Sborník geologických věd	Ložisková geologie, mineralogie, 31	Pages 67–73	3 figs.	– tabs.	– pl.	ČGÚ Praha 1997	ISBN 80-7075-204-1 ISSN 0581-9180

Geophysical position of granitoid plutons in the Bohemian Massif

Geofyzikální charakteristika granitoidních plutonů v Českém masivu

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Received September 28, 1993

Key words: Bohemian Massif, Granitoid pluton, Geophysical fields

POKORNÝ, J. (1997): Geophysical position of granitoid plutons in the Bohemian Massif. – Sbor. Geol. Věd, ložisk. Geol. Mineral., 31, 67–73. Praha.

Abstract: Granitoid plutons of the Bohemian Massif have been studied from the point of view of their structural position with respect to the geophysical fields and to the depth of the Moho. These plutonic bodies occur mostly above the slopes between the elevations and depression of the Moho-relief. The pre-Variscan plutons occur predominantly within the positive zones of the regional gravity field (indicating a decrease of the thickness of the upper part of the Earth's crust). Of the Variscan plutons, the younger ones are located in regional gravity depression zones where the upper crust is probably the thickest. The older Variscan intrusions are located in gravity gradient zones, i.e. between the zones of regional positive gravity anomalies and the negative ones. Another structural position show durbachite massifs and some small granitoid intrusions which are controlled by deep-seated faults. The regional anomalous geomagnetic field shows mostly similar relationship to the granitoid plutonism as does the gravity field. The exceptions (e.g. in the Krušné hory Mts. area) show differences in the interior structure of the upper crust.

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Introduction

A high frequency of granitoid rocks of different composition in the basement of the Bohemian Massif and comparative studies of their size, age, geochemical characteristics and mutual relationships have evoked question of the relationship between these phenomena and the structural position of individual plutonic bodies. This cannot be solved without the evaluation of regional geophysical and petrophysical data. While the petrophysical data together with the petrological and geochemical characteristics are of a great importance in characterizing individual intrusions, the regional geophysical patterns (in the Czech part of the Bohemian Massif recently, on the whole, precisely described) reflect some broader coherences in the deeper Earth's crust structure in the region of the interest.

There are three main types of geophysical information important for studying the position and character of individual plutons: the thickness of the Earth's crust (the depth of the Moho), their position within the regional gravity field and within the regional geomagnetic field.

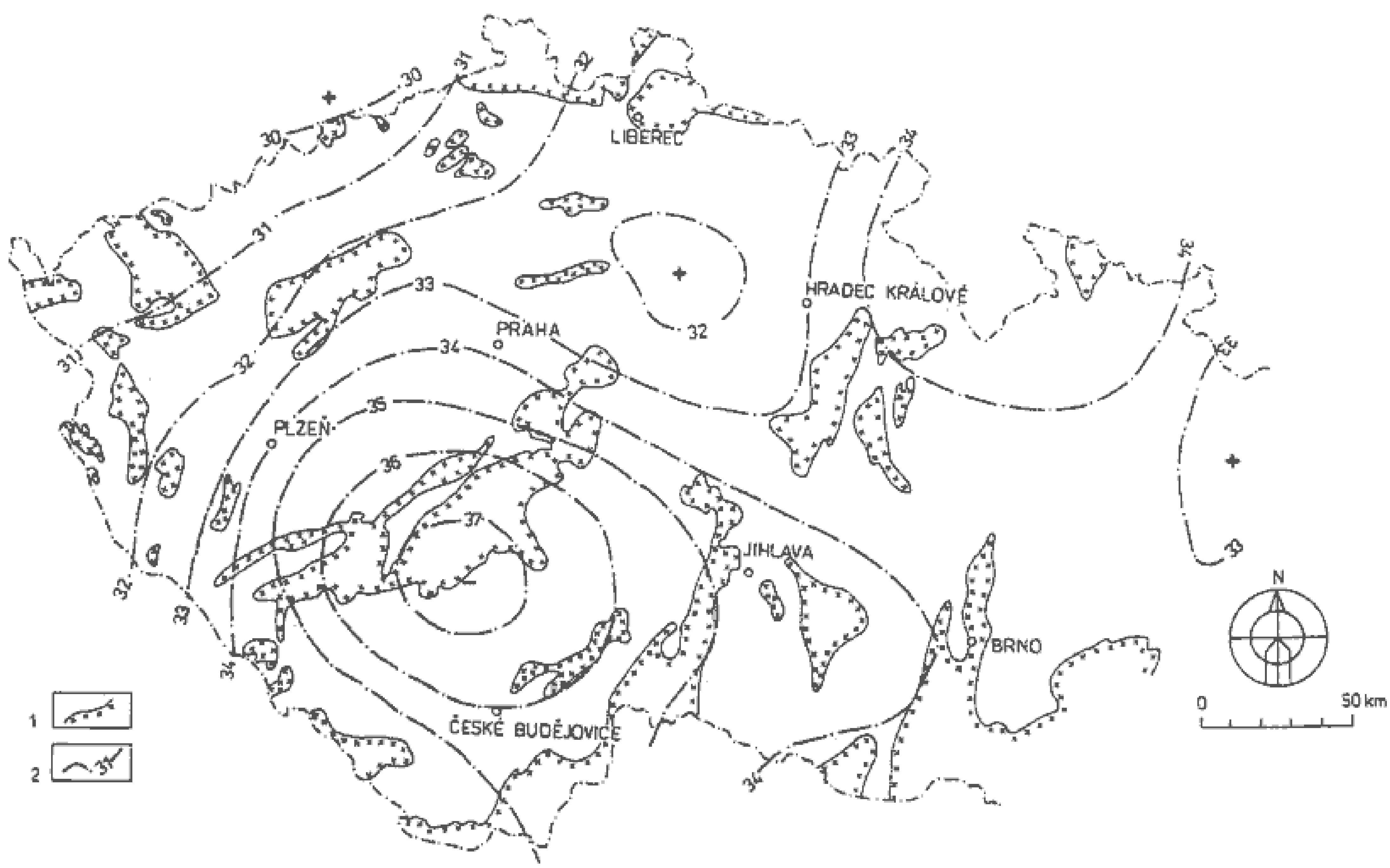
Thickness of the Earth's crust

Deep seismic sounding profiles and data of industrial explosions (particularly in quarries) outside these profiles have formed the basis of the map of the crustal thickness on the territory of the Czech Republic compiled by Mayerová et al. (1985). The deep pattern of the Moho is characterized there by the presence of a closed W-E depression zone of the Moho with the maximum thickness of the crust more than 37 km within the Moldanubian zone in the area south of the Central Bohemian pluton. This depression zone reaches in ESE even the Moravian branch of the Moldanubicum while in the area of the Moravicum and Brunovistulicum a cross-elevation of the Moho down to the depth of less than 34 km occurs. Within the area of this cross-elevation zone only pre-Variscan plutons are known (the Brno and Dyje plutons and some smaller intrusions in the Morava block). There are no indications of the presence of the Variscan plutonism in this area.

The depression zone of the Moho mentioned above is supposed by Zeman (1980) to be a relic of a pre-Cadomian or even pre-Carelian zone of intensive sialization, i.e. a nucleus of increasing continental crust. From the point of view of the plate-tectonics theory it can be interpreted as an indication of the presence of a W-E collision zone between the Laurasia and Gondwana plates (Suk 1986).

Outside this central depression zone, the Moho-relief is elevated in all directions. The thickness of the crust decreases to about 32 km in the NE (in the Bohemian Cretaceous Basin with a shallow separate depression in the area of the Lugian Orlice-Kłodzko Dome), to about 30 km in the NW (in the area of the Saxothuringicum including the Krušné hory Mts.) and to about 31 km in the W (in the area of the Moldanubicum of the Český les Mts.).

Comparing these data with the map of outcrops of granitoid plutons (see Fig. 1), it can be concluded that (with a partial exception of the southern part of the Central Bohe-



1. Structural position of granitoid plutons of the Bohemian Massif regarding to the Earth's crust thickness. 1 – schematized contours of outcrops of granitoid plutons in the basement of the Bohemian Massif, platform cover stripped (after Chaloupský 1983), 2 – isobaths of the Moho-discontinuity (in km).

mian pluton) no extensive outcrop of a granitoid plutonic body occurs downright inside the depression zone of the Moho. These bodies crop out much more above the slopes of this discontinuity or even inside the zone of elevation (this is the case of pre-Variscan plutons in the Morava block).

Gravity field

Relationships between the anomalous gravity field and the position of granitoid plutons in the Bohemian Massif were studied by Klomínský and Dudek as early as in 1978. The authors worked with a schematic map of Bouguer's anomalies of gravity and with empirically derived boundaries between positive and negative gravity areas as defined by Bernard et al. (1976). On the contrary, our discussion is based on a map of the second derivative of gravity for Elkins formula (for the radius of 15 km) treated by Beránek and Dudek (1981). By the latter method the influence of surface density inhomogeneities has been more effectively suppressed and the boundaries of positive and negative gravity anomalous areas reflecting the deeper patterns of the crust have been more accurately localized (see Fig. 2).

There are several regional anomalous zones of gravity in the Bohemian Massif on the territory of the Czech Republic, described by Buday et al. (1969), later by Blížkovský et al. (1985). Their general direction is SW-NE up to W-E. This pattern is usually explained by the different thickness of the upper part of the crust (i.e. of the "granitic layer") and by the presence or absence of extensive granitoid plutons. Except the margin of the positive gravity area of the Saxothuringicum-Lugicum (represented, on the Czech territory, by a small area of the Lužice pluton in northern Bohemia only), the following regional gravity anomalous zones are the most important:

1. the negative gravity belt of the Krušné hory Mts. and the Krkonoše Mts.,

2. the positive gravity area of the Bohemicum (including its parts covered with platform sediments),

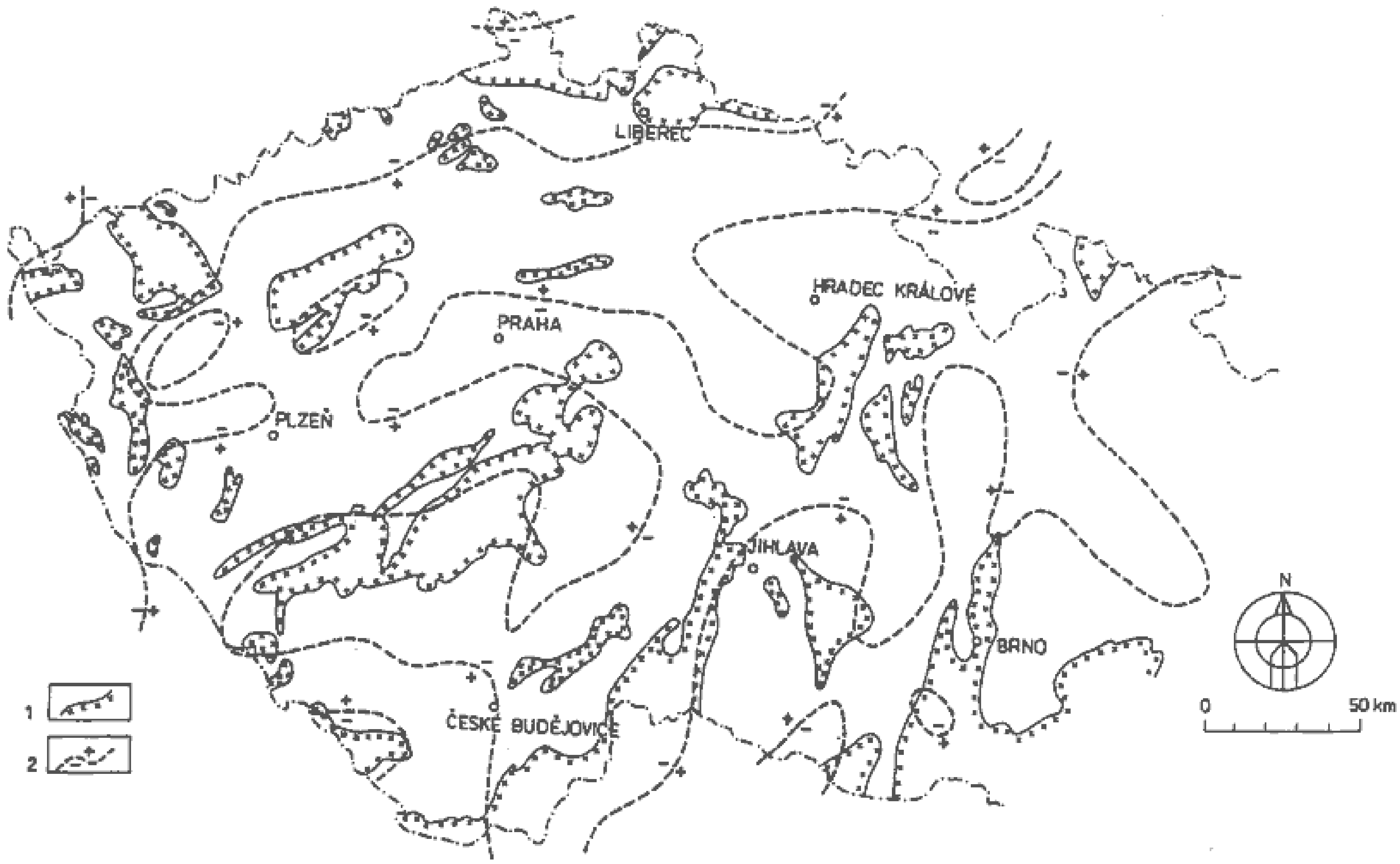
3. the continuous belt of negative gravity anomalies in the Bohemian branch of the Moldanubicum together with the southern part of the Central Bohemian pluton, the western part of the Moldanubian pluton, the Svratka Dome and the Orlice-Kłodzko Dome,

4. the positive gravity area in the easternmost part of the Bohemian Massif including the Moravian branch of the Moldanubicum, the Moravicum-Silesicum and the Brno pluton (as well as the Brunovistulicum partly covered with Tertiary sediments of the Carpathian Foredeep and the Flysch belt).

Regarding these gravity patterns granitoid plutons can be divided into two great groups:

1. the plutons occurring within areas of homogeneous (positive or negative) regional gravity characteristics,

2. the plutons extending in the gravity gradient areas



2. Structural position of granitoid plutons of the Bohemian Massif regarding to patterns of the regional anomalous gravity field. 1 – see fig. 1, 2 – zero lines of the second derivative of gravity for Elkins formula (radius of 15 km).

along boundaries between the positive and negative regional gravity zones.

Ad 1. The homogeneous positive regional anomalous gravity field is typical of the pre-Variscan plutons, i.e. of the Lužice pluton in the Saxothuringian-Lugian positive area, of the Čistá-Louny pluton and some smaller ones within the positive area of the Bohemicum and of the Brno and Dyje plutons in the Moravian positive zone. All these bodies consist mostly of biotite granodiorites and tonalites. As for the Čistá-Louny pluton (regarding its dominant part consisting of granites), it is bounded with a relative gravity depression, though, but on the background of the regional elevation zone of the Bohemicum.

Only two large granitoid bodies of Variscan age are localized in uniformly characterized regional gravity patterns, namely the Krušné hory Mts. pluton (mutual connection of its outcrops forming a number of partial massifs at depth has been generally proved) and the Krkonoše-Jizera pluton (as well as the smaller Strzegom pluton east of it in Silesia). These plutonic bodies have not only ascended within a conspicuous negative regional gravity zone but they still infill its essential part. A great deal of the regional anomaly is caused by lower values of density of granitic rocks of these plutons, nevertheless, the source of the regional gravity depression cannot be derived only from that phenomenon. According to the computations of Polanský (1973), who estimated the thickness of the granitoids in the Krušné hory Mts. area at more than 10 km, the presence of a relatively low density complex of metamorphites underlying the pluton should be proposed in this area. This conclusion has been partly confirmed by some data of reflection seismics by which a layer of frequent reflection horizons has been detected below the granites. The main type of the Variscan intrusive rocks in this whole negative gravity area is represented by granites (including the youngest type of tin-bearing granites). Also some pre-Variscan (supposed) relict granites are present in this area, e.g. in the form of the red orthogneisses of the Krušné hory Mts., of the Jizera orthogneiss etc. (Klomínský - Dudek 1978).

To a certain extent, the Moldanubian pluton of Variscan age can be assigned to this group. Its outcrops, mostly consisting of granite and granodiorite rocks, occur, indeed, near the margin of the negative gravity area of the Bohemian Moldanubicum but similar plutonic rocks are supposed to underlie metamorphites in a great part of this area. Thus the pluton can be recognized as a certain transition case between the first great group defined and the second one for which the position in a gravity gradient zone is significant. According to the research of Dudek and Beránek (1981), the NNE-SSW Přibyslav deep-seated tectonic zone separating (by the course of the zero line of the second derivative of gravity) the negative regional gravity area of the Bohemian Moldanubicum from the positive one in the easternmost (Moravian-Silesian) region of the Bohemian Massif, turns in the southern segment of its course (already in Austria) to the SW and intersects the southern part of the pluton (consisting here mostly of biotite granodioritic rocks). Hence a transition character of the pluton, documented by results of petrological, geochemical and geophysical researches, is fully comprehensible. As a matter of fact, this pluton represents by no means such an homogeneous plutonic body as it was formerly supposed. The isometric local gravity minima (at Landštejn, Čeřínek, Melechov and others) indicate the presence of the stock-formed bodies reaching down to the depth of 10–15 km and consisting mostly of coarse-grained granites. In other parts of the pluton considerably lower values of granitoid rocks thickness were computed from the gravity anomalous field by Tomek et al. (1975), Mottlová (1982) a.o. Therefore it can be concluded the genuine intrusions of the acid granitic magma under the local gravity minima mentioned can be supposed, whereas in other segments of the pluton outcrop granitoid rocks have been more affected by patterns and character of surrounding mantle during their emplacement.

As already mentioned, granitoid intrusions are supposed to underlie the dominant part of metamorphites of the Bohemian Moldanubicum (based on gravity data, Mísař et al. (1972) a.o.). Even in the very core of the gravity depression zone of the Moldanubicum, at a depth of about 2 km, Tomek (1976) presumes an extensive, by metamorphites covered batholith-formed granitic body. According to this author, this batholith may reach the depth of 16–20 km. The granodiorite bodies of the southern part of the Central Bohemian pluton (of Blatná, Červená and Sedlčany types) are thought by him to be satellite plutons of this batholith and they might have originated through a transformation of rocks of the upper crust of a continental character. (Nevertheless, the presence of mantle components in those granitoid rocks has been proved by recent geochemical researches.) The supposed deep connection with the Moldanubian pluton has to be sought in the eastern direction only, as it is shown by the course of the zero-lines of the second derivative of gravity. Finally, a deep covered connection between the granite of the Melechov massif (the northern part of the Moldanubian pluton) and the granite of the Říčany massif (contingently of a hypothetical pluton of Říčany-Kutná Hora reaching a depth of about 15 km, too) were supposed by this author; such a coherence is, however, on the basis of new geochemical results not much probable.

Some Variscan (as well as pre-Variscan) granitoid plutons occur within positive regional gravity areas, particularly in the Teplá-Barrandian area. Such bodies are manifested by relative gravity depressions of a lower order on background of a regional positive zone. This is particularly the case of the Kladruby massif, including its (by gravity interpretation presumed) covered continuation to the NE. A similar relative gravity depression in the Barrandian Prague Basin, formerly explained in the same way as an indication of a covered granitoid pluton, has been later interpreted on the basis of seismic research as an effect of light Palaeozoic basin sediments only (Tomek 1978).

Ad 2. A heterogeneous gravity field within gradient zones between positive and negative regional gravity areas is typical of the Bor massif in western Bohemia and namely of the Central Bohemian pluton. The former one is located at the western boundary of the positive Teplá-Barrandian area with the negative zone of the Český les Mts.; both its northern and the southern parts are characterized by negative gravity anomalies reflecting their granitic and granodioritic composition, the middle part consisting mostly of tonalites shows weakly positive gravity characteristics.

The most outstanding case of pluton with heterogeneous gravity effect is undoubtedly the Central Bohemian pluton. Its northern part pertains to the positive gravity area of the Bohemicum whereas the southern one occurs on background of the regional gravity depression zone of the Moldanubicum. The boundary between both the parts courses along the Central Bohemian suture consisting of the Klatovy and Benešov deep-seated faults according to Röhlich-Šťovíčková (1968), i.e. in the middle-axis of the pluton. The relationship of the southern part of the pluton to the Moldanubicum has been discussed above. In the northern part, with its expressively positive gravity characteristics, tonalite rocks of the Sázava type and of some similar smaller intrusions are dominant. In Tomek's (1976) opinion, these tonalite intrusions have been generated through Variscan remobilization of a hypothetical batholith of gabbrodioritic composition indicated by an impressive positive gravity anomaly. He has computed the depth of the top of this batholith to be about 4 km and the bottom of it to be about 18 km under the surface. This author considers this batholith-like body as a part of a Proterozoic island-arc. Other (e.g. Šalanský 1975) prefer the idea of assimilation of the mafic volcanics of the Jílové zone by the granitoid magma. It is remarkable that the granitoid rocks in this part of the pluton contain accessory minerals (particularly magnetite) controlling their extraordinary physical properties.

In a certain extent, an analogous boundary position as that of the Central Bohemian pluton is also typical of some other intrusions within the central belt of the Variscan granodiorite-tonalite plutonism (the Nasavrky pluton, the Strzelin pluton a.o.).

Independently of the regional gravity field durbachite massifs occur as well as a set of the so-called Variscan small intrusions (the Štěnovice massif, the Čistá stock within the older Čistá-Louny pluton, some small covered intrusions in the platform sediments etc.). All these intrusive bodies are characterized by a somewhat anomalous mineral composition controlling their anomalous physical properties (anomalous magnetization, especially). The origin of these intrusions has been obviously controlled above all by deep-seated tectonics.

Geomagnetic field

The regional geomagnetic field of the Bohemian Massif (see Fig. 3) shows, at the first sight, similar patterns as the gravity field. Regional geomagnetic elevations, as far as they correspond to regional gravity positive zones, indicate usually the presence of mafic rocks at various depths. This fact has influenced the character of granitoid rocks on the surface. The most expressive example of that is the northern (tonalite-granodioritic) part of the Central Bohemian pluton lying within the area of a many kilometres long geomagnetic anomalous belt of Central Bohemia, where surface rocks (the Sázava tonalite, the Požáry granodiorite and the so-called marginal type of granodiorite are frequently manifested by even extreme magnetization. Similar relations are obvious in the Nasavrky pluton (where Variscan acid granites as well as pre-Variscan granodiorites are strongly magnetized), partly also in the Brno pluton and in other similar bodies.

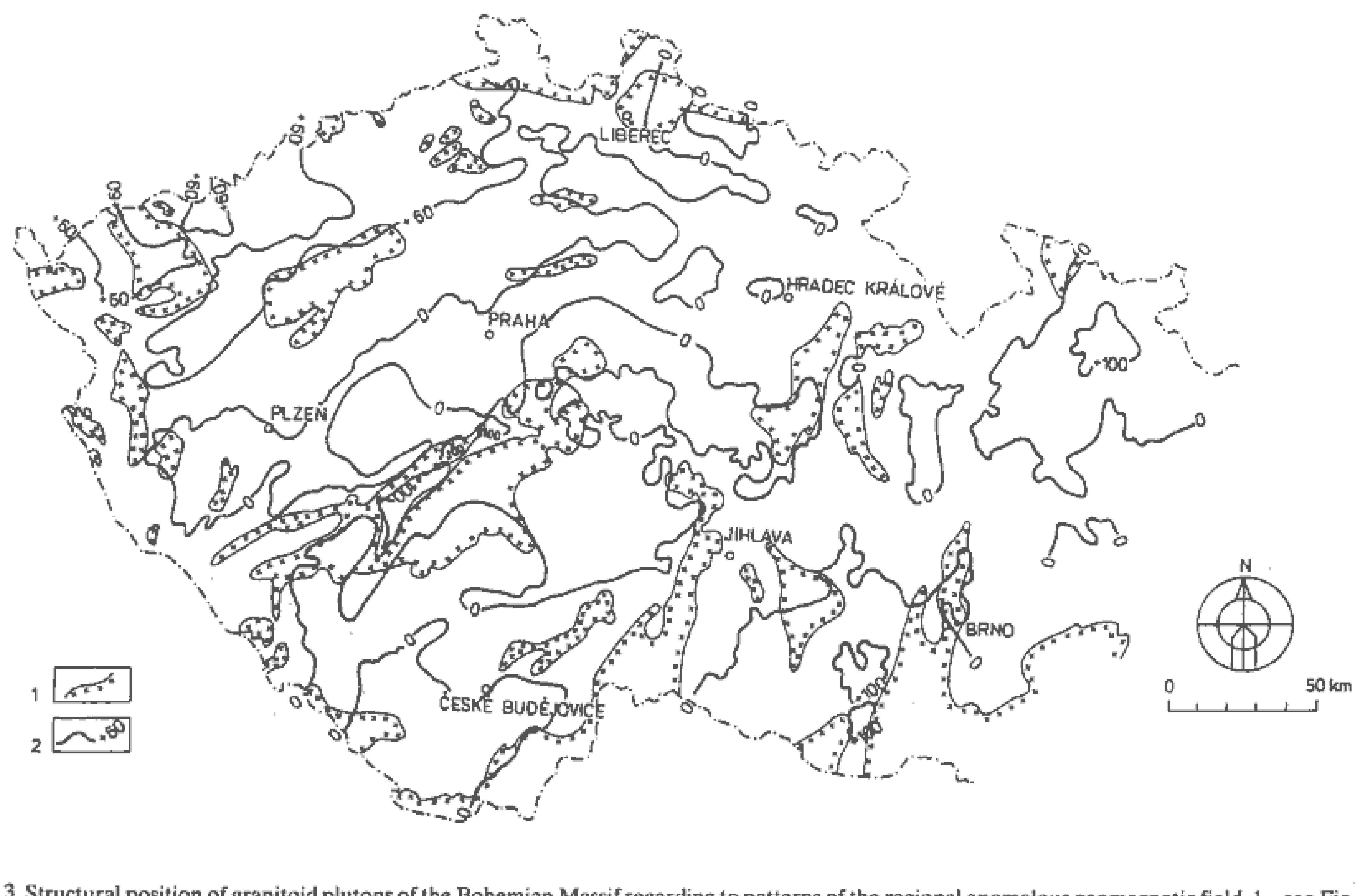
Another case is the position of the Krušné hory Mts. and Krkonoše-Jizera plutons. These occur predominantly on background of weak or stronger regional geomagnetic elevations, whereas, as mentioned above, the regional gravity field is expressively negative. As the outcrops of the most part of these intrusions behave as non-magnetic, practically, sources of the magnetic anomalies (perhaps of character of acid metavolcanics) have to be sought under the granitoids. At the surface, the granitoid rocks in some cases contain, however, also strongly magnetized magnetite-bearing horizons, namely within tectonic zones and especially when they are formed into circular structures. Magnetic anomalies of this character can be recognized in the endocontact zone of the Kirchberg massif, as well as in a similar zone in the western part of the Krkonoše-Jizera pluton, in linear tectonic zones within the Fláje massif etc. Phenomena of this kind are not known in areas of regional geomagnetic depressions.

An anomalous magnetization caused by accessory magnetite has often been found in the granitoids of the so-called small intrusions, too, controlled by linear tectonic patterns. It is possible to join some newly investigated small intrusions within the southern part of the Moldanubian pluton to this group (e.g. the supposed covered syenite intrusion body south of Nová Bystřice).

Outside tectonic patterns an anomalous magnetization of granitoid rocks within regional geomagnetic depression zones is quite extraordinary and it indicates mostly the presence of relics of the mantle of intrusions.

Remarks on radioactivity

The distribution of radioactive elements in granitoids belongs to their important petrophysical characteristics. Therefore it should be studied in detail in correlation with other physical properties and chemical and mineralogical composition of individual intrusions. It can be just stated here that the activity of the Variscan granitoids is generally higher than that of the pre-Variscan ones. The determination of the differences between the contents of the individual radioactive elements in different intrusive bodies as well as in different parts of the same intrusion has led in some cases to more precise distinguishing between the individual intrusion phases.



3. Structural position of granitoid plutons of the Bohemian Massif regarding to patterns of the regional anomalous geomagnetic field. 1 – see Fig. 1, 2 – isolines of analytical continuation of the anomalous geomagnetic field (total intensity) at the level of 1km above the terrain (in nT).

Conclusions

On the basis of he foregoing discussion the following conclusions can be drawn:

1. The pre-Variscan granitoid plutons, both of granite-granodiorite and tonalite composition, occur in the regional positive gravity areas indicating a lesser thickness of the upper crust. These areas are usually characterized by the presence of extensive complexes of unmetamorphosed or weakly metamorphosed volcano-sedimentary rocks of the Proterozoic or Early-Palaeozoic age forming the mantle of the granitoids. Volcanic, subvolcanic as well as plutonic bodies of various composition within these rock sequences often contain ferromagnetic accessories; as a consequence of that they produce both regional (deep bodies) and local (near-surface bodies) magnetic anomalies passing sometimes even into granitoid plutons. On background of regional positive gravity field the plutons consisting of granites and/or granodiorites manifest themselves by relatively negative gravity anomalies of a lower order (e.g. the Čistá-Louny pluton), whereas biotite-hornblende granodiorites and tonalites have either no gravity effect or produce weak, relatively positive gravity anomalies (e.g. the northern part of the Stod massif, the Brno pluton etc.).

2. The very different pole of geophysical position is represented by young Variscan plutons mostly of granite and granodiorite character occurring within areas of highly negative regional gravity anomalies. The mantles of these plutons are formed predominantly by meso- and catazonally metamorphosed rock complexes, in which mafic volcanics and subvolcanics are usually confined in narrow tectonic zones. The Krušné hory Mts. and the Krkonoše-Jizera plutons are typical cases of granitoids of this kind. The Moldanubian pluton belongs partly to this group, too. The regional geomagnetic field in these areas shows, as a rule, an indifferent or weakly negative character; as far as weak regional geomagnetic elevations (as an exception) occur there (above all in the Krušné hory Mts. area), an anomalously magnetized and light layer (perhaps consisting of metamorphosed pyroclastic sediments of unknown composition ?) should be supposed in the basement of the pluton.

3. There are some orthogneiss bodies in the Krušné hory Mts., Smrčiny Mts., Jizerské hory Mts. regions as well as in the Moldanubicum, usually considered to be derived from the pre-Variscan granitoids; they occur together with the Variscan granites on background of strongly negative regional gravity field. In some cases, they can show an anomalous magnetization, too. The origin of these rocks can be explicated, however, also in another way (e.g. by metamorphosis of old acid volcanics).

4. The plutons consisting mostly of intrusions of the older Variscan intrusion phase are characterized by the position on the boundary between positive and negative gravity areas. Such a typical example is the Central Bohemian pluton, partly also the Bor massif and the Nasavrky pluton. As a transition case to this type the Moldanubian pluton can be considered. As to the Central Bohemian pluton, within its northern (Barrandian) part an effect of contamination by products of the pre-Variscan basic volcanism and plutonism upon formation of the Variscan granitoid rocks is obvious; thus the positive gravity anomalies are characteristic of this part where tonalite rocks, often with an outstanding magnetization, are predominanting. The nature of the southern (Moldanubian) part of this pluton, characterized by the negative regional gravity field, approaches to the biotite granodiorite composition, being practically without any significant magnetization but showing a higher content of radioactive elements. A less obvious analog of these conditions can be observed within the Moldanubian pluton, too, where on the side of positive anomalous gravity values in the transition zone between the positive and negative gravity field the biotite granodiorites of the Weinsberg type are present. A probable deep coherence between the Moldanubian pluton and the southern part of the Central Bohemian pluton can be supposed through the area of the gravity minimum of the Moldanubicum and eastwards of it (based on gravity data).

5. So-called small Variscan intrusions as well as durbachite massifs are located more or less independently of regional geophysical patterns. They are controlled mostly by deep-seated fault structures.

6. The thickness of the Earth's crust as a whole does not show any direct relationship to the granitoid plutonism. This fact can be regarded as an evidence of dominantly crustal provenance.

Recommended for print by K. Šalanský
Translated by the author

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Geofyzikální charakteristika granitoidních plutonů v Českém masivu

(Resumé anglického textu)

LADISLAV POKORNÝ

Předloženo 28. září 1993

Granitoidní plutony Českého masivu jsou zkoumány z hlediska jejich strukturní pozice, jak se jeví v geofyzikálních polích, a to vzhledem k rozložení M-diskontiunity, regionálního tíhového a regionálního geomagnetického pole. Je konstatováno, že granitoidní plutony se vyskytují převážně nikoliv v místech největších mocností zemské kůry, nýbrž na svazích mezi depresemi a elevacemi M-diskontinuity určenými ze seismických měření. Prevariské plutony vystupují především v zónách regionálních tíhových elevací indikujících menší mocnost svrchní kůry, z variských pak plutony mladší fáze především v pásmech regionálních tíhových depresí ukazujících na větší mocnost této svrchní části kůry. Zvláštní postavení mají plutony s nejednotnou tíhovou charakteristikou, ležící na okrajových gradientech mezi regionálně kladnými a zápornými tíhovými oblastmi; typickým příkladem je středočeský pluton. Nezávislé postavení mají durbachitová tělesa, jakož i některé malé granitoidní pně, ovlivněné především průběhem hlubinných tektonických zón. Regionální magnetické pole má vzhledem ke granitoidnímu plutonismu převážně kladnou korelaci s polem tíhovým. Tam, kde tomu tak není (oblast Krušných hor), ukazuje to na odlišný typ stavby svrchní kůry.

Vysvětlivky k obrázkům

1. Strukturu pozice granitoidních plutonů Českého masivu vzhledem k mocnosti zemské kůry. 1 – schematizované obrysy výchozů granitoidních plutonů ve fundamentu Českého masivu při odkrytí platformního pokryvu (podle J. Chaloupského, 1983), 2 – izobaty Moho-diskontinuity (v km).

2. Strukturní pozice granitoidních plutonů Českého masivu vzhledem ke strukturám pole regionálních anomálních tíží. 1 – viz obr. 1, 2 – nulové linie druhých derivací tíže podle Elkinse (pro poloměr 15 km).

3. Strukturní pozice granitoidních plutonů Českého masivu vzhledem ke strukturám pole regionálních geomagnetických anomálií. 1 – viz obr. 1, 2 – izanomály analytického pokračování anomálního geomagnetického pole (totální intenzity) na hladině 1 km nad terénem (v nT).