Geophysical Characteristics of the Roztoky Volcanic Centre, The České Středohoří Mts., Bohemia

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ABSTRACT. Geophysical investigation of the Roztoky volcanic centre started by tentative modelling of a gravity low identified during gravimetric survey at scale 1:25,000. Gravity modelling was based on rock density data and rough depth estimation derived from borehole Pd-2 (600 m deep) and core samples. It resulted in a simple model of about 1 km thickness of the caldera filling, the density of which was considered lower than that of the surrounding country rocks. In the next stage, a complex geophysical survey including detailed gravity measurements, magnetometry, gamma-ray spectrometry and geoelectrical methods were performed. As shown by its results, the inner part of the volcanic centre is divided into two gravity minima separated by a zone where higher content of subvolcanic rocks (essexites, monzodiorite – "rongstockite") can be expected. The "rongstockite" body, clearly distinguished from the surrounding pseudotrachyte breccia filling of the caldera by all methods, is probably a part of a larger intrusive complex, as another distinct positive gravity anomaly was found in its close southwestern vicinity. Similar indications are present at the other side of the caldera (NW). On regular geophysical profiles, rocks or zones of different content of magnetic minerals and K-U-Th elements were localized, as well as the faults and indications of mineralization. These data were utilized to modify the geological map of the area. The whole study was supported by detailed rock sampling from surface outcrops and from boreholes Pd-2 and R-1.

KEY WORDS: gravimetry, geophysical survey, volcanic structure, Roztoky intrusive centre.

Introduction

The main volcanic centre of the České středohoří Mts. near Roztoky is located at the intersection of the Ohře Rift (SW–NE) and the Labe Tectono-Volcanic Zone (NW–SE), see Fig. 1. The structure was defined by Kopecký (1987) as a caldera filled by pseudotrachyte breccia with carbonatitic and feldspathic matrix, penetrated by both cone-sheets and dykes of trachytic, phonolitic and tinguaitic composition. The system of radial lamprophyric dykes trending to the Roztoky volcanic centre preceded the caldera formation. A detailed study of their geochemical and petrologic character was performed by Ulrych (1998).

The origin of the caldera was explained by a local uplift of a carbonatite intrusion (Kopecký 1987). The character of the structure was confirmed by borehole Pd-2 (600 m deep, location in Fig. 2) in pseudotrachyte breccia penetrated by a number of dykes of trachytic composition.

The body of "rongstockite" (historical name by Tröger 1935, *monzodiorite* according to Ulrych 1998) is located at the margin of the caldera. Essexitic bodies similar in composition to "rongstockite" are located outside the caldera. According to Kopecký (1987) both are derived from a deeper gabbroid intrusion or represent melted crustal rocks above the presupposed carbonatite intrusion. Pivec et al. (1984) and Ulrych (1998) derived these subvolcanic rocks from a common olivine basaltic magma.

Rocks of the Roztoky volcanic centre are surrounded by Upper Cretaceous sediments (thickness 500 m) covering the crystalline basement. At the contact of the pseudotrachyte filling of the caldera with the Cretaceous sandstones cover, some feldspathization can be recognized (Kopecký 1987). In the close NE surroundings of the Roztoky volcanic centre olivine nephelinite diatreme is present, older than dyke rocks associated with essexitic intrusions (Ulrych 1998).

A polymetallic epithermal mineralization of Pb-Zn-Cu (Ag, Te) is known from three carbonate dykes in the "rongstockite" intrusion (Pivec et al. 1998). According to Kopecký (1987) the polymetallic veins represent young carbonatites.

The region was covered by aeromagnetic and aeroradiometric survey documenting intensive magnetic disturbances (anomalies connected with essexite and basaltic intrusions) and increased radioactivity in the **volcanic centre zone** (Mrlina et al. 1987). The gravity map 1:25,000 shows a distinctive gravity low, which was interpreted by Mrlina (1986a, 1986b) as a result of low-density filling of the caldera.

The aim of this study was a general structural investigation of the Roztoky volcanic centre, determination of its extent and contacts with Cretaceous sediments, location of diverse rocks within the pseudotrachyte breccia filling, characteristics of the K-U-Th elements distribution and local tectonic features. Field data acquisition was performed by Geofyzika Praha in the period of 1986–1987 under the author's supervision for the project of the Geological Survey, Prague. The following geophysical methods were applied: gravimetry, magnetometry, gamma-ray spectrometry, geoelectrical methods. In this paper most attention will be paid to gravimetric data. At the same time physical properties of rocks were also studied on 180 samples in order to provide data for the geophysical and geological interpretation. During the investigation the former geological map of the Roztoky volcanic centre (Fig. 3 in Kopecký 1987) was modified according to new geological mapping and geophysical data, as presented in Fig. 2 of this paper.

The results should contribute to the discussion on the type of the hidden intrusive body, which is considered a principal factor of the origin and evolution of the volcanic centre.

Geophysical measurements

Based on the preliminary interpretation of old gravimetric data (Mrlina 1986b), a detailed gravity field investigation was selected as the key method. A total number of 642 new stations were measured in the area of the caldera and its close vicinity, with respect to the access and morphology. Scintrex CG-2 No. 173 gravimeter was used with 0.022 mGal (0.22 $\mu m.s^{-2}$) accuracy. In marginal parts of the area a few old stations were incorporated into the final map. An appropriate choice of the average density of rocks was a specific problem for data processing, as

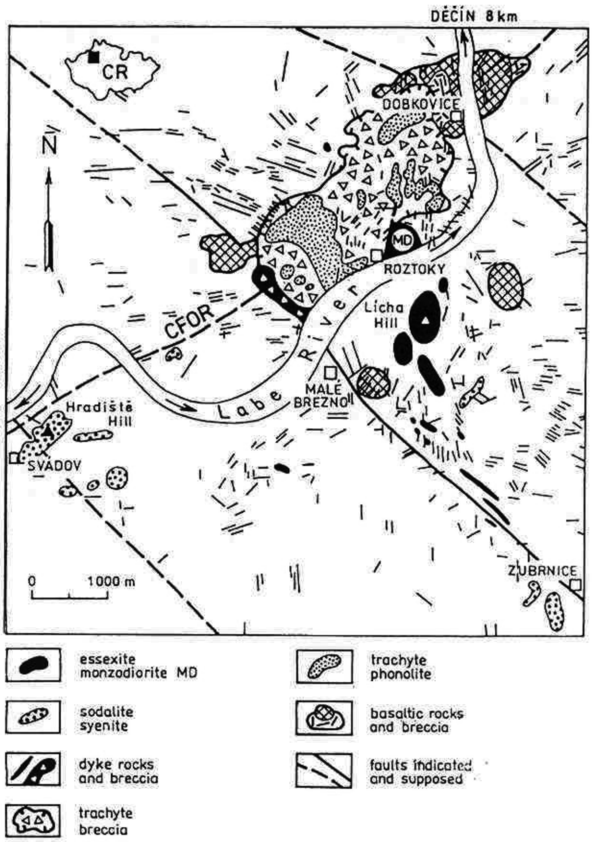

Fig. 1. Generalized geological setting of the Roztoky volcanic centre (modified by Ulrych 1998 after Hibsch 1900 and Kopecký 1987); CFOR – central fault of the Ohře Rift.

Tab. 1. Average densities, porosity, magnetic susceptibility and U-Th-K contents of rocks from the Roztoky volcanic centre. n – number of samples; Dm,b,p – mineralogic, bulk (dry) and natural (wet) density; p – porosity; ms – magnetic susceptibility; U, Th, K – contents of elements

a wrong selection may deform the shape and particularly the amplitude of the gravity anomaly. At first the structure was related to the anomaly indicated in the map 1:25,000 of the regular state gravimetric survey system. As it was clear that the 2.67 g.cm^{-3} density applied to this system is not relevant as an average value for the local geology, Nettleton's technique was utilized to determine the effective average density. The best fitting 2.50 g.cm^{-3} value was selected for data processing. In this way the most realistic shape/amplitude parameters were obtained.

On all straight-line profiles (Fig. 3), about 6,300 points of magnetometry, 5,900 of gamma-ray spectrometry, 4,300 of VLF (very low frequency), 530 of induced polarization and 500 of self-potential were measured. As an experiment, 200 atmogeochemical samples of soil air and snow cover were taken in order to locate deep crustal fracture zones. Most of the data were utilized for the construction of the scheme of geological features (Fig. 2).

Rock properties

The survey was accompanied by extensive rock sampling from boreholes and surface outcrops (total of 180 samples collected by the author in collaboration with L.Kopecký). Some samples were taken from Chlupáčová (1977). Petrophysical data provided information not only for the geophysical interpretation, but for petrological studies as well. The following parameters were investigated: mineralogic, bulk and wet densities, porosity, magnetic susceptibility, remanent magnetization, resistivity, induced polarization, K-U-Th content.

An anomalous rock type was found in borehole R-1 at the depth of 95 m with mineralogic density of 3.25 g.cm^{-3} and magnetic susceptibility of 210.10^{-3} u. SI. The rock was described as biotite-pyroxene gabbro with olivine and the sample was taken from brecciated marginal part of "rongstockite". The borehole is located in the Roztoky village and was drilled inclined to the north.

As the main result, it can be considered that the densities of pseudotrachytes (2.35–2.45 g.cm^{-3}) differ from Late Cretaceous country rocks (2.50–2.60 g.cm^{-3}) and provide a good explanation for the gravity low and a good basis for gravity modelling.

rock	n	Dm	Db	Dp	p	ms	U	Th	K
			g.cm^{-3}		%	10^{-3} SI	ppm	ppm	%
Regional :									
Cretaceous sediments				**2.50**		0			
basalts		3.00					1.8	6.9	1.0
trachyte	53	2.58					4.4	18.4	4.4
phonolite	35	2.53					12.6	36.7	4.5
Volcanic center :									
"rongstockite"	17	2.88	2.85	**2.86**	1	57	1.4	5.7	2.2
"rongstockite" breccia	11	2.82	2.71	**2.75**	4	2			
essexite	8	2.87	2.83	**2.85**	2	67	2.6	9.1	2.8
sodalite syenite	5	2.56				33	4.9	17.4	4.0
monchiquite, camptonite, tephrite	60	2.85	2.78	**2.81**	3	70	2.4	8.9	2.3
basalts	6	2.99	2.91	**2.94**	3	86			
mondhaldeite	8	2.75	2.48	**2.58**	10	48			
bostonite, gauteite	26	2.63				46	3.1	14.2	3.9
tinguaite	14	2.55	2.49	**2.51**	2	20	5.1	16.5	3.2
phonolite	3	2.52	2.52	**2.52**	0	4	12.6	36.4	4.7
caustic metamorph. marlstones	7	2.63	2.45	**2.52**	7	0.3			
feldspathic sandstone	16	2.63	2.34	**2.45**	11	0			
porous pseudotrachyte	14	2.65	2.15	**2.33**	18	1.4			
rheomorphic pseudotrachyte	31	2.63	2.34	**2.45**	11	8			
pseudotrachyte breccia	33	2.67	2.38	**2.50**	12	0.9			

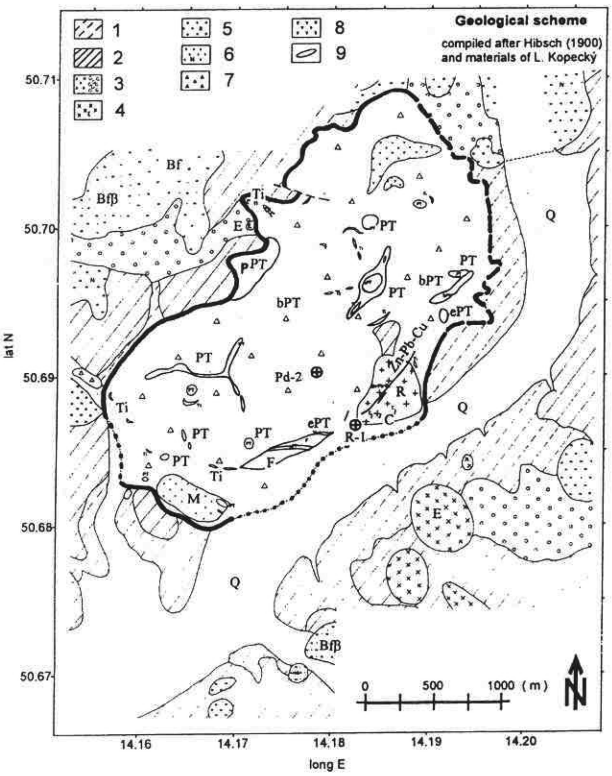

Fig. 2. Geological scheme of the Roztoky volcanic centre (adopted from field maps of Kopecký) with the thick contour of the caldera margin (also in Figs. 3, 6 and 9); positions of boreholes Pd-2 and R-1.

1 – Createaceous marlstone (Coniacian); 2 – Cretaceous sandstone (Santonian); 3 – olivine nephelinite N, breccia Nb, olivine basalt Bf, breccia Bfb, basaltic tuffs; 4 – essexite; 5 – rongstockite; 6 – mondhaldeite; 7 – pseudotrachyte breccia; 8 – trachyte; 9 – PT – massive pseudotrachyte, bPT – brecciated porous pseudotrachyte, pPT – porous pseudotrachyte, ePT – egirine pseudotrachyte, F – phonolite, Ti – tinguaite, Q – Quaternary, C – carbonatite, Ag-Pb-Zn sulphides.

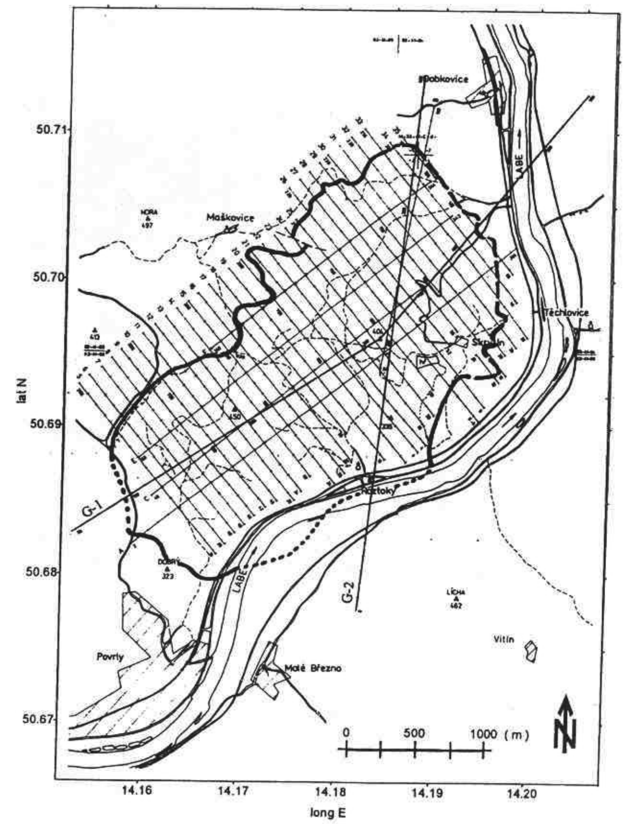

Fig. 3. Location of geophysical profiles and of special gravimetric interpretation profiles G-1 and G-2; situation elements – Labe River, roads, villages, etc.

Sandstones in the northern contact zone are thermally altered and do not differ from the caldera filling in their average density, which in case of breccias even exceeds that of sandstones (2.50 vs. 2.45 $g.cm^{-3}$). On the contrary, caustic marlites exhibit higher density values (2.52 $g.cm^{-3}$), see Tab. 1.

Essexites and "rongstockite", forming subvolcanic intrusions, are characterized by the densities between 2.75 and 2.95 $g.cm^{-3}$, by high contents of magnetic minerals (magnetite), and by magnetic susceptibility of $57–67.10^{-3}$ SI. Increased porosity of these rocks correlates with decreased susceptibility. In the filling of the structure the lowermost densities come from endocontact pseudotrachytes (2.33 $g.cm^{-3}$). After rheomorphic processes the rock density increases to 2.45 $g.cm^{-3}$ and massive breccias with carbonatic or feldspathic matrix reach even 2.50 $g.cm^{-3}$.

With respect to borehole Pd-2 data, the breccia varies a lot as for the matrix, porosity, alteration and disintegration with values around 2.00 $g.cm^{-3}$ being not exceptional. The total average bulk density can be estimated at 2.40–2.45 $g.cm^{-3}$.

Results

With respect to particular analyses of various data sets the following conclusions can be highlighted:

The Roztoky volcanic centre (caldera according to Kopecký 1987) is not formed by two separate trachytic breccia bodies as it could be estimated from gravity anomalies A1 and A2 (Fig. 4). The source of separation of the gravity low is a number of hidden small essexite or "rongstockite" intrusive bodies as relicts of an older structure. One of them is obviously located at the margin of the caldera (anomaly J1) with only Quaternary cover (Fig. 5). The "essexite line" (Kopecký 1987) is a tectonic element giving origin to these basic intrusions in the direction SSE–NNW across anomaly K to anomalies J2 and M2 (Fig. 6). The filling of the caldera shows generally lower densities than the surrounding Cretaceous sediments, and can be considered the main source of the large gravity low. In Fig. 7 and 8 the results of the gravity data analysis are exploited for the construction of the two profiles G-1 and G-2. The geometry of anomalous masses was calculated using 2.5-D modelling approach. Within the range of uncertainty the polygons were approximated by tentative geological contours. Especially, the volume of basic intrusive rocks in the form of either large blocks or blocks with increased amount of such rocks relicts should be highlighted. This is particularly evident in Fig. 8 at the northern part of the profile G-2. In this area the connection with a deep-seated magma source is most probable. The presence of basic rocks is well documented by indications in both gravity (Fig. 4) and magnetic fields.

According to the elevated content of U-Th-K and weak magnetic anomalies, the extent of the caldera at its northern limit may be reduced, see Fig. 9.

Some unknown basic intrusive bodies are indicated by gravimetry and magnetometry with densities around 2.80–2.90 $g.cm^{-3}$ and susceptibility of $60–70.10^{-3}$ SI. At the same time the

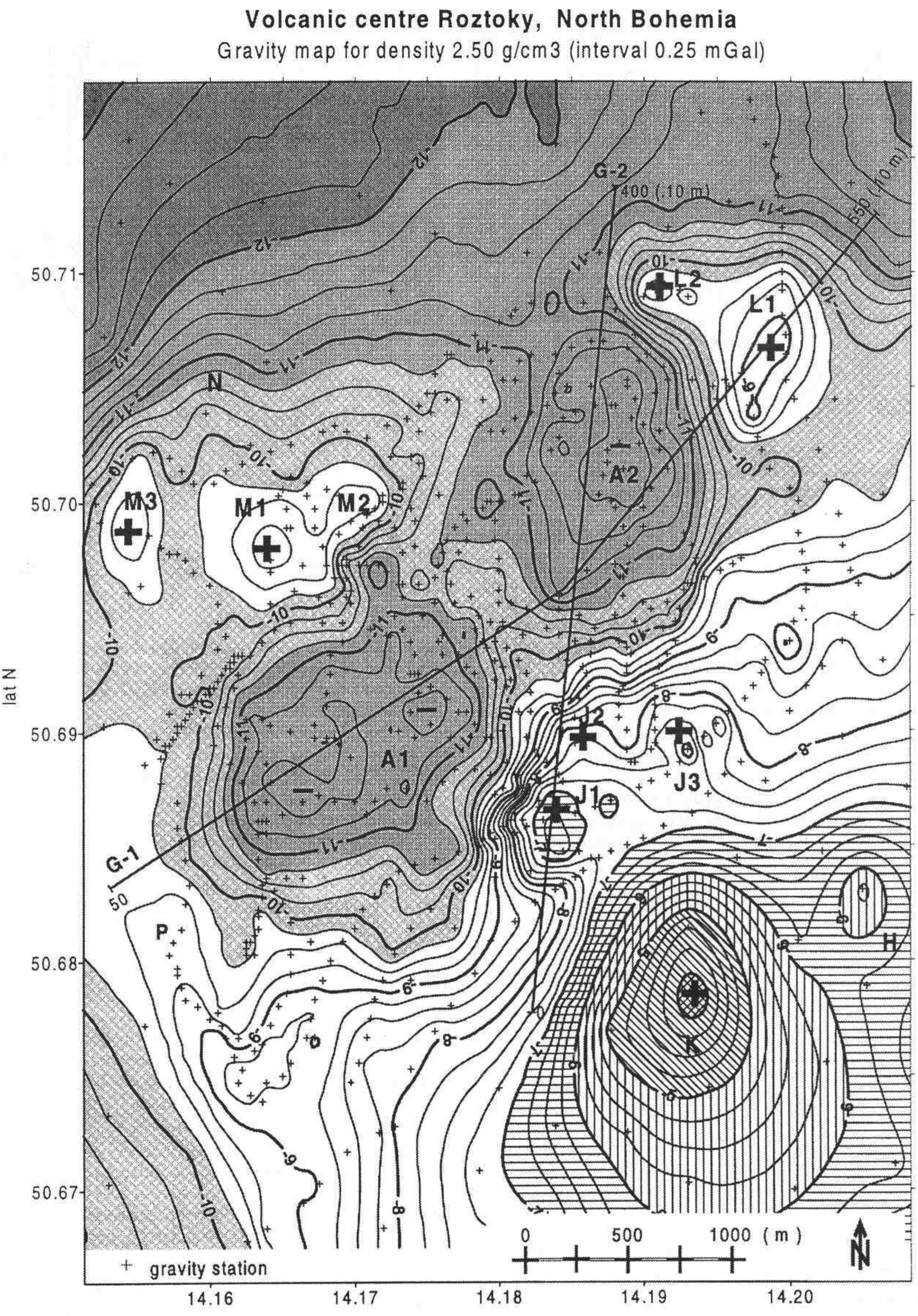

Fig. 4. Gravity map of the area (reduction density 2.50 g.cm[-3]) constructed from detailed measurements with additional old data at the margins; significant negative (A) and positive (H–N) anomalies; position of gravimetric stations (crosses).

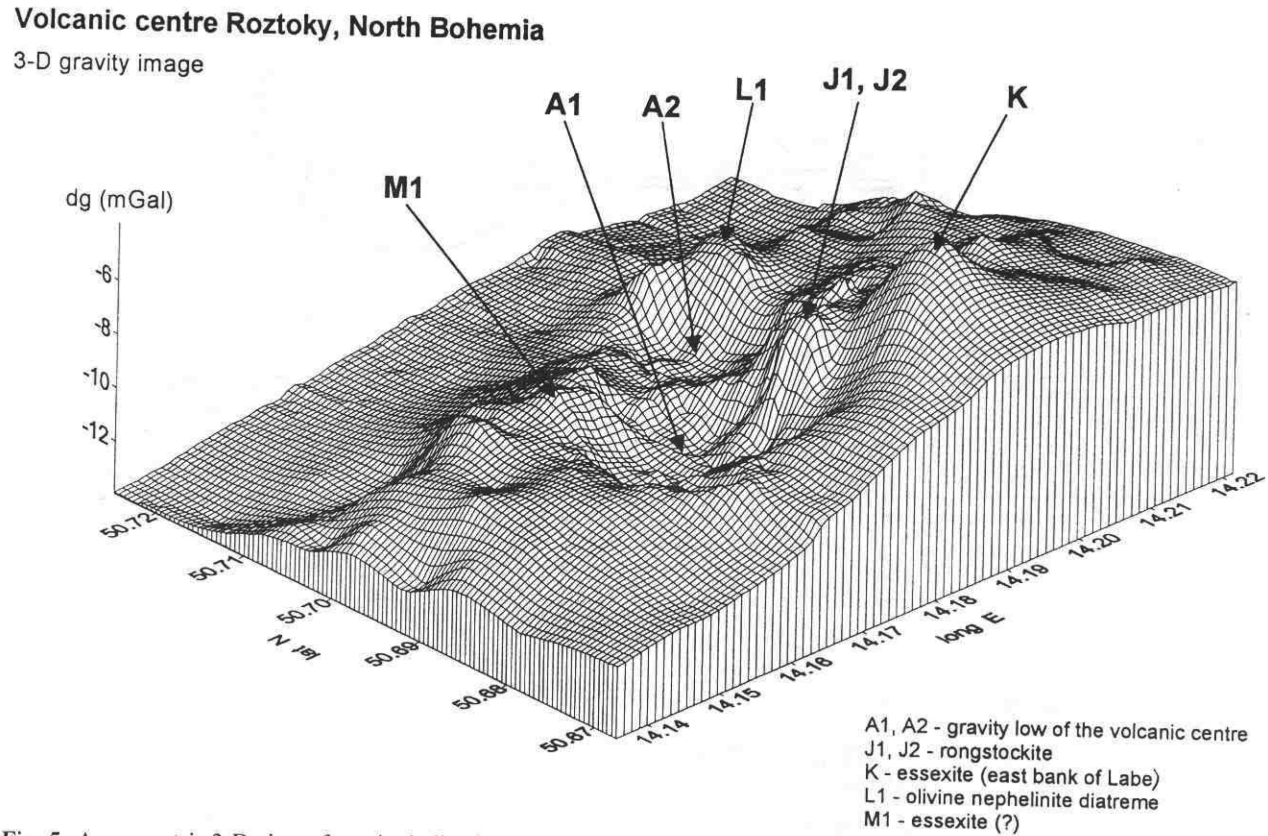

Fig. 5. Axonometric 3-D view of gravity indications with corresponding sources suggested.

U-Th-K content is low with relative prevalence of Th over U. A new area with hidden essexitic bodies is defined by anomalies M1–M3. The intensive indications of anomaly J1 (Fig. 4 and Fig. 8) determine one of the possible magmatic source positions (hidden carbonatite intrusion according to Kopecký 1987).

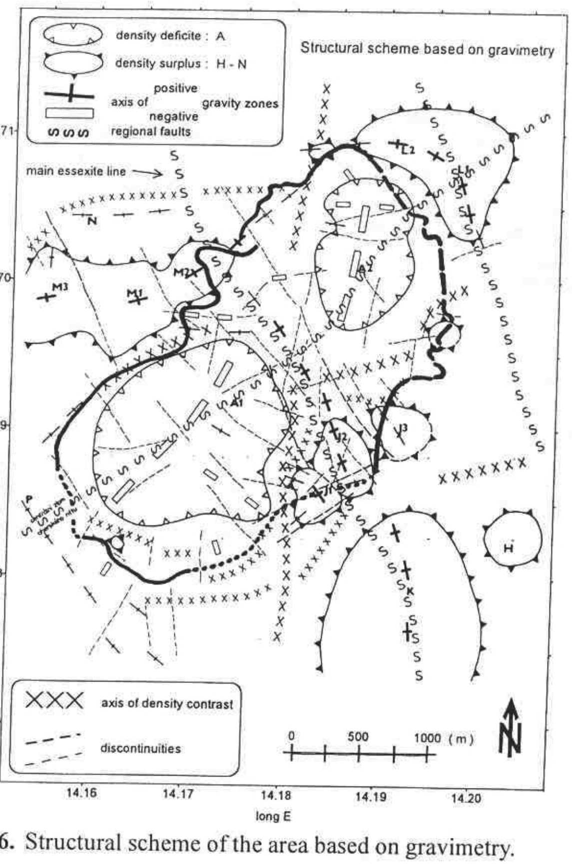

Fig. 6. Structural scheme of the area based on gravimetry.

Some of the positive gravimetric and magnetometric anomalies are connected with different basaltic intrusions, e.g. south of Dobkovice in the NE margin of the caldera, see anomalies L1 and L2 in Figs. 4–6.

Some of the local magnetometric anomalies may be considered an effect of small dykes of tinguaites (42 $.10^{-3}$ SI), as is probably the case of the hill (elev. point 404 m a.s.l.) in the centre of the structure. Phonolites and trachytes are characterized by high content of U-Th-K and increased susceptibility in some cases, see Tab. 1. In Fig. 9, the phonolite body is well indicated in the southern side by a distinct anomaly. The central maximum of U is connected with local pseudotrachyte intrusions. The 3 ppm contour along the NW side of the caldera can be used for a more precise identification of its margin.

Tectonic elements were determined by two different methods:

1) electromagnetic method VLF together with the analysis of surface magnetometry and spectrometry – mainly shallow fractures, often connected with dyke systems and local intrusive centres or with mineralized fractures.
2) deeper elements indicated by gravimetry – the main essexite line striking NNW–SSE and central fault of the Ohře Rift striking SW–NE (Fig. 6), significant density boundaries often corresponding to tectonic boundaries (defined as access of density contrast – Fig. 6), and other discontinuities derived from the changes of the local gravity field.

According to VLF, induced polarization and magnetometry measurements, mineralization was indicated in the area of the "rongstockite" intrusion J2 (the famous Anna vein with Pb-Zn-Cu (Ag, Te) mineralization described in detail by Pivec et al. 1984

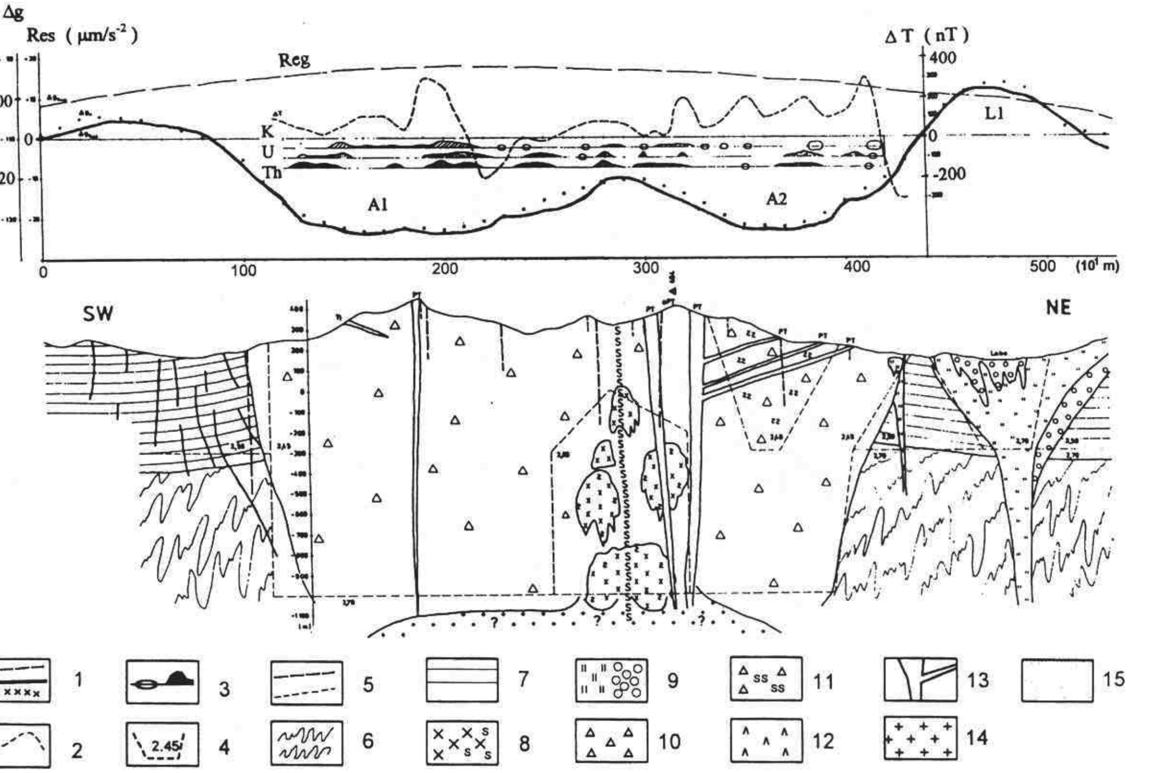

Fig. 7. Tentative interpretation of a density model – profile G-1. 1 – regional, residual and calculated gravity; 2 – magnetometry; 3 – deficit and surplus of U,Th,K; 4 – density model; 5 – geophysical fault indications; 6 – crystalline basement; 7 – Cretaceous sediments; 8 – essexite, "rongstockite"; 9 – basalts and tuffs; 10 – pseudotrachyte breccia (PTB); 11 – porous, altered PTB; 12 – trachyte; 13 – dyke rocks (pseudotrachyte, tinguaite); 14 – carbonatite; 15 – Quaternary sediments.

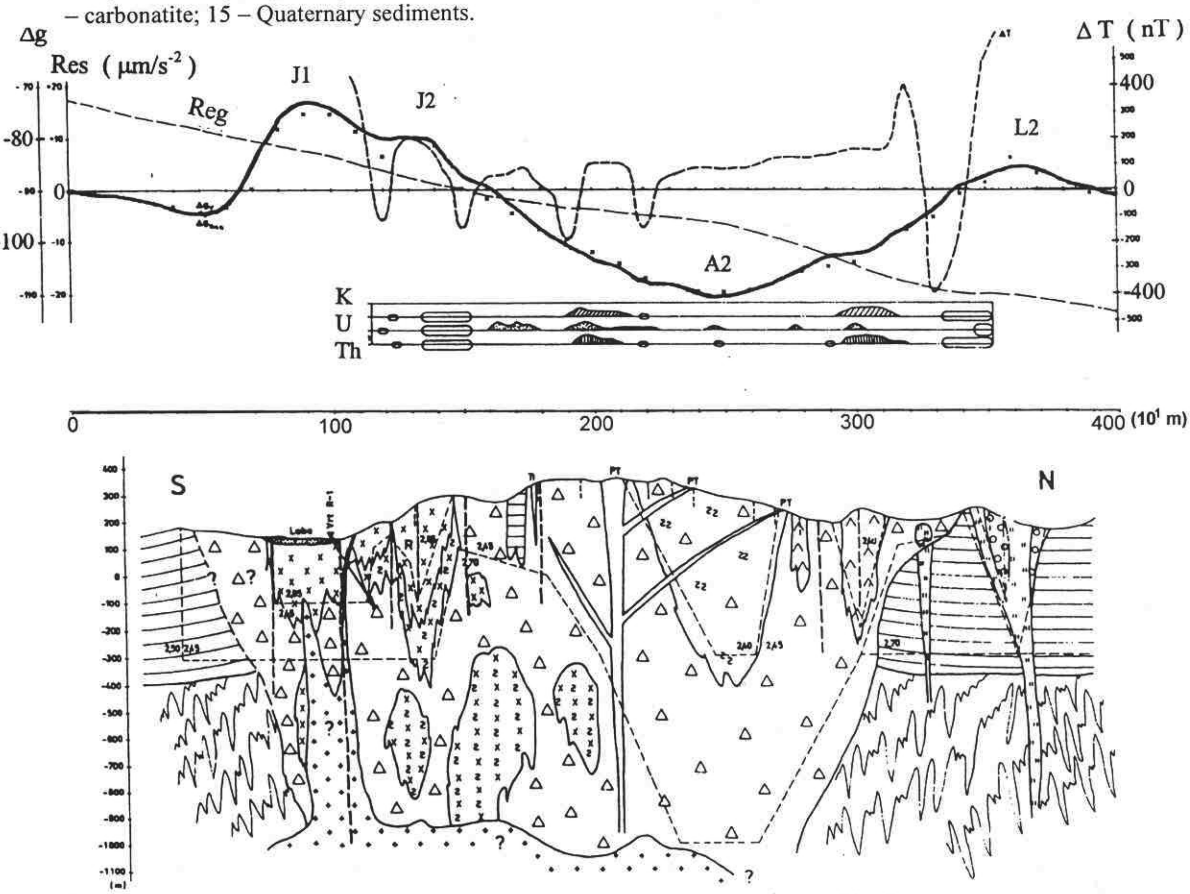

Fig. 8. Tentative interpretation of a density model – profile G-2. For explanations see Fig. 7.

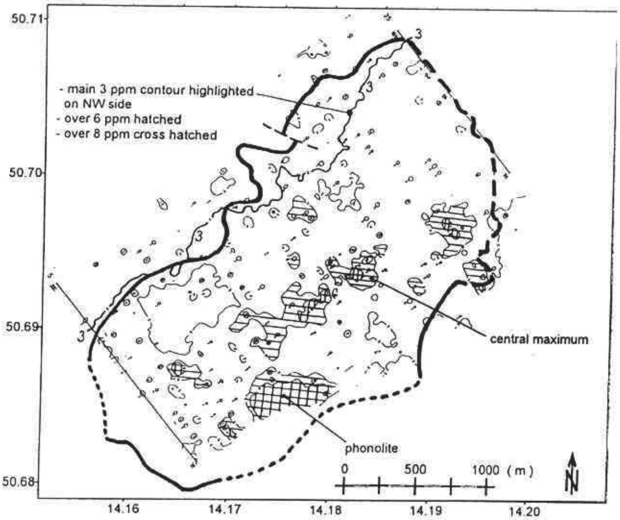

Fig. 9. Gamma-ray spectrometry – uranium (ppm).

and 1998). Some indications were found in its close vicinity, and also in the central intrusive area N of Roztoky (near elev. point 404). Few veinlets with young carbonatites were described in the "rongstockite" intrusion by Kopecký (1987). The location of the above mentioned geological features is given in Fig. 2.

Conclusions

Geophysical investigation of the Roztoky volcanic centre of the České středohoří Mts., North Bohemia, was initiated by gravimetric modelling of the negative anomaly recognized from old gravity maps. In consequence, detailed gravimetry, magnetometry, gamma-ray spectrometry, VLF, induced polarization and some other methods were applied for the survey.

Rocks or zones of different contents of magnetic minerals and K-U-Th elements were localized, as well as indications of mineralization and faults. Tentative calculations were performed at selected profiles G-1 and G-2 to provide a comprehensive output of the survey. However, detailed geological interpretation in Figs. 7 and 8 represents only one (and not unique) possible solution. The Roztoky structure was analysed by means of detailed gravimetric data so that the presence and amount of particular rocks could be determined. Special attention was paid to basic intrusives (essexite, "rongstockite") and "caldera" filling (pseudotrachyte breccia). More basic bodies were localized inside and in the close vicinity of the "caldera" and a significant magma accumulation can be expected at a deeper level as the main source of all kinds of phenomena (subvolcanic stocks, dykes, vents).

The investigation was supported by large amounts of petrophysical data from boreholes and from extensive surface sampling.

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