wave and part of its code (Fig. 4).

The subsequent processing operation was reduced to the summation of the standardized components of all earthquakes in order to suppress noise and release the exchange waves associated with various boundaries in the crust and mantle. The time of the exchange wave depends on the epicenter distance and is calculated for each path. The summation of all traces is carried out with time shifts relative to some reference epicentral distance, which is taken equal to 60 degrees. Figure 5 shows the summarized Q-traces of the receiving functions on which the Moho boundary with a delay time of 4.0 sec is clearly distinguished.

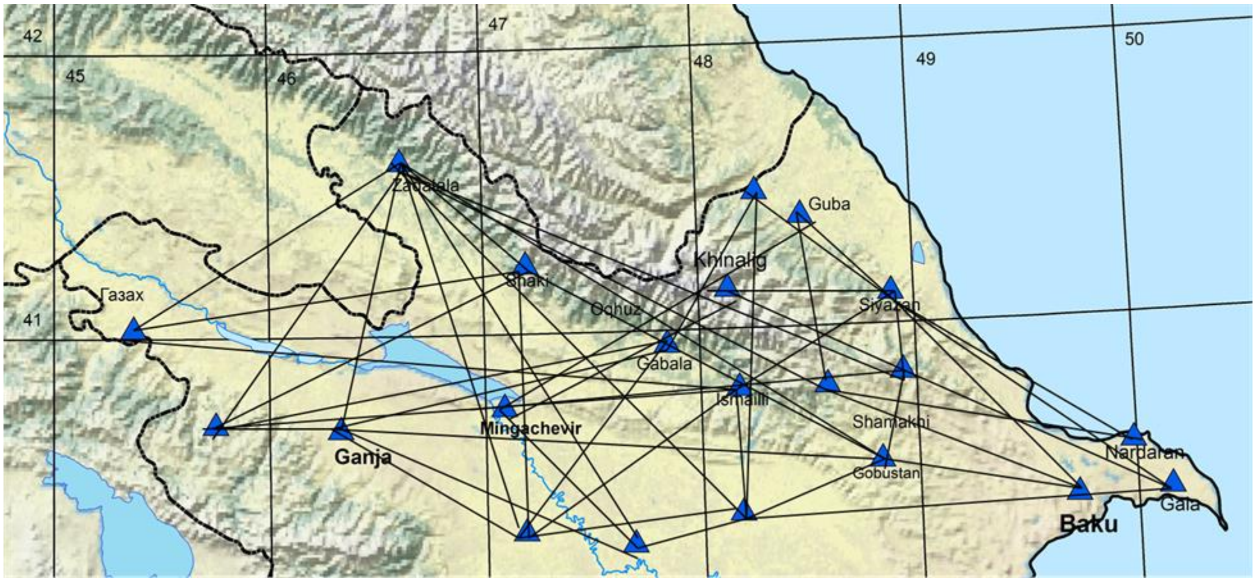

Figure 3. Network of seismic stations used in processing

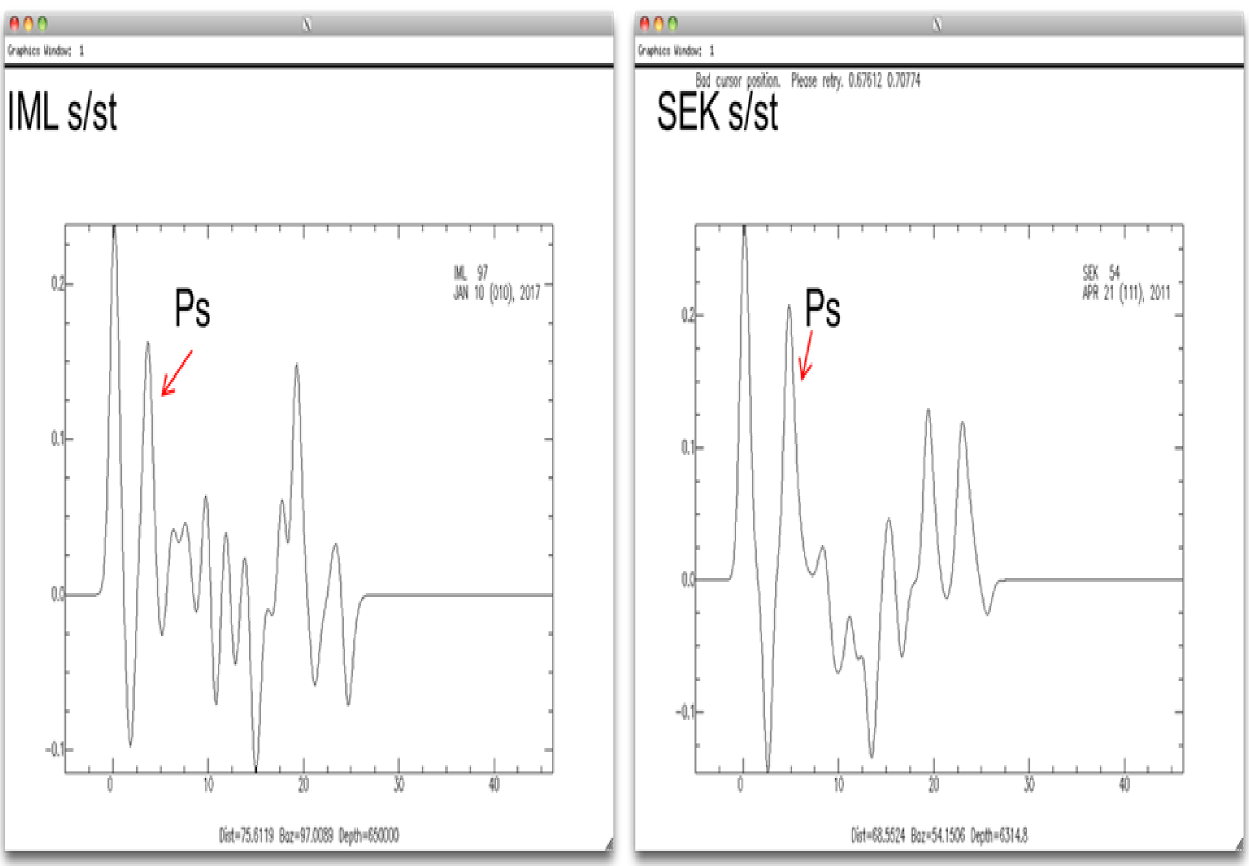

Figure 4. Standardized seismograms for the Ismayilli and Sheki seismic stations

Thus, having processed the data for all stations, the depths of the Moho border for the territory of the Greater Caucasus were calculated and a schematic map of isolines and a three-dimensional model were constructed (Fig. 6, 7).

Main conclusions:

For the first time, based on the analysis of the wave characteristics of distant earthquakes recorded at seismic and telemetric stations of the RSSC, the depths of the Moho border for the Azerbaijan part of the Greater Caucasus were clarified by the method of exchange reflected Ps waves (receiver functions).

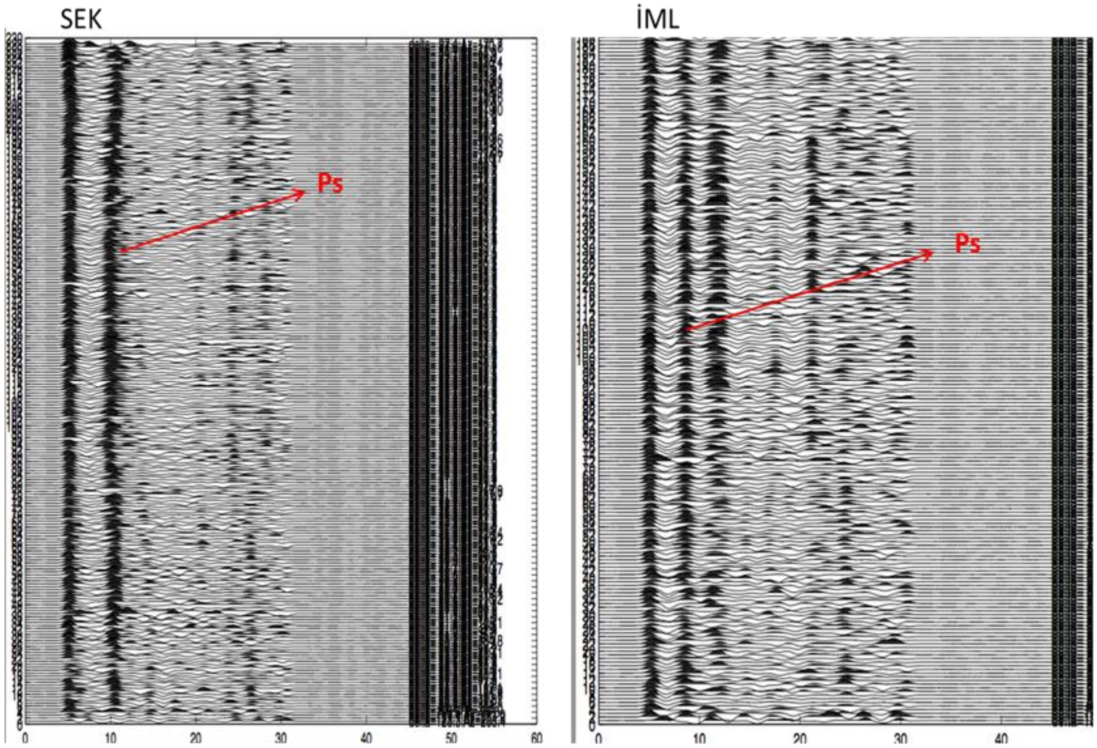

Figure 5. Summarized standardized components of all earthquakes for the Ismayilli and Sheki seismic stations

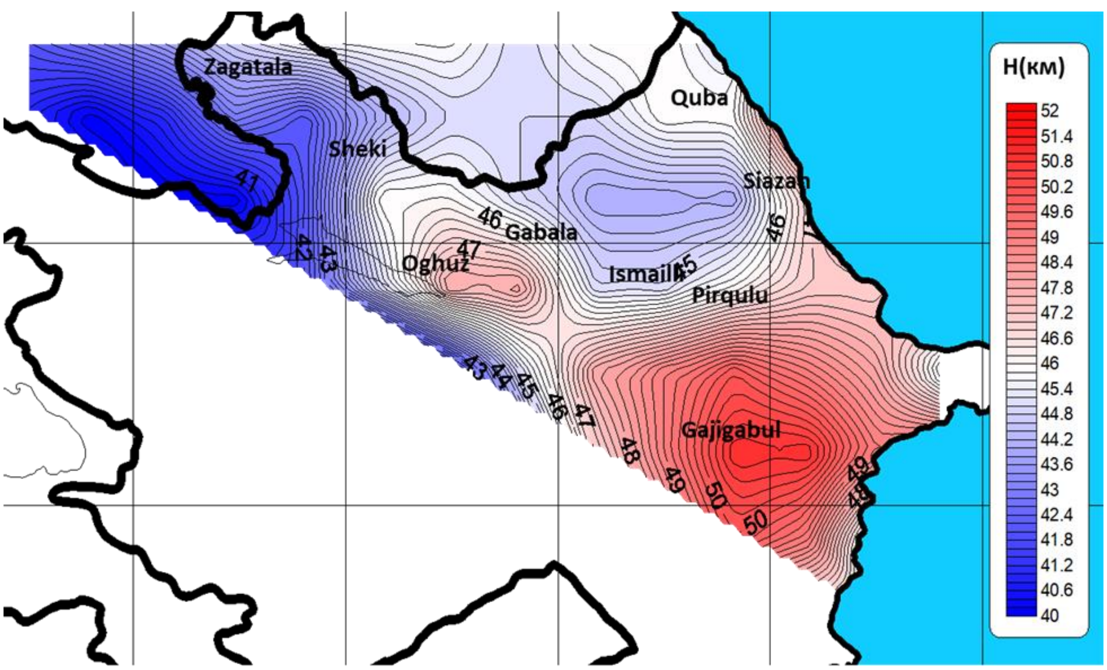

Figure 6. Map of contour lines of the Moho depth for the Greater Caucasus

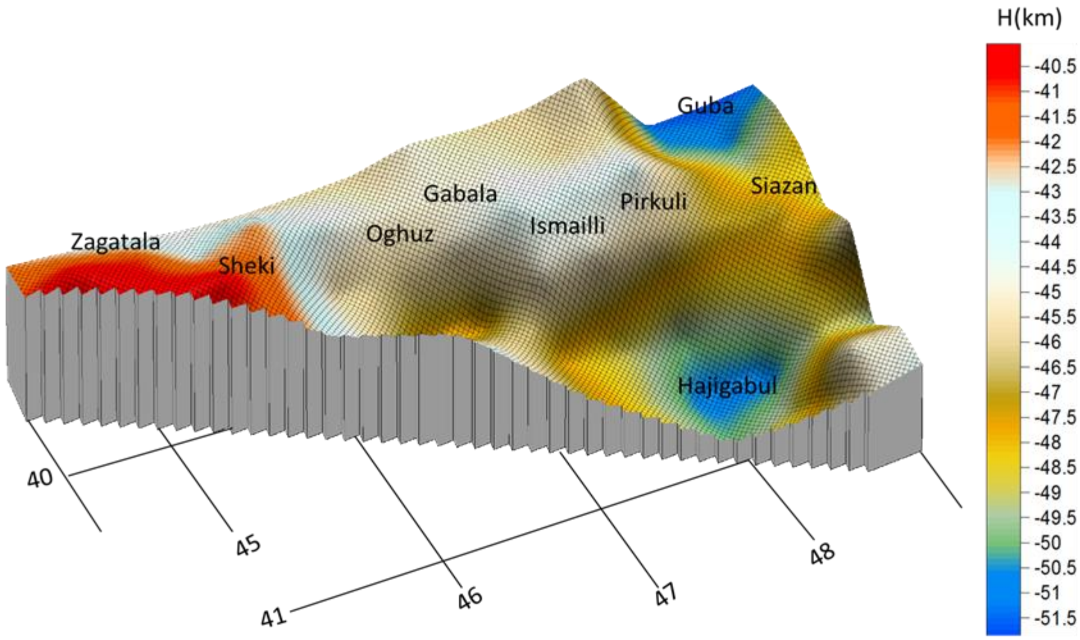

Figure 7. Three-dimensional model of the depth of Moho for the territory of the Greater Caucasus

Thus, a map of isolines of the depths of the Moho border was constructed and depths were determined for the territory of the Guba-Gusar region 48-50 km, the Zagatala-Balakan region 46-47 km, the Shamakhi-Ismayilli region 48-52 km. As it was said earlier, the first definitions of the depth of the surface of Mokhorovich in Azerbaijan were made on the basis of the data from the state earthquake and the gravitational model of the Earth's crust. Such models were built by Gadjiyev R.M. in 1965 and Shikhalibeyli E.Sh. in 1996. The data obtained are consistent with the available data, but discrepancies have been received. Compared with the map constructed according to the DSS-MCRW and gravimetry data (Gadjiyev R.M., 1965) [2] the difference in the thickness of the Earth's crust was from 1 to 15 km. Compared with the map constructed according to the DSV and gravimetry data (presented in the book by Shikhalibeyli E.Sh., 1996) [7], the difference in the thickness of the Earth's crust varied from 1 to 10 km.

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