REPUBLIC OF AZERBAIJAN

On the rights of the manuscript

ABSTRACT

of the dissertation for the degree of
Doctor of Philosophy

A GRAVITY MODEL OF THE DEEP STRUCTURE OF THE EARTH'S CRUST AND GEODYNAMIC PECULIARITIES OF THE SOUTH-EASTERN CAUCASUS

Speciality: 2507.01 - Geophysics, geophysical methods of minerals exploring

Field of science: Earth Sciences

Applicant: **Gunel Rafael Sadigova**

Baku – 2021

The work was performed at the Institute of Geology and Geophysics of Azerbaijan National Academy of Science.

Scientific supervisor:	Doctor of sciences in Geology and Mineralogy, academician, professor **Fakhraddin Abulfat Kadirov**
Official opponents:	Doctor of sciences in Geology and Mineralogy, associate professor **Abdulvahab Sharif Mukhtarov**
	Doctor of Philosophy in Geology and Mineralogy, associate professor **Elkhan Huseyn Isgenderov**
	Doctor of Philosophy in Geology and Mineralogy, associate professor **Ilyas Eldar Kazimov**

Dissertation council ED 1.01 of Supreme Attestation Commission under the President of the Republic of Azerbaijan operating at the Institute of Geology and Geophysics of Azerbaijan National Academy of Sciences.

Chairman of the Dissertation council:

Doctor of Sciences in Geology and Mineralogy, academician, professor **Akper Akper Feyzullayev**

Scientific secretary of the Dissertation council:

Doctor of Philosophy in Technical sciences, associate professor **Dilgusha Ramzey Mirzayeva**

Chairman of the scientific seminar:

Doctor of Sciences in Geology and Mineralogy, academician, professor **Parviz Ziya Mammadov**

GENERAL CHARACTERIZATION OF WORK

Relevance and state of knowledge of the topic

Gravity anomalies and their transformations play an important role in the study of the geological structure of the Earth's crust, and their analysis with the results obtained from other geophysical methods (seismic, electrical, magnetic, etc.) allows us to obtain fundamentally new information about the geological and tectonic structure.

Beginning at the end of the 20th century, digital methods were rapidly applied to the interpretation of geopotential areas. In this area can be noted V.I.Aronov, E.Q.Bulakh, R.J.Blakely, R.W.Simpson, F.A.Kadirov, A.K.Malovichko, T.S.Amiraslanov, S.A.Serkerov, V.A.Gadirov, V.O.Mixaylov, V.I.Starostenko, İ.E.Stepanova, V.N.Straxov, A.V.Tsirulskiy, S.A.Tikhotskiy and the work of other scientists.

Over the last decade, the mathematical theory of the interpretation of gravity anomalies has developed significantly. Currently, the digital analysis of gravity field data is considered a new direction in the theory of the interpretation of potential fields. The development and application of gravity field transformation methods to determine the density boundaries in the geological structure of any area are very relevant. The development and practical application of new algorithms for the calculation of gravity field transformations expands the possibilities of analysis in solving geological problems.

The issues of digital modelling of gravity field data of the South-East Caucasus (PreCaspian-Guba zone) are considered in the dissertation. The territory of Azerbaijan is located in the zone of active interaction between the Arabian and Eurasian plates (Mckenzie, 1972, Philip et al., 1989). The interaction between these plates began 10-30 million years ago and continues to this day (Robertson, 2000; Allen et al., 2004). The long-term interaction of plates determines the geodynamic conditions of the area and plays an important role in forming density boundaries in the Earth's geological structure. Taking this into account, the obtained digital gravity models in the South-East Caucasus are interpreted in a complex way together with the parameters characterizing the geodynamic conditions of the research area (seismic, horizontal and vertical velocities, strain and deformations).

In the dissertation, the geodynamic conditions and kinematic properties are studied using the results, obtained by the method of space geodesy, GPS (Global Positioning System) and compared with gravity models. At the same time, the results of measurements conducted with the new ZLS BURRIS gravimetry and modern geodetic instruments (GPS Trimble 5700, Level Pentax-AFL320, LEICA total station TS06), available at the institute allowed us to obtain new information and make new interpretations of the gravity field and modern movements in the selected Samur-Baku profile.

It should be noted that the correlation between the digital gravimetric models of the depth structure in the area and the new kinematic parameters characterizing the geodynamic conditions has not been sufficiently studied to date. The study of this problem is of great scientific and practical importance, and the results of the complex analysis conducted in the research area can be used to study the geodynamic hazard for infrastructure in the region (Baku-Novorossiysk oil pipeline, Takhtakorpu reservoir and Shollar water pipeline, etc.) and the detection of oil and gas structures.

Purpose and objectives of the research

Digital modelling of Bouguer gravity field data of the South-East Caucasus and study of the correlation of the obtained results with the parameters characterizing the geodynamic conditions of the area.

In this regard, several main issues have been resolved:

- Determination of the power spectrum and density boundaries of the gravity field of the research area;
- Development and application of a program for calculation of local anomalies of the gravity field;

- Construction of a 3D digital gravity model of the sedimentary layer;

- Conduction gravity field measurements in the Samur-Baku profile, construction of a 2D gravity model of the depth structure;

- GPS data is used to calculate the strain caused by horizontal movements on the Earth's surface;

- Investigation of regularities between digital gravity models of the research area and the parameters characterizing the geodynamic conditions.

- **Research methods:**

In the dissertation, the following research methods were used:

-The Hartley transform was used to calculate the power spectrum and local anomalies of the research area Bouguer gravity field;

-The Spector-Grant method was applied to determine the average depth values of the main density boundaries in the depth structure;

-The Butterworth filter was used to calculate low-pass and high-pass gravity anomalies;

-The 3D digital gravity model of the sedimentary layer was constructed by the GR3DSTR program;

-E.Q.Bulakh's matching method was used to construct a 2D gravity model of the Earth's crust depth structure in the Samur-Baku profile.

Main defending statements:

- 3D digital gravity models of the research area depth structure;

- Regularities between digital gravity models of depth structure and parameters characterizing geodynamic conditions.

Scientific novelty of the research:

- The average depth of the density boundaries (16.6 km and 1.8 km) of the research area, which causes intensive anomalies in the Earth's crust, was determined;

- Low-pass and high-pass gravity anomalies were calculated using the cut-off wavenumber of the power spectrum;

- A computer program was developed to calculate local anomalies in the gravity field;

- The correspondence of the Bouguer gravity field local anomalies to oil and gas structures was determined;
- The sedimentary layer depth 3D digital gravity model was constructed using a quadratic density function. The maximum depth was determined in the Guzdek and Maraza regions (11 km) and the minimum depth in the Gonagkend, Gilazi, Garabulag, Dubrar regions (4 km);
- A 2D gravity model of the Samur-Baku geological-geophysical profile depth structure was constructed and the MOHO boundary was clarified;
- Comparison of the sedimentary layer gravity model and the velocity model at a depth of 5 km has determined the presence of small seismic wave velocities in the deep part and high seismic wave velocities at low depths of the sedimentary layer;
- Comparison of the gravity field regional anomalies and the velocity model at a depth of 15 km showed a decrease in seismic wave velocity in the zone of regional minimums and an increase in the velocity in the transition zone of anomalies;
- The minimum deformation velocity was observed in the zone of regional anomalies and the deformation velocity increased in the transition zone of anomalies.

Theoretical and practical significance of the research:

The methodology developed in the dissertation is of theoretical importance and can be applied in other regions. The results of the complex analysis of the South-East Caucasus are of great practical importance in the study of geodynamic hazards for the infrastructure located in the region (Baku-Novorossiysk oil pipeline, Takhtakorpu reservoir and Shollar water pipeline, etc.). At the same time, the sedimentary layer depth gravity model and local gravity anomalies are of practical importance in oil and gas exploration and well location selection.

Approbation and application:

On the topic of the dissertation, 19 scientific works have been published, of which 6 articles, 1 conference material and 12 abstracts. The main results and statements of the dissertation were presented and discussed at republican and international conferences: Republican Scientific Conference "Actual Problems of Geology" (Baku, 2015, 2018, 2019), I, II, VI, VII International Scientific Conference of young scientists and specialists (Baku, 2014, 2015, 2018, 2020), International Student Scientific Conference on "Perfect education - the key to success in oil production" (Baku, 2016, 2017), XX All-Russian International Scientific Conference "Deep construction, mineralogy, modern geodynamics and seismicity of the East European platform and adjacent regions" (Voronezh, 2016), Scientific seminar of young scientists and researchers at the Institute of Geology and Geophysics (Baku, 2018), I International School-Seminar of Oil and Geoecology (Baku, 2018), "Exploration and Production in the Black Sea, Caucasus and Caspian Region" (Batumi, 2019).

Name of the organization where the dissertation was performed:

The work was performed at the Institute of Geology and Geophysics of ANAS.

Structure and volume of work

The dissertation consists of an introduction, four chapters, conclusions, a program, a list of references, including 291 titles, and a list of abbreviations. The work is presented on 208 pages, contains 53 figures and 8 tables. The total number of characters is 239623, of which the introduction is - 11027, the 1st chapter - 82471, the 2nd chapter - 49908, the 3rd chapter - 35027, the 4th chapter - 56465 and the conclusions - 4725.

This work was supported by the Science Development Foundation under the President of the Republic of Azerbaijan – Grant No EIF-KETPL-2015-1(25)-56/27/2

The personal contribution of the author:

The basis of the dissertation is the research conducted by the author. The author personally participated in all stages of the research. The author has developed an extensive database for the construction of geological-geophysical sections, seismic and geodynamic surveys. The calculation of the power spectrum, the determination of density boundaries by the use of the Spector-Grant method and the construction of a 3D digital gravity model were performed by the author based on software developed at the Institute of Geology and Geophysics. An algorithm and program were developed by the author to calculate local anomalies of the gravity field. The author actively participated in gravimetric and geodetic work in the area and the processing and interpretation of GPS data.

Acknowledgments:

The author is sincerely grateful to the scientific supervisor, academician F.A.Kadirov, for valuable advice, help and constant attention at all stages of the dissertation writing.

The author thanks the director of the Institute of Geology and Geophysics of ANAS, academician A.A.Alizadeh, for the opportunity to perform the dissertation, the management of the Republican Seismic Survey Center of ANAS, the correspondent member of ANAS, professor Q.C.Yetirmishli, as well as the head of the "Dynamic earthquake parameters" departament of the Republican Seismic Survey Center of ANAS, Doctor of Philosophy in Geology and Mineralogy, Associate Professor S.E.Kazimova, the leading researchers of the Institute of Geology and Geophysics of ANAS, Doctor of Philosophy in Geology and Mineralogy, associate professor S.T.Agayeva, Doctor of Philosophy in physical and mathematical sciences, associate professor A.H.Qadirov, Doctor of Philosophy in Earth Sciences, associate professor R.T.Safarov, for their assistance.

SUMMARY OF WORK

In the **introduction,** the relevance of the dissertation is presented, the purpose, research objectives and methods for their solution are formulated, the main defending statements are listed, and the scientific novelty of the work and its practical value are justified.

The **first chapter** of the dissertation presents an overview of the history of geological investigation, tectonic structure, results of modern geophysical studies, sediment density characteristics of the South-Eastern Caucasus, and comments on a general overview of the main features of the Earth's crust geological structure.

The investigation of geological and geophysical materials of the region deep structure and the information about tectonic structure are widely described in the work of the following authors: R.M.Hajiyev (1965); T.S. Amiraslanov (1986); L.P.Zonenshain (1990); Shikhalibeyli (1996); V.Q.Qadirov (1996); F.A.Kadirov (2000); A.Q.Hasanov (2001), V.E.Khain (2005); T.N.Kangarli (2005); F.S.Akhmadbeyli (2010); A.M.Aliyev (2018), A.M.Salmanov (2015); Kh.M.Yusifov (2015, 2018); B.S.Aslanov (2005) and others.

The South-Eastern Caucasus region covers Azerbaijan part of the Pre-Caucasus megasynclinorium and the southeastern end of the Greater Caucasus megaanticlinorium. The main part of the Pre-Caucasus megasinclinorium is located in Azerbaijan and is described as the Gusar-Shabran trough. The Gusar-Shabran trough is bordered in the north-west by the Samur fault, in the south-west by the Siyazan fault, and in the northeast by the Caspian sea coast. This Pre-Caucasus marginal trough is characterized by the advantages of the Paleogene-Neogene and modern sediments.

The southeastern end of the Greater Caucasus megaanticlinorium is bordered by the Siyazan fault in the northeast, the Langabiz-Alat fault in the southwest, the West-Caspian fault in the northwest, the Central Caspian fault in the southeast and the Shamakhi-Gobustan trough, Absheron and Shahdag-Khizi tectonic zones are separate inside of the zone.

The Lower-Middle Jurassic age sandy-clays, the Upper Jurassic-Cretaceous and Paleogene age terrigenous, carbonate-terrigenous flysch complexes, the Neogene age shell-limestones, continental-marine pebbles, conglomerates, sandstones, and the Quaternary period marine and continental lithofacies are involved in the geological structure of the Greater Caucasus megaanticlinorium southeastern end.

More than 80 local uplifts were discovered and studied in the area of the Shamakhi-Gobustan oil and gas region through prospecting work. In recent years (since 1975-1979 and 1990), seis-mic works in the region have been carried out using the Common

Depth Point method. The investigations allowed us to obtain information about the structure of the deeper layers. 92 local uplifts were discovered in the Absheron oil and gas region. The 28th structure was discovered in the mainland part, and about a tenth of the structures were discovered in the shallow-water part of the region. Over the last 8-10 years, all other uplifts, including oil and gas deposits, have been discovered using geophysical exploration methods, particularly seismic survey work.

Despite the long-term application of geophysical methods in the Gusar-Shabran trough, the tectonics of Mesozoic sediments, which are considered promising in terms of oil and gas potential, have not been sufficiently studied. The reasons for this situation include the inability to apply seismic survey methods in many parts of the region due to the complexity of the seismological conditions (development of a thick layer of gravel, intensive dislocation, the presence of numerous tectonic faults and structural layers of different ages) and the location of Mesozoic sedimentary complexes below the depth obtained by methods of a seismic survey. The insufficient volume of data from the Deep Seismic Sounding and deep parametric wells can be provided by gravimetric data.

The model of the research area is constructed based on gravity data, as well as density data. The modelling covered the sedimentary complex, the main structures below it and their material composition.

The **second chapter** investigates gravity anomalies in the South Eastern Caucasus. The study of local and regional components of the research area gravity field is conducted by a filtration method. The Spector - Grant method is used to determine the depth of mass causing the anomaly by estimates of the gravity field power spectrum. The Hartley transform and Butterworth filter are used for this purpose. In addition, the first-order derivatives of the gravity field are studied. Local and regional anomalies of the gravity field are separated by an averaging method using the Hartley transform. The depth of the sedimentary layer and the gravity effect are calculated.

The Spector-Grant method consists of applying logarithmic curves of the gravity anomaly power spectrum in the frequency range.

Spectral analysis is one of the most accurate methods for detecting density boundaries that cause anomalies. This method is considered in the works of many researchers [A.Spector, F.S.Grant (1970) [1]; R.J.Blakely (1995) [2]; S.A.Serkerov (2000) [3]; F.Ə.Kadirov (2000) [4]].

The gravity field of the research area is characterized by negative anomalies. The PreCaspian-Guba gravity minimum covers only the north and central parts of the Samur-Baku profile. The gravity field in the northern part of the profile characterized by an amplitude values of -70-80 mGal. The East Azerbaijan gravity minimum covers the southern part of the profile. This part of the gravity field is characterized by an amplitude value of -115 mGal.

The dependence graph of the spatial frequency from the power spectrum logarithm is constructed to determine the source depth causing intense anomalies in the frequency range of the gravity field data (Figure 1). The resulting graph is made up of straight-line segments. As the frequency increases, the inclination angles of the line decrease. Each linear part corresponds to the discrete density boundary.

The power spectrum of the gravity data shows a cut-off wave number separating two domains of high and low-wavelength information. The low and high-wave number parts of the power spectrum, associated with deep and shallow gravity sources, were taken as representing the regional and local anomalies, respectively. The cut-off wave number is determined by the crossing point of fitted straight lines approximating the power spectrum data in the high and low –wavelength domains.

---

[1] Spector A., Grant F.S. Statistical models for interpreting aeromagnetic data // - Tulsa: Geophysics, - 1970, - V. 35, - No 2, - p. 293-302

[2] Blakely R.J. Potential theory in gravity and magnetic applications / R.J.Blakely - Cambridge: Cambridge University Press, - 1995, - 441p.

[3] Serkerov S.A. Potential theory in gravity and magnetic prospecting / S.A.Serkerov - M.: Nedra, - 2000, - 350s. (in Russian)

[4] Kadirov F.A. The gravity field and models of the deep structure of Azerbaijan / F.A. Kadirov - Baku: Nafta-press, - 2000, - p. 112. (in Russian)

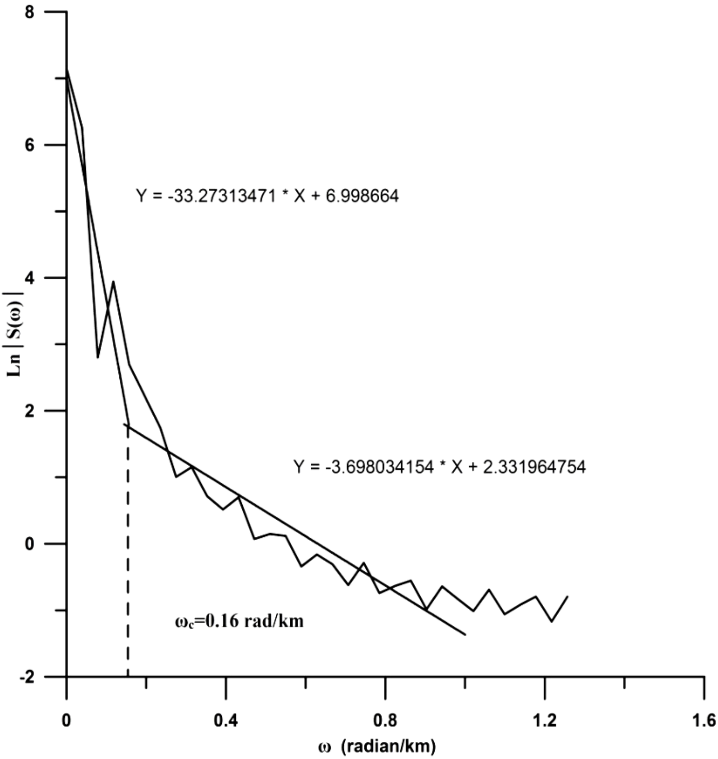

Fig.1. Power spectrum of the Bouguer gravity anomaly in the South-Eastern Caucasus

A cut-off wave number of ω = 0.16 rad.km^{-1} is found in the power spectrum of the Bouguer gravity field of the research area. Regional and local anomalies were separated by a filtering process using cutoff wavenumber.

The Hartley transform[5] and the Butterworth filter[6] are used to separate regional and local anomalies in the Bouguer gravity field.

The low-pass Batterworth filter is given by:

---

[5] Bracewell R. Hartley Transform. Theory and applications. Translator A.I.Papkov, Ed. I.S. Ryzhak. - M.: Mir, 1990. - 175 p. (in Russian)

[6] Nikitin A.A. Theoretical foundations of geophysical information processing / A.A. Nikitin - M.: Nedra, - 1986, - 342p. (in Russian)

$$H_B(\omega) = \frac{1}{\sqrt{\left(\frac{\omega}{\omega_c}\right)^{2n}}}$$

where $\omega = 2\pi/\lambda$ is the wavenumber, $\omega_c = \frac{2\pi}{\lambda_c}$ is the cut-off wave number and n is the degree of the filter. In this study, n was taken to be equal to 1.

Analysis of the gravity field power spectrum for the South-Eastern Caucasus regions allows estimation of the average depth of density boundaries generating intensive anomalies varying from 16.6 km to 1.8 km. A depth of 16.6 km is associated with the crystalline basement surface and 1.8 km with the surface within the Cenozoic sediments. [7,8]

In the research area, regional and local anomalies were calculated by the averaging method using the Hartley transform for the values of the Bouguer gravity field with grid spacing at every 5 km ($N_x = 29$, $N_y = 40$)

The gravity field local anomalies were studied using squares of size L = 15 and 30 km. High frequencies are amplified and low frequencies are turned off as a result of the averaging method. The gravity field local anomalies obtained by the averaging method using a square of size L = 15 km are associated with structural elements up to a depth of 2.25 km.

Negative local gravity anomalies were noted between Guba-Gusar, Gusarchay, Agzibirchala, Zeynalabdin, Heybat, Jeyrankechmez, Jangi and Cheyildag areas. Local maximums of the gravity field were observed in the Gonagkend and Garabulag areas (Figure 2, a).

Local gravity anomalies obtained by the averaging method

[7] Sadigova G.R. Parameters of the South-Eastern Caucasus depth structure by the Spector-Grant method based on gravimetric data // Baku: Azerbaijan Geologist. Scientific Bulletin of the Azerbaijan Society of Petroleum Geologists, - 2019, - No 3, - p.32-36. (in Azerbaijani)

[8] Sadigova G.R. Gravity anomalies of the South-Eastern Caucasus // Geophysical Journal, 2020, vol. 42, No 2, c. 138-151. (in Russian)

using square of size L = 30 km are associated with structural elements up to a depth of 4.5 km. Negative local anomalies were noted between the Gusar-Guba, Talabi-Tengialti-Qaynarja areas (Figure 2,b). Estimated hydrocarbon deposits in the gravity field are associated with characteristic local minimums. Positive local anomalies were noted in the Gonagkend and Sitalchay areas. These maximums were observed with closed anomalies reflecting anticlinal structures. Closed anomalies were noted in the areas of Agzibirchala, Qaynarja and Sitalchay anticlinal uplifts. Most of the identified local anomalies are consistent with known oil fields.

Negative regional anomalies were noted between the Guba-Gusar-Khachmaz, Gaynarja, Yekakhana, Jangi, Agzibirchala, Dubrar, Mudri, Jeyrankechmez, Cheyildag, Sitalchay and Heybat areas as a result of the averaging method using a square of size L = 15 km. As a result of the averaging method using a square of size L = 30 km, negative regional anomalies were observed in the area covering Zeykhur-Guba-Gusar-Charkhi-Khachmaz and Jangi-Zeynalabdin-Sumgayit stations. Regional anomalies can be explained by changes in the boundaries within the crystalline basement.

Calculation of the first-order derivative from the values of the Bouguer gravity anomaly is one of the methods of separating local anomalies of the gravity field for exploration purposes.[3,9]

The first-order derivative of the frequency field is calculated by the product of the two-dimensional spectrum of the input function and the weight function:

$$F_u(u,v) = A(u.v)\left(u^2 + v^2\right)^{\frac{1}{2}}$$

where $F_u(u,v)$ the first-order derivative of the gravity field in the frequency field, A (u, v) is the spectrum of the input function, u and v are the spatial frequencies in the X and Y directions, respectively. Then we return to the spatial field using the inverse Hartley transform.

[9] Gravimetric exploration: Geophysics Handbook. / Ed. E.A.Mudretsova, K.E.Veselova. - M.: Nedra, - 1990. - 607 p. (In Russian)

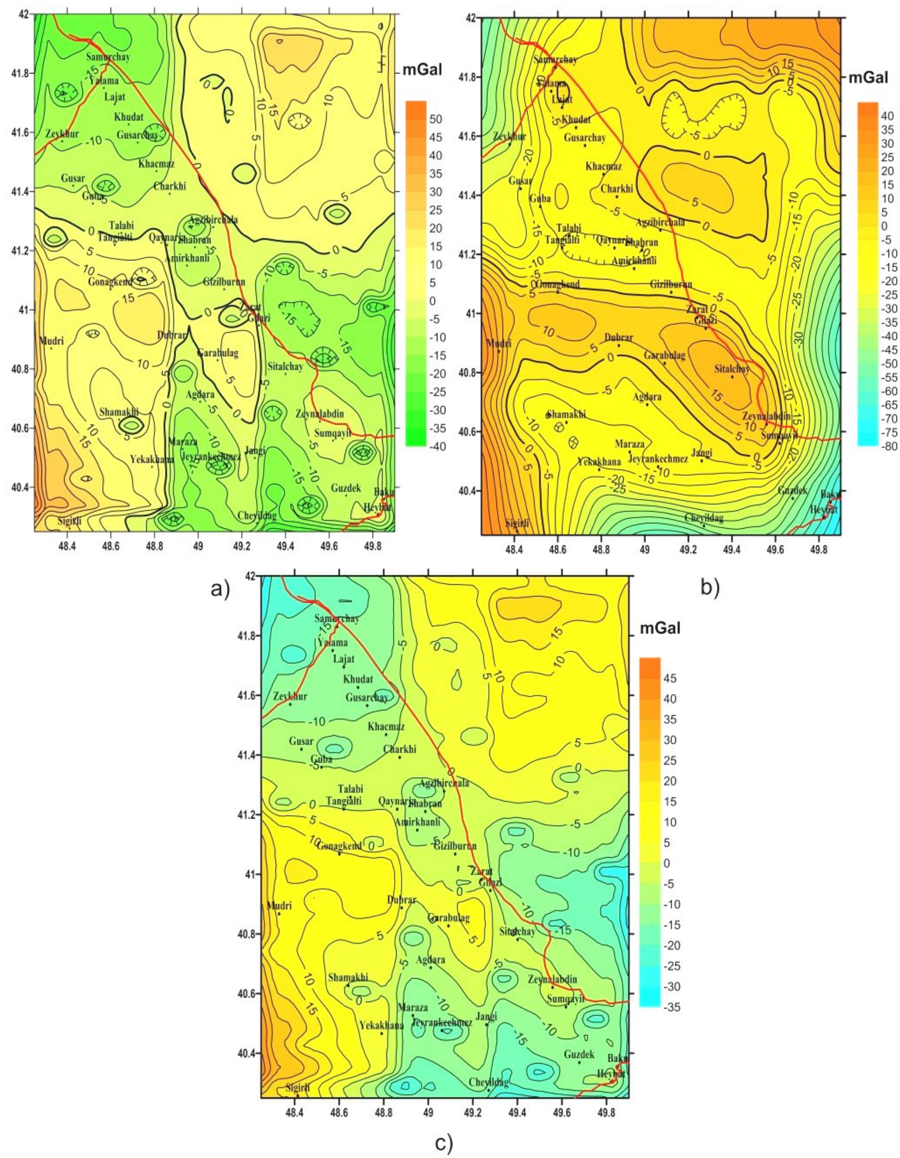

Figure 2. Local gravity anomalies obtained by the averaging method using squares of size L = 15 km (a) and 30 km (b) and a first-order derivative (c) map of the research area gravity field

Negative local anomalies were noted between the Guba-Gusar-Khachmaz, Agzibirchala, Maraza, Jeyrankechmez, Guzdek, Heybat areas (Figure 2,c). Positive anomalies were observed in the Gonakkend and Gilazi areas, which were interpreted as an uplift of the Mesozoic sedimentary layer. The anomalies obtained from the first-order derivative of the gravity field are probably explained by the ups and downs of the density boundaries, which cover a depth range of 3 to 5 km.

The computer program GR3DSTR was used to calculate the topography of the sedimentary layer depth based on the gravity field.[10] The density parameter of the sedimentary layer was included in the program by approximating it as a quadratic function based on known density values of rocks. The depth of the sedimentary layer is investigated based on quantitative analysis of the gravity field, taking into account the following: a) density change at the bottom of the low-speed zone 0.3-0.4 g / cm^3, b) the dependence residual density from the depth according to the quadratic function.

An approximation of density-vs.-depth data for the research area by a quadratic function is shown in figure 3, a. The quadratic function coefficients are given below:

$$a_0 = -0.4090,\ a_1 = 0.03041,\ a_2 = -\ 0.00092$$

The sedimentary layer depth was calculated by the GR3DSTR program using the values of the calculated quadratic function coefficients and the South-Eastern Caucasus Bouguer gravity anomaly. After 10 iterations, the depth distribution of the sedimentary layer was calculated, as shown in figure 3 b.

Large depths were obtained in the Guzdek and Maraza areas from the sedimentary layer depth gravity model (Figure 3, b). The average depth here is 11 km. The rise of the sedimentary layer is observed in the Gonagkend, Gilazi, Garabulag, Dubrar areas. The average depth of the sedimentary layer was calculated at 4 km in the Gonagkend, Gilazi, Garabulag and Dubrar areas. In the sedimentary layer depth gravity model, the thickness is 8 km in the Gusar-

---

[10]Bhaskara R.D., Ramesh B.N. A fortran-77 computer program for three-dimensional analysis of gravity anomalies with variable density contrast // - Amsterdam: - Computers and Geosciences, - 1991, - vol. 17, - No 5, - p. 655-667

Shabran trough and the Agzibirchala area is 6 km. The depth values in the sedimentary layer gravity model are close to the data obtained from the previously studied profiles.

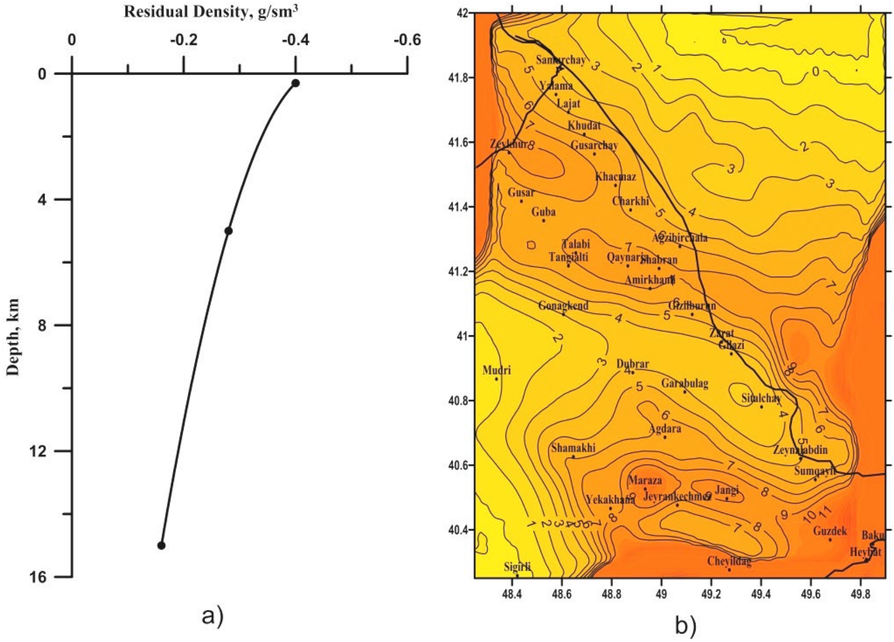

Figure 3. Approximation of density-vs.-depth data for the research area by a quadratic function (a) and the sedimentary layer depth 3D gravity model (b)

In the **third chapter,** the gravity model of the Earth's crust depth structure along the Samur-Baku profile, which intersects the South-East Caucasus in the submeridional direction, was constructed by the matching method.[11] To calculate the gravity model of the deep structure based on previous studies, an initial density model of the profile was constructed. The gravity field anomalies on the profile (from the initial and selected model) and the selected gravity model are shown in Figure 4.

---

[11] Bulakh E.G., Markova M.N. Solution of inverse problems of gravimetry by the matching method // - K.: Geophysical Journal, - 1992, - No4, - p. 9-19. (in Russian)

A forward problem was solved based on the initial model and a calculated gravity field was obtained. The calculated values of the gravity field for the initial model do not explain the observed gravity field. This procedure was repeated with adjustment of the model parameters until the calculated and observed anomalies were considered a sufficient match.

The surface of the granite layer is 5-16 km, the surface of the basalt layer is 28-32 km, and the Moho border is 47-57 km, according to the gravity model. The maximum depth of the basalt layer and the Moho border is in the Zarat area, and the maximum depth of the granite layer is in the Samur area.[12]

The **fourth chapter** of the dissertation, the geodynamic conditions of the South-East Caucasus, was evaluated by the Samur-Baku profile, which intersects the eastern part of the territory, and by area. Modern vertical and horizontal movement velocities of the Earth's crust were analyzed. Strain accumulation zones were determined by the Samur-Baku profile according to the modern vertical movement velocities, deformation velocities were calculated according to the GPS velocities, and the relationship between the distribution of mud volcanoes and earthquake epicentres in the area with the defined strain accumulation zones was considered. Also, the distribution of heat flux in the South-East Caucasus and the temperature change along the Samur-Baku profile were considered. The correlation of the 3D digital gravity models of the research area with seismicity, modern vertical movement velocities, deformation velocity field and velocity changes of seismic waves was studied.

Using the curve of modern vertical movement velocities on the Samur-Baku profile, the zones of strain accumulation are noted according to the boundaries of ascent and descent. The main strain accumulation zones were observed near Khudat, Charkhi, Siyazan and Baku.

[12] Sadigova G.R. Gravity model of the Earth's crust depth structure by the Samur-Baku submeridional profile (Gusar-Shabran trough) // -Baku: Geophysical innovations in Azerbaijan, - 2018, No3, - p. 14-19. (in Azerbaijani)

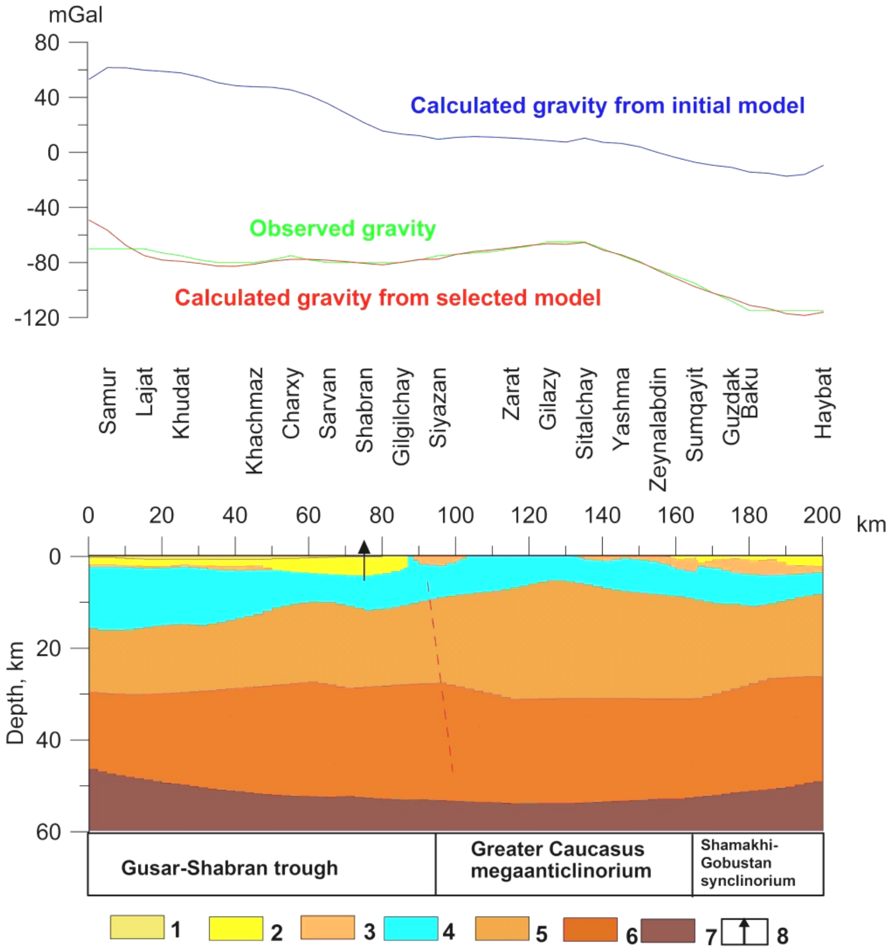

Figure 4. 2D gravity model on Samur-Baku profile.

1-Quaternary sediments, 2-Neogene, 3-Paleogene, 4-Mesozoic sediments; Granite layer; 6- Basalt layer; 7-Upper mantle, 8-Agzibirchala-1 well.

Earthquake data (2003-2018) was used to analyze the relationship between strain accumulation zones and seismicity. Earthquake hypocenters were recorded in the mentioned strain accumulation zones.[13,14] Temperature increase was observed in strain accumulation zones (Khudat, Siyazan, Baku).[15] The maximum value of temperature was observed near Siyazan. The highest temperature zone may be related to the Siazan fault with high seismic activity. Active mud volcanoes were observed near Baku station. The highest ascent (+ 12.5 mm/year) and descent velocities (–4.7 mm/year) of modern vertical movements were also recorded in the same area, from Guzdek to Heybat.[16]

GPS velocity data of the points close to the profile Samur - Baku was used to calculate the average value of the strain using the horizontal movement velocities. The total deformation velocity was calculated between stations Baku-Khizi of 8.9 nanostrain/year, Siyazan-Khizi of 97.5 nanostrain/year and Siyazan-Samur of 22.3 nanostrain/year. The high value of deformation velocity observed between Siyazan-Khizi stations corresponds to the ascent of the relief and the area where the Siyazan fault is.[13,14]

The relationship between the deformation velocity field and the seismicity in the South-East Caucasus was considered (Figure 5, a). The strain distribution map shows the compression zones in blue and the tension zones in red. High strain accumulation velocities were observed at MEDR ($70 \cdot 10^{-9}$/year) and SIYE ($60 \cdot 10^{-9}$/year) stations on the deformation velocity field map. A large number of earthquake epicentres with magnitudes greater than 3 were distributed throughout the compression zones.

---

[13] Gadirov A.G., Sadigova G.R., Agayeva S.T. Deep structure and geodynamic peculiarities of the Earth's crust of the western coast of the Caspian Sea // Geophysical Journal, -2018, -p. 40, -No 4, -c.191-208. (in Russian)

[14] Sadigova G.R. Inhomogeneity of the lithosphere, deep structure and modern geodynamic characteristics of the western coast of the Caspian Sea // - Baku: News of the Azerbaijan National Academy of Sciences, Earth Sciences, - 2018, No 1, - p. 70-77. (in Azerbaijani)

[15] Sadigova G.R. The geodynamic pecularities of the South-Eastern Caucasus territory // -Bishkek: Modern problems of mechanics, -2018, -No 33 (3), -p.210-221. (in Russian)

[16] Sadigova G.R. Modern movements of the Earth's crust by the Samur-Baku geodynamic profile // - Baku: Azerbaijan Geologist. Scientific Bulletin of the Azerbaijan Society of Petroleum Geologists, - 2015, No 19, - p.71-77. (in Azerbaijani)

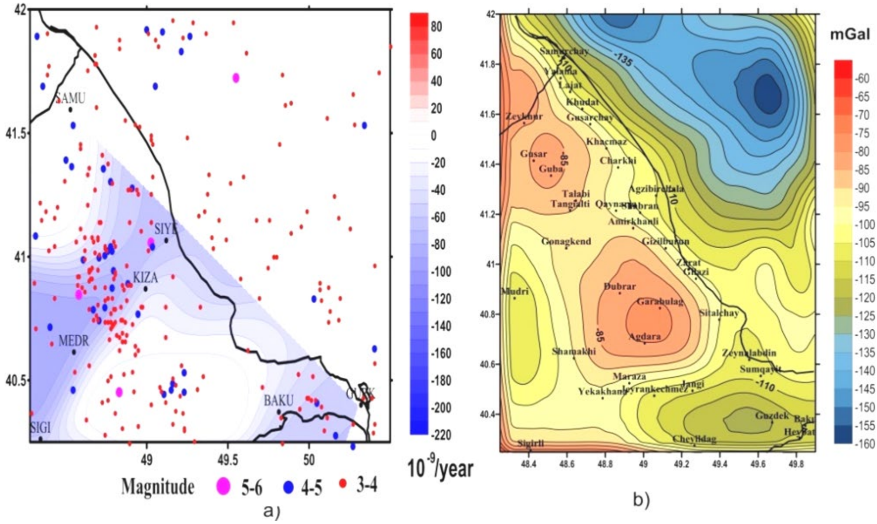

Figure 5. Distribution of earthquake epicentres with magnitude M≥3 (2003-2018) on the deformation velocity map[17] (a) and the gravity field regional anomalies map (b)

The gravity field regional anomalies are compared with the deformation velocity field in the South-East Caucasus (Figure 5, b). The minimum deformation velocities are noted in the Dubrar-Agdara-Garabulag and Baku-Guzdek-Cheyildag (-120 mGal) regional minimum zones. This zone is surrounded by mud volcanoes. The decrease in deformation velocity is explained by the clay and the plasticity of the rocks that form the sedimentary layer. The decrease in deformation velocity is also noted in the Guba-Gusar minimum zone. The increase in deformation velocity (80 nanostrain/year) is observed in the zone between the two regional minimums.

The deformation velocity in the north part of the research area in the Quba-Gusar regional minimum zone and the south part of the research area in the Dubrar-Agdara-Garabulag, Baku-Guzdek-Cheyildag regional minimum zones was minimal. A high deformation velocity was

[17] Kadirov F.A., Safarov R.T. Deformation of the Earth's crust in Azerbaijan and adjacent territories according to GPS measurements // - Baku: News of the National Academy of Sciences of Azerbaijan, Earth Sciences, - No1, - 2013, - p. 47-55. (in Russian)

observed in the transition zone of anomalies. A large number of earthquakes were observed in the area between the two regional minimums, where a high deformation velocity was observed.

The strain caused by horizontal movements on the Earth's surface was calculated based on GPS data. High deformation velocity was observed between Baku-Gurgan (65.6 10^{-9}/year) and low strain accumulation velocity between Khizi-Siyazan ($7.5\cdot10^{-9}$/year) stations, according to the eastern component of the GPS velocity.

The high deformation velocity was observed between stations Khizi-Siyazan ($112.5\cdot10^{-9}$/year) and Madrasa-Khizi ($74\cdot10^{-9}$/year), and the low value of strain accumulation between stations Samur-Khizi ($5.8\cdot10^{-9}$/year) according to the northern component of the GPS velocities. In high strain accumulation zones, the distribution of earthquakes with magnitudes greater than 3 was observed.

High strain accumulation was observed between Khizi-Siyazan ($97.5\bullet10^{-9}$/year) and Madrasa-Khizi ($82.9\bullet10^{-9}$/year) stations using both components of the GPS velocities and low strain accumulation between Samur-Khizi (6.9 10^{-9}/year). It was determined that the low value of the strain accumulation corresponds to the deep part of the sedimentary layer, and the high value corresponds to the shallow depth.

The relationship between the gravity field regional anomalies, seismicity and modern vertical movement velocities in the research area was considered (Figure 6). The Earth's crust modern vertical movement velocity map shows the velocity increase in the Greater Caucasus meganticlinorium zone. The vertical movement velocity of the Earth's crust decreases from +8 mm/year to +1 mm/year in the southwest to the northeast direction in the PreCaspian-Guba zone. A descent occurs at a velocity of −1 mm/year in the PreCaspian-Guba zone coastal part. On the gravity field Bouguer anomaly map, the PreCaspian-Guba gravity minimum is observed in this zone.

An increase in velocity was observed of +7 mm/year in the zone covering the Shamakhi-Maraza-Agdara stations. The descent occurs on the Absheron peninsula. The maximum value of the descent velocity is -8 mm/year. This zone covers the part of East Azerbaijan gravity minimum on the gravity field map.

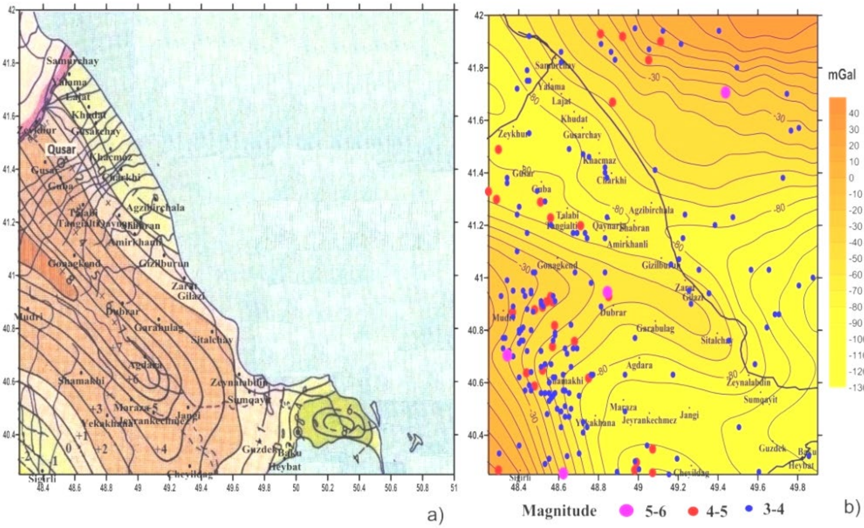

Figure 6. Map of modern vertical movement velocities [18] (a) and distribution of earthquake epicentres with magnitude M≥3 on the Bouguer gravity field map (2003-2018) (b)

The earthquake epicentres with a magnitude of M ≥ 3 were distributed in the gradient zones of gravity anomalies (Figure 6,b).

It is interesting to compare the velocity changes of seismic waves with the research area digital gravity models. Figure 7 shows the velocity model horizontal section map at 5 km depth obtained as a result of seismic tomographic studies and the sedimentary layer depth 3D gravity model.

In the northern part of the research area, in the Zeykhur-Gusar-Gusarchay zone, the sedimentary layer deep part is represented by low velocities (4.25 km/sec). A partial high velocity (4.75 km/sec) is observed in the zone of the Tangialti-Qaynarja trough. The velocities have increased (4.85-4.95 km/sec) in the Dubrar-Sitalchay relative uplift zone. In the Maraza-Jangi-Cheyildag zone, the velocity decreases to 4.60 km/sec, where the sedimentary layer is deep.

[18] Neotectonic Map of Azerbaijan / M. 1: 500000 / Scientific editors: F.Ahmadbeyli, A.Mammadov, N.Shirinov [etc.] - B.: Azerbaijan aerogeodesy. 1991. (in Azerbaijani)

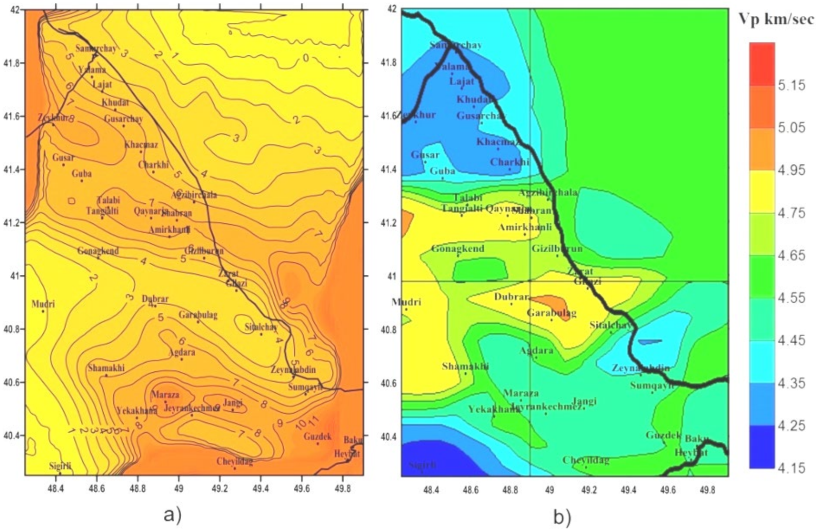

Figure 7. The sedimentary layer depth 3D gravity model (a) and the velocity model horizontal section map at 5 km depth[19] (b)

As a result of the comparison of the sedimentary layer depth gravity model with the velocity model at 5 km depth, a decrease in seismic wave velocities were observed in the deep part of the sedimentary layer and an increase in velocity in the partial rise zone.

Figure 8 shows the velocity model horizontal section map at 15 km depth and the gravity field regional anomalies map. The velocity model at 15 km depth shows that the velocity increases in the zone between the two regional anomalies surrounding the Tangialti-Qaynarja-Agzibirchala-Amirkhanli stations and reaches a maximum in the Qaynarja (6.65 km/sec). The velocity decrease (6 km/sec.) was observed in the Gusar-Guba-Khachmaz-Charkhi regional anomaly zone, in the research area northern part. The velocity decrease was also observed in the Maraza-Sitalchay-Zeynalabdin regional anomaly region. The velocity value was 5.5 km/sec near Jangi. Such a velocity change in this zone can be explained by a density change in the lateral direction.

[19] Yetirmishli G.D. Kazimova S.E. The Earth's crust velocity model of Azerbaijan according to the data of digital seismic stations // - Vladikavkaz: Geology and geophysics of the South of Russia, - 2012, No. 1, - p.59-74/ (in Russian)

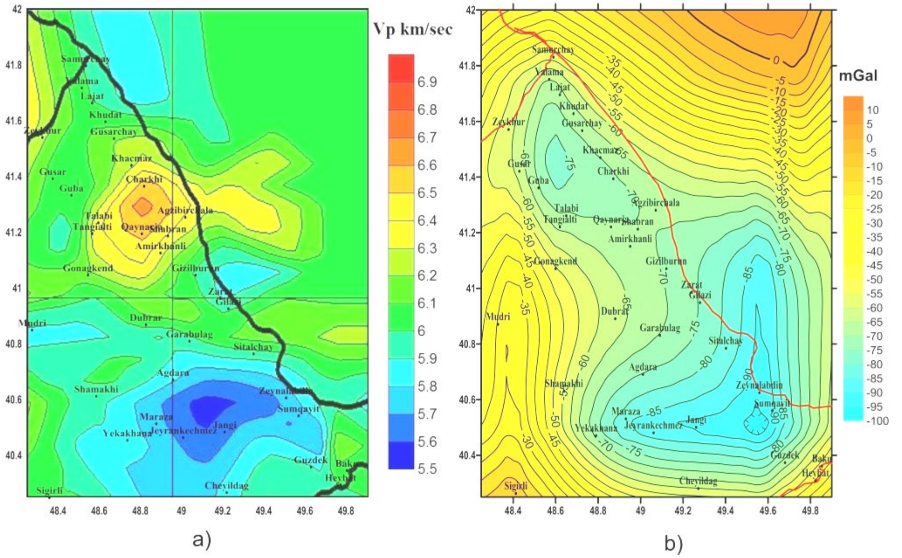

Figure 8. The velocity model horizontal section map at 15 km depth[19] (a) and the gravity field regional anomalies map obtained from the averaging method with a square of size L = 30 km (b)

As a result of the comparison of the gravity field regional anomalies with the velocity model at 15 km depth, a decrease in seismic wave velocity was observed in two regional gravity minimum zones of the research area and an increase in velocity in the transition zone of anomalies.

CONCLUSIONS

The Hartley transform, Butterworth filter, and spectral analysis method are used to study transformations of the gravity field in the research area, and the sedimentary layer depth gravity model was studied with the GR3DSTR program, taking into account the parabolic change in density and analyzing it together with geodynamic-kinematic parameters, allow us to draw the following main conclusions:

1. As a result of the analysis of the gravity field power spectrum of the South-Eastern Caucasus by the Spector-Grant method, the average depth of density boundaries that cause an intensive gravity anomaly was determined at 16.6 and 1.8 km. The depth of 16.6 km is

related to the surface of the crystalline basement, and 1.8 km is related to the density boundary within the Cenozoic sediments.

2. Low-pass and high-pass gravity anomalies of the boundaries generating intensive anomalies were calculated with the Butterworth filter using the cut-off wavenumber determined by the power spectrum curve.

3. Based on the developed program, local and regional anomalies were separated from the gravity field data by the averaging method with squares of size L = 15 km and L = 30 km, and the first-order derivative was calculated.

4. As a result of the averaging method with squares of size L=15 km, negative local gravity anomalies were noted between the Guba-Gusar, Gusarchay, Agzibirchala, Zeynalabdin, Heybat, Jeyrankechmez, Jangi and Cheyildag areas and positive local anomalies in the Gonagkend and Garabulag areas.

5. The gravity field local anomalies obtained by the averaging method with a square of size L = 15 km can be explained by the boundary changes within the sedimentary layer of Cenozoic age to a depth of 2.25 km.

6. As a result of the averaging method with squares of size L = 30 km, negative local gravity anomalies were noted between the Guba-Gusar, Talabi-Tengialti-Qaynarja and positive local anomalies in the Gonagkend and Sitalchay.

7. The gravity field local anomalies obtained by the averaging method with squares of size L = 30 km can be explained by the boundary changes within the sedimentary layer of Mesozoic age to a depth of 4.5 km.

8. There was determined a correlation between the observed local anomalies with known oil structures, and the closed anomalies were noted in the Agzibirchala, Qaynarja, and Sitelchay Anticlines.

9. As a result of the averaging method with squares of size L = 15 km, negative regional gravity anomalies were noted between the Guba-Gusar-Khachmaz, Qaynarja, Yekakhana, Jangi, Agzibirchala, Dubrar, Mudri, Jeyrankechmez, Cheyildag, Sitalchay and Heybat areas.

10. As a result of the averaging method with squares of size L = 30 km, negative regional gravity anomalies were observed in the zone covering the Zeykhur-Guba-Gusar-Charkhi-Khachmaz and

Jangi-Zeynalabdin-Sumgayit stations. Regional anomalies can be explained by boundary changes within the crystalline basement.

11. As a result of the Bouguer gravity field first-order derivative, negative local anomalies were observed in the Guba-Gusar-Khachmaz, Agzibirchala, Maraza, Jeyrankechmez, Guzdek and Heybat areas and positive local anomalies in the Gonagkend and Gilazi areas.

12. The sedimentary layer depth 3D gravity model was constructed. It was determined that the maximum depth is in the Guzdek and Maraza areas (11 km). The minimum depth is in the Gonagkend, Gilani, Garabulag, and Dubrar regions (4 km).

13. The sedimentary layer depth around the Agzibirchala well is 6 km. The correlation between the sedimentary layer depth distribution with the seismic section and the well section was determined.

14. Using a 2D gravity model constructed by the Samur-Baku profile by the matching method, it was determined that the Moho boundary is at a depth of 47-57 km.

15. The comparison of the velocity model at 5 km depth and the sedimentary layer depth gravity model shows that the deepest part of the sedimentary layer has low seismic wave velocities, while the shallow part has high seismic wave velocities.

16. The comparison of the gravity field regional anomalies and the velocity model at 15 km depth shows a decrease in seismic wave velocity in the zone of regional minimums and an increase in the velocity in the transition zone of anomalies.

17. The minimum deformation velocity was observed in the zone of regional minimums, and the deformation velocity was increased in the transition zone of anomalies.

18. The magnitude $M \geq 3$ earthquake distribution (2003-2018) was determined in the gradient zones of gravity anomaly.

9. High strain accumulation was observed between the Khizi-Siyazan (97.5·nanostrain/year) and Madrasa-Khizi ($82.9 \cdot 10^{-9}$/year) stations and low strain accumulation between the Samur-Khizi (6.9 10^{-9}/year) stations according to GPS velocities. It was determined that the low value of the strain accumulation corresponds to the deep part of the sedimentary layer, and the high strain accumulation value corresponds to the shallow depth.

The main content of the dissertation reflected in the following scientific works:

1. Sadigova G.R. Key features geological structure of South-Eastern Caucasus (an example of the Samur-Baku-Astara geodynamic profile). 1^{st} International Scientific Conference of young scientists and specialists. “The role of multidisciplinary approach in solution of actual problems of fundamental and applied sciences (earth, technical and chemical)” Dedicated to the oil workers day of Azerbaijan Republic and 20^{th} anniversary of the contract of the century. Book of Abstracts. 15-16 October. Baku, 2014, p.108-109. (in Azerbaijani)
2. Sadigova G.R. Modern movements of the Earth's crust by the Samur-Baku geodynamic profile // Azerbaijan Geologist. Scientific Bulletin of the Azerbaijan Society of Petroleum Geologists, 2015, No. 19, p. 71-77. (in Azerbaijani)
3. Sadigova G.R. Density characteristics of the South-eastern Caucasus Earth’s crust. Materials of the Republican scientific conference "Actual problems of geology", dedicated to the 92nd anniversary of Azerbaijan national leader Heydar Aliyev. Baku, 2015, p.297-298. (in Azerbaijani)
4. Sadigova G.R., Zamanova A.H. The density model of the Earth’s crust along the Samur-Baku geodynamic profile. VI International Conference of young scientists and students. “Multidisciplinary approach to solving problems of geology and geophysics” Dedicated to the 70^{th} anniversary of Azerbaijan National Academy of Sciences. Abstract Book. October 12-15. Baku, 2015, p.42-43
5. Sadigova G.R. Results of gravimetric observations in the South-eastern Caucasus. The International Student Conference “Perfect education – the key to success in oil production” 20-23 April. Baku, 2016, p.24-25. (in Azerbaijan)
6. Sadigova G.R., Gadirov A.G. The gravity model of the deep structure of the South-Eastern Caucasus by the Samur-Baku profile. XX All-Russian Conference with International Participation "Deep structure, mineralogy, modern geodynamics and seismicity of the East European platform and adjacent regions" September 25-30. Voronezh, 2016, p.328-331. (in Russian)

7. Sadigova G.R. Repeated gravimetric observations in the South-eastern Caucasus. The International Student Conference "Perfect education – the key to success in oil production" 19-22 April. Baku, 2017, p. 32-33. (in Azerbaijani)
8. Sadigova G.R. The gravity model of the Earth's crust deep structure by the Samur-Baku submeridial profile (Gusar-Shabran trough) // Geophysics news in Azerbaijan, 2018, №3, p. 14-19. (in Azerbaijani)
9. Sadigova G.R. The geodynamic pecularities of the South-Eastern Caucasus territory // Modern Problems of Mechanics, Scientific and technical journal, Materials the Second International Symposium on 75th anniversary of the NAS KR, 2018, No. 33 (3), p. 210-221. (in Russian)
10. Gadirov A.G., Sadigova G.R., Agayeva S.T. Deep structure and geodynamic peculiarities of the Earth's crust of the western coast of the Caspian Sea // Geophysical Journal, 2018, v. 40, No. 4, p. 19. (in Russian)
11. Sadigova G.R. Inhomogeneity of the lithosphere, deep structure and modern geodynamic characteristics of the western coast of the Caspian Sea // ANAS Transactions, Earth Sciences, 2018, No.1, p. 70–77. (in Azerbaijani)
12. Sadigova G.R., Sharifova A.T. Seismicity of the South-Eastern Caucasus. I International School-seminar of young scientists and students. "Oil and Geoecology" Dedicated to the 100th anniversary of the Azerbaijan Democratic Republic. Book of Abstracts. 03-05 December. Baku, 2018, p.120
13. Sadigova G.R. The gravity model of the deep structure by the matching method. VII International conference of young scientists and students. "Information technologies in solving modern problems of geology and geophysics" Dedicated to the 80th anniversary of Institute Geology and Geophysics, ANAS. Book of Abstracts. 15-18 October. Baku, 2018, p. 44-46
14. Sadigova G.R. The gravity field power spectrum and depth structure of the research area. Materials of the Republican scientific conference "Actual problems of geology", dedicated to the 95th anniversary of Azerbaijan national leader Heydar Aliyev. Baku,

2018, p.327-329. (in Azerbaijani)
15. Sadigova G.R. Parameters of the South-Eastern Caucasus depth structure by the Spector-Grant method based on gravimetric data // Baku: Azerbaijan Geologist. Scientific Bulletin of the Azerbaijan Society of Petroleum Geologists, - 2019, - №3, - p.32-36. (in Azerbaijani)
16. Sadigova G.R. Geodynamic analysis of the gravity model. AAPG GTW: Exploration and Production in the Black Sea, Caucasus, and Caspian Region. 18-19 September 2019, Batumi, Georgia. p.39
17. Sadigova G.R. Geodynamic model of the depth structure by Samur-Baku profile. Materials of the Republican scientific conference on "Actual problems of geology" dedicated to the 96th anniversary of Azerbaijan national leader Heydar Aliyev. Baku, May 15-16, 2019, pp.101-103. (in Azerbaijani)
18. Sadigova G.R. Gravity anomalies of the Southeastern Caucasus // Geophysical journal, 2020, vol. 42, no. 2, p. 138-151. (in Russian)
19. Sadigova G.R. Determination of the average depth of density boundaries by the Spector-Grant method. Second International Scientific Conference of young scientists and specialists. “Multi-disciplinary approaches in solving modern problems of fundamental and applied sciences” Dedicated to the 75th anniversary of Azerbaijan National Academy of Sciences. Book of Abstracts, 3-6 March, Baku, 2020, p. 159-160. (in Azerbaijani)

Personal contribution of the applicant

The works [1-3, 5, 7-9, 11, 13-19] were independently performed, in works [4, 6, 10, 12] participation in setting of objective, performing of calculations and in interpretation of results.

The defence will be held on 11 October 2021 at 14^{00} at the meeting of the Dissertation council ED 1.01 of Supreme Attestation Commission under the President of the Republic of Azerbaijan operating at the Institute of Geology and Geophysics of Azerbaijan National Academy of Science.

Address: Az1143, Azerbaijan, Baku, H.Javid ave., 119.

Dissertation is accessible at the Institute of Geology and Geophysics of Azerbaijan National Academy of Science Library.

Electronic versions of dissertation and its abstract are available on the official website of the Institute of Geology and Geophysics of Azerbaijan National Academy of Science.

Abstract was sent to the required addresses on 8 September 2021

Signed fo print: 03.06.2021

Paper format: 60x84 1/16

Volume: 37648

Number of hard copies: 20