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Gravimetry contribution on investigation of oil shales – alginite in ring structures in Lučenec depression

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Abstract: The aim of the contribution is to show possibilities of gravimetry by investigation of structures perspective for the occurrence of oil shales - alginite. Gravity investigation in this problematics was succesfully realized first time in Slovakia. The results from profile and areal measurements are documented from two prospection areas in the Lučenec - Rimava Depression at localities Pinciná and Jelšovec. At this localities volcanic structures were successfully detected and contoured. It was a maar nearby Pinciná and diatreme nearby Jelšovec. At the same time I call attention to differences by the interpretation of areal data gained from detail measurements and data gained from regional gravity mapping at scale 1: 25 000.

Key words: gravimetry, map of complete Bouguer anomalies /CBA/, maps of residual gravity anomalies, oil shales - alginite, diatomite, maar

Introduction

In the period 1992 - 1996 a complex geophysical-geological prospection was realized on the basis of the project of geological-geophysical works (Zbořil et al. 1992, Puchnerová et al. 1993, Puchnerová et al. 1995) in the area of Lučenec - Rimava depression. The prospection was aimed to find suitable structures - maars for potential accumulation of oil shales - alginite. We gathered in considerable extent suggestions for investigation from the prospection results of Hungarian geophysicists and geologists who have long-term experience and positive results from application of geophysical methods for the oil shale - alginite prospection.Considering the available contemporary geological knowledge about the potential occurrence of oil shales, in Slovakia the area of Lučenec - Rimava depression, particularly the area of volcanics assigned to the Podrečany basalt Formation, was chosen for the project. Maar volcanic structures of the Pontian age were the main objective of the work.

The theoretical and practical knowledge of Hungarian geophysicists and geologists from the Geophysical Institute of Lorand Etvös (ELGI, Toth 1975, 1978, 1990) and from the Hungarian Geologic Survey (MAFI) in Budapest (Solti 1987, Ravasz et al. 1992, 1993, 1994) served as a basis for choosing suitable geophysical methods and elaboration of methodologic procedures. Naturally, we considered differences in geology and development of mollase formations in the area of South-Slovakian Basin (Vass et al. 1988, Elečko in Bodnár et al. 1988).

The first etape of the geological-geophysical prospection in the area interested comprised evaluation of the material available, mainly satellite images and areal photographs, aeromagnetic and regional gravity measurements. On the basis of the above mentioned data together with geological knowledge the following localities were chosen for detail geophysical prospection (Fig. 1):

A) Halič - Mašková
B) Podrečany - Točnica - Tomašovce
C) Jelšovec
D) Baňa - Chudač - Čakanovce
E) Pinciná
F) Boľkovce

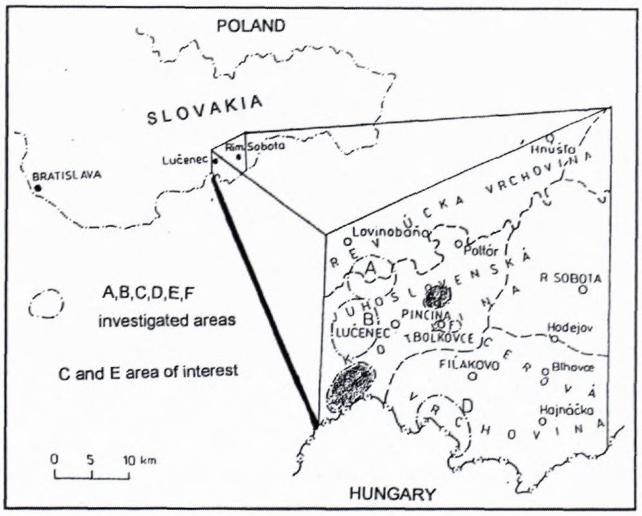


Fig. 1 Locality map

In the second etape a detail geophysical prospection was realized at selected localities. It consisted of profile magnetometry, complex geoelectric methods and of profile and areal gravimetry. The profile gravimetry was applied at localities: Jelšovec, Podrečany, Halič and

Pinciná (Puchnerová et al. 1994, 1996a, 1996b, Šantavý 1993). The following localities were investigated by areal gravimetry prospection: Pinciná and Jelšovec with the density up to 20 points per km^2 (Šantavy in Puchnerová et al. 1996, Puchnerová et al. 1995). The results of the detail areal gravity mapping were found as very effective because they brought more complex view on structure of volcanic structures and, mainly, they pointed out in more detail on the spatial distribution of the sedimentary - maar fill (Šantavý in Puchnerová et al. 1997).

Geophysical investigation of the interested area

a. Regional gravity measurements at scale 1:25 000

For purpose of the characterisation of regional gravity measurements in a wide surrounding area were mainly used the following works: Šefara et al. 1987 and regional gravity measurements at scale 1:25 000 (Fig. 2) of regional geophysical investigation works (Bárta et al. 1965, Obernauer 1969, Šefara et al. 1970, Bodnár et al. 1973, 1975, 1979). The main objective of gravimetry was observation of morphostructural elements of pre-Tertiary basement beneath mollase deposits and observation of tectonics. A system of high and relatively sunken tectonic blocks has been defined on the basis of areal gravity data interpretation and at the same time more conspicuous density anisotropies in pre-Tertiary substrate were detected (Bodnár et al. 1979).

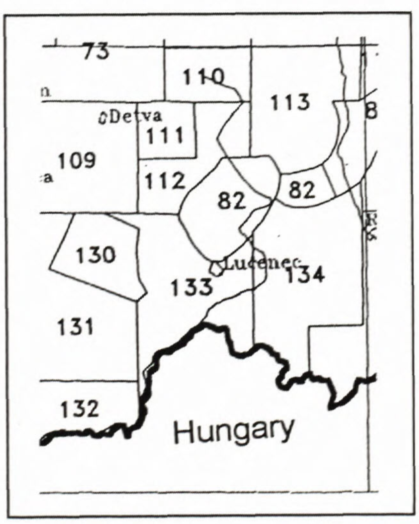


Fig. 2 Regional gravity measurements in the scale of 1:25 000 (Szalaiová and Šantavý, 1994)

b. Detail gravity measurements

The density anisotropies in the Tertiary fill is expressed less conspicuous in the map of complete Bouguer Bouger anomalies (CBA) because rock complexes differ only little in natural densities. Similarly, also neovolcanic bodies are demonstrated uncospicuously in regional gravity maps because they are represented by areally little extended bodies. From this reason the success of contouring of neovolcanic structure depends on good selection of methodology and on scale of the prospection e.g. the higher

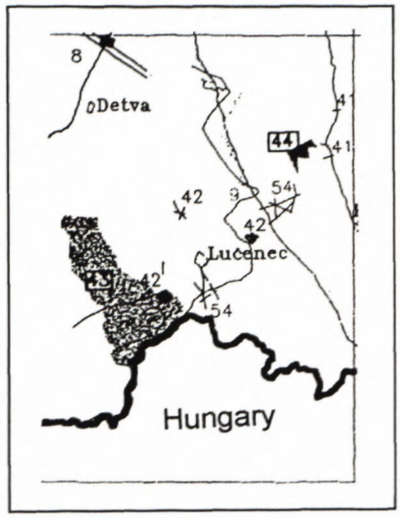


Fig. 3 Local gravity measurements (Szalaiová, Šantavý and Alfoldy, 1996)

density of measured gravity points per km^2 the higher probability of contouring even relatively smaller volcanic structures. For this purpose more detail gravity measurements were performed (Fig. 3) - areal mapping and also profile measurements. The aim of the work Velich and Mezovský (1988, on the Fig. 3 marked as 54) was to verify possibilities of geophysical methods - detail profile gravimetry and vertical electric sounding measurements by distinguishing the quality of the pre-Tertiary basement of the Lučenec depression. In the area of Luboriečka a geophysical prospection was realized which was aimed at selection of coal-bearing horizons (Džuppa et al. 1987, 1989, 1991). Except areal and profile gravimetry (on Fig. 3 marked as 43) geoelectric measurements of vertical electric sounding were realized. For the purposes of this contribution I mostly used measurement results from the work Puchnerová et al. 1994, 1996 (on Fig. 3 marked 42).

Two gravity measurements, differing by purpose and methodology, are compared in the next chapters. We put emphasis on the possibilities of gravimetry for detection of smaller volcanic bodies.

Brief geological characterization of choosen localities

The choosen localities - Jelšovec and Pinciná, belongs to the Lučenec Depression of the South-Slovakian Basin. The geologic characteristics was mostly made on the basis of the latest data, mainly on the basis of the geologic map of the Lučenec depression and Cerovo hilly land at scale 1:50 000 (Vass et al. 1992).

Pre-Tertiary rocks are represented by two tectonic units - Veporicum and Gemericum which do not crop out in the area under investigation. From the Tertiary molasse deposits Miocene deposits and volcanics of the Eggenburgian age are present at choosen localities. The lower part consists of Fiľakovo Formation of the marine origin overlying Lučenec Beds. The upper part is composed of Bukovina Formation of continental origin. In the northeastern area of the Jelšovec locality Jelšovec conglomerates belonging to the Fiľakovo Formation occur. Bukovina Formation consists of cyclic alternation of gravel, sand and motley clay. These sedimentary rocks contain beds and layers of rhyodacite tuffs and tuffits. Motley clays and silts are the most common lithotype of the formation. The Otnangian is represented by Salgotarian Formation consisting of two Member successions - from Pôtor and Plachtiná Members. Pôtor Member forms the lower part of the Salgotarian Formation and it is mostly composed of sand containing coal layers, sandy clays and silts. Plachtiná Member lies conformably on Pôtor Member. It is represented by clay, claystone and siltstone. The prevailing part of Plachtiná Member has originated in either lacustrine or brackish environment which is important for genesis of alginite. The Karpatian is absent in investigated areas - it is extended only in the southeastern part of the Lučenec Depression. The Middle Miocene is represented in the investigated area by the rocks of alcaline-calcareous andesite volcanism. The Pontian is characterized by Poltár Formation extending into southwestern part of the depression and into suroundings of Jelšovec village. The formation mostly lies on the Lučenec Formation (Egerian), in the western part of the Depression it lies on the Fiľakovo or Bukovina Formation. The relationship between Poltár and Podrečany basalt Formations is various. The Podrečany Basalt Formation either overlies or underlies Poltár Formation, or eventually it interfingers the Poltár Formation. Two facies were distinguished in Poltár Formation - fluvial and lacustrine (nearby Pinciná) facies, the fluvial one prevails. It consists of gravel, sand and clay. Clay and silt comprise an important part of the Poltár Formation (Vass et al. 1992).

Podrečany Basalt Formation includes relics of lava flows in the northeastern part of the depression (Podrečany, Mašková), maar nearby Pinciná and relics of two maars on the southwestern margin of the depression (west from village Jelšovec). The relationship between the Basalt Formation and Poltár Formation was described above. If Podrečany Formation does not lie within or on the Poltár Formation then it lies on the either Lučenec Formation (nearby Pinciná, partly also nearby Mašková), Plachtiná and Pôtor Members (nearby Jelšovec, partly nearby Mašková) or on the pre-Tertiary basement as it is nearby village Točnica. The assignment of maars located nearby Jelšovec to the Podrečany Basalt Formation is supported only by structural similarity to the other relics of basalt volcanism on the western margin of the depression (Vass et al. 1992).

The Quaternary deposits consist mostly of fluvial sediments of terraces and flood plains of creeks and rivers and alluvial fans of tributaries of axial river system.

For better documentation of the detail geologic structures of Jelšovec and Pinciná localities profiles of selected boreholes drilled on the basis of geophysical investigation are depicted on Figs. 4a, b, c. The results of the borehole investigation were subsequently used for the quantitative interpretation of geophysical profiles.

Results of gravimetry by the investigation of oil shales

A. Locality Jelšovec

Two profile gravity measurements were realized along profiles PF-A and PF-1 at locality Jelšovec. Besides profile gravimetry geoelectric measurements and profile magnetometry were also realized. In the second etape on the basis of the positive results from locality Pinciná a detail areal gravimetry prospection of volcanic structure was realized aimed at more detail areal location of the structure.

Maps CBA for reduction density 2.00 g.cm^{-3} are calculated from data of regional gravity mapping at scale 1:25 000 with density of 3 – 6 pints per km^2 and from detail measurements. Isolines Δ g in milligals interpolated from gravity data obtained by regional gravity mapping at scale 1:25 000 are depicted on fig. 6. The fig. 5 showes isolines calculated or constructed from detail gravity measurements at scale 1:10 000 with density up to 20 points per km^2 which were realized in the framework of the project "Geophysical investigation of oil shales in Slovakia" (Puchnerová et al. 1995, 1996).

A conspicuous gravity gradient of NW-SE direction as well as a gradual increasing of gravity values toward north, resulting from the map of CBA, is obvious. It reflects a gradual pinching out of the pre-Tertiary basement toward surface (Šantavý in Puchnerová et al. 1996). A relatively negative anomaly about 400 m northeasterly from the elevation point 265 m and a relatively positive anomaly about 150 m north of the borehole VJA-3 are considered as the most conspicuous gravity anomalies in the area investigated (Fig. 6). The positive anomaly can be explained by the presence of the Pontian volcanics, but comparison with the positive anomaly obtained by data interpolation from detail gravity investigation at scale 1:10 000 shows its obvious areal inconsistency with these measurements. This is determined by lower density of measured points per km^2 causing possible record of the anomalous body of lesser areal extent only by one or in some cases by no measured point. The mentioned positive anomaly obtained from regional measurements is caused by the gravity value gained by the measurement only at one point. Generally one-point measurements are not considered as reliable. Anomaly has to be recorded at least by three points. Similarly, negative anomaly from regional measurements is also detected only by one point. By one-point anomalies we can not surely exclude possible errors which could for example originate by uncorrected record of measured gravity, uncorrectly determined topographic correction or bad located point on map. Just from this reason it is necessary for operator to be careful to interpret individual anomalies. One always should make sure about the degree of probability of generation of anomaly or its source.

The results of detail gravity investigation (Figs. 5 and 7) render comparison of two methodologic and for purpose different measurements from the same area. The greatest difference is the fact that the regional measurements did not record positive anomaly (or they recorded

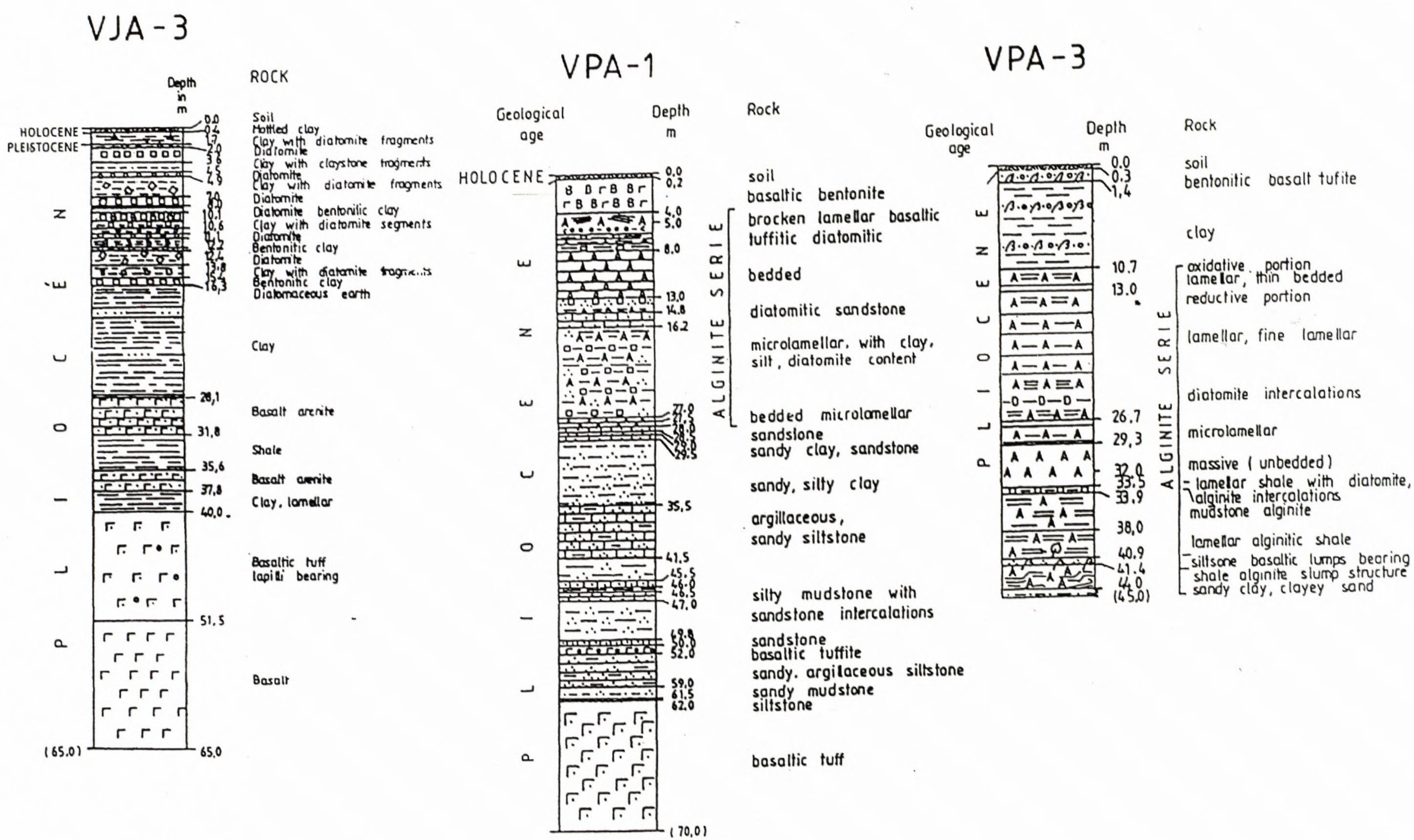


Fig. 4 (a, b, c) Lithological profile of borehole Jelšovec, Pinciná – (after Ravasz and Solti, 1994) only its NNE margin) as a result of low density of measured points. The anomaly with its centrum located about 100 m southwest of the borehole VJA-3 was detected by detail investigation. At the same time the location of the negative anomaly, suggested by results of regional measurements to lie about 400 m northeast of elevation point 265 m, was not confirmed. In this case the anomaly can be considered as "artificial". As a matter of fact, we can not talk about an error of regional gravity investigation because the accuracy of meausurements according to the Technical-organization norm of gravimetry and according to the Instructions for gravity mapping at scale 1:25 000 is 0.5 mGal. The negative anomaly shows intensity -0.3 mGal and, of course, corresponds to the accuracy and purposes of regional gravity measurements. The differences can be also observed on the derived maps. The gravity residuum from regional measurements is generally very unconspicuous as a result of weak representation of high-frequency part while just the high-frequency part represented in detail measurements is a source of frequent local residual anomalies in the given area like is shown on Fig. 5 and more conspicously on Fig. 7.

Results of the detail gravity investigation at locality Jelšovec have contributed to detect the volcanic structure – diatreme, and appoint areal distribution of sedimentary rocks.

Kvantitative interpretation - modelling on profile PF-A

On the profile (Fig.8) besides profile gravimetry also geoelectric and magnetometric measurements were done. The profile orientation is NW - SE with the commencement nearby elevation point Hajcov vrch (256 m). Nettleton methods (Šantavý 1993) was used for choosing the reduction density suitable for modelling. The character of particular curves Δg calculated for various reduction densities is basically this same even if on the curve CBA for reduction density 2.2 g/cm^3 is obvious decreasing of positive anomaly in intervals 550 - 700 m and on the curve CBA for reduction density 2.00 g/cm^3 this anomaly practically disappeares. The anomaly source could be seeking in volcanics of the Pontian but the results of magnetometry and geoelectrics are in this part of the profile non-anomalous. According to the change of the gravity field on curves CBA calculated for various reduction densities, we can assume that the above mentioned positive anomaly is probably reflection of the terrain relief and does not connect directly with the geological structure. The second positive anomaly in the interval 1200 - 1600 m is not that conspicous as to intensity, but it includes the influence of both Pontian volcanics and pre-Tertiary basement.

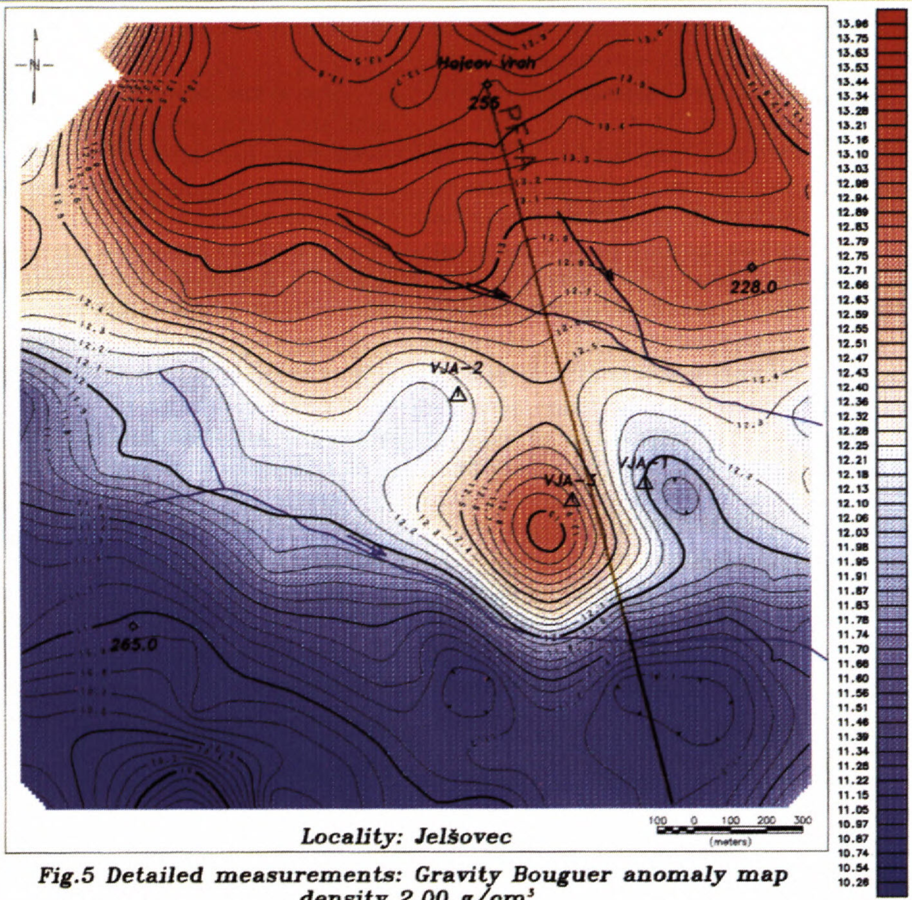
The aim of quantitative interpretation of gravity data was modelling of volcanic structure and its filling. As input data for modelling well data, results of geoelectric measurements (VES - Vertical Electrical Sounding) and petrophysical parameters were used. On Fig.8 we can see a model of volcanic structure and interpreted layer of diatomit, too.

B. Locality Pinciná

Also at this locality a complex of geophysical methods similar to measurements realized at locality Jelšovec, was performed. In contrast to the Jelšovec locality, magnetometric investigation could be not realized here because of fenced vineyard.

Similarly to previous case also for this locality maps CBA for reduction density 2.00 g/cm^3 were calculated. The calculation was based on data from regional gravity mapping (Fig. 10) at scale 1:25 000 and data obtained from a detail investigation (Fig. 9) made in the framework of the project "Geophysical investigation of oil shales in Slovakia" (Puchnerová et al. 1996). On the processing of detail areal gravity measurements at this locality Dr. Szalaiova, Mgr. Švastová and Dr. Grand took part during the project.

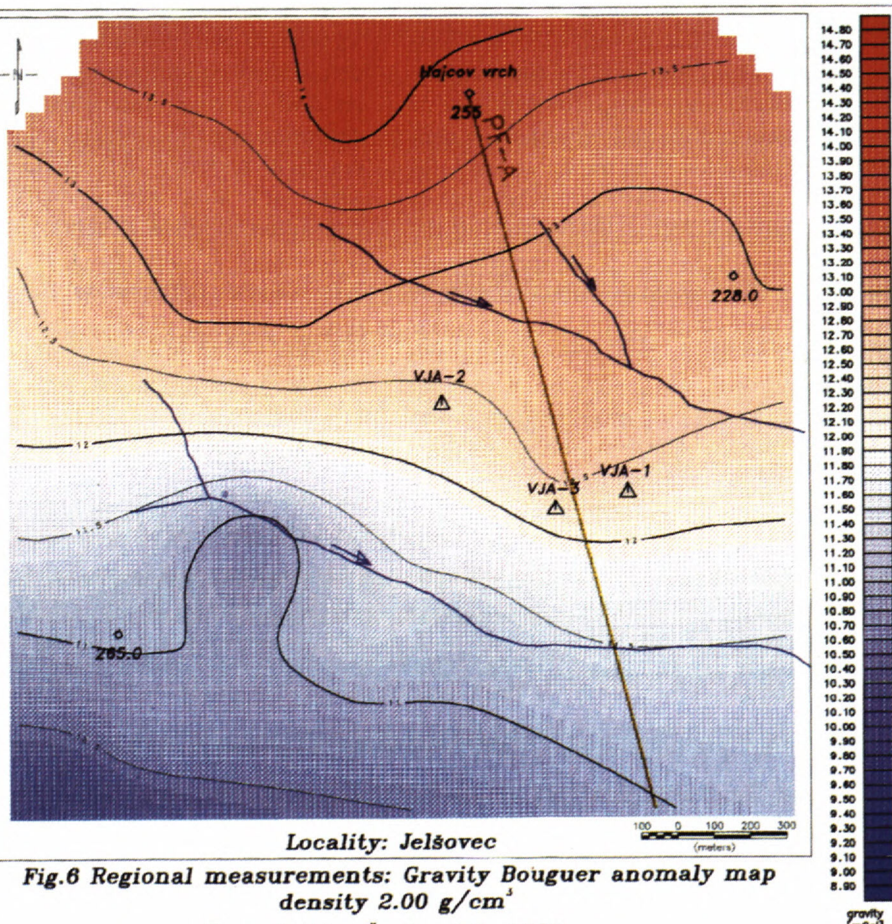
On the first look the gravity isolines obtained from regional measurements are well correlated to results of more detail gravity investigation due to location of the one of the measured point from the regional gravity mapping almost in the centre of the anomalous structure. The anomaly centre obtained from regional measurements is shifted only slightly in about 100 m. The difference is only in the contouring of the volcanic structure. Some disproportions can be observed in the intensities of the gravity, in fact, in their interpolated values between two measurements. This is caused by both different density of the measured points and by interpolation. While on the CBA map computed from detail measurements is a local negative anomaly closed and it is forming a ring structure, on the other hand regional data suggest a certain opening of the structure in its western and southern part. This is also obvious from detail areal measurements and particularly from map of residual gravity anomalies (Fig. 11). The western deformation of the structure forming an elongated local negative anomaly inform us about probable influx (drainage) area which might occurred here during deposition in maar structure. A less intensive northern deformation is suggested from detail measurements. The less intense deformation is probable due to lower thickness of deposits. The southern deformation or opening of the maar has not been confirmed according to these measurements, especially according to the results from residual gravity anomalies map. In the map of residual anomalies we can also divide a NW - SE trending linear deformation crossing the maar centre. The map inform us about the spatial distribution of light deposits belonging to the maar fill. The higher intensity of the negative anomaly in the northern and northeastern part of the maar indicates thicker accumulations of light rocks - deposits, which generate this anomaly. This implies a direct location of spatial distribution of potential alginite deposit by gravimetry determining a suitable location of following prospection works or drilling investigation. The surrounding positive anomalies comprising ring structure are generated by relatively heavier complexes of volcanic rocks of Pontian age, mainly basalt tuffs and basalt s.l.



Locality: Jelšovec

Fig.5 Detailed measurements: Gravity Bouguer anomaly map density 2.00 g/cm^3

Compiled by Šantavý J., 1997



Locality: Jelšovec

Fig.6 Regional measurements: Gravity Bouguer anomaly map density 2.00 g/cm^3

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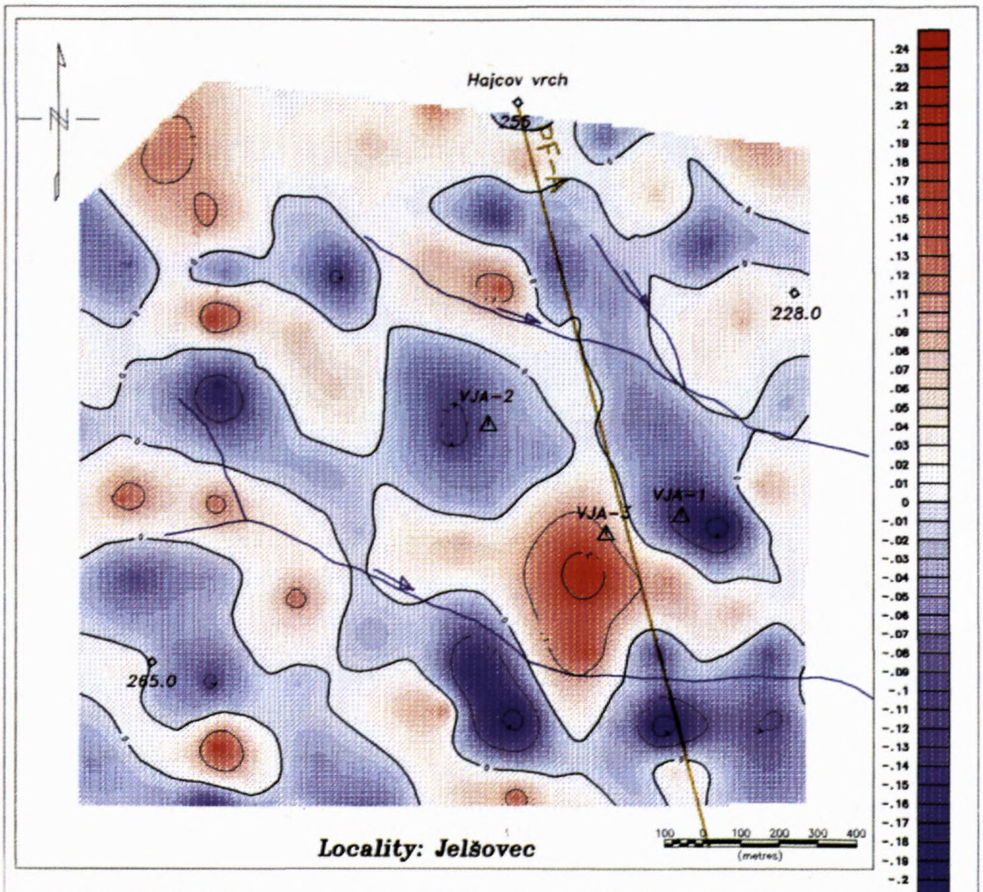

Fig. 7 **Detailed measurements: Gravity residual anomaly map Griffin r=150 m, density 2.00 g/cm³ Compiled by Šantavý J., 1997**

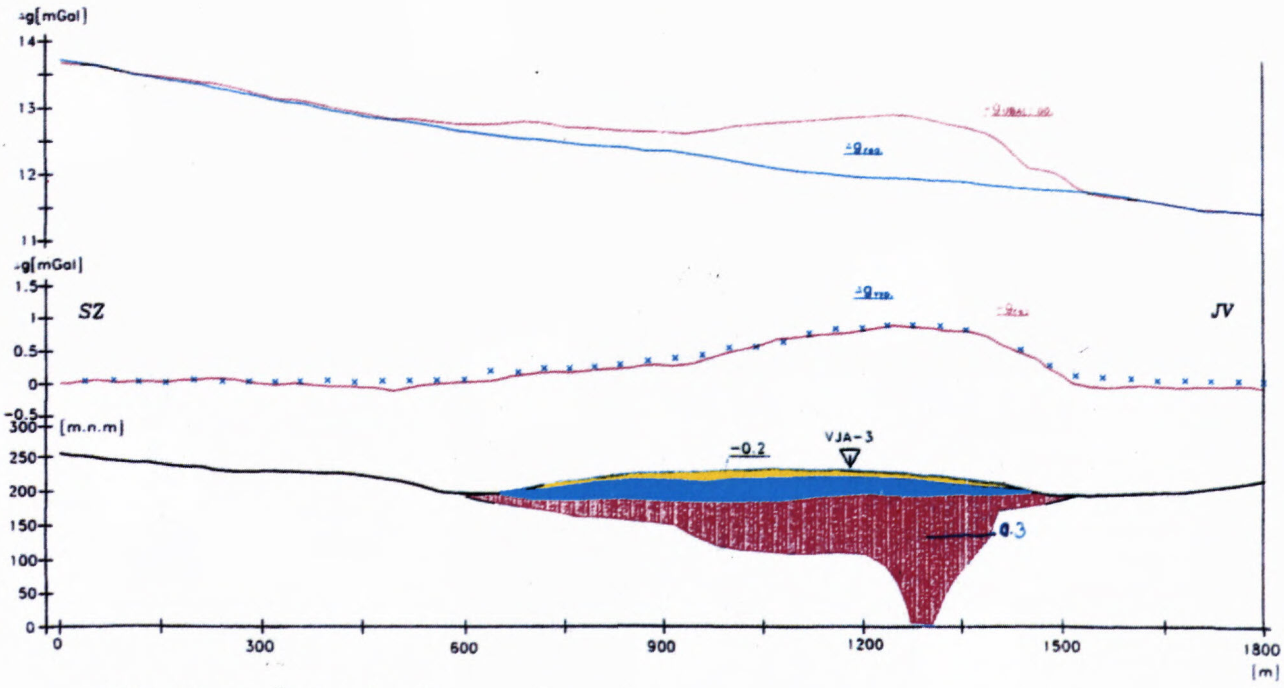

Fig. 8 Locality Jelšovec – gravity profile PF-A (Šantavý M. in Puchnerová et al., 1996)

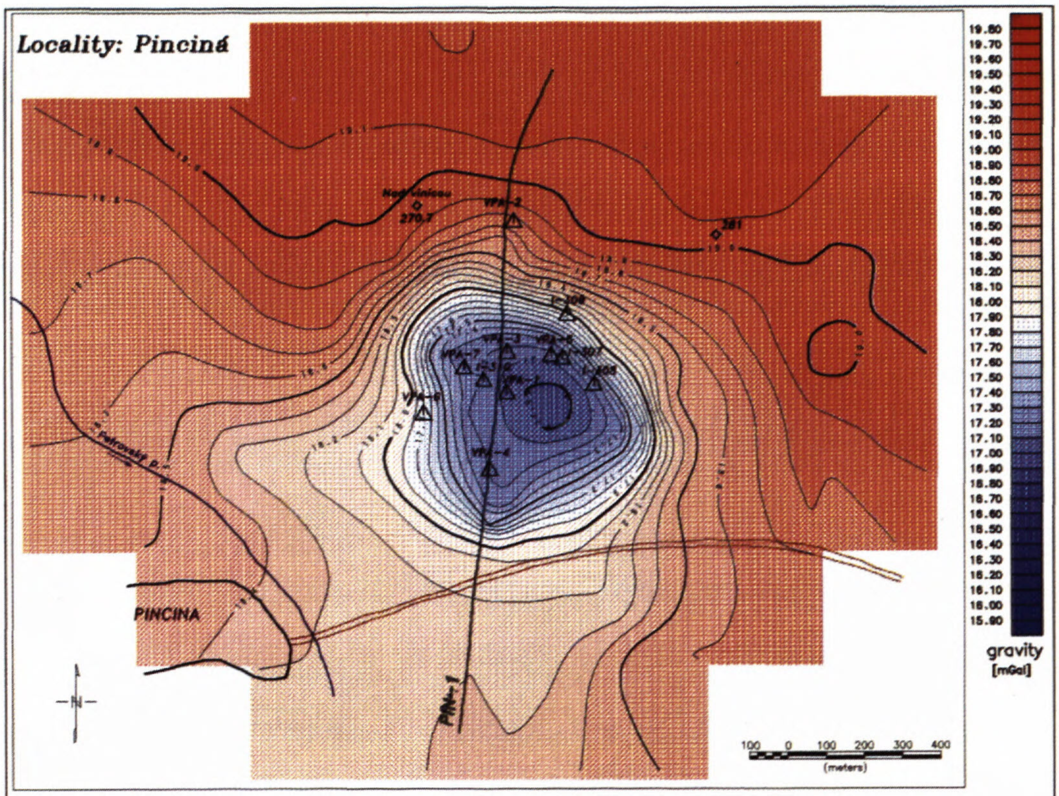

Fig.9 **Detailed measurements: Gravity Bouguer anomaly map**
density 2.00 g.cm^{3}
Compiled by Šantavý J., 1997

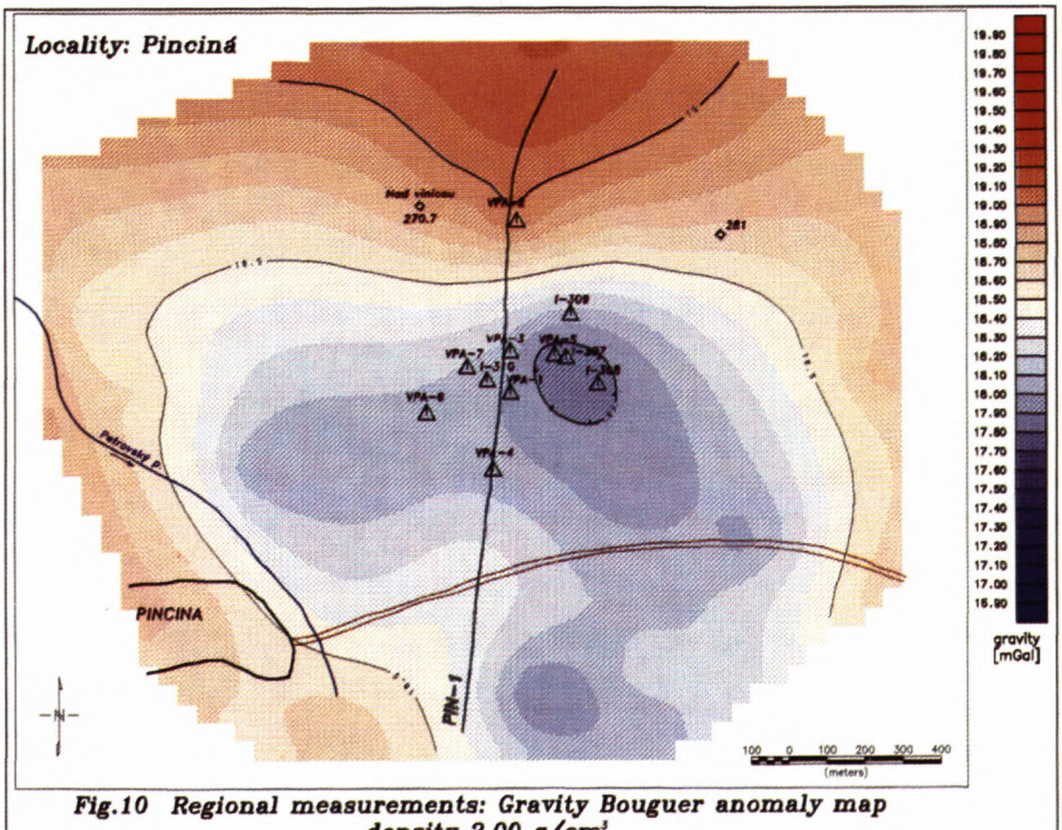

Fig.10 **Regional measurements: Gravity Bouguer anomaly map**
density 2.00 g/cm^{3}
Compiled by Šantavý J.,1997

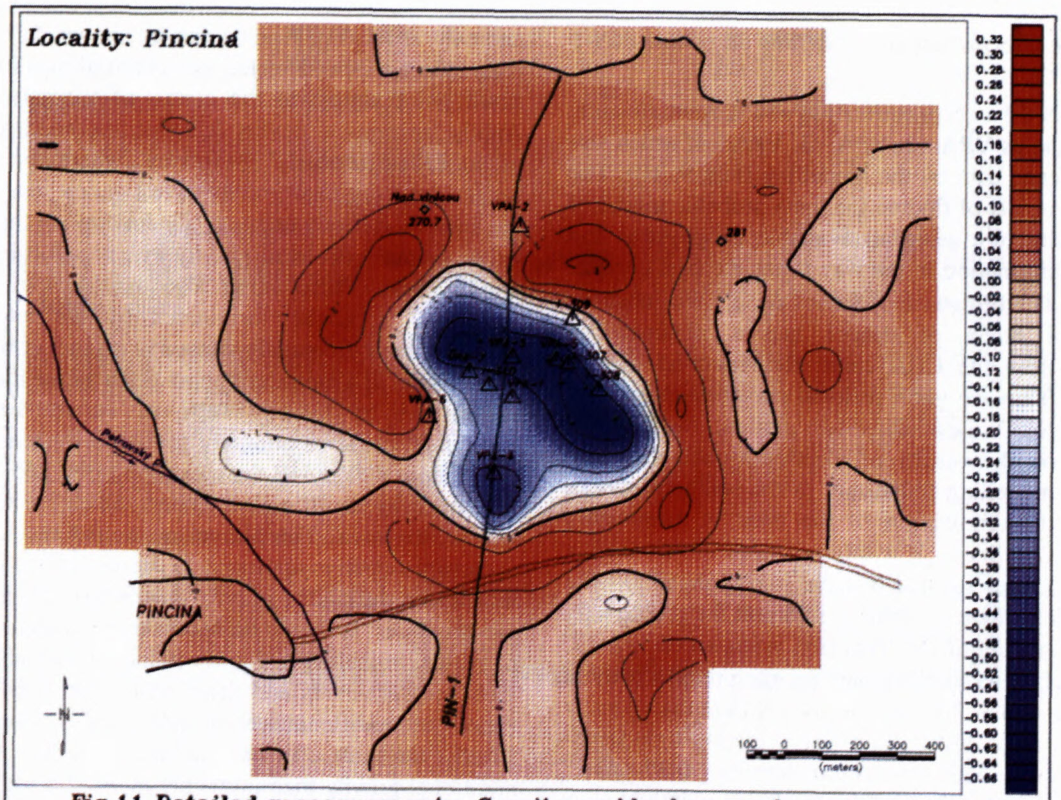

Fig.11 Detailed measurements: Gravity residual anomaly map
Griffin r=150 m, density 2.00 g.cm³
Compiled by Šantavý J., 1997

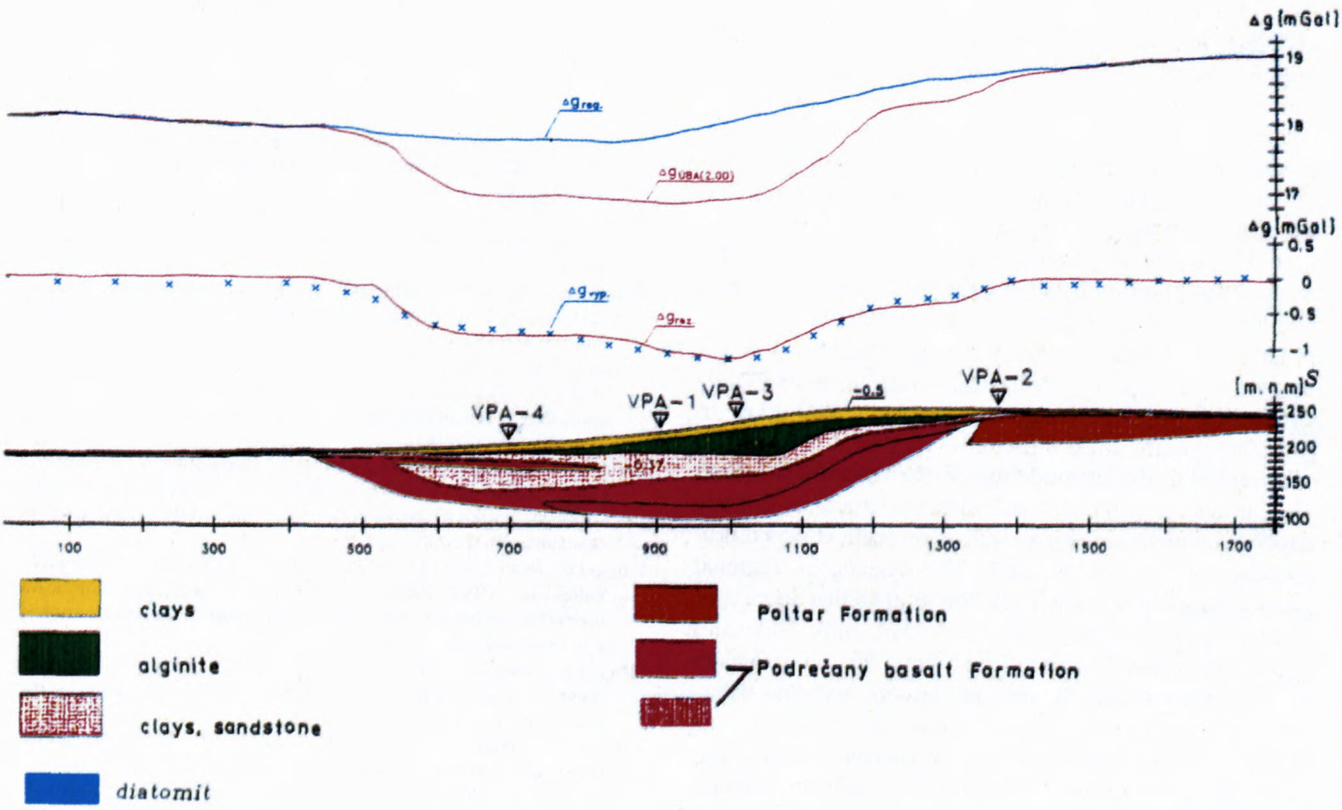

Fig. 12 Locality Pinciná - gravity profile PIN-1 (Šantavý M. in Puchnerová M. et al., 1994)

Quantitative interpretation - modelling on profile PIN-1

Profil PIN-1 has N-S orientation and it approximately crosses boreholes VPA - 2, VPA - 3, VPA - 4, which served as reference data by the modelling (Fig. 9, 10). The modelling consists of finding the most probable model of geological structure using all available geophysical and geological information in the way it has the best correlation to calculated (measured) values Δg_{rez}. We substracted regional effect of deeper masses obtained by calculation from the CBA curve for reduction density 2.00 g/cm^3. Thus we got a residual curve which we further interpreted. We calculated two models. The first one was based on the results of electromagnetic measurements. The modelling found that in the southern part of the profile the termination of the maar is presumably about 150 m earlier as it is inferred from the curve Δ g UBA. This model seemed to have low probability. The second model, where we tried to interpret the problem by the geologic model of Dr. Konečný, is shown on Fig. 12. In this model, in its southern part we interpreted a body in the interval 600 - 800 m showing differential density +0.05 g/cm^3 as an tuffitic interlyer overlying light deposits of maar fill with differential density - 0.37 g/cm^3, which were absent in the first model. Subsequently, below this layer of maar deposits we consider volcanics comprising a basis of maar.

Conclusion

It is remarkable that this ecological uncommon kind of raw material has not been discovered until 1995 in Slovakia. The discovery may be prescribed to application of suitable chosen methods of geophysical investigation as well as to knowledge obtained during a cooperation with Hungarian experts who have a long experience and positive results in solving this problematics. Slovak geophysics has completed Hungarian methodology and has introduced of the profile and areal gravimetry the first time for the prospection of oil shales - alginite. This method was testified for contouring of volcanic structures and considerable contributed to the knowledge of spatial distribution of sedimentary fill in maar structure. A considerable advantage of geophysical investigation is mainly contrasting physical parameters of individual kind of rocks comprising maar structure - ring as well as its fill with regard to the surroundings of the volcanic structure. The success to contour small volcanic structures directly depends on methodology as well as on scale at which prospection works are realized. The results of regional gravity mapping at scale 1: 25 000 implies that success of contouring of smaller structures (not only volcanic) depends on network of localized points. The point density 3 - 6 points per km^2 for regional gravity mapping determines average distance between points about 700 m. This is not sufficient for contouring of structures which diameter is smaller than 700 m. In this case the success depends on the accidental location of measured point into the area of anomaly - structure. As an example a negative anomaly at locality Pinciná can be shown. In this case a maar structure was detected as a result of location of measured point almost to the centre of anomaly structure. Another example - locality Jelšovec is a practical example of so called anomaly shadowing, where the measured point of the regional gravity investigation lies outside of the anomalous body causing "shadowing" of the local positive anomaly of detail gravity investigation by regional gravity field. There exists also examples of so called "artificial" anomalies originated by the interpolation. They are most frequently caused or triggered by an erroneous value of a measured point. Such a case it is possible to observe at locality Jelšovec where there is an "artificial" negative anomaly triggered by one measured point about 400 m NE the elevation point 265 m. This is confirmed by detail measurements which are not anomalous in the area. The above mentioned results imply a necessary selective approach to the individual anomalous indications during the gravity prospection of small geologic structures. It should be necessary to keep the principle of critical reliability and to try to increase reliability of the local measurements and their interpretation by an application of additional geophysical and geological data. Finally, the most efficient method is realization of detail additional gravity measurements as we successfully realized at the mentioned localities.

Finally, I would like to state that the application of both detail areal and detail profile gravity investigation brought very positive results for contouring of structures perspective for occurrence of oil shales - alginitu and because of this we recommend application of detail gravity measurements for further prospection works at perspective localities of similar thematic orientation.

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