# Deep low velocity layers inferred by the MSS – indicators of the asthenosphere structure in Bulgaria.

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**Key words**: microseismic sounding method, asthenosphere structure in Bulgaria

**Abstract**
The new data about the seismic low velocity layers under the earth's crust of Bulgaria, obtained by the method of MSS are interpreted as the representative bodies of asthenosphere. The structure and locations of the asthenosphere are presented as 3D diagrams for better visualization and interpretation. The blocks of the asthenosphere are conditionally presented with their average depth and thickness. Due to the limitation of the MSS the lower boundary is rather uncertain, but the tendencies and trends are clear and useful. The future performance and search of relationships with other geophysical fields are intended.

# Дълбочинни нискоскоростни слоеве получени по ММС – индикатори за астеносферната структура в България.

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**Ключови думи**: метод на микросеизмично сондиране, структура на астеносферата в България

**Резюме**
Нови данни получени по метода на микросеизмичното сондиране за нискоскоростнинеоднородности под територията на България са интерпретирани като прояви на астеносферата. Структората и разположението на нискоскоростните тела са предстажени в 3D проекции за по-добра визуализация и интерпретация. Поради някой ограничения в дълбочинността на Метода, долните граници на „астеносферата" са неясни и несигурни, но тенденциите които се наблюдават дават основание за тренд анализ, който може да е много полезен. Бъдещото приложение и търсенето на взаимни връзки с други геофизияни полета предстои да бъде направено.

## Introduction

During the last years the research interest to the vertical and lateral inhomogeneities in the deeper earth's interior increased dramatically. Most of the geodynamic features are related to the under crust located low seismic velocity layers called with the general word "asthenosphere". As an origin of deep fluids, movable substrate and fast changing surface this medium varied in the depths of 60-100 km to the 500-600 km, mostly developed in the interval of 100 to 300 km. The main reason this depth interval to be constructed of partially melted strata is the P-T relationship. The possible high temperature for some deep formed rocks higher then the melting point for them even at this higher pressure is the main reason to the existence of the asthenosphere. High temperatures, high conductivity, low velocity of the S-waves and the large variations of the upper boundary of this layer (under continents and oceans) are the main geophysical characteristics of the asthenosphere.
Using the methods of so called "passive seismics" - such method of the microseismic noise sounding (called MSS) apply the microseismic noise as a probing signal. This method was performed and well explored to study deep structure of some seismogenic zones. The high effectiveness of the method (related mainly with the exploitation of the existing digital broadband seismic stations) and relatively good resolution in vertical and horizontal domain permit to use the method for the research and investigation of the low velocity layers and bodies at the depths of Bulgaria. The low velocity layers and bodies are interpreting as representative for the asthenosphere. The lower boundary of these inhomogeneities is not always possible for stable outlining due to the relatively low efficiency of the method at higher depths of 300 km, but the obtained results are enough correct to give the representative picture of the tendencies and trends of asthenosphere behavior.

## Methodology

The method of Micro Seismic Sounding (MSS) is based on the inversion of the amplitude-frequency domain of the microseismic noise to depths. [А.Горбатиков. 2006]. The main assumption is that the vertical component of the low frequency part of the noise amplitudes is determined by the fundamental modes of the Raleigh waves representing the main part of the seismic noise. The method is based on the suggestion that the inhomogeneities in the earth crust and upper mantle change the spectrum of the low frequency seismic noise as follows:
The spectral amplitudes of a fixed frequency $f$ decrease over high seismic waves velocity zones and vice versa – they increased over low seismic velocity zones. Thus the low velocity layers and bodies can be determined in the 3D space domain.
The technology of measuring and processing provide [8]:
1. Consistent measurements of statistical sustainable microseismic spectra at all points of the network or profile. Reaching statistical sustainability micro seismic signal accumulated over the experimentally determined time-interval of stationary signal is equal to 1-2 hours.
2. Building on the map or profile of distribution of the amplitudes of each frequency in the spectrum.
3. Calculation of the received maps or accounts to the appropriate depth, proceeding from the relationship:

$$H(f) = k_G \lambda_R(f) = k_G \frac{c_R(f)}{f} \qquad (1)$$

where *H (f)* - the depth of the layer of which is being built image, $\lambda_R$- wavelength of the fundamental Raleigh mode, *f* - frequency in the spectrum of the micro-seismic signal for which calculations is made, cR - phase velocity of the fundamental mode wave of Raleigh respective frequency *f*, $k_G$ - coefficient of the depth attached to the attenuation experimentaly estimated in the range 0.4-0.5.
The processing and construction of the image consists of the following procedure. For each frequency f in the obtained spectrum a spatial curve (or map) is plotted. The distribution of the variation of the intensity of the micro-seismic signal is indicative for the inhomogenities modified the amplitude-frequency spectrum. The obtained curves (in 2D) and/or map (in 3D) are attached to depth. Based on the obtained profile curves plotted to the horizontal axis of the coordinates and the vertical axis – the depths corresponding to the profile or map. [А.Горбатиков. 2008.]
The horizontal resolution of the method is about 4% of the wave length and about 8% determination of the depth – respective /vertical resolution of the investigated anomalous inhomogeneous body. The vertical resolution thus can reach 15-16%. All established resolution are due to the previous experimental works and can change according the conditions of the strata. [E. Oynakov. 2016.], [Е. Ойнаков, Б.Рангелов 2015], etc.
The frequency $f$ is related to the depth of the inhomogeneous body *H* and the velocity of the fundamental mode of the Raleigh wave $V_r$ *(f)* by the relationship [А.Горбатиков. 2008].

$$H = 0.5\, V_r(f)/f. \qquad (2)$$

As a result of the application of this method the velocity contrast of the seismic waves is the main parameter obtained in 2D and 3D views of the deep Earth's interior structures. For easier visualization the attenuation in the amplitude-frequency domain is presented in dB.

## Equipment location

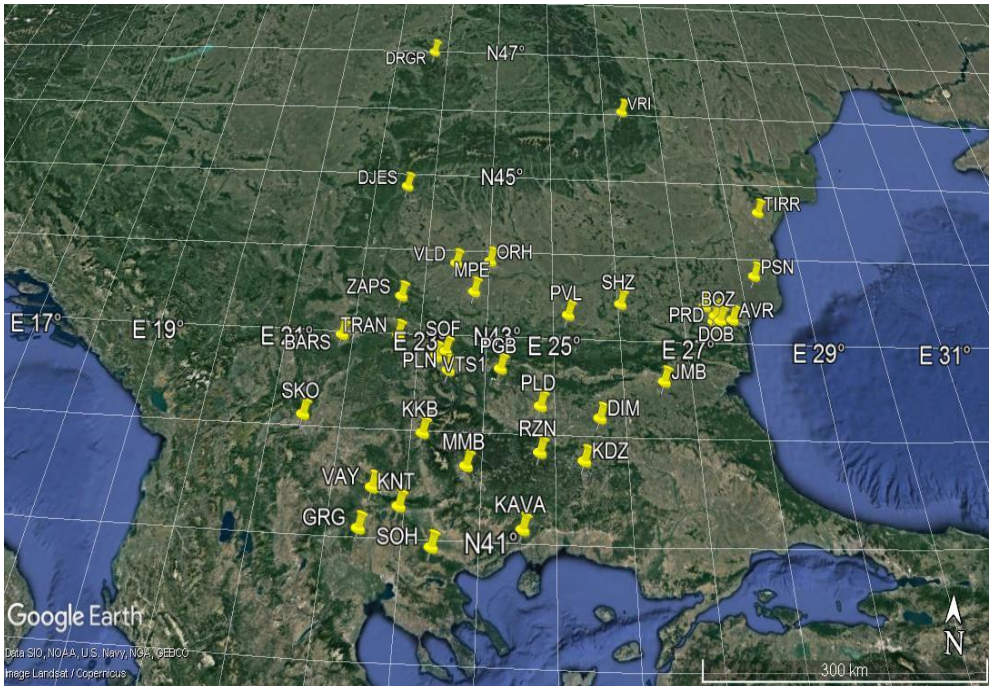



Fig.1 Map of the seismic stations locations used in this study

An important factor providing high resolution of the MMS is the density of the broadband seismic stations registering the microseismic noise. The higher density provides best resolution both – at shallow and deeper horizons. The presented map compromises the density with the availability –Fig.1. The data provided by each broadband station is reliable for each specific location of this station (Tab.1). [Емил Ойнаков, Бойко Рангелов, 2016] The intermediate information is inferred by interpolation and extrapolation of the results obtained after the attenuation is calculated. The average distance of less then 50 km is considered satisfactory. [Емил Ойнаков, Бойко Рангелов, 2016] The time interval for the records is selected to be 1 hour during the night (low artificial noise). The basic station is PSN (Preselenci).

Table 1 Seismic stations and their apparatus -collateral, used in the study.

| Station code | Digitizer | Longitude | Latitude | Elevation (m) | Seismic sensors |
|---|---|---|---|---|---|
| KDZ | DAS 9887 | 25,3396 | 41,6303 | 343 | GURALP CMG 3ESPC/120 |
| PLD | DAS 9905 | 24,7475 | 42,1469 | 195 | GURALP CMG 40T |
| DIM | DAS 9888 | 25,5778 | 42,0457 | 138 | S13 |
| PGB | DAS 9908 | 24,1735 | 42,5137 | 569 | GURALP CMG 40T |
| AVR | DAS 9AF3 | 27,6685 | 43,1178 | 513 | GEOPHON |
| ROIA | DAS 9913 | 27,3778 | 43,0934 | 353 | GEOPHON |
| BOZ | DAS 98B6 | 27,4786 | 43,1044 | 31 | GEOPHON |
| DOB | DAS 9C9D | 24,4628 | 43,179 | 230 | GEOPHON |
| RZN | DAS 9C57 | 24,7388 | 41,6942 | 1730 | GURALP CMG 40T |
| MMB | DAS A940 | 23,7496 | 41,547 | 618 | STS-2 |
| KKB | DAS A914 | 23,1287 | 41,8417 | 451 | GURALP CMG 3ESPC/60 |
| JMB | DAS A867 | 26,5297 | 42,4912 | 200 | GURALP CMG 40T |
| PSN | DAS A646 | 28,1359 | 43,6376 | 182 | KS 2000/60s |
| NEF | DAS 986E | 27,2753 | 43,2644 | 343 | S13 |

| | | | | | |
|---|---|---|---|---|---|
| PVL | DAS 990C | 25,1732 | 43,1227 | 210 | GURALP CMG 3ESPC/120 |
| SZH | DAS 990C | 25,9762 | 43,2653 | 329 | GURALP CMG 3ESPC/60 |
| VTS1 | DAS 9877 | 23,2342 | 42,6143 | 1387 | GURALP CMG 3ESPC/120 |
| MPEP | DAS A910 | 23,7401 | 43,356 | 342 | S13 |
| ORH | DAS 9D18 | 23,9664 | 43,7263 | 231 | S13 |
| VLD | DAS 9B2E | 23,4356 | 43,6899 | 93 | S13 |
| SOF | DAS 9FA2 | 23,2699 | 42,676 | 580 | S13 |
| PLN | DAS 98C5 | 23,4254 | 43,4762 | 1236 | GURALP CMG 3ESPC/120 |
| PRD | DAS 990A | 27,4099 | 43,1602 | 128 | GURALP CMG 40T |
| TRAN | DAS 98C5 | 22,6512 | 42,8345 | 421 | GURALP CMG 3ESPC/120 |
| TIRR | E D D | 28,41,28 | 44,4511 | 77 | STS2 + Episensor |
| VRI | Q330 | 26,7277 | 45,8657 | 475 | STS2 + EpiSensor |
| DRGR | Q330 | 22,7111 | 46,7917 | 923 | KS2000 + EpiSensor |
| KAVA | TAURUS | 24,5137 | 40,9999 | 95 | TRILLIUM 120P |
| GRG | Trident-B | 22,4014 | 40,9567 | 600 | CMG-3ESP/100 |
| KNT | HRD24 | 22,8981 | 41,1619 | 380 | CMG-3ESP/100 |
| SOH | TAURUS | 23,3539 | 40,8217 | 728 | TRILLIUM 120P |
| SKO | Q330 | 21,4396 | 41,9721 | 346 | SSR-1 |
| VAY | Q330 | 22,5201 | 41,3211 | 168 | SSR-1 |
| BARS | Q330 | 21,8155 | 42,8165 | 392 | STS-2 |
| ZAPS | WAVE32 | 22,6336 | 43,2737 | 638 | SS1 |
| DJES | K2 | 22,5199 | 44,6659 | 116 | PBB-200S |

## General assumptions

The asthenosphere is the most dynamic part of the upper mantle providing forces and material of the geodynamic machine of the Earth. The seismologists obtain data about a low velocity layer investigation the travel times of the seismic waves (in particular the S-waves). Later the geologists and geophysicists obtain the reason for such behavior and since these times the interest to the depth and time development of the asthenosphere has an increasing interest. The main reason of the existence of the asthenosphere is the P-T relationships for some deep originated rocks which have melting point above pressure crystallization – Fig.2

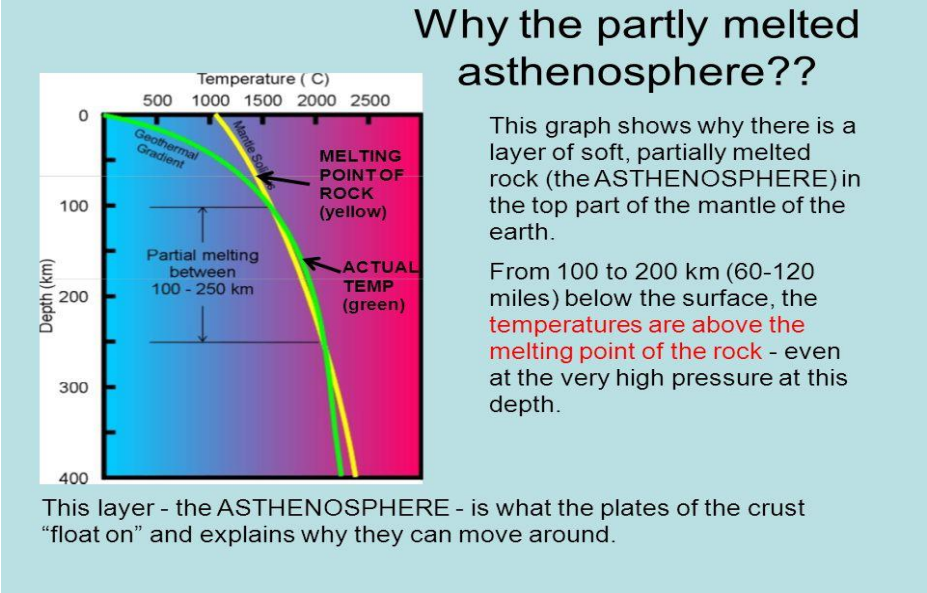


Fig.2. The explanation of the asthenosphere origin.

It is important to mention that under the ocean bottom the asthenosphere has low depth of the upper boundary and is thicker then under the continents, where the low velocity layer is located deeper and has lower thickness [Ringwood A., 1970]. This is easy explainable having in mind the Erath crust has larger thickness in the continents and thinner in the oceans. The fluids (partially melting rocks) saturated asthenosphere appeared as a good stratum for the continental movements, easy explains the subduction process, volcanism and deep magmatism.

## High and low velocity (interpreted as asthenosphere) layers and their position in the deep Earth's interior of Bulgaria

As a result of the performed methodology and used equipment the deep structure obtained by the MMS is presented at different levels of signal frequency-amplitude attenuation in dB (respective depths) in 3D diagrams used for better visualization (Figures: 3; 4; 5).

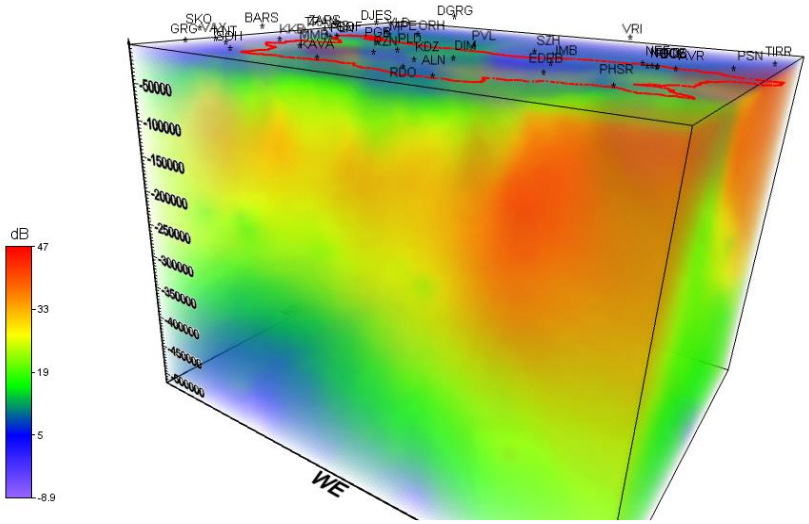



Fig.3 Deep 3D view of the low velocity (warm colors) and high velocity (colder colors) structures according the depth. (View from SE)

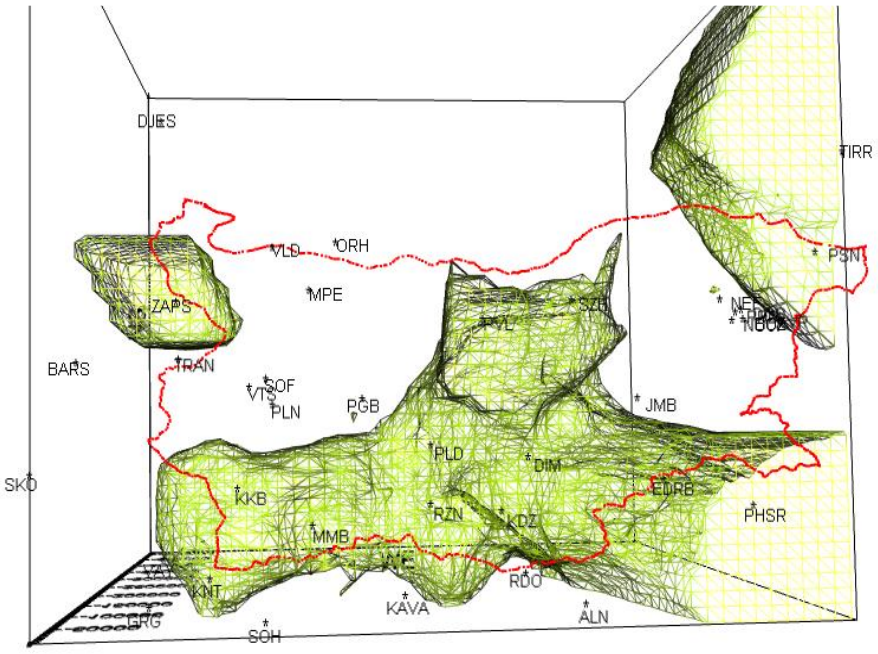



Fig.4 Projection on the earth surface of the low velocity layers

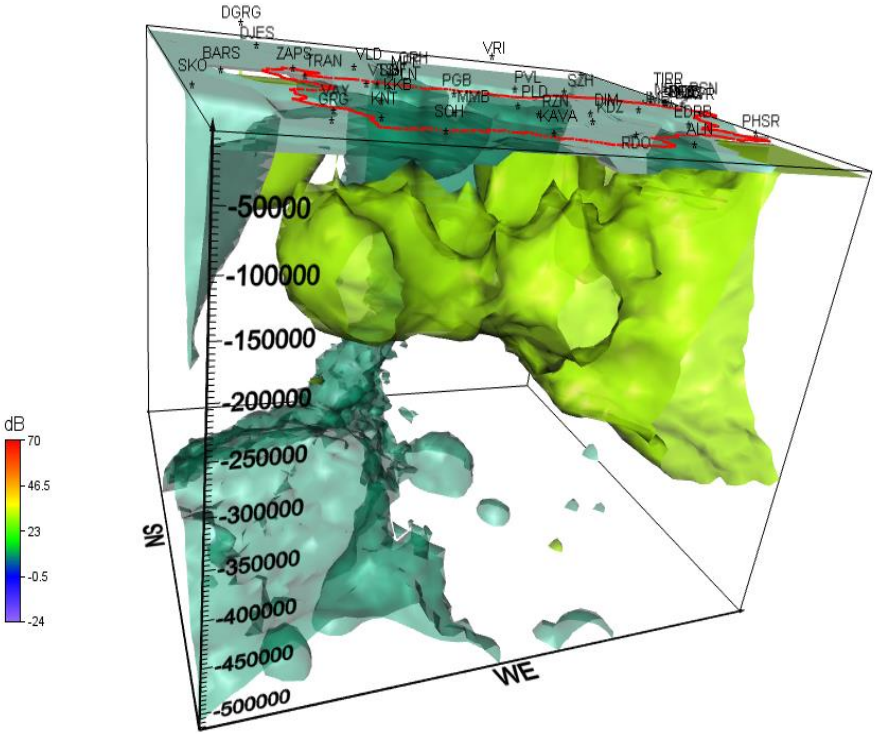



Fig.5 3D stereogram of the low velocity layers (light green) and high velocity layers (dark green). The intermediate velocity layers are not colored.

The detailed study of the low velocity and high velocity layers (bodies) reveal the complex character of the asthenosphere (if accepted as interpretation of the low velocity layers). The block regionalization could be extracted. The main criteria for such a regionalization could be the behavior of the average depth of asthenosphere as well as the thickness of the layers (Fig.6).
The high velocity layers are interpreted as solid bodies which are stable, with low permeability and thus can serve as isolators between the low velocity layers and the earth crust (Fig.7).

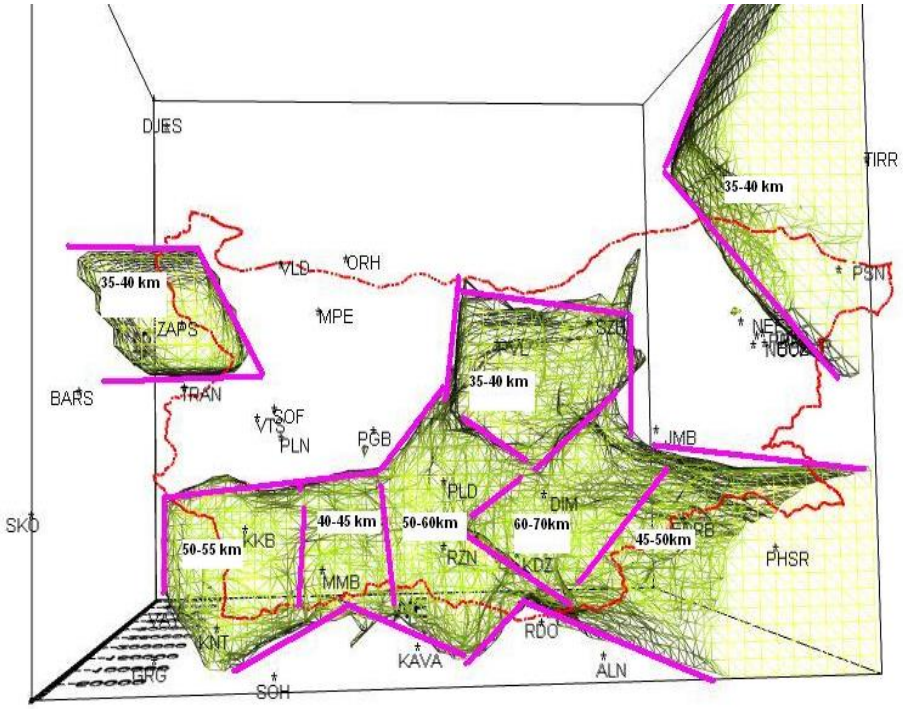



Fig.6 Block regionalization of the low velocity layers (projection to the surface). Numbers are average depths.

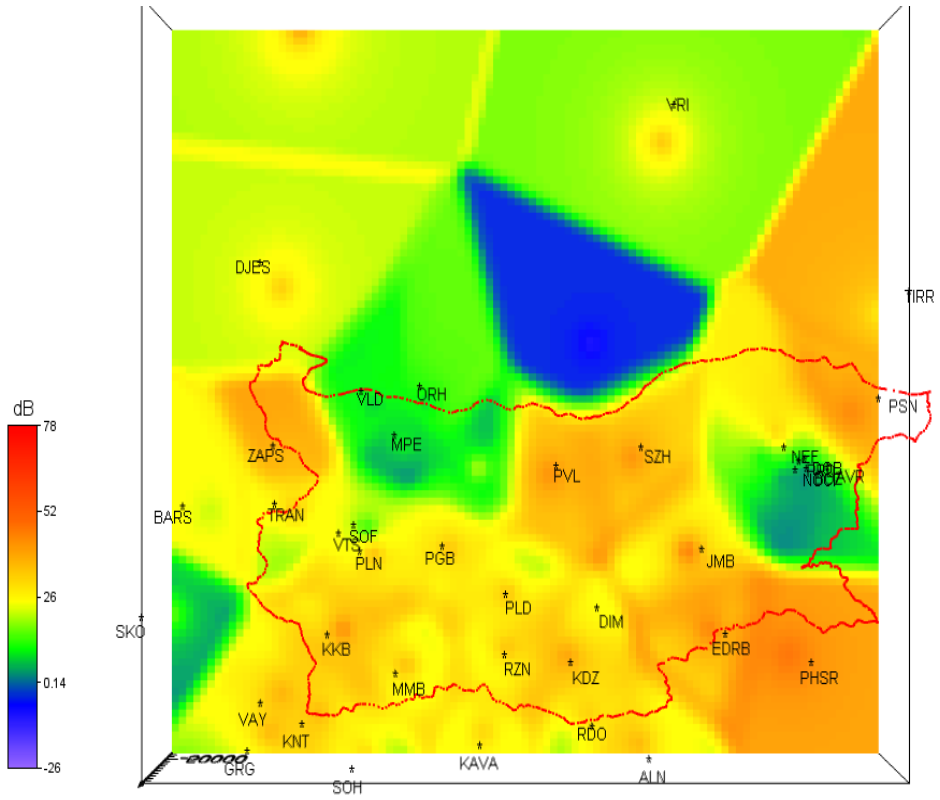



Fig.7 High velocity bodies (blue and green) at 60 km depth. They are interpreted as stable, not permeable block which isolate the earth crust from the asthenosphere.

## Conclusions

The deep structure of the low and high velocity layers (bodies) under the territory of Bulgaria is presented. The results obtained are due to the performance of the Method of the Micro Seismic Sounding (MSS) and give 3D diagrams at different depths.

The horizontal and vertical resolution tends to be enough with the presented density of the digital broadband seismic stations. The stationary of the microseismic noise is provided by the same 1 hour records in the calm time intervals during the night time and stability of the selected basic station.

The low velocity layers are interpreted as a first approximation of the asthenosphere in Bulgaria. The block regionalization is performed for different block structures, as a fundamental issue of further research.

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