Journal of Georgian Geophysical Society,
Issue (A), Physics of Solid Earth, v.18a, 2015, pp. 49-58

Reinterpretation of Geophysical Data for the Study of Deep Structure of the Greater Caucasus

S. Ghonghadze, P. Mindeli, J. Kiria, N. Ghlonti, A. Esakia

Preface. The issue of orogenesis mechanism is one of the most difficult tasks to study in Geodynamics and it attracts attention of many specialists of different spheres of the Earth sciences. The region of the Greater Caucasus, considered in this paper, is a part of the greatest of the Earth the Alpine-Himalayan collision belt, alongside of which the highest mountain complexes are observed. In most cases the initial mechanism of orogenesis is collision – convergence of continental plates that leads to mutilation and thickening of the crust.

For the best conception of the deep mechanisms of regional geological processes it is important to use the information on geophysical investigations of the structure of the crust and mantle.

Many national and foreign scientists have been studying the deep structure of the Greater Caucasus. On the basis of existing gravimetric, magnetometric and seismometric data we attempted to process these materials qualitatively by new technologies of the latest computers and make conclusions on the issue.

We made comparative analysis between our data and the ones of the local and regional tomography processed by means of LOTOS software (headed by Kulakov) and other new geophysical methods of microseismic sounding (MSS) of A. V. Gorbatikov's and E. A. Rogozhin's works. In the *Figure 1* the gravimetric profiles, deep seismic sounding (DSS) and microseismic sounding (MSS) are shown.

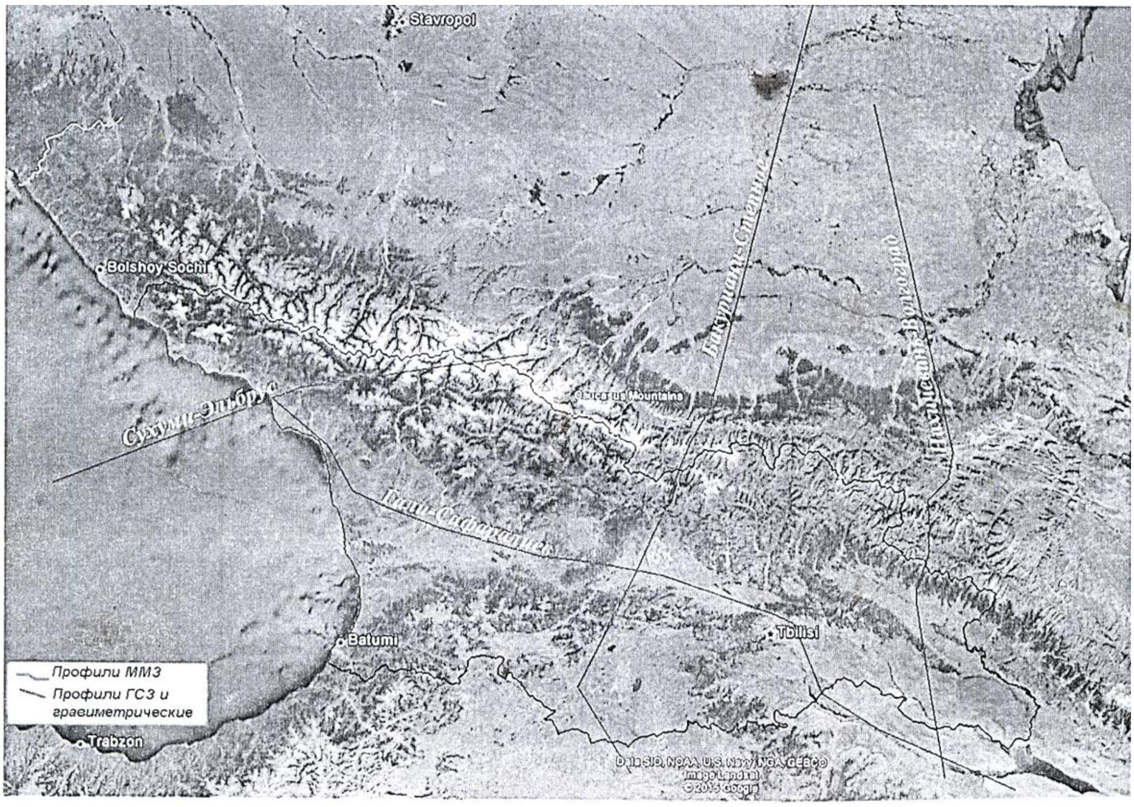

Figure 1. A scheme of the profiles.

Processing of gravimetric and magnetometric data. The single solution to the task taking into account the two deep seismic sounding profiles is involvement of anomalous gravity field, which contains information about the bottom of the Earth crust as the boundary with significant density jump.

Unfortunately, the observed gravity field expresses the influence of nearly all the inhomogeneity of the Earth. Thus, to distinguish the mantle structure it is necessary to maximally free the observed gravity field from external influences. Firstly, it is necessary to define and prevent the effects of the crust, which on the one hand is very important and on the other – may be reliably defined regardless of the gravity field by seismometric data (DSS). The residual anomalies of the gravity force, which with the precision of the crust model may be called the mantle anomaly, are the most relevant for the geodynamic structure and for determining the nature and intensity of processes.

The trend in the theory of interpretation of potential fields, which is connected with attempts to study in some cases the vertical distribution of magnetism and density according to the data of magnetic prospecting and gravity prospecting, was named as interpretation tomography. Interpretation tomography (Greek words *tomos* – to break, part, layer and *grapho* – to write, draw) is a system of study of geological structures either by gravity or by magnetic fields and enables obtaining their layered image. At present, in this trend there are several approaches offered by a number of researchers (though not all of them obviously call the object of their research as tomography in their researches) and they may be divided into two groups: approximation (Y.Y. Vashchilov, A.I.Kobrunov, A. P. Petrovsky, V.I.Segalovich, A.V. Ovcharenko, D.Oldenburg, Y.Lee, etc.) and filtration (P.S.Martishko, V.M.Novoselitsky, B.Y.Podgorny, I.I.Priezzhev, I.L.Prutkin, A.F.Shestakov, etc.).

It is obvious that precisely solving the task of the study of the vertical distribution of magnetism and density according to the data of magnetic prospecting and gravity prospecting is practically impossible. However, such works should be carried out hoping that the local situation in a certain region is more favourable than the common one. The filtration technology is implemented in the software *Oasis Montaj* created by Canadian company *GeoSoft* and is based on applying procedures of optimal filtration and approximation continuity of fields. For mathematical arrangement MAGMAP module applies filters in Fourier sphere or the sphere of wave numbers. Mathematically, the Fourier transformation *f(x,y)* is determined as follows:

$$\mathbf{f(\mu,\nu)=\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(x,y)\cdot e^{-i(\mu x+\nu y)}dxdy}$$

the inverse relation

$$\mathbf{f(\mu,\nu)=\frac{1}{4\pi^2}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(\mu,\nu)\cdot e^{-i(\mu x+\nu y)}d\mu d\nu}$$

where μ,ν are wave numbers, accordingly in the directions x and y measured in radians per meter, on condition that x and y are expressed in meters. They are connected with spatial frequencies f_x and f_y expressed in period per meter.

The analytical continuation of the field in the upper semi-sphere is considered as a *pure filter* as it does not create any side effects that may require application of other filters or procedures for correction. Therefore, this filter is often used for elimination or minimization in regular grids of fields of non-deep sources or noises.

The Butterworth filter is quite suitable for the application of direct high or low quality filters for data, i.e. it enables easily regulating the smoothening degree of the filter and at the same time leaves the central wave number unchanged.

It is possible to obtain more general image of depths of certain points and sources of gravity and magnetic anomalies by analyzing the energy spectrum of the fields. *Figure 2* shows a scheme of the logarithm of the radial averaged amplitude spectrum of the anomalous gravity and magnetic fields depending on the spatial frequency received by means of the special option of the set of softwares *Oasis Montaj*, and also estimation by the same system of the source depths in different diapasons of spatial frequencies. The analysis of the gravity field scheme shows that the narrow frequency line in the low quality part of the spectrum is connected with the sources located very deeply, the special points of which correspond to the depths above 16 km. the most of the mentioned depths are 18 km. Thus, when considering the spectrum included in the anomalous gravity field the information is referred to the upper layer of the Earth crust with approximately 16 km thickness. In the scheme of the anomalous magnetic field it corresponds to the 18 km depth.

Let us note that the certain “vulnerability” based on the transformations of the geophysical field division methods was obvious from the moment of its appearance. The transformation fields enable only improving the obviousness of the influence of separate perturbing factors.

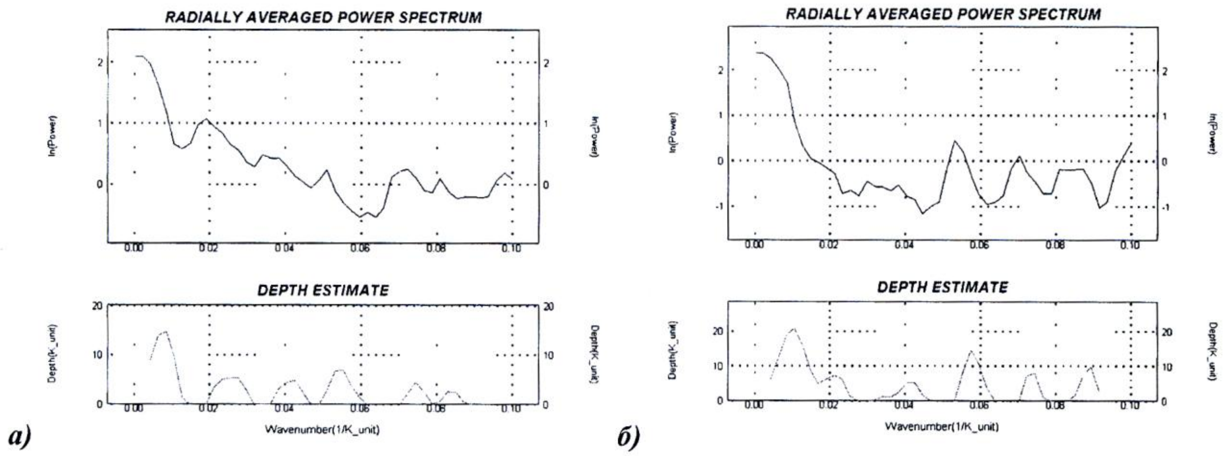

Figure 2. a) Estimation of source depths in different diapasons of spatial frequencies by the scheme of the logarithm of the radially averaged amplitude spectrum of the gravity field.
b) Estimation of source depths in different diapasons of spatial frequencies by the scheme of the logarithm of the radially averaged amplitude spectrum of the magnetic field.

The residual anomalies of the gravity field shown in the figure were obtained by recounting the anomalous field in the Bugge reduction with the density of the interlayer 2.67 g/sm^3 and correction of the relief up to 200 km at different heights up to 100 km. The error in the measurement for the image of 1:50 000 scale was 0.5 mGl and at the 1:200 000 scale – 1 mGl (*Figure 3*). Different height transformed fields were removed from the anomalous gravity field created by residual cover by the anomalies caused by the variations of depths up to boundary M and the regional fields connected with the influence of the most significant masses. The *Oasis montaj* software was used as an interpretation instrument taking into account the above recounted filters.

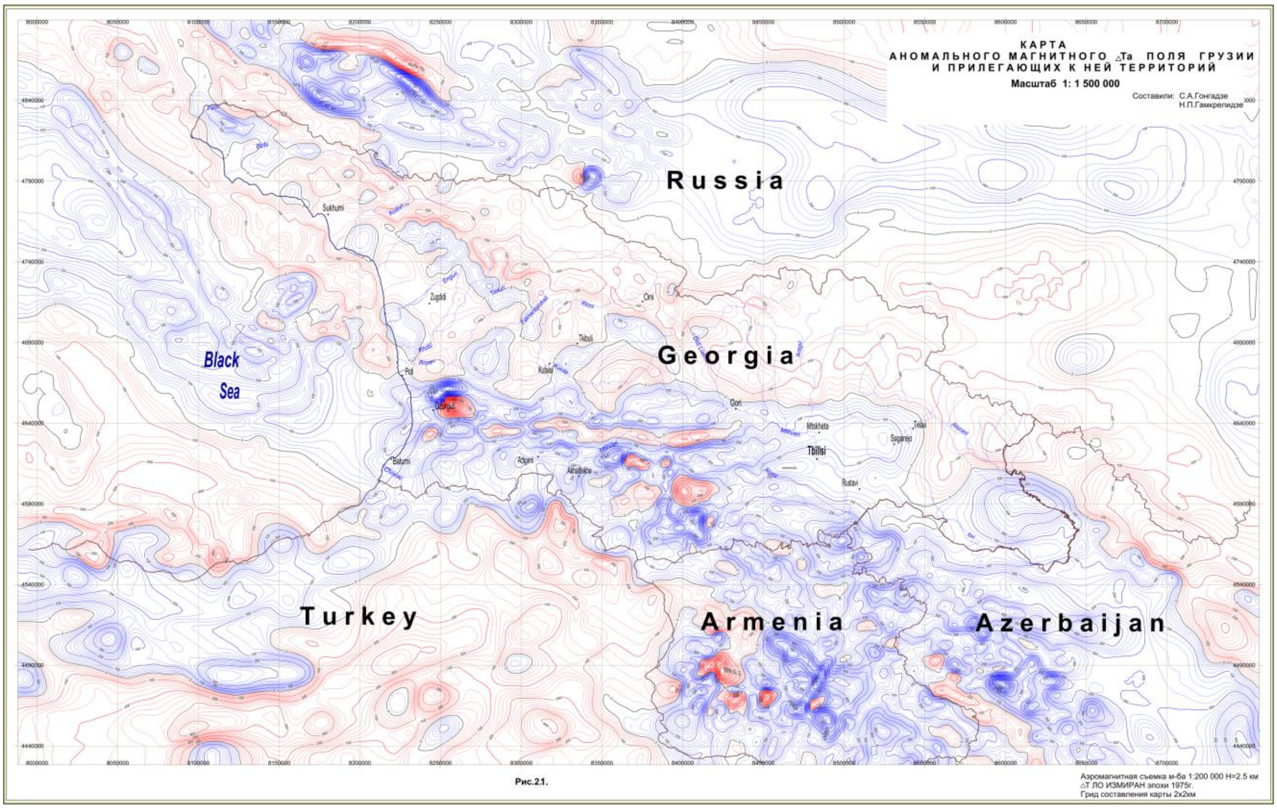

Figure 3. A Map of the anomalous gravity field of Georgia and its adjacent territories.

Figure 4 shows the horizontal sections at 15 and 45 km depths of the gravity and magnetic field for the transformed and residual field, on which the variation of the fields together with depth connected with low and high density inhomogeneities are shown.

Comparative analysis of the gravimetric and seismometric data of the local seismography and microseismic sounding method. For comparison the data of the local seismography are taken. The seismic data were processed by means of Local Tomography Software, LOTOS-09 (Novosibirsk). The algorithm of the tomography LOTOS-09 is used for the simultaneous application of P and S speeds of the structures and source coordinates. For the tomography a referent model of the Earth crust of the study area was used:

Depth	Vp	Vs	
0.000	4.53	2.78	speed in the residual layer
6.000	5.70	3.35	speed in the granite layer
21.000	6.43	3.70	speed in the basalt layer
44.000	7.98	4.70	speed on the Moho surface

The data of the P and S wave travels during the period of 1964-2007 are taken from the Catalague of the International Seismic Centre (ISC).

On the basis of the data shown in *Figure 4* showing also the results of the inversion of the real data of P and S anomalies for the 15 and 45 km depths the coincidence of the low anomalies with the fold-fault mountain ranges of the Greater Caucasus and the link between high anomalies and the intermountain depression of the Transcaucasus are obviously seen. It is especially well observed in the residual gravity field and inversion of the P-anomaly. In the sections for the 45 km depth area of the lowered values of the gravity field and the low anomalies of P-waves the dominating situation of the area is taken.

In the three profiles of the DSS of Bakuriani-Stepnoye, Nakhichevan-Volgograd and the one, as we called it, Sokhumi-Elbrus shown in *Figure 4* the vertical sections of the residual gravity and magnetic fields were constructed.

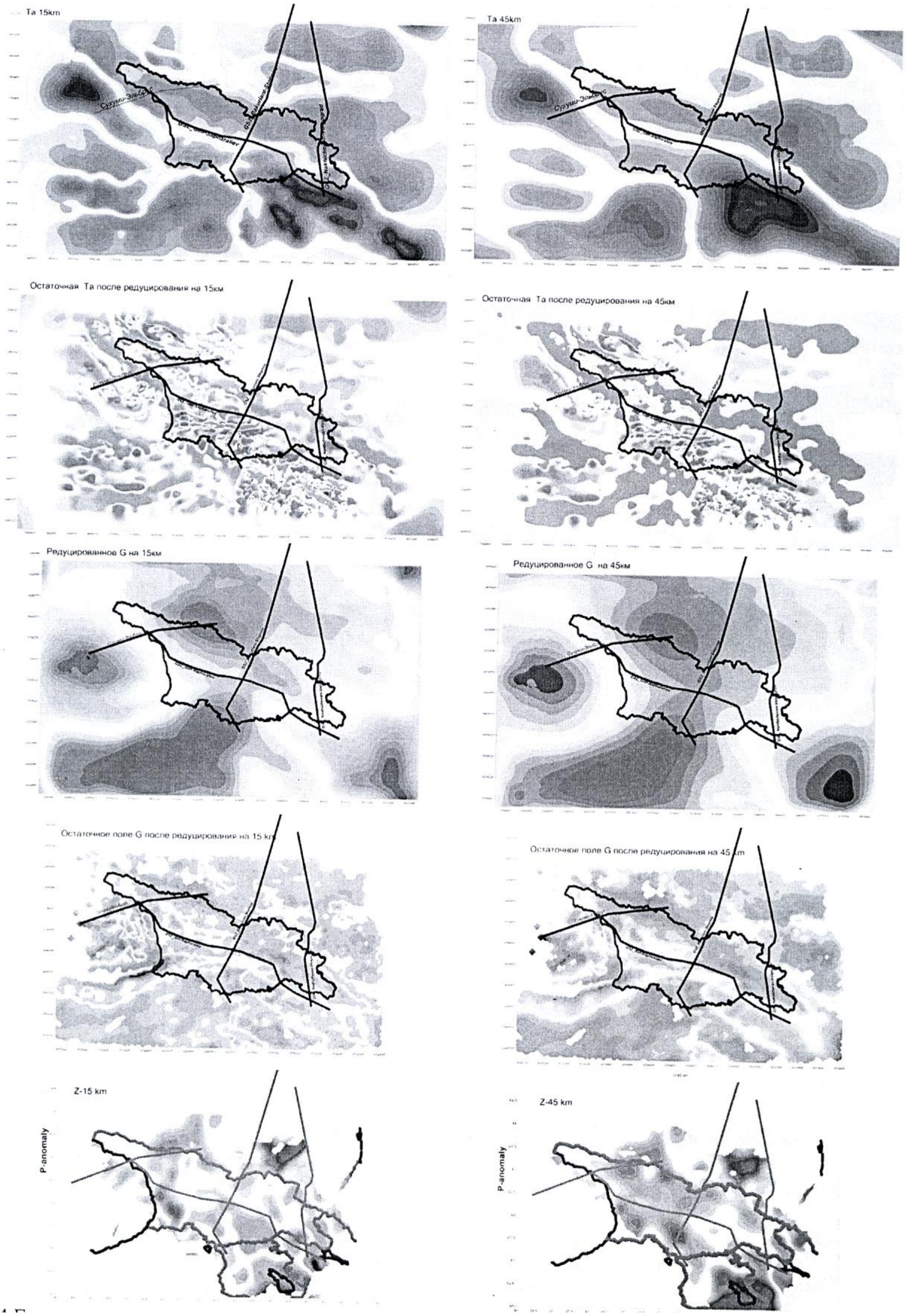

Figure 4. Horizontal section of the reduced and residual magnetic, gravity fields and the local seismotomography in 15 and 45 km.

In the Bakuriani-Stepnoye profile, in the residual gravimetric field the region of the Greater Caucasus is distinguished with alternation of the areas of high and low parameters, namely, vertical inhomogeneities. Only on the DSS tomography it is possible to mark horizontal conditional boundary for distinguishing of so called granite, basalt (the Conrad surface) layers and the Moho surface. *Figure 5* shows the interpretation of the Bakuriani-Stepnoye profile tomography, on which the three above mentioned horizons are distinguished. Several faults are illustrated by impairing the integrity of the speed inhomogeneity.

The same figure shows the model of the profile constructed by G.A. Pavlenkova (2012) as a new variant by means of the Zeld ray modeling software. This software, unlike the one we use, solves direct tasks.

There is a correlative connection between the two tomographies. Although, some differences in speed take place, both images coincide with each other (*Figure 5*).

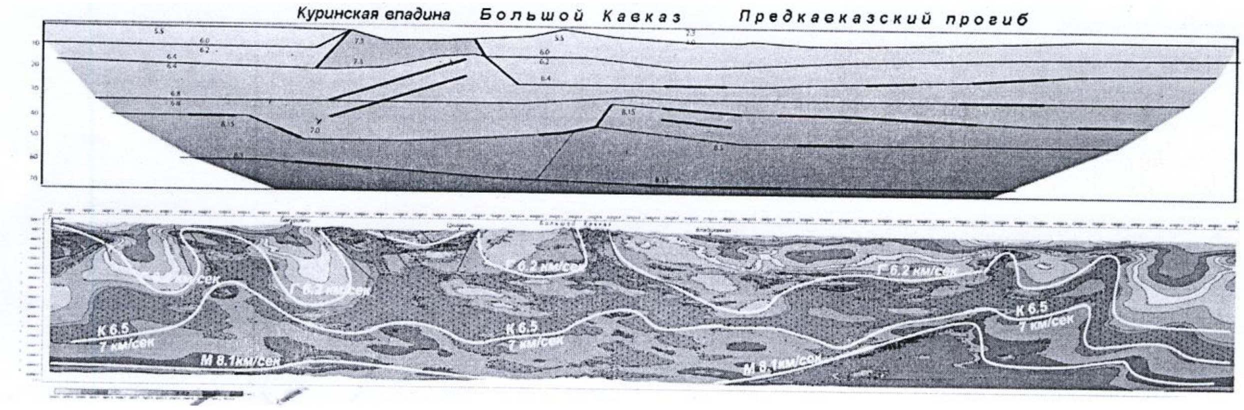

Figure 5. Interpretation of the Bakuriani-Stepnoye DSS profile seismotomography and the model of G.A. Pavlenkova with the new reinterpretation.

In the Nakhichevan-Volgograd profile (*Figure 6*) the Greater Caucasus is distinguished in the vertical section of the P-inversion in two areas, from the South by high values of the P-anomaly and to the North – by low ones. A qualified analysis shows the G alternation of the vertical low and high density inhomogeneities in the residual field as in the DSS profile. It is noteworth that a speed section for the P-inversion is constructed only for the 65 km depth as the reference model was given for up to 65 km and the residual fields - up to 100 km. The depth of the DSS method for the Bakuriani-Stepnoye profile is 70 km and for the Nakhichevan-Volgograd profile – 75 km. The interpretation of the CMRW (Correlation Method of Refracted Waves) tomography of the Nakhichevan-Volgograd profile enables distinguishing three conditional probable layers of granite, basalt and the Moho surface. When comparing this profile with the Pavlenkova model, similarity in speed boundaries is observed, though there are some differences.

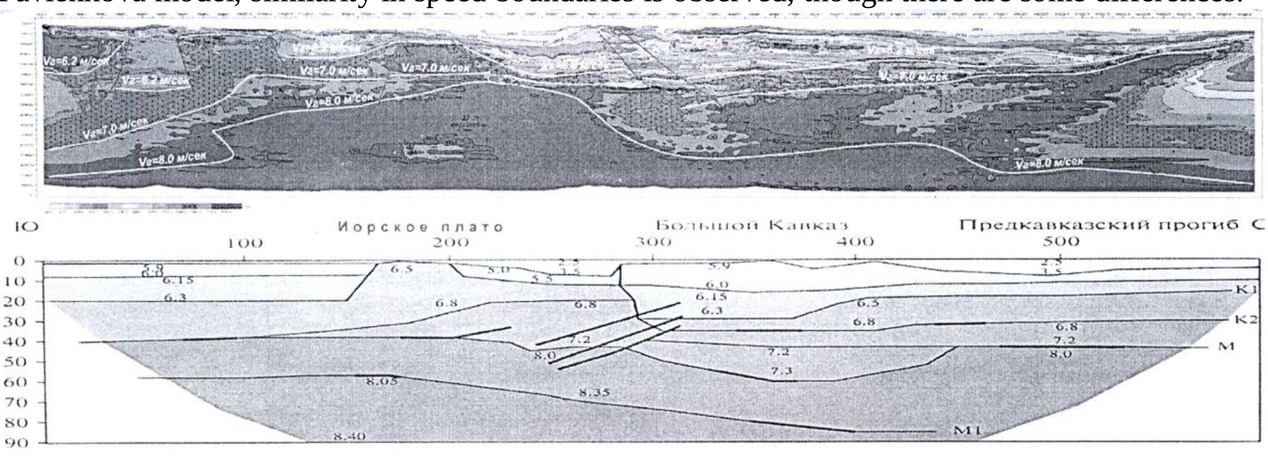

Figure 6. Interpretation of the Nakhichevan-Volgograd DSS profile seismotomography and the model of G.A. Pavlenkova with the new reinterpretation.

For comparison of the cross profiles of DSS Nakhichevan-Volgograd and Bakuriani-Stepnoye the interpretation of the longitudinal profile of Gali-Safaraliev, also called the profile from-sea-to-sea, was conducted. However, our data belong only to the 512 km long profile (*Figure 7*).

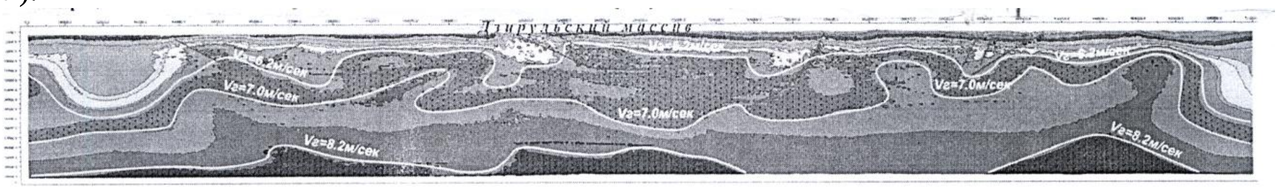

Figure 7. The seismotomography of the Gali-Safaraliev DSS profile

Here three boundaries belonging to the “granite” layer V=6.2 km/s, the “basalt” layer V=7.0 km/s and the Moho layer V=8.2 km/s are also distinguished.

Figure 8 shows the spatial layout of the DSS profile for determining the correlation of the distinguished conditional boundaries. When the cross profiles are crossed by the longitudinal profiles the horizons become interconnected.

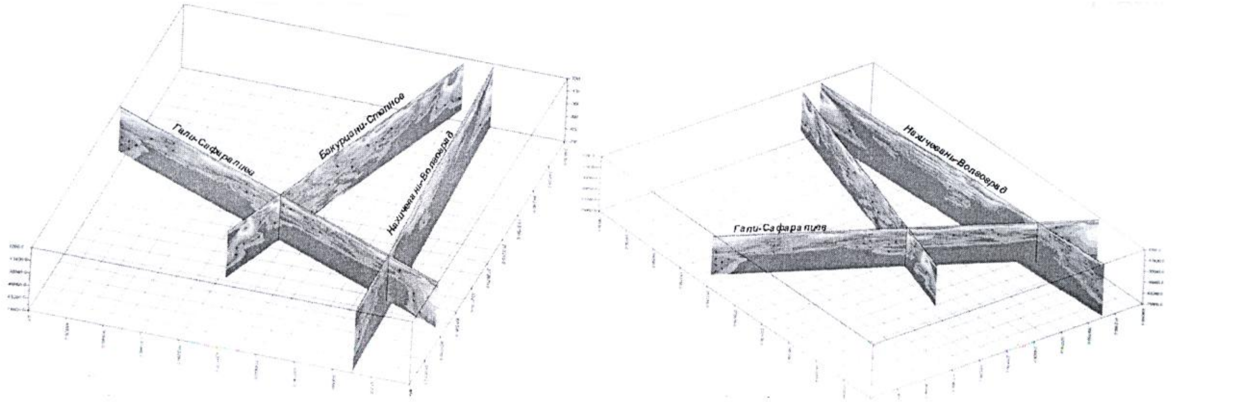

Figure 8.

The works were carried out by Balavadze B.K, Shengelaia G.Sh., Mindeli P.Sh, taking into account the data of the gravity filed, geologic-geophysical information and the interpretation results of the Bakuriani-Stepnoye and Nakhichevan-Volgograd DSS profiles. The schemes of the surface variation of the crystal foundation, the Conrad and Moho surfaces were constructed (*Figure 9*).

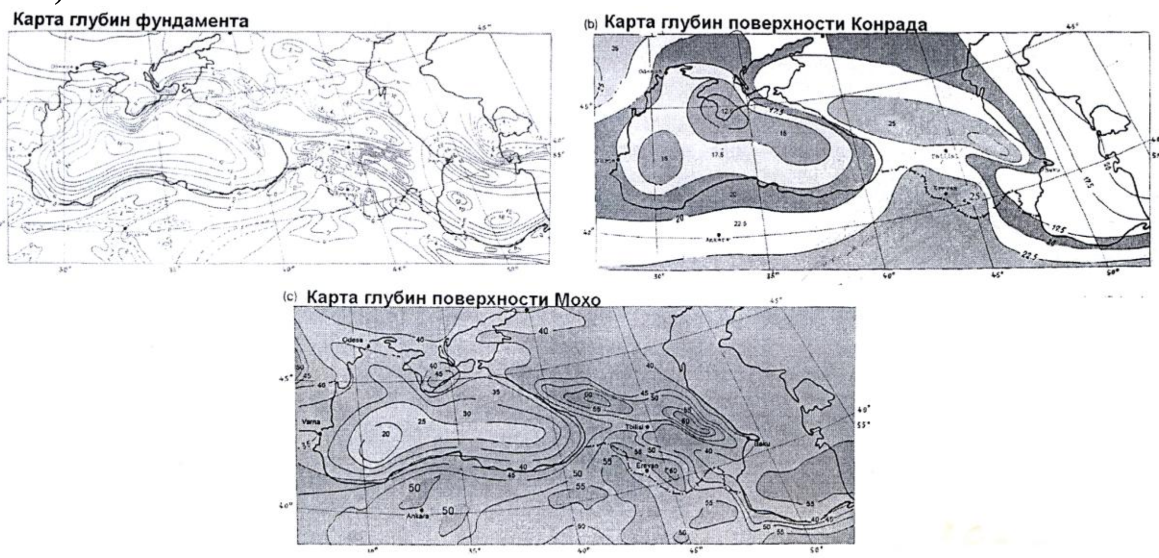

Figure 9.

It is obvious that the Greater Caucasus is mostly a unique deep geological structure. Tectonically it is characterized with block-folded structure. The formation of the Greater Caucasus is connected with the development of many geological processes on its adjacent territories.

The analyses of the reinterpretation of the DSS profile tomographies were conducted by Balavadze B.K, Shengelaia G.Sh., Mindeli P.Sh. In the structural maps of the granite, basalt and Moho surfaces some correlation dependence is observed: rising of the granite and Conrad surfaces in the zone of the Greater Caucasus and bending of the Moho surface.

It is noteworthy that in 1980-ies in the works by the magnetotelluric sounding method G.E. Gugunava suggested a generalizing model of the deep structure of the region. *Figure 9* shows the scheme of the locations of the points for observation of the electromagnetic complex.

As a result of the investigation of the Earth crust, or more correctly, at its boundary with the mantle so called conductive interhorizon was marked. It also revealed the correlation between the depth of the bedding of the conductive interhorizon and 600ºC isotherm, which on the territory of Georgia varies in the depths from 35 to 55-60 km. In the 300-350 km and 800-900 km depths the conductive layers of the upper mantle was revealed. The comparison of these results with our investigations of the gravimetric field made it obvious that under the Greater Caucasus in the Bakuriani-Stepnoye and Nakhichevan-Volgograd profiles the differential section from the 50 km depth completely changes with negative values of the field. In the Sukhumi-Elbrus profile the gravimetric field is completely negative and it decreases together with the depth that might be connected with the zone of volcanic activity. In the vertical sections of the regional seismotomography under the Greater Caucasus a low speed zone up to 400 km is distinguished. There is a correlative link among magnetotelluric, gravimetric and seismologic investigations.

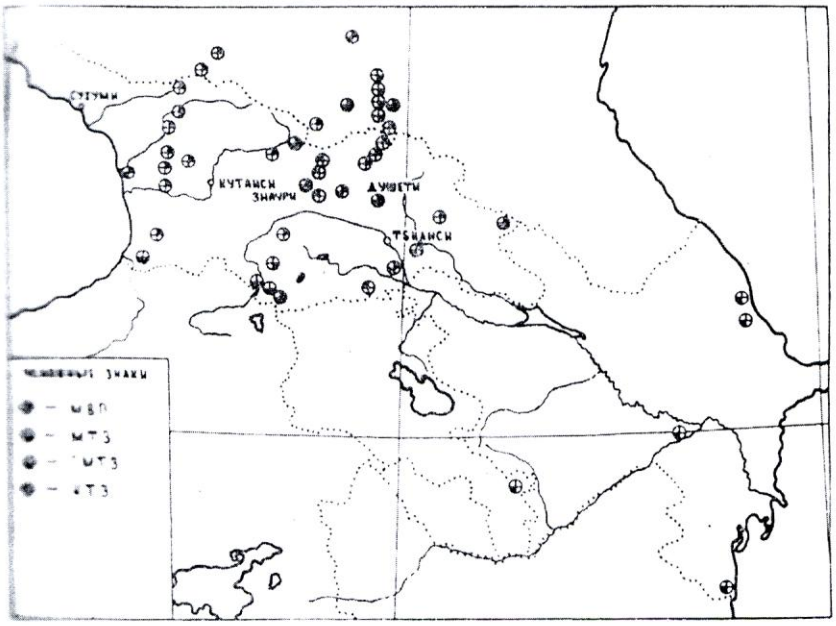

Figure 10. Scheme of the locations of the points for observation of the electromagnetic complexes (G.E. Gugunava, 1985)

Main conclusions. On the basis of the data shown in the *Figures 3, 4, 5, 6, 7* and *8* describing the results of gravimetric, seismometric DSS, MSS and the results of the inversion of the P- and S-anomalies up to the 100 km depth, despite the complex situation, it is possible to make conclusions about the interrelation between these anomalies and the geological structure of the Greater Caucasus:

The Greater Caucasus by all considered methods is distinguished with low speed and density parameters. In the seismotomography sections of the DSS and MSS profiles under the Greater Caucasus the Moho boundary is sinking, a zone of thrust represented with fault series declining to the north-east (it is obviously seen in the DSS profiles due to the speed inhomogeneity variations) is distinguished. The conditional boundaries of the surfaces of granite (the thickness of the Bakuriani-Stepnoye profile granite is 40 km and over and the one of the Nakhichevan-Volgograd profile is up to 50 km), basalt and Moho (the cover bends up to 60 km) in the tomography images of the DSS are not continuous. All the Earth crust is disintegrated and is characterized with a block structure or zonality.

In the vertical sections of the gravimetric data and the MSS method the correlation between the speed and density parameters corresponding to the zonal division of the Greater Caucasus is seen.

A clear spatial link between the lowest values of the P and S speeds and the gravimetric anomalies in the Sokhumi-Elbrus profile is observed. It is obvious that this is connected with the areas of the Neogene-Quaternary volcanic activity.

Thus, according to the geophysical methods with the depth up to 100 km we may obtain some detailed image of the Greater Caucasus. In the DSS tomography sections a subduction process represented with the fault series of the main thrust declining to the north-eat of the Greater Caucasus is observed.

References

1. Adamaia S., Alania V., Chabukiani A., Kutelia Z., Sadradze N. Greater Caucasus (Cavcasioni): a long-lived North-Tethian back-arc basin. Turk J Earth Sci 2011; 20:611-28.
2. Balavadze B.K., Shengelaia G.Sh., Mindeli P.Sh. The gravity model of the Earth crust of the Caucasus. Monograph. The gravity model in the upper mantle of the Earth. Kiev, “Naukov Dumko”, 1979, p.p. 149-160 (in Russian).
3. Bloch Y.I. Interpretation of gravity and magnetic anomalies, 2009, p.p. 126-170 (in Russian).
4. Gamkrelidze N.P., Ghonghadze S.A., Mindeli P.Sh., Kiria J.K., Yavolovskaya O.V. Physics of the Earth crust of Georgia. Monograph. Institute of Geophysics, Tbilisi, 2012, (in Russian).
5. Gugunava G.E., Kiria J.K, and Bochorishvili T.B. Thermogeodynamic manifestations in the Caucasus and their genesis, eEarth Discuss., 4, 77-89, 2009.
6. Gorbatikov A.B., Rogozhin E.A., Stepanova M.Yy., Kharazova Yu., V., Andreeva N.V., Perederin F.V., Zaalishvili V.B., Melkov D.A., Dzeranov B.V., Dzeboyev <.A., Gabarayev A.F. Pecularities of the deep structure and modern tectonics of the Greater Caucasus in the Ossetian sector according to the complex of geophysical data, 2014. (in Russian).
7. Dolgal A.S., Sharkhimulin A.F. Gravitation tomography – practice – preceding theory? Geoinformatika, 2009. # 3, p.p. 59-64. (in Russian).
8. Strakhov V.N. Interpretational processes in Gravimetry and Magnetometry – realization of a unique approximation approach. I. The basic ideas and construction principles. Earth Physics, 2001, # 10, p.p. 3-18. (in Russian).
9. Koulakova I.Yu. A look at the processes under volcanoes through a prism of seismic tomography, A bulletin of the Russian Academy, 2013, vol. 83, # 8, p.p. 698-710. (in Russian).
10. Koulakov I., Zabelina I., Amanatashvili I., Meskhia V. Nature of orogenesis and volcanism in the Caucasus region based on results of regional tomography. Solid Earth. 2012. V. 3. P. 327-337.
11. Mindeli P.Sh. The gravity model of the lithosphere of the Caucasus and Eastern Mediterranean. Publishing house GCI, Tbilisi, 1999, p.133. (in Russian).
12. Mellors R., Jackson J., Myers Sc, Gok R, Priestly K., Yetirmishli G, et al. Deep earthquakes beneath the Northern Caucasus: evidence of active or recent subduction in western Asia. Bull Seismol Soc Am 2012; 102:862-6.

13. Mumladze Team Adam M. Forte, Eric S. Cowgill, Charles C. Trexler A. Niemi, M. Burak Yikilmaz, Louise H. Kellogg. Subducted, detached and torn slabs beneath the Greater Caucasus. GeoResJ 5 (2015) 36-46.
14. Pavlenkova G.A. The structure of the earth crust of the Caucasus according to the Stepnoye-Bakuriani and Volgograd-Nakhichevan Deep Seismic Sounding profiles (The results of reinterpretation of initial data). Earth Physics, 2012, # 5, p.p. 16-25. (in Russian).
15. Chelidze, T.; Gugunava, G.; Gamkrelidze, N.; Mindeli, P.; Kiria, J.; Ghongadze, S.; Yavolovskaya, O. The Deep Structure and 3D Thermo-geodynamics of the Caucasus by Geophysical Data. EGU General Assembly 2012, held 22-27 April, 2012 in Vienna, Austria. p.8242.

გეოფიზიკური ველების ახალი ინტერპრეტაცია დიდი კავკასიონის სიღრმული აგებულებისათვის

ს. ღონღაძე, პ. მინდელი, ჯ. ქირია, ნ. ღლონტი, ა. ესაკია

რეზიუმე

ჩატარებულია შედარებითი ანალიზი ჩვენს მიერ მიღებულ მონაცემებსა და რეგიონის ტომოგრაფიის ლოკალურ მონაცემებს შორის რომელიც მიღებულია პროგრამა ლოტოსის დამუშავებით.

მიღებულია სქემა კრისტალური ფუნდამენტის, კონრადის და მოხოროვიჩის ზედაპირების ცვლილებისა. ნაჩვენებია აგრეთვე, რომ დიდი კავკასიონი წარმოადგენს ერთიან გეოლოგიურ წარმონაქმს.