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The Čistá-Jesenice pluton in western Bohemia: Geochemistry, geology, petrophysics and ore potential

Čistecko-jesenický pluton v západních Čechách: geochemie, geologie, petrofyzika a rudní potenciál

LUBOMÍR KOPECKÝ, Jr.[1] - MARTA CHLUPÁČOVÁ[2] - JOSEF KLOMÍNSKÝ[3] - ADOLF SOKOL[4]

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Abstract: The Čistá-Jesenice pluton forms a large elongated body (over 1000 sq. km) in the Teplá-Barrandian zone of the Bohemian Massif. It consists predominantly of the Tis biotite granite which intruded into an anticlinorial zone of Upper Proterozoic rocks probably during Late Cambrian (or Early Ordovician ?). This granite body was later penetrated by the Čistá granodiorite stock during Early Devonian and deeply eroded and extensively exposed before Late Paleozoic. The Tis granite and Čistá granodiorite were later affected by processes of alkali metasomatism (fenitization) connected with hypothetical carbonatite magmatism, in the contact zone of both the granite and granodiorite intrusions. Mylonitization, fenitization and feldspathization, which occured at the contact of granite and granodiorite and on radial faults in the granodiorite body, carry a Mo-Zr-REE mineralization. During Late Carboniferous the whole pluton was covered by continental sediments. The pluton crops out in several isolated areas only (Tis, Jesenice-Oráčov, Petrohrad and Čistá). The granite pluton of Late Cambrian age and the Early Devonian Čistá granodiorite body differ in their geophysical, structural, and geochemical characteristics.

[1] *Aquatest Stavební geologie, a. s., Geologická 4, 152 00 Praha 5*
[2] *Boháčova 866/4, 149 00 Praha 4*
[3] *Czech Geological Survey, Klárov 3, 118 21 Praha 5*
[4] *Loretánské náměstí 2, 110 00 Praha 1*

Introduction

This paper summarizes results of geological, geophysical, geochemical and isotopic studies and other related investigations in the Čistá-Jesenice pluton.

The first accounts of the distinctive geological and petrographical characteristics of the Čistá-Jesenice pluton were given by Smetana (1927) and namely by Orlov (1932) who published the first chemical analysis of the Tis granite from a quarry near Tis. Klomínský (1962) discussed the geological aspects of ore mineralizations connected with the Čistá-Jesenice pluton and a new Bi-Pb mineral heyrovskite was described (Klomínský et al. 1971). The following mapping provided a comprehensive picture of petrography, tectonics and age relations between individual magmatic types and the first description of the mineralization (Klomínský 1960, 1963, 1966). In the course of this investigation dykes of cancrinite-nepheline syenite were found (Klomínský 1961a).

Petrophysical and petrographical investigations of the Tis granite and Čistá granodiorite were carried out by Šťovíčková (in Bartošek et al. 1969) and Chlupáčová (1970).

The find of cancrinite-bearing syenite led Kopecký (1969) to the discovery of alkaline metasomatism connected with Mo-Zr mineralization of a genetic type yet unknown in the Bohemian Massif (Kopecký 1982).

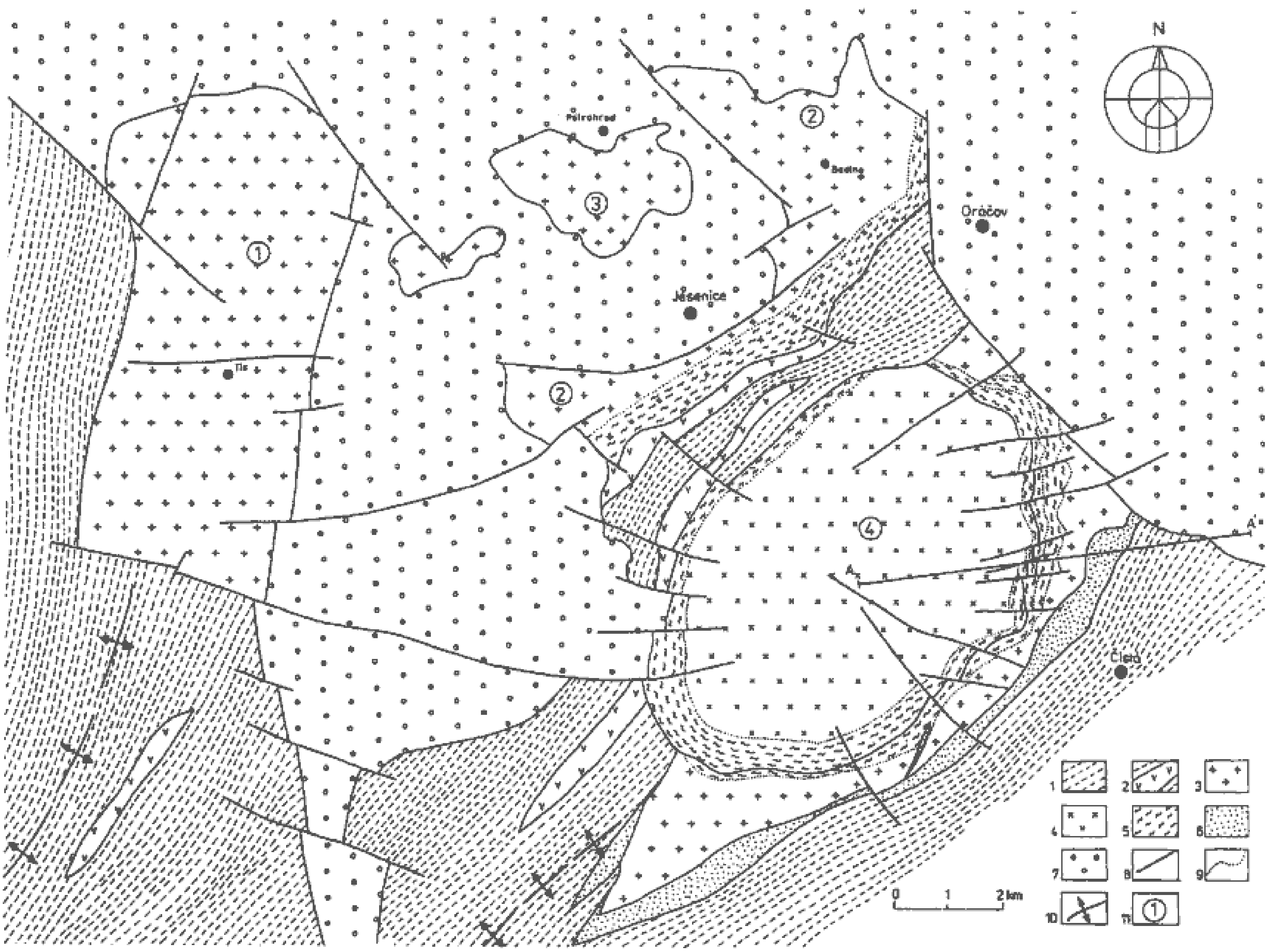
The subsurface extent of the pluton is known from a borehole at Martiněves (Mt-1) near Roudnice nad Labem (Fig. 2). In this borehole indications of weak alkaline metasomatism (fenitization) were also found (Kopecký 1993).

1. The main geological features

1.1. Regional geology

The Čistá-Jesenice pluton crops out in Western Bohemia on area of 118 sq. km (Fig. 1). Its exposed parts have been described as the Tis, Jesenice-Oráčov, Petrohrad and Čistá bodies. Most of the Čistá-Jesenice pluton is covered by Carboniferous (Westphalian B/C), Permian and Late Cretaceous platform sediments. The pluton was exposed to weathering and erosion during Late Devonian and Early Carboniferous (Škvor et al. 1990, Holub et al. 1991).

The pluton intruded into low grade metamorphosed Upper Proterozoic sequences of the Teplá-Barrandian zone characterized by phyllitic shales with intercalations of tuf-

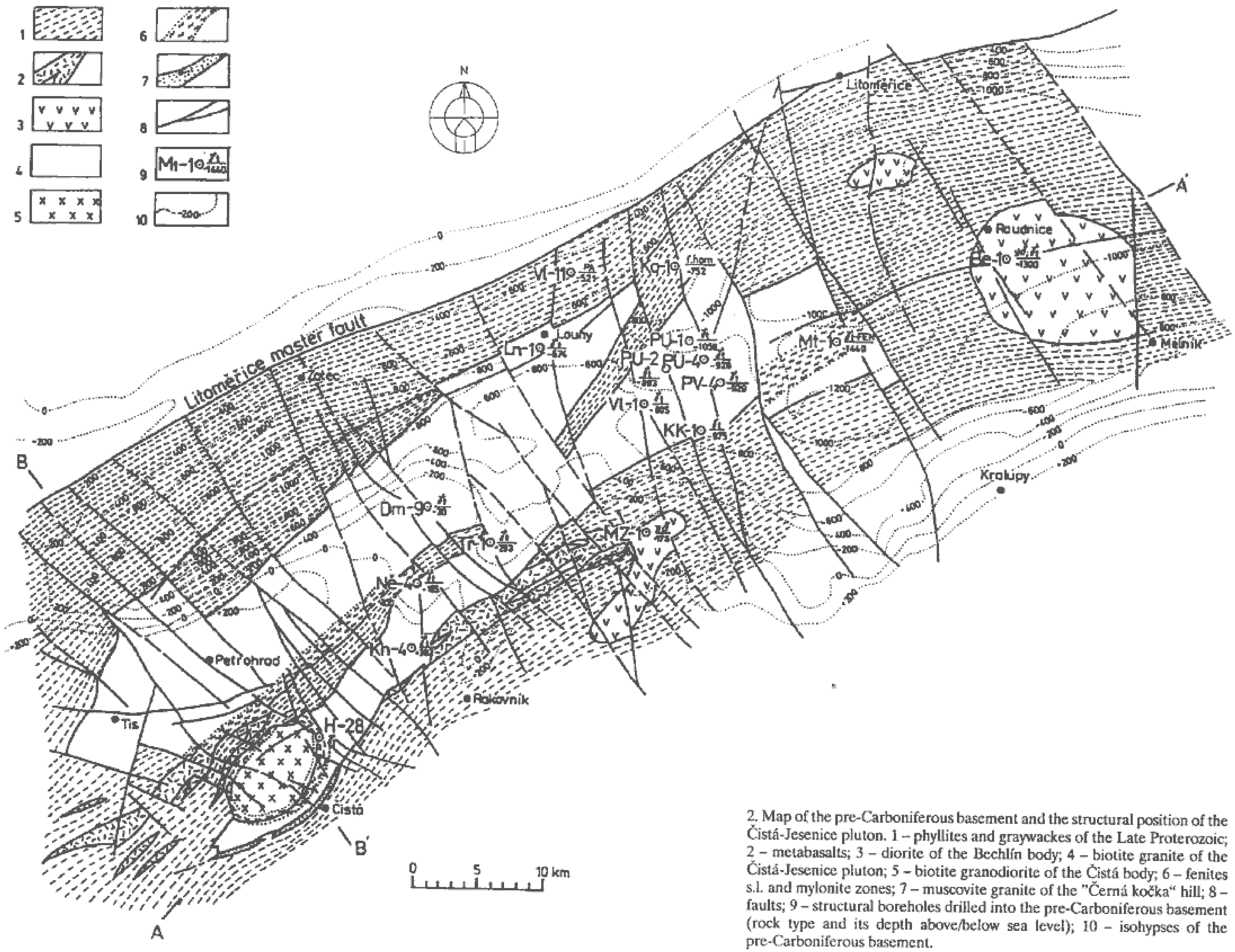


1. Geological situation of the uncovered parts of the Čistá Jesenice pluton. Compiled from Klomínský (1966), Kopecký (1987), Fediuk (1993) and Blažek et al. (1993). The granitoid bodies (numbers in circles): 1 – Oráčov; 2 – Tis; 3 – Jesenice; 4 – Čistá granodiorite; 5 – "Černá kočka" Hill – muscovite granite.
Rock types: 1 – phyllites and graywackes of the Late Proterozoic; 2 – metabasalts; 3 – biotite granite of the Tis type; 4 – biotite granodiorite of the Čistá body; 5 – mylonite zone with fenites; 6 – tourmaline-bearing muscovite granite of the "Černá kočka" Hill; 7 – Late Carboniferous platform cover; 8 – faults; 9 – petrographical transitions; 10 – main anticlinorial structure of the Late Proterozoic; 11 – individual granitoid bodies.

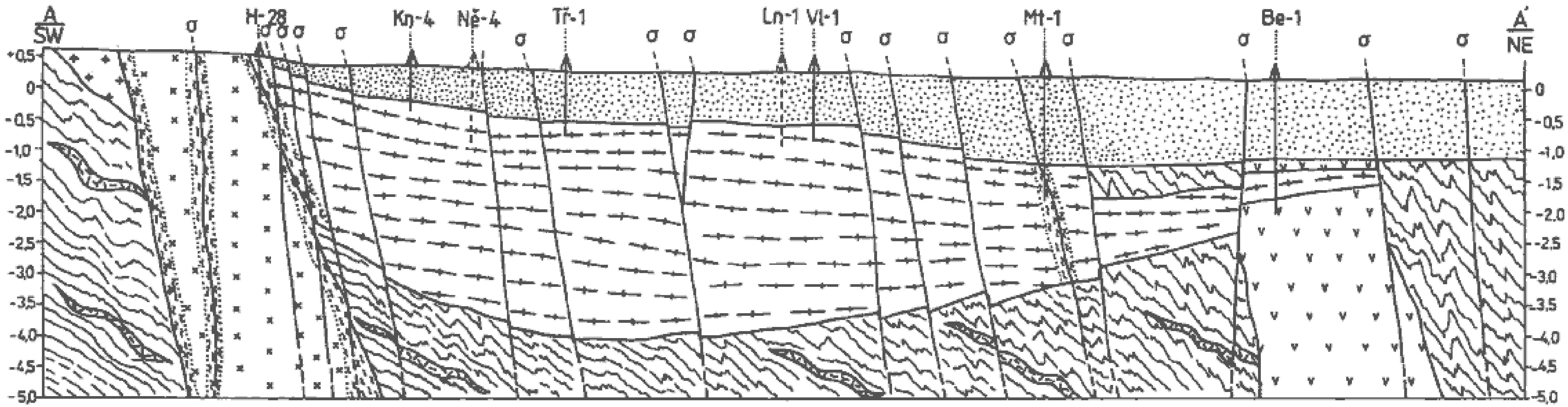
faceous material, metabasalts, silicites and black shales. Towards the W phyllites pass to two-mica schists. The exocontact of the pluton with Upper Proterozoic shales is accompanied by an aureole of cordierite hornfels and spotted schists (Klomínský and Sattran 1965).

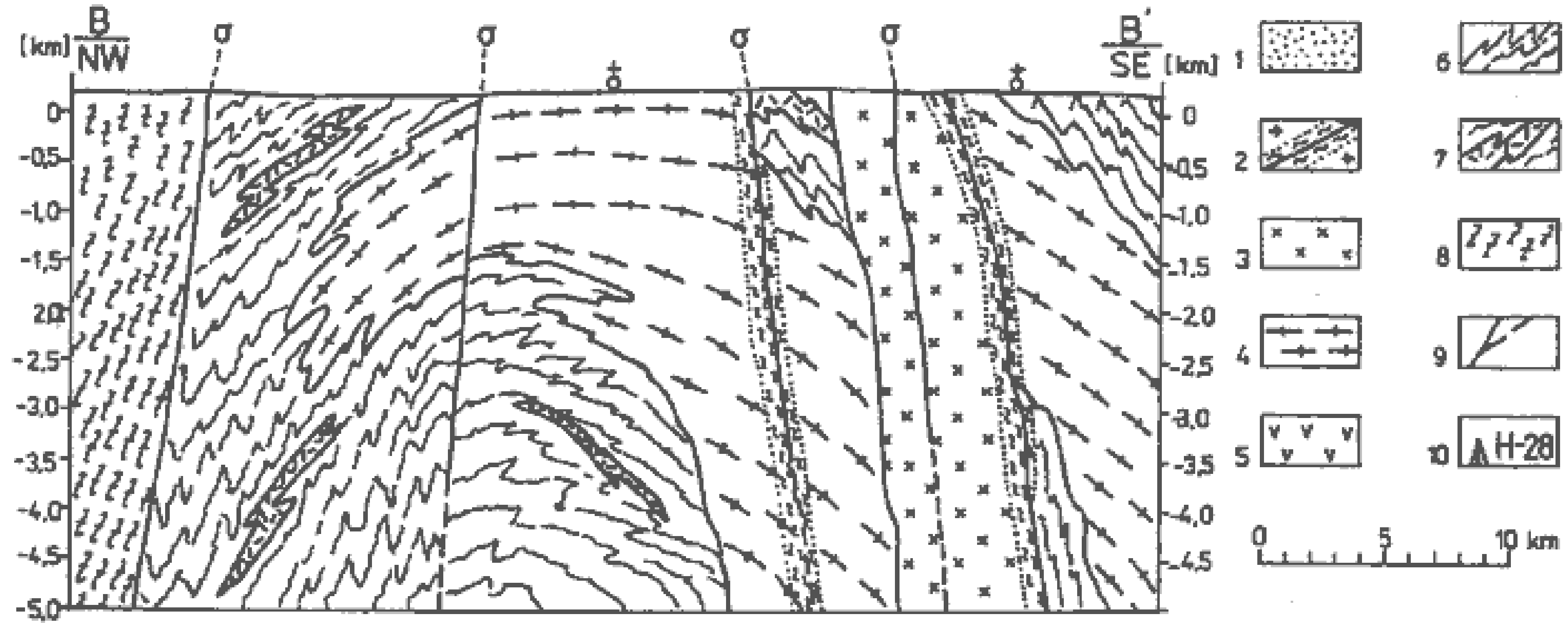
The spatial extent of the pluton was inferred from gravimetric data (Polanský and Dobeš 1957, Dobeš and Polanský 1967), and later verified by several boreholes, drilled in the course of exploration for Carboniferous coal (Figs. 2, 3). The estimated thickness of the pluton is 3 to 4 km. A positive gravity field in the Teplá-Barrandian zone excludes interpretations by Vejnar (1967) assuming the existence of large granitic masses ("Western Bohemian pluton"). All deep boreholes [i.e. Ln-1, Louny (Klomínský and Sattran 1965), VL-1, Vrbno nad Lesy (Klomínský 1965), Be-1, Bechlín (Cháb in Prouza et al. 1968, Cháb 1975) and Mt-1, Martiněves (Ledvinková in Prouza et al. 1986, Kopecký 1993)], situated towards NE, revealed pre-Carboniferous (pre-Variscan) surface of the pluton dipping toward N and NE (Fig. 2). The deepest verified presence of the pluton (its lower edge) is an upper granite contact in the Mt-1 borehole at a depth of –1740 m. Transverse faults of NW-SE direction (as well as longitudinal faults of ENE-WSW direction) divided the body to a number of segments during the Variscan orogenesis and the post-Variscan platform development of the Bohemian Massif. A rather monotonous composition of the buried NE portion of the pluton was recognized (Polanský and Dobeš 1957, Klomínský 1965). We estimate the areal extent of the whole intrusion to be 1000 km^2 (Fig. 4).

Both the Čistá-Jesenice pluton and the pre-Variscan Late Cambrian Stod massif (510 Ma, K-Ar, Šmejkal and Vejnar 1965; 518 Ma, K-Ar, Kreuzer et al. 1991) intruded into the main folding structure of the hosting crystalline rocks of Late Proterozoic age. Beneš (1974) considered its emplacement to be associated with the two SW-NE elongated



2. Map of the pre-Carboniferous basement and the structural position of the Čistá-Jesenice pluton. 1 – phyllites and graywackes of the Late Proterozoic; 2 – metabasalts; 3 – diorite of the Bechlín body; 4 – biotite granite of the Čistá-Jesenice pluton; 5 – biotite granodiorite of the Čistá body; 6 – fenites s.l. and mylonite zones; 7 – muscovite granite of the "Černá kočka" hill; 8 – faults; 9 – structural boreholes drilled into the pre-Carboniferous basement (rock type and its depth above/below sea level); 10 – isohypses of the pre-Carboniferous basement.





3. The longitudinal (A-A') and transversal (B-B') cross-sections across the pluton and the space relationships between the intrusive bodies (for location of the cross-sections see Fig. 2). 1 – post-Variscan platform sedimentary cover; 2 – faults and associated mylonitization and fenitization s.l.; 3 – biotite granodiorite of the Čistá stock intrusion; 4 – biotite granite of the Čistá-Jesenice pluton; 5 – diorite of the Bechlín body; 6 – phyllites and graywackes of Late Proterozoic; 7 – metabasalts; 8 – mica schists, paragneisses and orthogneisses of the Saxothuringicum (over the Litoměřice master fault); 9 – faults; 10 – structural boreholes.

extensive anticlinal structures: The Tis granite body intruded into the same anticlinal structure as the Kladruby massif but the Petrohrad granite body was conformly emplaced into the anticlinorium into which the Stod massif also intruded. Fold axes run over long distances, and well defined *ac*-cross faults and *bc*-longitudinal faults, which coincide with assumed deep seated shear zones, represent peculiar features of the Late Proterozoic rock sequences of the Teplá-Barrandian zone (Beneš 1974).

1. 2. Age relations of the individual granitoid bodies

The Čistá-Jesenice pluton, originally considered to be a Variscan intrusive body (Orlov 1932), and later assumed to be pre-Variscan (Klomínský 1965), is very likely of Late Cambrian-Ordovician age (Klomínský and Dudek 1978, Cháb and Šmejkal in Prouza et al. 1968, Cháb 1975). The rocks of the Čistá-Jesenice pluton have been dated only by the K-Ar method. The Upper Cadomian (550 Ma, K-Ar) Bechlín diorite body (Cháb and Šmejkal in Prouza et al. 1968, Tab. 1) is penetrated by 60m thick (1539-1599.9 m in borehole Be-1) sill shaped body of amphibole-bearing biotite granite of the Tis type (Fig. 3). Sattran (1981) ascribed this body to the "Northern zone of pre-Variscan intrusive complexes, comprising the Red gneiss complex of the Krušné hory (Erzgebirge) Mts., the Rumburk granite within the Lusatian pluton and smaller granite and granodiorite to tonalite (Lestkov, Hanov) massifs of the Teplá-Barrandian zone" (Fig. 4).

The main features of the pre-Variscan granitoids of the Bohemian Massif were outlined by Klomínský and Dudek (1978) and by Škvor and Klomínský (1990). They form shallow subsurface intrusions often concordant with neighbouring structural patterns. The pre-Variscan granites of the Bohemian Massif are frequently influenced by younger tectonometamorphic events. Lower grade of magmatic differentiation is common when compared with the Variscan granites.

Radiometric dating carried out in the sixties showed a broad range of ages from 289 to 450 Ma (Tab. 1), which are compatible with field observations. However, only data from the easternmost part of the pluton, where younger (probably Variscan) thermal and metasomatic processes are not known, appear to be acceptable. Šmejkal (1968) reported an age of 550 Ma for the Bechlín amphibole diorite and 450, 415 and 410 Ma for biotite granite of the Tis type which intruded as a thick apophysis into diorite of the Bechlín body (Fig. 3). The data, obtained simultaneously on both biotite and amphibole apparently indicate the ages of Late Ordovician and/or Silurian/Devonian boundary, however, an Ordovician (or Late Cambrian) age is more probable. The intrusion of the biotite granite is well preserved inside the diorite body. The effects of Variscan tectonometamorphic events are scarce in this area of very low grade metamorphosed Upper Proterozoic shales as host rock of both intrusions.

The magmatic history of the Čistá-Jesenice pluton is presented in Tab. 1. The large time span of the K-Ar data

4. A synoptic sketch of the main granitoid bodies of the Bohemian Massif (after Klomínský and Dudek 1978). A – the northern zone of the pre-Variscan intrusive complexes; B – plutonic rocks of the Moravian block. 1 – the Smrčiny-Krušné hory granitic massifs; 2 – the Lusatian (Krkonoše, Jizerské hory and Silesian) pluton; 3 – small granitic bodies in western Bohemia; 4 – the Central Bohemian pluton; 5 – the Nasavrky-Skuteč pluton; 6 – the Central Moldanubian pluton.

for both the Tis granite and Čistá granodiorite is due to the younger affects of alkaline metasomatism as well as intrusions of dyke rocks around Hůrky village. It is evident that the higher K-Ar ages are more reliable. With the exception of some intrusive dyke rocks and products of alkaline metasomatism, Variscan elements in the magmatic history of the Čistá-Jesenice pluton are unlikely.

1.3. Internal structure, time sequence and composition of rock types

The exposed parts of the Čistá-Jesenice pluton known as the Tis massif, Jesenice-Oráčov and Petrohrad bodies and the uncovered part of the relatively independent Čistá granodiorite massif are separated by Upper Proterozoic shales and Upper Carboniferous sediments (Fig. 1).

Based on field observations and petrological studies three members of the Čistá-Jesenice pluton were distinguished:

1.3.1. Tis granite

The oldest and most widespread member is the Tis granite including isolated outcrops (i.e. the Tis, Jesenice-Oráčov and Petrohrad bodies), (Fig. 1). It is formed by a coarse grained biotite granite. The intrusion incorporates platy blocks of Upper Proterozoic phyllites at the contacts.

The Tis granite is characterized by ductile cataclasis of different intensity, which locally passes by shear friction into a ductile deformed texture resembling orthogneiss. These oriented shear planes are characterized by anomalous perthitization of K-feldspar and fairly high contents of quartz of blue color (up to 30 vol. %), (Klomínský 1966).

The westernmost granite endocontact is formed by a hybrid melanocratic granite, showing parallel texture conformable with Late Proterozoic mica schists (Klomínský 1966).

The Tis granite displays the following mineral composition: K-feldspar (phenocrysts), plagioclase An_{10-15}, quartz and biotite, (zircon, apatite and muscovite, present as accessory minerals) (Chlupáčová 1970). The superimposed alkaline metasomatism led locally to a change in color, texture, chemical and mineral compositions of the Tis granite.

1.3.2. The Čistá granodiorite

It crops out in an elliptical form, covering an area of 38 sq km (Fig. 5). Its longer axis trends SW-NE. The body intrudes the Tis granite and Upper Proterozoic phyllites. The Čistá granodiorite contact dips periclinally from 30° NE to 90° E, exceptionally centroclinally as much as 85° SE (Klomínský 1966). The Čistá granodiorite shows a concentric internal structure. The more basic granodiorite developed at the margins displays an intensive foliation. The relics of primary flow structures are in places represented by xenoliths composed of Late Proterozoic country rocks.

Klomínský (1963) distinguished two principal facies of granodiorite (as products of magmatic differentiation). Šťovíčková (in Bartošek et al. 1969) proposed three subtypes:

The foliated medium- to coarse-grained hornblende biotite granodiorite forms the marginal part of the body, with parallel planar structure of biotite which often encloses zircon. Oscillatory zoned plagioclase (An_{20-30}) displays often a totally epidotized core. K-feldspar (microcline) is rare. The heteroblastic texture with penetration of symplectic texture of quartz and feldspars is an important feature. Abundant accessories, idiomorphic titanite and magnetite (total up to 1 %), are both accumulated into the mafic stripes of biotite with subordinate hornblende. Magnetite penetrating along the interstices is evidently younger. Also the appearance of abundant zircon, apatite and also fresh non-metamict allanite with a rim of small epidote grains is genetically significant.

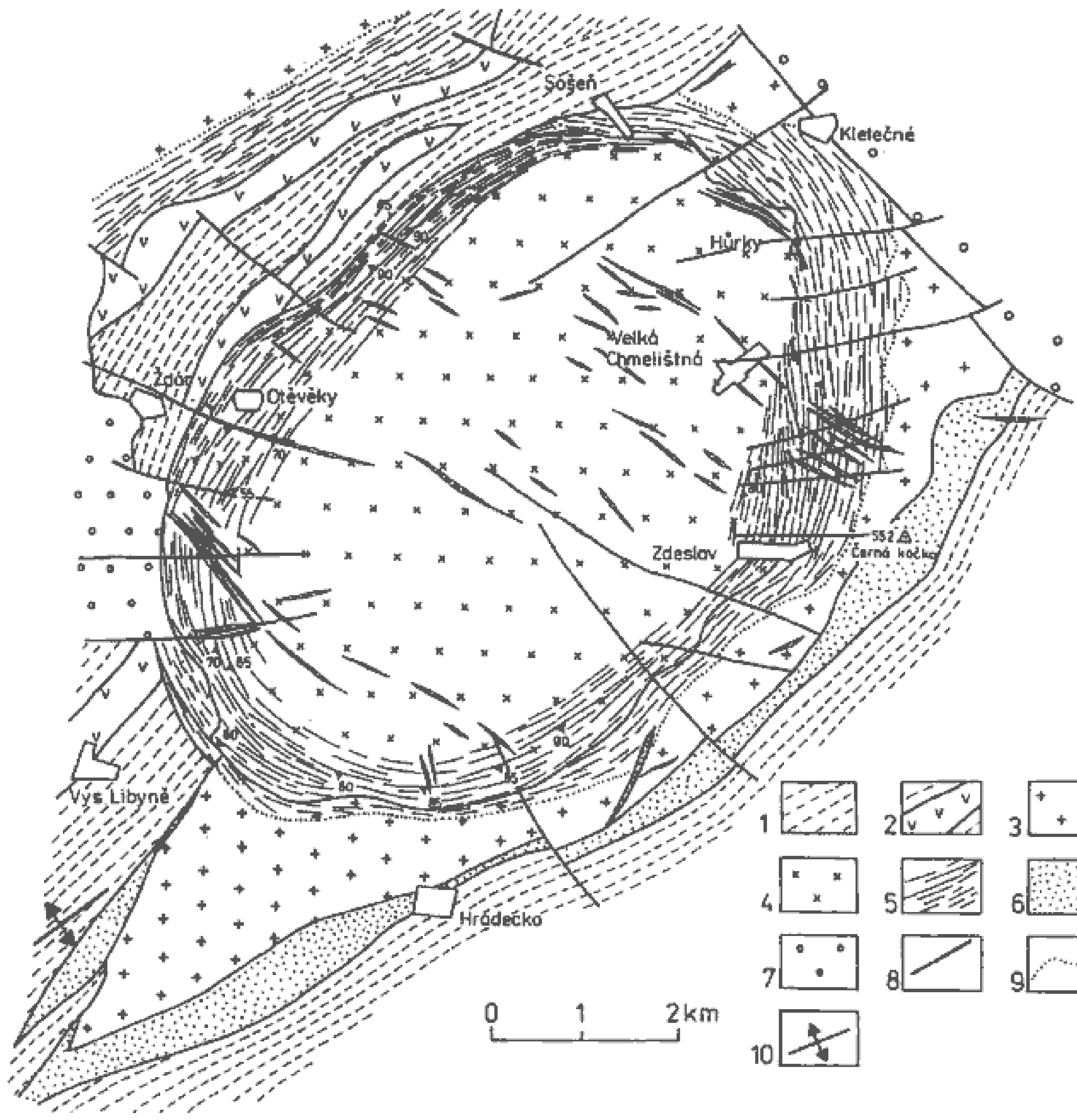
The so-called transitional type is medium- to coarse-grained hornblende biotite granodiorite, which differs from the marginal type by more or less granular texture and somewhat lower basicity of plagioclase (An_{12-20}). The subordinate K-feldspar is again microcline, however, orthoclase also appears. The accessories are present in somewhat smaller amount when compared with the marginal zone.

The central part of the Čistá granodiorite is composed of medium-grained, unfoliated biotite granodiorite. Locally chloritized biotite is almost without inclusions of accessories. The zonal plagioclase (An_{12-25}) has locally epidotized core, but its internal portions are often metasomatically replaced by hematite. Unzoned, often twinned acid oligoclase to albite (An_{07}), penetrated sometimes by myrmekite,

Table 1. Major events in the magmatic history of the Čistá-Jesenice pluton as dated by K-Ar method

Body rock type	K-Ar data (Ma)	space relationships (Ma)
Bechlín amphibole diorite	550 Šmejkal in Prouza et al. (1968)	intersected by the Tis granite (348–450)
Tis biotite granite up to adamellite	348–450 Šmejkal in Prouza et al. (1968)	intruded by the Čistá granodiorite (311–423)
Čistá biotite granodiorite	311–423 Klomínský (1963)	effected by alkaline metasomatism (289–300)
Hůrky alkaline metasomatism (i.e. fenites s.l. and syenites)	289–300 Klomínský (1961a)	intersected by post-fenitic tourmaline-muscovite granite (metasomaticaly uneffected) (290)
Černá kočka-Hill tourmaline-muscovite granite	290–300 (?), Kopecký Sr. (1987)	intersects fenites and contains xenolites of metasomatites s.l.
Hůrky granodiorite porphyrite	290 (??) Kopecký Sr., ed. (1987)	contains fenite xenolites

The wide time span for both the Tis granite and Čistá granodiorite is due to a younger alkaline metasomatism.



5. The geological situation in the vicinity of the Čistá granodiorite stock intrusion (according to Klomínský 1966 and Kopecký 1985). 1 – phyllites and graywackes of the Late Proterozoic; 2 – metabasalts; 3 – biotite granite; 4 – biotite granodiorite of the Čistá intrusion; 5 – centroclinally dipping ring faults and the zone of mylonitization with fenites s.l.; 6 – tourmaline-bearing muscovite granite of the "Černá kočka" Hill; 7 – Late Carboniferous sandstones and conglomerates; 8 – radial faults of the Čistá structure; 9 – transition from fenite to granite; 10 – anticlinorial structure of the Late Proterozoic.

is present as well. K-feldspar is locally porphyroblastic and obviously younger. The difference between marginal and central parts of the granodiorite massif is in the rapidly increasing amount of K-feldspar vs. plagioclase, locally reaching a ratio of about 3:1 in the internal part. Magnetite as the most common accessory mineral (up to 1 %), represents one of the youngest rock components. For its idioblastic crystallization intergranular spaces and the planes of mechanical inhomogeneity were used. Along the cleavage biotite is often replaced by magnetite. Idiomorphic grains of titanite are locally opaque as a consequence of leucoxenization.

All these phenomena together with an increasing volume of K-feldspar in the internal part of the stock were later interpreted as symptoms of K-feldspathization (Kopecký 1987).

1.3.3. Granite of the "Černá kočka" Hill

The muscovite granite of the "Černá kočka" Hill is supposed to be the youngest granitoid member (Kopecký 1987). It forms an arc-shaped intrusion between biotite granite of the Tis type and Upper Proterozoic phyllites (Fig. 5). This leucocratic acid muscovite (locally tourmaline-bearing) granite seems to be post-fenitic. It is more acidic if compared with the biotite granite of the Čistá type. Allotriomorphic apatite, zircon and hematite belong to common accessories. Its rare pegmatitic development is rich in tourmaline (Kopecký 1987). The rock is composed of K-feldspar, quartz, plagioclase and muscovite.

Klomínský (1963) noted slight mylonitization (undulose extinction of quartz), albitization of plagioclase and muscovitization of microcline and described this granite as a near-contact leucocrate subtype of the Tis granite. This rock type was effected neither by fenitization nor feldspathization, and according to Kopecký (1987) is post-fenitic. These characteristics along with the time-space relations (low grade fenites are intersected by thin dykes of muscovite granite in the old quarry, 1650 m ESE of the chapel in Hůrky), led Kopecký (1987) to the "postfenitic" interpretation of the near-contact granite.

1.3.4. Dyke rocks

The dyke swarms of the Čistá-Jesenice pluton were studied in more detail only in the area of the Čistá granodiorite massif (Klomínský 1963, Kopecký 1987). They are represented by granodiorite and diorite porphyrites as well as aplitic rocks. According to Kopecký (1987), they are both of pre- and post-fenitic age. The question arises whether the dyke suite evolved in the context of the main plutonic activity, or was derived from younger magmatism and thus connected only with the granodiorite intrusion. The available data appear to favor the latter interpretation. The youngest in succession are hydrothermal quarz-aplitic veins bearing Fe-, Pb-, Zn-, Cu-, Mo- and Bi-sulphides and barite-fluorite mineralizations.

a) Hornblende diorite porphyrites occur as dykes of a thickness of up to 1.5 m. They are dark gray in color with linearly oriented zoned phenocrysts of plagioclases (An_{15-20}) up to 1 cm in size. The alteration of hornblende in the matrix resulted in a mixture of biotite, chlorite and epidote.

b) Biotite quartz diorite porphyrites are similar to the previous type. Quartz occurs in aggregates of biotite in the matrix.

c) Biotite granodiorite porphyrites form dykes up to 2 m thick and 400 m long. They are yellow brownish with phenocrysts of plagioclase (An_{15-25}) up to 2 cm in size.

d) Aplites form abundant dykes (thickness varying from 5 cm to 5 m), penetrating both the Tis granite and the Čistá granodiorite. The dykes are zonal with pegmatite occurences in their internal part. In mineral composition orthoclase, Na-rich plagioclase (An_{10}) and quartz prevail.

All the above mentioned types of porphyrites are rich in apatite and zircon.

e) Cancrinite-nepheline syenitic rocks have a genetic relationship to other rocks of the fenite zone (see below). Klomínský (1961a, 1961b) reported alkaline cancrinite syenite in the form of dykes from the village of Hůrky, localized at the eastern margin of the Čistá massif. Šťovíčková (in Bartošek et al. 1969), described two types of nepheline syenite with a substantial amount of nepheline porphyroblasts (up to 20 %) from the same rock series. This led her to suggest a metasomatic origin of the rock. Kopecký et al. (1970) interpreted these rocks as a final product of alkaline metasomatism. Cancrinite-nepheline syenitic fenites occur only in the fenite zone that originated from granite ultramylonites, which is formed by fine-grained muscovite-biotite albititic fenites with a pronounced foliation to albitites poor in mica and lacking characteristic foliation.

In the internal part of the muscovite-biotite albititic fe-nite zone very fine grained biotite-pyroxene to medium-grained porphyric pyroxene (acmite)-cancrinite-nepheline syenites occur. These rocks according to Kopecký (1987) penetrate arfvedsonite syenitic fenites and biotite-quartz syenitic fenites and rarely also the cataclastic biotite granite and form subvertical dykes of a small thickness (up to 1m) and length (10 m to 300 m).

1.3.5. Alkaline metasomatism

The peculiarity of the Čistá-Jesenice pluton is the alkaline metasomatism which is characterized by Na-fenitization and Na-K or K-feldspathization of granitoids. The first product according to Kopecký (1969, 1987) forms a broad asymmetrical rim around the contact zone between the Čistá granodiorite stock and the Tis granite and its development was controlled by a progressive degree of mylonitization.

An earlier theory explaining mylonitization as a synemplacement effect of the granodiorite intrusion (Klomínský 1963), has been recently reinterpreted by Kopecký (1987) who emphasized the role of a shear strain in the relation to an assumed ijolite-carbonatite magmatism. The ascension of ijolite-carbonatite derived magma and metasomatic media were both preceded by mylonitization on centroclinally dipping (conic) faults. The injections of volatile-rich derivates of ijolite-carbonatite melts followed the-se faults and created fenites s.l. in the forms of cone-sheeted dykes (sensu of Le Bas 1977).

Similar indications of fenitization were recently recognized also in the NE, buried part of the Čistá-Jesenice pluton, in the Mt-1 and Mt-1a boreholes near Martiněves (Kopecký 1993).

Four stages of Na-metasomatism were recognized by Kopecký (1987). Fenitization has affected biotite granite of the Tis type, biotite granodiorite of the Čistá stock intrusion, as well as some rock dykes. The effects of fenitization slightly differ in each rock type. K-metasomatism occurs only in biotite granodiorite (Fig. 6).

a) Fenitization

Fenitization of the porphyritic biotite granite (the Tis type) mylonite is widely developed in the NE portion of the Čistá massif. The cataclastic biotite granite passes here into distinctly foliated biotite- and biotite-arfvedsonite-quartz syenitic fenite (fenitization of grades I and II) and into arfvedsonite-aegirine-augite syenitic fenite (grade III). The two latter rock types show typical rounded, partially strongly albitized relic grains of primary orthoclase phenocrysts of granite. The chemical composition of arfvedsonite is that of magnesioarfvedsonite. Its crystallochemical and lattice parameters as well as paragenetic association of low albite led Ulrych (1978) to the conclusion about a low-temperature origin of fenites. Aegirine-augite is very rich in the aegirine component. Increased contents of sphene and magnetite in fenites and accessory zircon and allanite are also typical.

The fenitized biotite granite (the Tis type) ultramylonite occupies the inner belt of the fenite zone along the contact with the fenitized granodiorite (Kopecký 1987). Fine-grained muscovite-quartz syenitic fenites to biotite syenitic (albititic) fenites of fenitization grades I-III pass here into biotite-cancrinite and biotite-cancrinite-nepheline syenitic fenites of grade III-IV and further into aegirine-cancrinite-nepheline syenites. These rocks are rich in zircon and magnetite, and contain accessory allanite, eudialyte, fluorite and pyrochlore. The richest in accessories is ultramylonitic fenite type, especially in biotite (phlogopite)-rich sövite syenitic fenite, forming narrow (0.1 – 1.0 m thick) stripes. The rock is conspicuous by primary crystallized groundmass of carbonate rhombs.

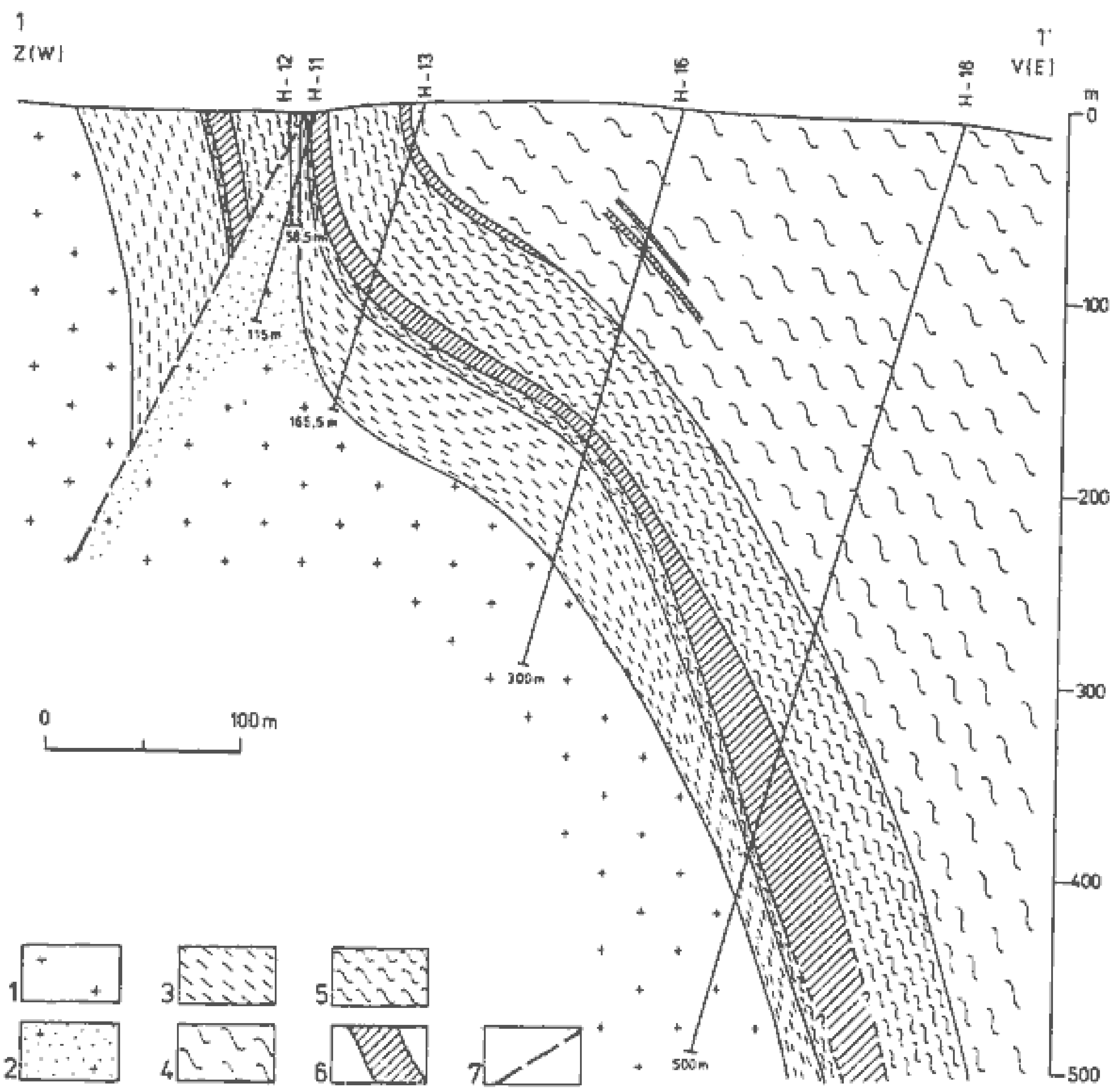
Fenitization of the Čistá granodiorite mylonite roughly following the SW contact between the Tis granite and Čistá granodiorite is, according to Kopecký (1987), manifested by a distinct foliation defined by layers of dark minerals (newly formed brown biotite, purple-green chlorite, lepidomelane and arfvedsonite as with an increasing degree of fenitization replacing biotite). These new minerals are formed around relics of oligoclase grains. Titanite, zircon, allanite, wide columnar apatite and magnetite are accessory minerals.

Fenitization of porphyrite dykes mostly occurs in the Hůrky area (Kopecký 1985). Foliation of fenitized porphyrite is more distinct in comparison with the surrounding fenitized granodiorite and/or granite. Biotite recrystallized first and was replaced by alkaline hornblende (arfvedsonite) and slightly alkaline pyroxene (aegirine-augite). The third stage of fenitization of porphyrites is rich in sphene, fluorite and allanite, as well as zircon and pyrochlore, concentrated in dark purple-colored belts of a thickness to 5 cm. These stripes are highly enriched in LREE as well as Nb-Ta, Zr and Ti (Kopecký Jr. 1990).

K-feldspathization is limited in the internal portion of the Čistá granodiorite body and along the radial faults (Kopecký 1987).

b) K-feldspathitization of the central portion of biotite granodiorite (the Čistá stock)

The inner mylonitization- and Na-fenitization-free part underwent potassium feldspathization (microclinization). According to Klomínský (1963), this part of the granodiorite intrusion is enriched in K-feldspar and depleted in plagioclase and magnetite. Large poikilitic microcline phenocrysts (to 1.5 cm) include primary zoned idiomorphic



6. The diagrammatic section across the fenite zone near the village of Hůrky (according to Kopecký 1985). 1 – biotite granodiorite of the Čistá stock intrusion; 2 – slightly cataclastic and albitized biotite granodiorite of the Čistá stock intrusion; 3 – cataclastic biotite granite of the Tis type and the IInd stage of fenitization; 4 – biotite granite of the Tis type (mylonitization free); 5 – cataclastic biotite granite of the Tis type and the Ist stage of fenitization; 6 – late stage of fenitization and biotite ultramylonite of the biotite granite of the Tis type; 7 – faults.

oligoclase crystals (strongly sericitized and epidotized) and these microcline phenocrysts are enclosed by newly formed plagioclase. Primary quartz is strongly undulose, in contrast to newly formed hypidiomorphic quartz grains.

c) Na-K-feldspathization at radial faults
in the vicinity of Hůrky

These processes are confined to the evolution of radial faults later in succession (Kopecký 1987). Newly formed albite and K-feldspar and a generation of apatite, zircon, galena, sphalerite, chalcopyrite, arsenopyrite and uraninite are common. Granodiorite transforms to a metasomatic albitite (syenite) with zircon and apatite in clusters of sericite replacing biotite or feldspars. In zones of repeated mylonitization, fragments of albitized granodiorite are cemented with carbonates (H-25 borehole, [depth 219.4 to 220.0 m and 222.55–224.20 m], E of the village of Hůrky), which exhibit rich impregnations of Pb-, Zn-, Cu-sulphides with accessory fluorite, apatite and zeolite. In a more intensively mylonitized zone (depth 202.30–202.45 m) uraninite stockwork mineralization occurs in feldspathized and slightly carbonatized granodiorite (Kopecký 1985). The rock was partly recrystallized with newly formed arsenopyrite, apatite, zircon and rutile. All these accessories are enclosed in carbonate clusters.

The radiometric age of fenitization determined by the K-Ar method (whole rock) on biotite-cancrinite-nepheline syenitic fenite is in the span of 300–289 Ma (Klomínský 1963).

1.4. Tectonic development of the Čistá granodiorite massif

Klomínský (1960, 1963) first carried out a systematic investigation of the internal structure of the Čistá granodiorite stock and recognized two principal tectonic systems within the body:

(1) "granite tectonic" system, syngenetic in origin, caused by cooling of the stock intrusion and described as an Q-L-S system.

(2) NE/SW and NE/SW trending fault system closely associated with the post-Variscan development of the Bohemian Massif.

Kopecký (1969) recognized the following structures:

a) Foliation. An internal structure formed by oriented distribution of planar shaped mineral constituents in the endocontact zone. Caused by stress anisotropy within the crystallizing melt close to the contact. Klomínský (1963) explained the anisotropy by differentiation of the granodiorite intrusion, where the relatively basic (mafic) and biotite rich subtype has concentrated along the endocontact zone of the granodiorite intrusion.

b) Faults. Kopecký (1969, 1970) described the following main fault systems:

(1) A centroclinally dipping ring fault system recognized in the fenite zone along the contact of the granite with the central granodiorite stock.

(2) The younger system of radial (subvertical) faults, trending to the center of the inferred ring structure.

The first of these fault systems is generally accompanied by mylonitization, and served as a feeding zone of fluids producing Na-fenites.

2. Geophysical pattern of the pluton

2.1. Petrophysical properties of rocks

2.1.1. Tis granite

The Tis granite from the vicinity of the Čistá body was petrophysically characterized by Chlupáčová (1970) as a low-density granite with very low magnetic susceptibility and low radioactivity (Tab. 2a).

Fe-Ti minerals of the Tis granite are ilmenite, rutile (sagenite) and hematite. Sulfides are scarce. Magnetite is almost absent. In the area SW of Čistá, higher radioactivity is a result of both abundant pyrite and higher U-contents. These features might be explained by minor fenitization of the Tis granite in this area (Chlupáčová 1987).

2.1.2. Čistá granodiorite

Geophysical properties reflect a distinct zonal composition of the granodiorite intrusion (Tab. 2b).

a) Grain densities

Grain densities decrease from the marginal hornblende biotite granodiorite towards the central biotite granodiorite ranging mostly from 2.63 to 2.66 $g.cm^{-3}$. The densities reflect very low contents of dark minerals and a high amount of feldspars. In contrast, porosity increases from the marginal to the central type. This trend is probably influenced by alteration of central parts of the granodiorite body represented by epidotization of zoned plagioclases, sericitization, kaolinitization and hematitization of plagioclases, martitization of magnetite, and chloritization of biotite (Bartošek et al. 1969). It is likely that porosity of 1 % to 2 % is developed not only in the surface part of granodiorite but also at the depth of several kilometers and causes relatively low natural bulk density. Bulk density is about 2.60–2.62 $g.cm^{-3}$ based on laboratory measurements and gravimetric interpretation.

Magnetite is a common and typical accessory mineral in all three rock types of the granodiorite body. The chemical composition of magnetite reveals a nearly pure and stoichiometric end member (Curie-temperature of 575 °C and Mössbauer spectroscopy).

A study of thin sections and magnetic anisotropy showed that magnetite partly crystallized along already existing fabric features, and thus is probably epigenetic (Bartošek et al. 1969, Chlupáčová et al. 1975).

b) Magnetic susceptibility

The magnetic susceptibility is variable, indicating different amounts of magnetite in individual rock types on regional as well as local scale. The highest values reaching 10 to

Table 2a. Petrophysical properties of the Tis granite from the Čistá segment (calculated using data of Chlupáčová, 1970)

Rock type	N	p	Dg (g.cm^{-3})	Db (g.cm^{-3})	Pef (%)	κ (10^{-3}SI)	Th (ppm)	U (ppm)	K (%)
biotite to muscovite-biotite Tis granite	7	M D	2.650 0.010	2.594 0.019	2.1 0.9	0.100 0.049	9.7 2.7	3.9 1.3	3.8 0.4
muscovite granite	5	M D	2.642 0.008	2.577 0.024	2.5 0.8	0.030 0.027	3.7 1.02	5.6[1)] 2.7	3.5 0.2

N – number of samples; p – statistical parameter; M – arithmetical mean; D – standard deviation; Dg – grain density; Db – bulk density; Pef – porosity; κ – magnetic susceptibility;
[1)] – the anomalous value of 30.7 ppm is not included into calculation; the contents of Th and U were recalculated using standards since 1972 (measured by gamma spectrometry).

Table 2b. Petrophysical properties of the Čistá granodiorite (after Bartošek et al. 1969 and Chlupáčová et al. 1975)

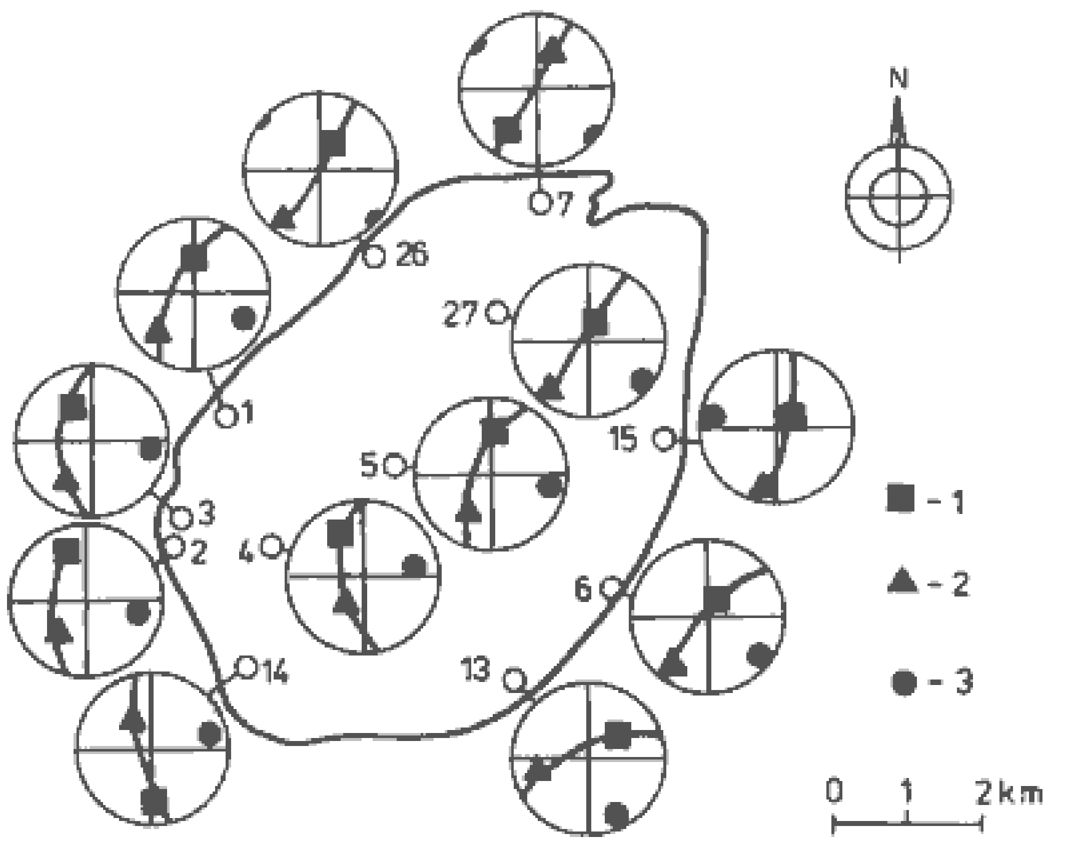
Type	marginal		transitional		central	
Rock	amph-biotite granodiorite (fenitized)		amph-biotite granodiorite (slightly fen.)		biotite granodiorite (non-fenitized)	
N	7 91		9 32		7 34	
p	M	D	M	D	M	D
Dg (g.cm^{-3}) Db (g.cm^{-3})	2.674 2.654	0.005 0.014	2.653 2.606	0.007 0.030	2.641 2.577	0.007 0.031
Pef (%)	0.7	0.4	1.8	1.0	2.5	1.2
κ (10^{-3}SI)	11.830	1.257	5.270	3.057	4.923	1.117
Jrn (nT)	160	91	60	29	48	48
p	1.532	1.275	1.254	0.152	1.168	0.041
Th (ppm) U (ppm) K (ppm)	8.2 3.1 1.6	0.8 0.2 0.2	14.6 4.4 2.1	2.0 1.1 0.2	20.1 8.1 2.7	2.8 3.1 0.3

Explanations see Table 2a.

Table 2c. Distribution of Th, U and K in fenites from the locality Hůrky, Tis granite, vicinity of Čistá

Rock	N	p	Th (ppm)	U (ppm)	K (%)
fenitized biotite granite, stage I, H-4 borehole	25	AM GM	53.8 31.6	12.5 9.3	2.9 2.8
fenitized biotite granites stage II, H-4 borehole	17	AM GM	70.0 31.2	21.3 18.1	2.8 2.6
muscovite-biotite syenitic fenites, H-4 borehole	29	AM GM	19.9 13.8	11.1 9.9	2.6 2.4
syenitic fenites rich in zircon, JK-1 borehole	18	AM GM	80.6 53.9	19.4 16.9	2.9 2.8
aegirine-cancrinite nepheline syenites, Hůrky	11 2	AM AM	12.8 340.0	10.1 5.9	3.5 4.8
lepidomelane-cancrinite-nepheline syenite, Hůrky	1	–	47.2	10.2	3.6

AM – arithmetical mean, GM – geometrical mean; statistical values for the JK-1 borehole (NE of the village of Hůrky) were calculated using data of Chlupáčová and Šťovíčková (1971) and corrected according to standards of the laboratory in Brno since 1972, measured by gamma spectrometry.



7. Magnetic anisotropy of the Čistá granodiorite (Chlupáčová et al. 1975). Mean directions of principal susceptibilities in individual localities: 1 – maximum; 2 – intermediate; 3 – minimum susceptibility; large circles – magnetic foliation.

15 . 10^{-3} SI, are characteristic for the marginal type. In this rock magnetite shows excellent dimensional orientation which is evidenced by a high degree of magnetic anisotropy (Hrouda et al. 1971, Chlupáčová et al. 1975). The mineral is conform to the planar fabric owing to preferred orientation of biotite flakes and lensoid aggregates of light minerals. The high magnetic anisotropy originated through mimetic crystallization of magnetite, whose fabric reflects structure of the primary rocks. Anisotropic behavior of magnetic susceptibility was also shown for the transitional and the central type of granodiorite, even though the latter type is macroscopically massive, without any apparent orientation. However, the degree of anisotropy is much lower than that of the marginal type. The dimensional orientation of magnetite in this case is also planar and mimetic in origin. As seen in Fig. 7, magnetic foliations are nearly vertical throughout the whole body and the magnetic lineation is often nearly horizontal (Chlupáčová et al. 1975). This pattern of magnetic anisotropy reflects very likely the effect of combination of both a simple shear and pure shear deformation caused by a penetrating and solidifying granodiorite mass (Chlupáčová et al. 1975).

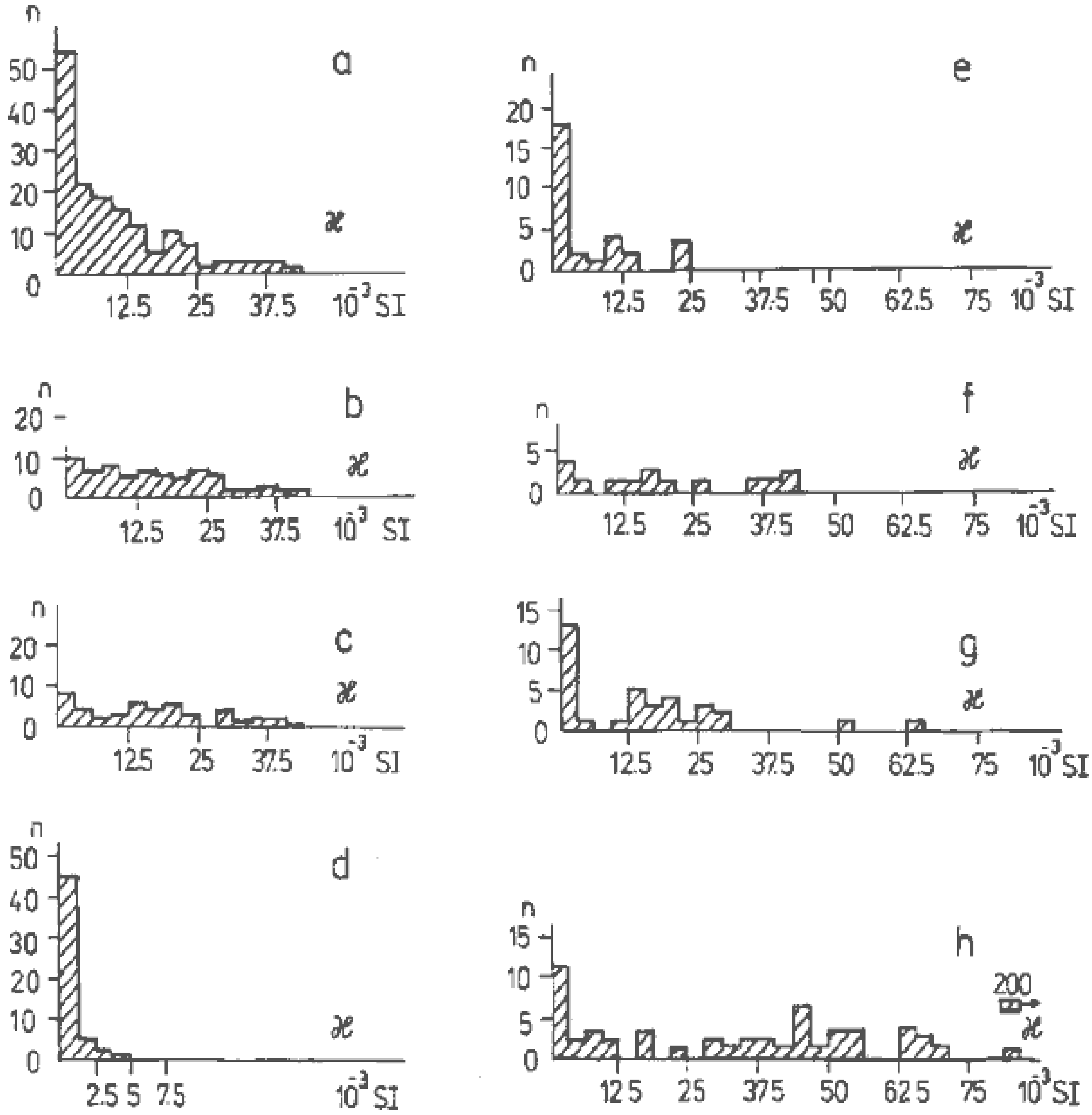
c) Radioactivity

In contrast to grain density and magnetic susceptibility, radioactivity shows an increasing trend from the marginal to the central type. The marginal type being weakly, the transitional type medium and the central type strongly radioactive (in the sense of an average value of radioactivity of granodiorite, Tab. 2b).

2.1.3. Fenitized rocks

Fenitization changed the original petrophysical properties of the Tis granite, Čistá granodiorite and some granodiorite porphyrites during the transformation of their structure and mineral composition.

Fenitized rocks occur in the zone near the village of



8. Distribution of magnetic susceptibility in fenites. Left side: histograms after Chudáček et al. (1983): a – fenitized granites and ultramylonites, stage II; b, c – mica fenites and ultramylonites, stage III; d – albitites.
Right side: histograms constructed using data by Jelen and Racková (1972): e – fenitized granites, stages I and II; f – mica fenites and ultramylonites, stage II; g – mica fenites and ultramylonites, stage III; h – nepheline syenites, stage IV.

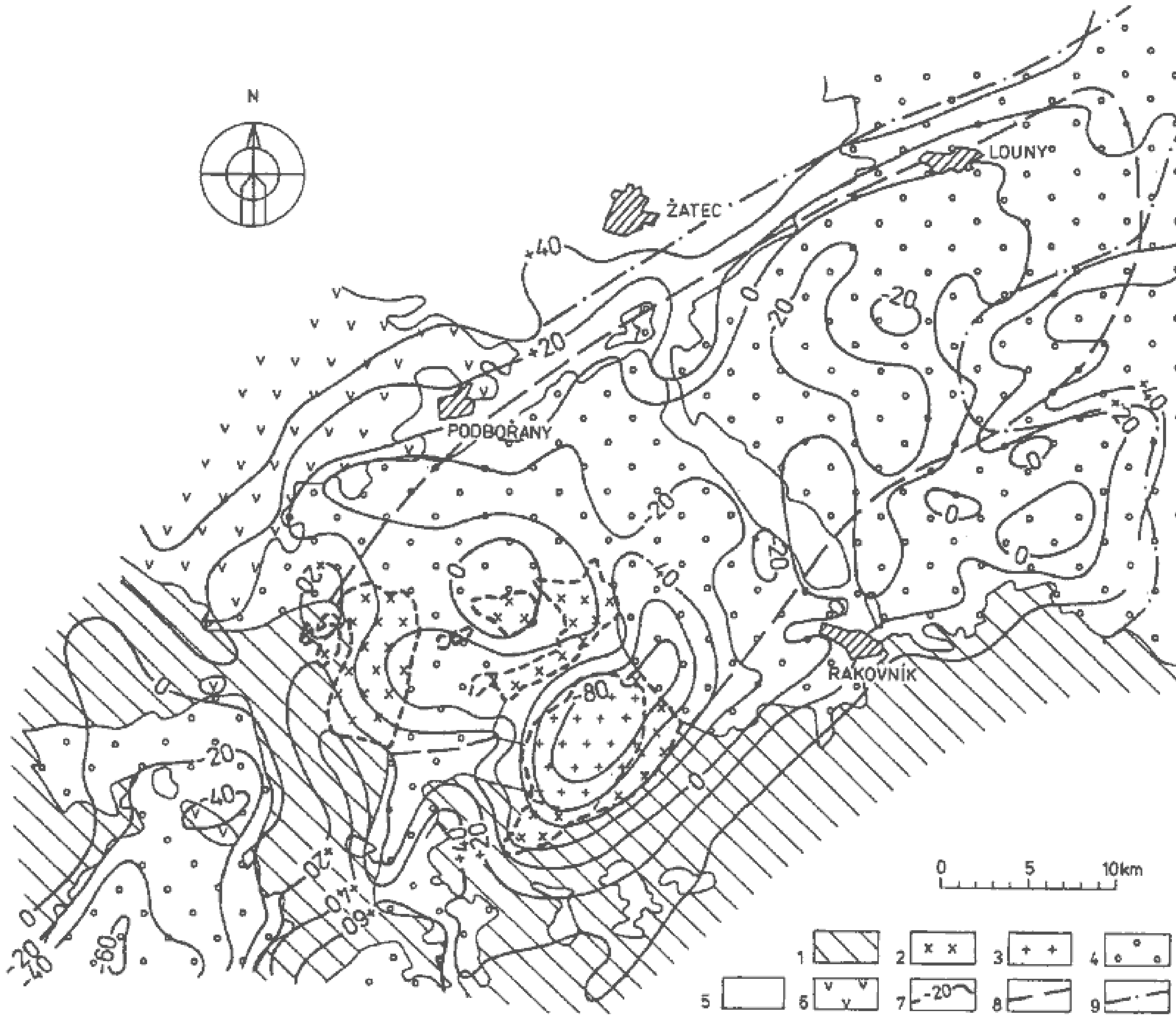
Hůrky. A remarkable increase in magnetic susceptibility during fenitization was found in fenites which originated from the Tis granite, especially in those which underwent ultramylonitization (Fig. 8).

It is apparent that magnetic susceptibility increases statistically with the intensity of fenitization. The highest values occur more frequently in fenites of the final stage, i.e. in syenites containing nepheline. Fenites of the first and second stage exhibit only low magnetic anisotropy, slightly higher than that of the parental rocks, while fenites of the final stage display extremely high magnetic anisotropy. Magnetite in fenites of the third and fourth stage crystallized partly during component movements – axial compression and slip along one set of planes – and partly through imitation of fabric elements already present in rocks (Hrouda et al. 1972). At about the same time radioactive trace elements were imported (Chlupáčová and Šťovíčková 1971, Chudáček et al. 1983). It is not clear whether distribution of Th and/or U reflects the intensity of fenitization. High contents of these elements were found in fenites of the first and second stages. Autoradiography has confirmed that the principal carriers of Th are dark metamict minerals, filling microcracs, which must have been formed later than the rock itself (Bartošek et al. 1980). The contents of Th and/or U vary widely in all types of other fenites. As documented by alpha autoradiography, titanite is only slightly radioactive. Allanite, zircon, eudialyte and pyrochlore (described from concentrates of heavy minerals) are the most common among radioactive accessories of fenites and their activity varies widely (Chlupáčová 1987). There are other dark and strongly radioactive accessories which remain unidentified. Examples of autoradiograms are shown in Pl. I–IV; and Th, U and K contents are given in Tab. 2c.

2.2. Geophysical pattern of the Čistá granodiorite stock intrusion

2.2.1. Gravitational field

There is an intensive negative gravity anomaly of elliptic shape over the region of the Čistá granodiorite massif (Fig. 9). Its existence points to an individual and inde-

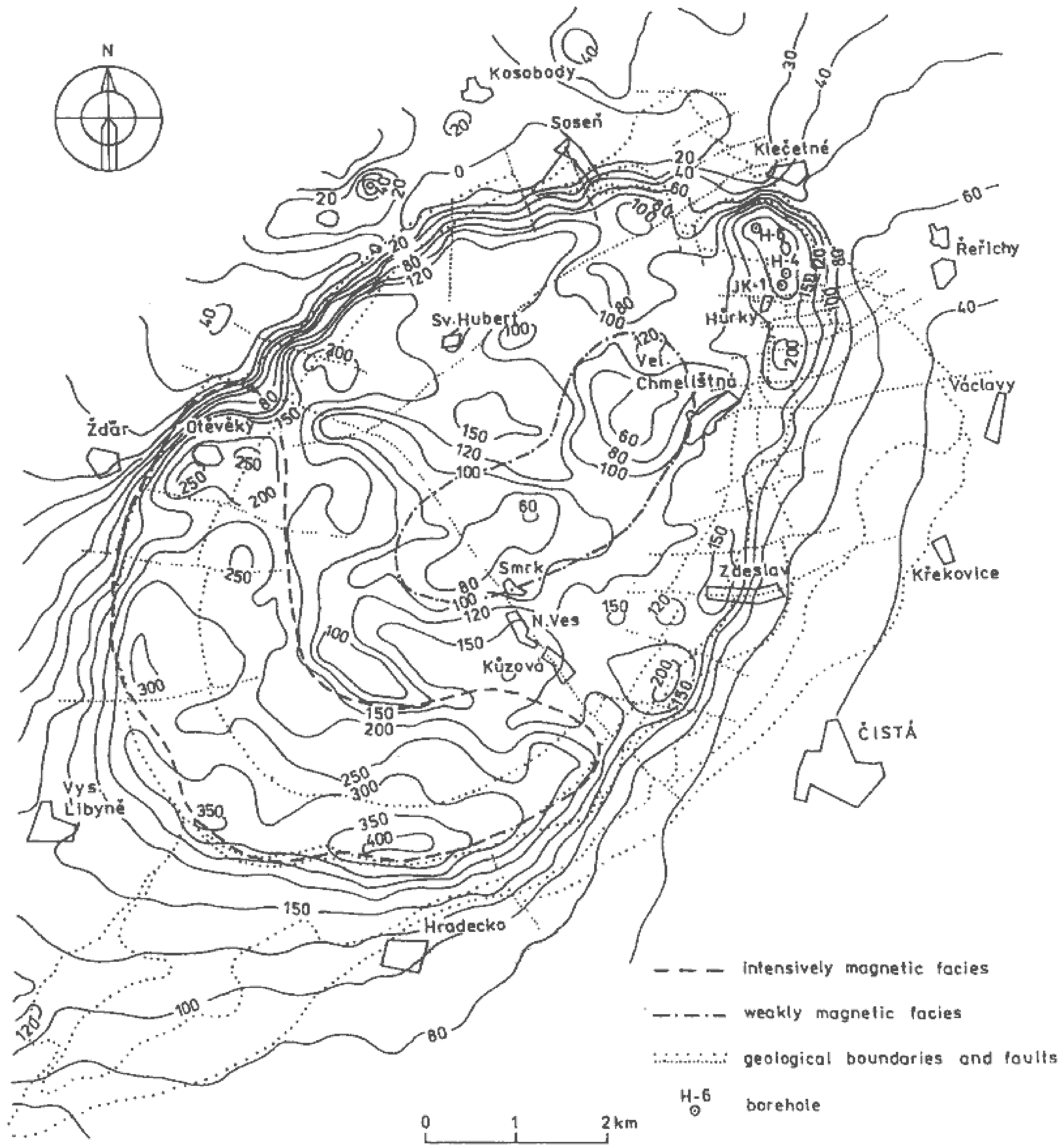


9. Gravity pattern of the Čistá-Jesenice pluton (after a map of Bouguer anomalies in the scale 1 : 200 000 of Ibrmajer ed. 1965). 1 – Proterozoic rocks; 2 – Tis granite; 3 – Čistá granodiorite; 4 – Carboniferous and Cretaceous sediments; 5 – Tertiary sediments; 6 – Tertiary volcanics; 7 – isoanomals of g ($\mu m.s^{-2}$); 8 – outline of the Čistá-Jesenice pluton at the base of Carboniferous (after Klomínský 1966); 9 – extent of the pluton at depth of 1300 m (after Dobeš and Polanský 1967).

pendent position of the Čistá granodiorite within the Čistá-Jesenice granitic pluton. Detailed gravity measurements provided an absolute minimum in g of $-100\ \mu m.s^{-2}$ which is located 1 km WNW of the village of Velká Chmelištná. This negative anomaly was interpreted as a result of a stock-shaped body of uniform density of 2.62 $g.cm^{-3}$ with a root at the depth of about 10 km (Odstrčil in Gnojek et al. 1982). This is in good agreement with previous profile gravity interpretations made by Dobeš (in Kopecký et al. 1970). The Tis granite which covers about 1000 km2 and is mostly buried under a sedimentary cover (Fig. 9), has very likely a much smaller vertical extent (2–3 km), producing only a moderate negative anomaly of –20 to $-30\ \mu m.s^{-2}$ (Dobeš and Polanský 1967).

2.2.2. Magnetic field

A complex magnetic anomaly ΔZ was revealed over the whole granodiorite body and fenite zone during a ground magnetic survey (Čejchanová 1958). This study also led to distinguishing the Čistá granodiorite from the Tis granite and to the discovery of "veins" of alkaline syenite rich in zirconium (Klomínský 1961a, 1961b, 1963). A pattern of magnetic anomalies ΔT over the Čistá massif was obtained through a recent airborne survey carried out in the scale of 1 : 25 000 (Gnojek et al. 1982), (Fig. 10a). The marginal regions of granodiorite in the NW and SE of the structure are characterized by steep horizontal gradient ΔT, while isolines overlap in the SW part of the granodiorite body providing evidence for a lesser plunge of the Čistá granodiorite body. An anomaly in the NE corresponds to the N-S



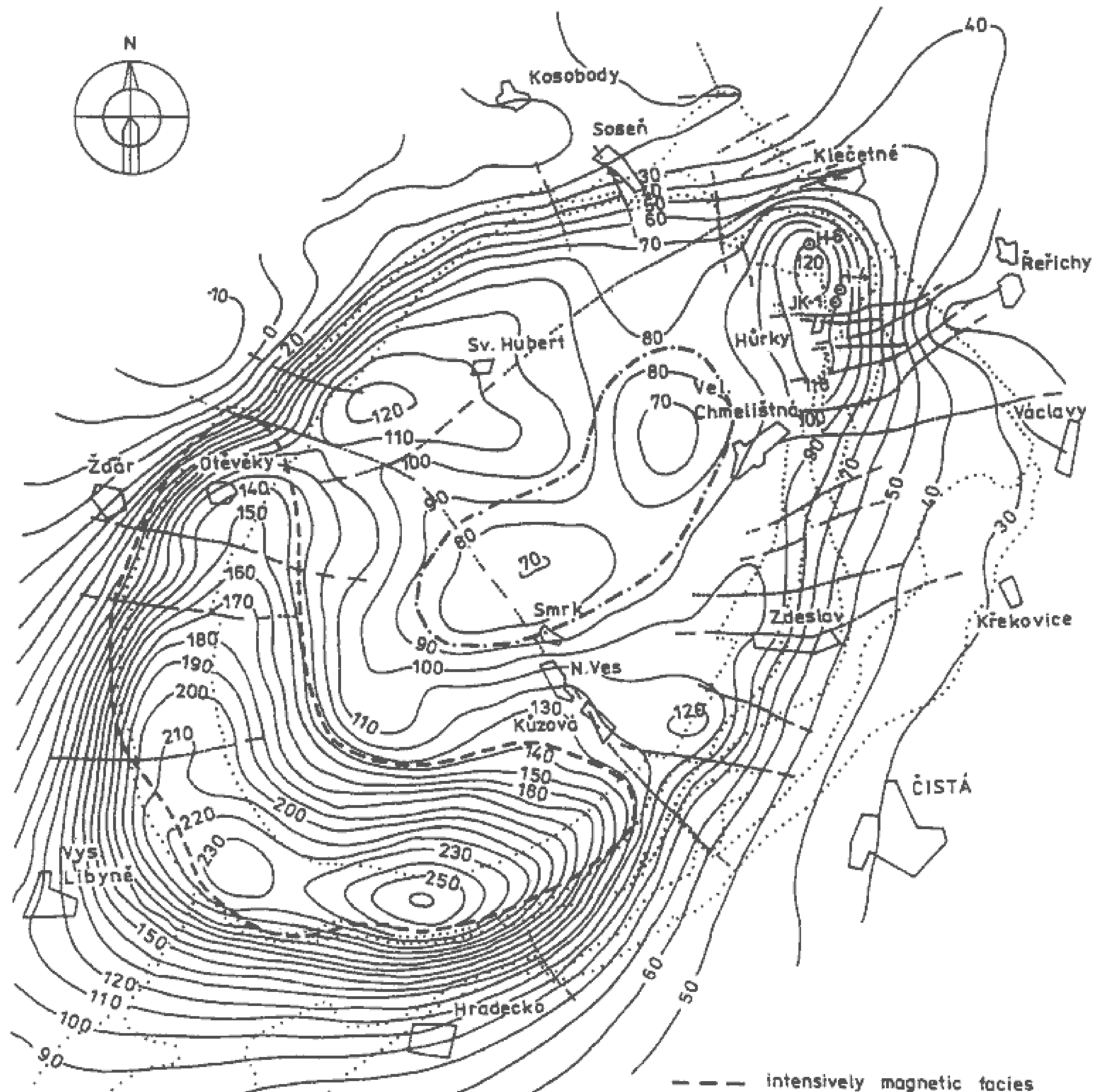
10a. Map of ΔT [nT] anomalies, measured in an elevation of 80 m above the surface. Magnetic pattern of the Čistá structure and distribution of uranium and thorium over its surface outcrop, after aerogeophysical measurement (Gnojek et al. 1982).

trending fenite zone, cropping out in the vicinity of the village of Hůrky.

Analytical continuation of the magnetic field upwards, on a level of 400 m, has been calculated (Fig. 10b). Local anomalies were obliterated and such a method provided a good idea about the distribution of both highly and weakly magnetized parts of the Čistá intrusion. An intensive arc-shaped anomaly is located in the SW, over the marginal facies of granodiorite with a similar clearly visible anomaly over the fenitized zone in the NE.

2.2.3. Distribution of K, U and Th

The distribution pattern of K, Th and U over the Čistá massif was obtained by low level gamma-ray aerospectrometry (Gnojek et al. 1982). The Čistá granodiorite is

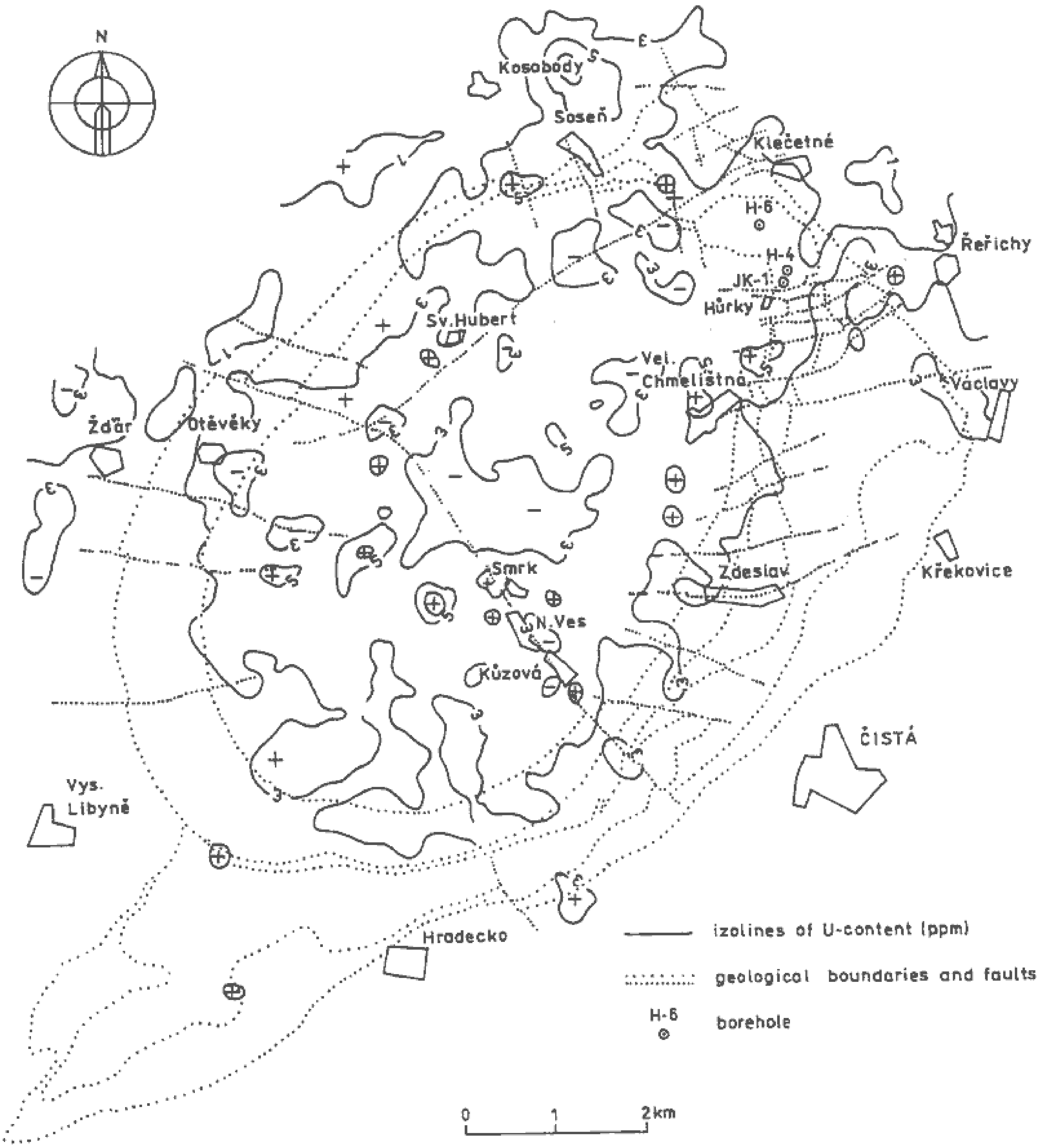


10b. ΔT anomalies, calculated as an analytical continuation of the field upwards to the level of 400 m.

poor in K (contents below 2 %), while K-contents over 2 % are more common in the Tis granite.

In contrast to potassium, U-contents are higher in granodiorite (3 ppm of U), except in marginal parts, than in the Tis granite, which is characterized by values ppm (Fig. 10c). Small maxima, exceeding 5 ppm were found south of the village of Soseň, over the fenitized zone, and in the vicinity of the village of Velká Chmelištná, in the northern part of the massif. Higher values of U associated with an arc-shaped zone occur westward of the village of Nová Ves. However this zone, as apparent from geoelectric survey, does not seem to be promising in terms of ore mineralization (Krs and Petrák 1983).

The central and northern parts of the Čistá granodiorite are slightly enriched in Th in comparison with other parts of the structure (Fig. 10d). Th-contents higher than 12 ppm were found over the fenitized zone. Other elevated Th-concentrations occur near the village of Velká Chmelištná and along the earlier mentioned ring structure near the village of Nová Ves. It seems that this structure may represent a



10c. Distribution of U [ppm] contents of both trace radioelements measured in an elevation of 80 m above the surface.

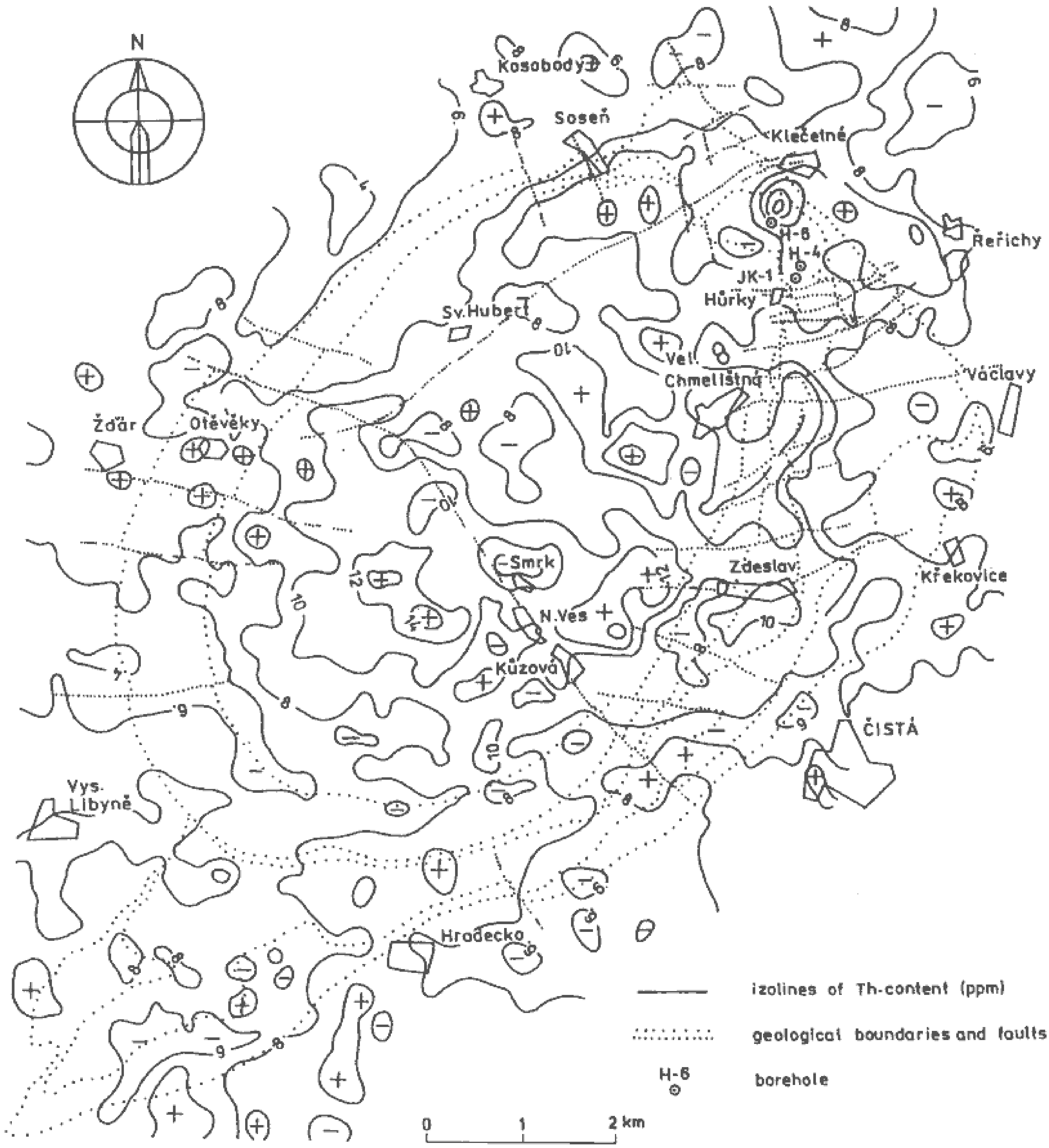
zone enriched in radioactive elements, connected perhaps with later metasomatism.

A detailed ground radiometric survey of the fenitized zone confirmed its anomalous radioactivity. Two N-S trending bands were identified, one with strong Th enrichment, the other bearing anomalous U-values. Both anomalies are nearly spatially coincident, but overlap only partly (Anft and Krištiak 1982, Anft 1983).

3. Geochemistry

3.1. Methods

Data on eighty representative samples covering almost all known rock types from the Čistá-Jesenice-(Louny-Martiněves) pluton were compiled from older (Klomínský 1961a, 1961b, 1963, 1966, Cháb 1968, Čadková et al. 1984) and



10d. Distribution of Th (ppm) contents of both trace radioelements measured in an elevation of 80 m above the surface.

more recent papers (Kopecký Jr. 1990). Complete rock analyses including silicate analyses, XRF analyses of minor and trace elements As, Ba, Cr, Nb, Ni, Rb, Sr, Y, W, Zn, and Zr, optical emission analyses of B, Be, Cu, Ga, Mo, Sn and W and INAA or ICP analyses of REE, Th, U, Hf, Cs and Ta, were newly obtained for 44 samples.

It is necessary to note that the data from the project "Regional Geochemistry of the Bohemian Massif" (Čadková et al. 1984) cover a large spectrum of elements only from the outcropped parts of the Čistá-Jesenice pluton. There are no chemical data from the part of the pluton covered by platform sediments.

The data were processed by several multivariate statistical methods. Grouping by cluster analysis was tested against geological field data to identify possible new rock types.

Chemical composition of all main rock types is summarized in Table 3.

Table 3. Geochemistry of the main rock types from the Čistá-Jesenice pluton

No.	1	3	10	13	14	18	22	27	42
Rock type	AT	AT	AJ	B	B	FUB	PFG	F3	BA3
SiO_2	74.34 %	75.27	75.66	70.48	70.41	57.88	74.54	60.36	60.51
TiO_2	0.21	0.12	0.15	0.29	0.23	2.15	0.07	0.01	0.22
Al_2O	13.22	13.12	12.81	15.49	15.85	9.31	13.71	21.07	13.59
Fe_2O	0.41	0.45	0.32	0.94	0.78	2.55	0.13	0.86	0.46
FeO	1.51	1.01	1.33	1.22	0.75	14.68	0.16	2.04	1.00
MnO	0.04	0.04	0.03	0.06	0.05	1.11	0.01	0.13	0.07
MgO	0.41	0.17	0.12	0.63	0.55	8.91	0.05	0.15	0.52
CaO	0.65	0.45	0.49	2.23	2.22	4.29	0.34	1.13	8.34
Na_2O	3.56	3.71	3.54	5.27	5.47	0.96	3.92	5.88	4.52
K_2O	4.68	4.61	4.65	2.46	2.81	7.18	5.71	5.68	3.52
P_2O_5	0.09	0.11	0.07	0.12	0.10	0.23	0.30	0.02	0.05
CO_2	0.02	0.01	0.01	0.01	0.01	n.d.	n.d.	0.76	5.07
[%]	99.14	99.07	99.15	99.20	99.23	99.25	98.94	98.09	97.87
Li	54 ppm	53	39	20	17	1234	10	300	40
Rb	131	145	121	37	54	448	130	140	78
B	50	29	28	27	27	n.d.	n.d.	n.d.	n.d.
Sr	27	10	20	609	889	327	28	570	706
Ba	464	245	397	1020	858	n.d.	n.d.	557	767
Y	31	28	24	2	4	167	15	244	13
La	15	13	10	27	23	265.41	2.4	529.4	20.3
Ce	27	23	17	34	42	450	4.4	960.6	30.8
Sm	3	3.1	2.3	3.3	2.4	26.3	1.0	41.3	1.7
Eu	0.34	0.21	0.28	1.16	0.87	2.45	0.1	1.9	0.4
Tb	0.3	0.2	0.3	0.6	0.7	3.89	0.4	6.17	1.0
Yb	3.0	2.0	1.8	1.1	0.6	9.2	0.85	16.6	0.4
Lu	0.4	0.2	0.3	0.1	0.1	1.08	0.04	2.5	0.2
Zr	117	81	100	89	78	82	21	2161	122
Th	10	7	9	8	17	n.d.	n.d.	n.d.	n.d.
Nb	2	5	3	10	10	176	4	98	15
Ta	0.2	0.3	0.2	1.7	0.8	n.d.	n.d.	n.d.	n.d.
Cr	25	12	18	37	15	296	16	5	31
Mo	7	5	4	4	2	150	3	2	1
U	3	6	4	6	6	11	6	7	6
Ni	48	32	54	39	29	235	2	3	3
Zn	53	57	46	38	30	1589	4	153	27
Ga	18	15	23	16	12	n.d.	n.d.	68	10
Sn	3	5	4	2	1	74	24	16	1
Pb	22	13	22	20	30	15	21	46	13
Cu	4	3	3	3	1	8	4	5	4

1 – AT=Tis granite (southern part of the body); 3 – AT=Tis granite (northern part of the body); 10 – AJ=Jesenice granite (Petrohrad body); 13 – AC=Čistá granodiorite (SW part of the body); 14 – B=Čistá granodiorite (central part of the body); 18 – FUB=biotite ultramylonite syenite fenite (H-13A bore hole, 37.5m); 22 – PFG=muscovite granite „Černá kočka" Hill (SE-rim of the Čistá granite); 27 – F3=III-IV stage of fenitization of albitite mylonite with arfvedsonite (H-28 borehole, 105.7m); 42 – BA3=strongly albitized granodiorite (H-28 b.h., 423.9m), n.d.=not detected.

3.2. Geochemical classification and interpretation

Based on cluster analysis and field data six groups of rocks were identified:

1. Tis granite (A) with subtype of the Tis granite s.s. (AT) forming the Tis granite body, the Petrohrad granite (AJ) forming the Jesenice-Oráčov and Petrohrad granite bodies.
2. Čistá granodiorite (B),
3. Pre-fenitic dyke rocks (almost all subsequently fenitized),
4. fenites s.l. (F1-F3) with ultramylonite fenites (FUB),
5. albitized and K-feldspathized Čistá granodiorite with granodiorite porphyrites (BA1-BA3),
6. post-fenitic rock dykes (occur rarely) and the tourmaline bearing muscovite granite ("Černá kočka" Hill) (PFG).

Four rock types represent magmatic intrusive bodies both prefenitic and postfenitic (i.e. granites s.l., granodiorite and associated dyke rocks), while fenites s.l. and feldspathized rocks have their origin in processes of alkaline metasomatism.

Magmatic differentiation and later metasomatic processes have significantly influenced the geochemistry of major, minor and trace elements. This can be documented on Rb/Sr and Rb/Zr plots (Figs. 11a, 11b), where differences between both the older Jesenice granites (Petrohrad and Tis) and the younger granodiorite are evident. A relative enrichment in LILE (Rb as well Na, K) in the Tis granite and an accumulation of incompatible elements such as Zr, Nb and Sr in the Čistá granodiorite is illustrated in the Rb/Zr plot (Fig. 11b).

The REE patterns (Fig. 12a) clearly reflect the character of the main rock types. Apart from dykes and metasomatites, all three main plutonic types are characterized by different REE plot. Both subtypes of the Jesenice pluton (i.e. Petrohrad and Tis) have similar REE patterns. The Petrohrad-subtype is rather enriched in bulk REE-contents while the Tis-subtype has a stronger negative Eu-anomaly.

Granodiorite is geochemically different from granites in terms of higher contents of Ba, Ce, Nb, Sr, Th and lower contents of Li, Rb and Y. The positive Eu-anomaly which is comparable with the distribution of Eu in the Štěnovice granodiorite massif (western Bohemia, vicinity of Plzeň, Čadková et al. 1984)) seems to have magma derived from a different source than other granites of the Čistá-Jesenice pluton. Both the presence of Ca-rich plagioclases and a positive Eu-anomaly (relative Eu-enrichment) are symptomatic for cumulate derivates.

All types of fenites (i.e. fenitized granite and fenitized ultramylonites) are remarkably enriched in REE with strong prevalence of LREE (Fig. 12b). Albitized granodiorite shows a similar pattern (Fig. 12c), however, with the lower REE contents. The position of slightly feldspathized granodiorite (sample No. 43) reflects the Eu-enriched character of non-metasomatized rocks.

The REE patterns of fenitized (or feldspathized) dykes resemble those of granodiorite and are associated with magmatic activity during which the granodiorite intruded (Fig. 12d).

Among the post-fenitic rocks the muscovite tourmaline-bearing granite ("Černá kočka" Hill) situated between the SE-contact of granite and crystalline schists in the vicinity of the town of Čistá (Fig. 12e, anal. No. 22), bears mention.

The REE pattern reflects magmatic differentiation and the succession of several magmatic subtypes. A relative REE-enrichment in the Petrohrad subtype is in accordance with the Rb/Sr plot, and could support the suggestion of a multiphase intrusion if compared with the Tis granite (Fig. 11). The REE pattern with higher $(La/Lu)_{CN}$ ratio supports the idea of a later intrusion of the Tis-subtype.

Both plutonic and dyke rocks were plotted in the Q-ANOR diagram of Streckeisen and Le Maitre (1979) (Fig. 13). Granite of the Tis-subtype reflects a slight alkaline tendency if compared with the Petrohrad-subtype. This is in good correlation with both Rb/Zr and REE plots. Fenites and rheomorphic syenite fenites fall into the field undersaturated in silica and/or foid-bearing rocks.

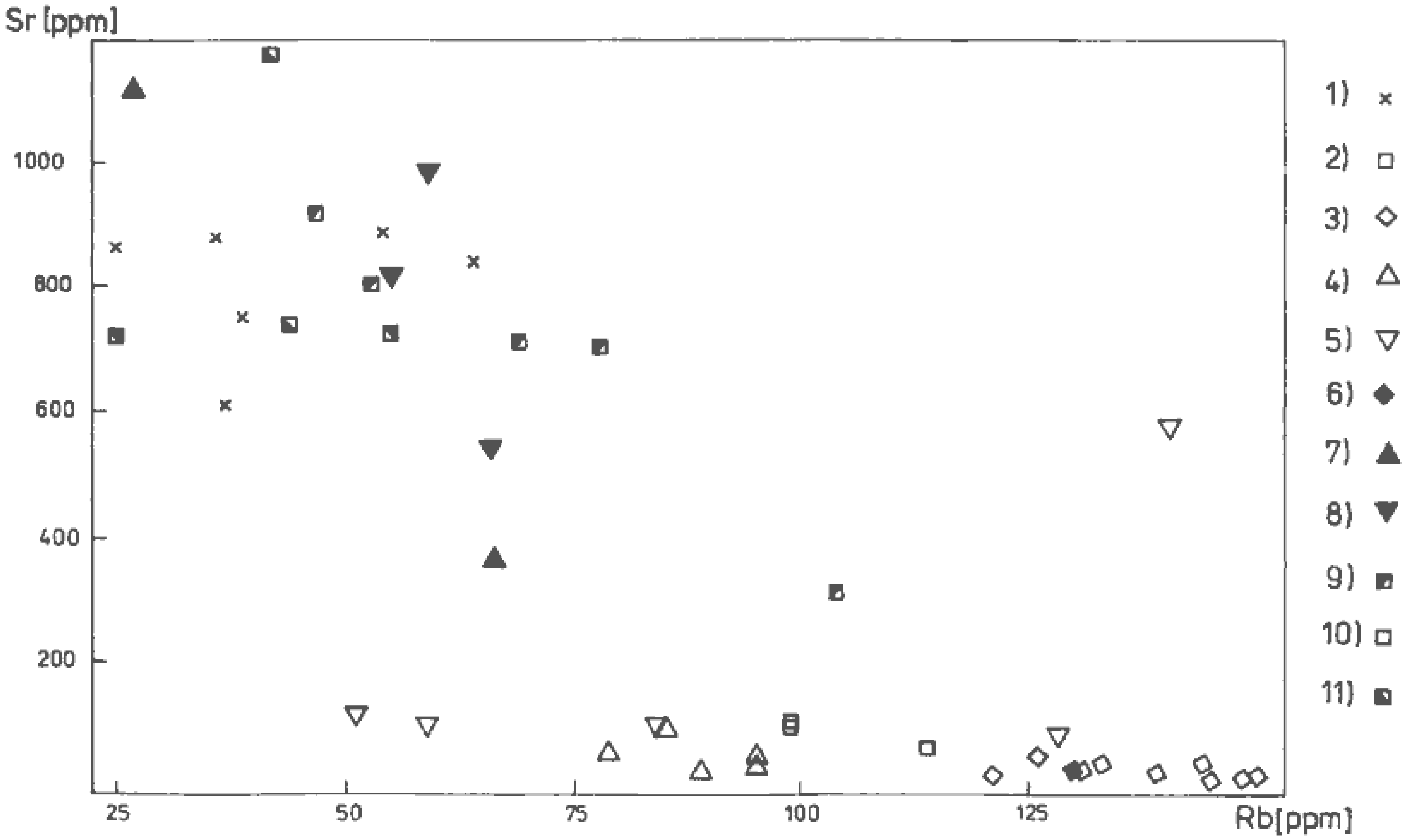
The de La Roche R1-R2 multicationic diagram (after Batchelor and Bowden 1985) (Fig. 14), based on data from well-defined tectonomagmatic environments, gives the distribution of all principal rock-types.

A very good discrimination of different rock types was obtained on the Zr + Nb + Ce + Y vs. $(K_2O + Na_2O)/CaO$ plot (Fig. 15). This diagram is thought to be relatively insensitive to moderate degrees of alterations. It was originally used to distinguish A-type granites (Whalen et al. 1987), considered as medium differentiated. They occupy the more alkaline and more Zr, Nb, Ce, Y enriched segment of the diagram. The fenitized granite mylonites, fenites and/or alkaline syenites also plot within the field proposed by Eby (1990) for A-type granites.

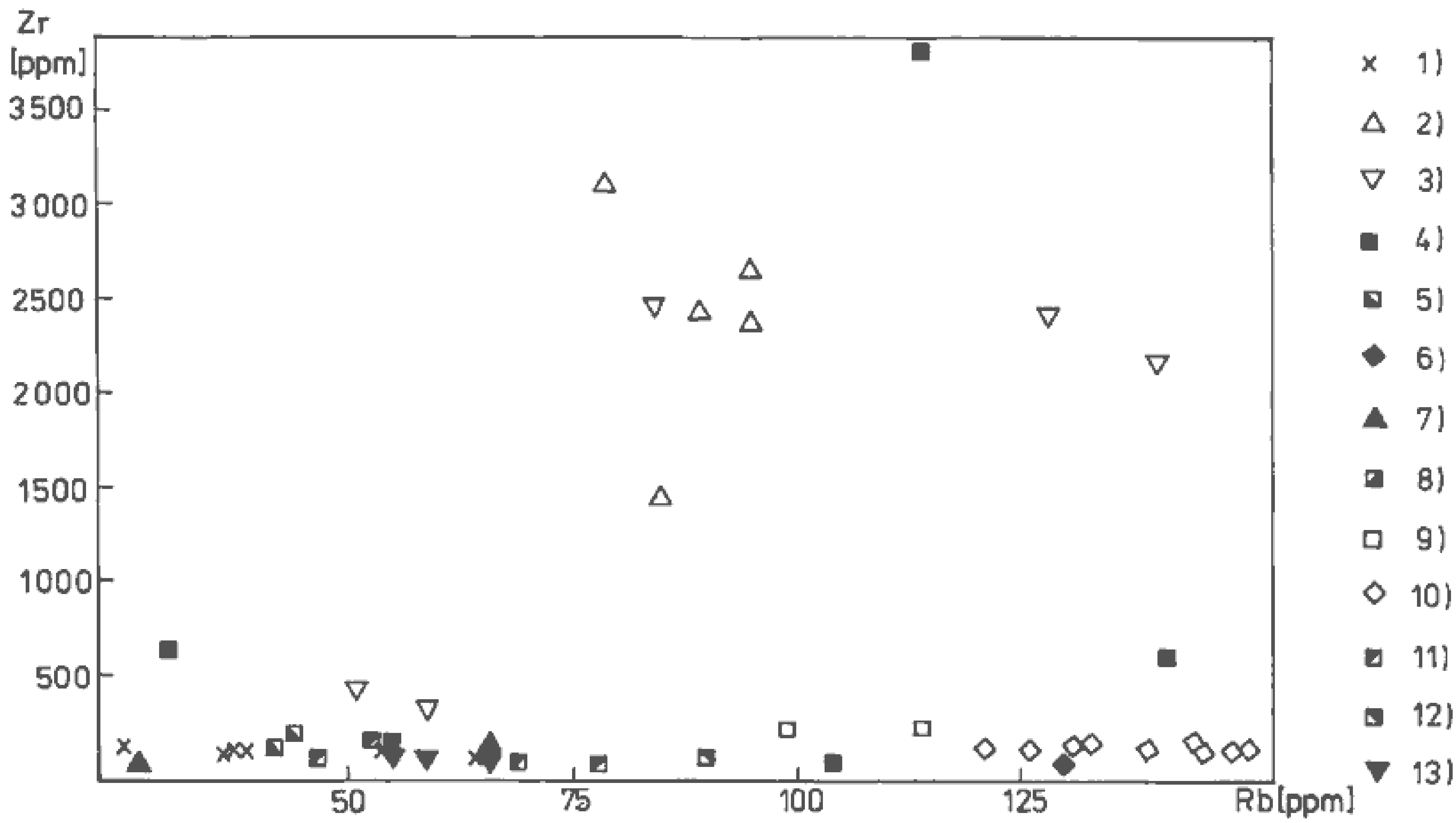
The A-type granitic suits are assumed to be emplaced into non-orogenic setting (within plate setting during the waning stages of subduction zone-related magmatism). Excluding high SiO_2, the granites are also characterized by high alkali (Na_2O+K_2O = 7–11 %) and low CaO (below 1.8 %) contents and high FeO_{tot}/MgO ratio. The major element chemistry corresponds to occurrence of iron-rich micas, amphiboles, pyroxenes and their peralkaline (Na-) varieties: riebeckite-arfvedsonite and aegirine-augite. Also the higher contents of high field strength elements (HFSE), are distinctive, and they are symptomatic for fenites s.l. The distinction of all main rock populations is striking (Fig. 15).

Data for both the Petrohrad (Jesenice) granite-subtype and for the Čistá granodiorite plot into the field of I- S- and M-types granitoids (OGT field). This group exhibits distinctively low contents of Zr, Nb, Ce, Y and a low ratio of (K+Na)/Ca as a consequence of cumulate fractionation. It represents magma in combination with the lower crustal or mantle derived source. This latest interpretation corresponds with the REE-pattern of the Čistá granodiorite intrusion (Fig. 12). The plot of sample No. 22 in the Zr+Nb+Ce+Y vs. $(K_2O+Na_2O)/CaO$ diagram and REE -pattern of the post-fenitic muscovite (tourmaline-bearing) granite support the theory of a spatially and temporally different character of this intrusion as compared with other granitic rocks of the Čistá-Jesenice pluton.

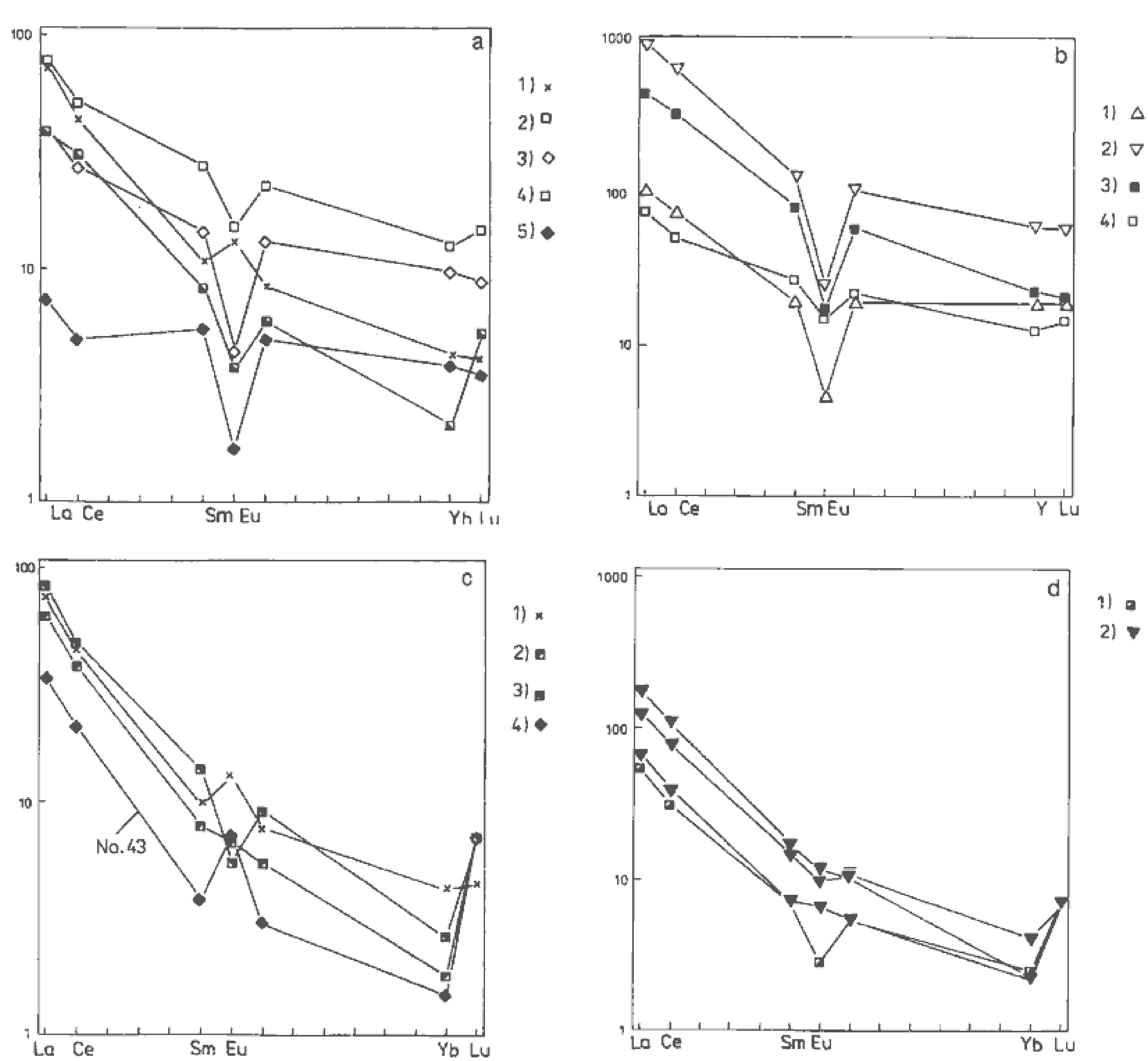
For the discrimination of the tectonic regime during

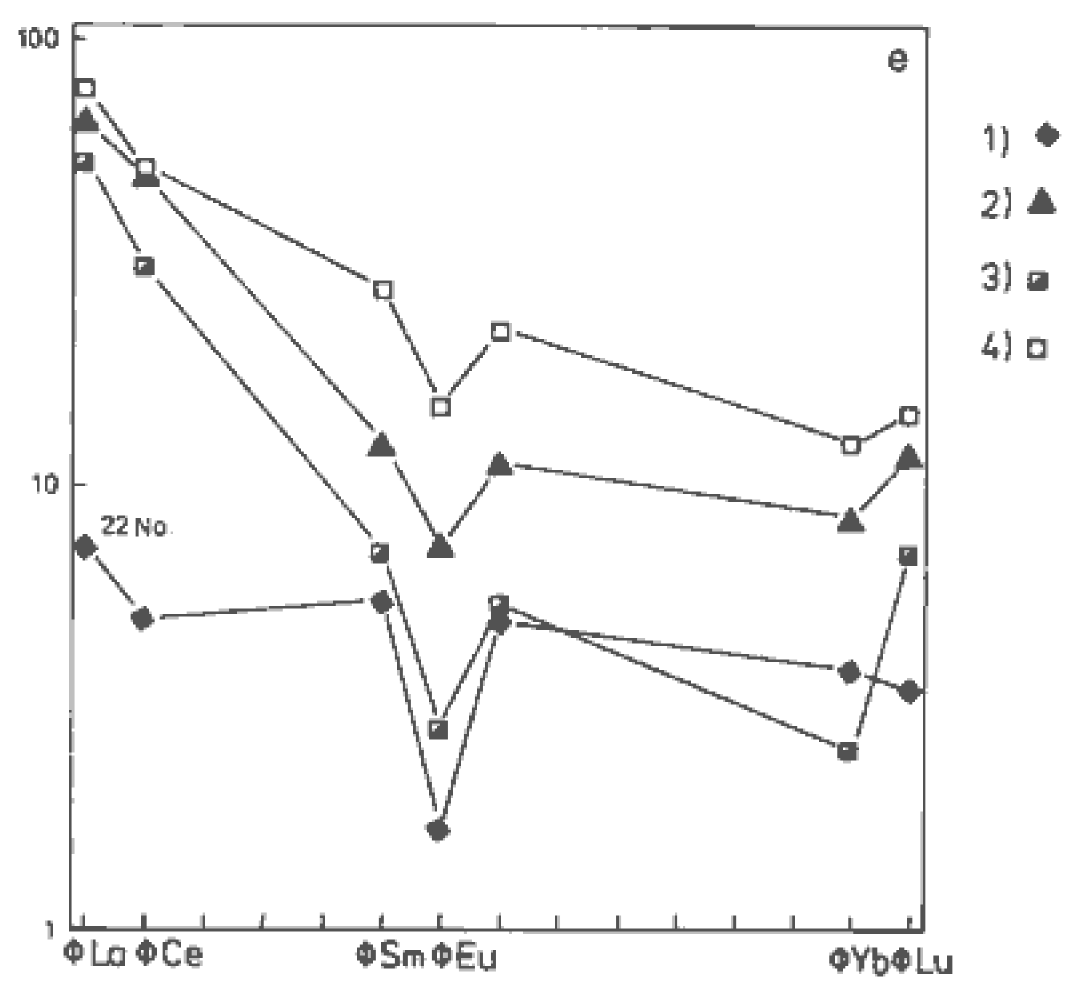


11a. Rb vs. Sr relation in granitoids. 1 – Čistá granodiorite; 2 – Petrohrad-subtype of granite; 3 – Tis-subtype of granite; 4 – fenites s.l of lower degree; 5 – fenites of higher degree; 6 – post-fenitic muscovite granite ("Černá Kočka" Hill); 7 – post-fenitic granodiorite porphyrite dykes; 8 – fenitized granodiorite porphyrite dykes; 9 – strongly albitized granodiorite (Čistá body); 10 – slightly albitized granodiorite (Čistá body); 11 – aplites (fenitization free).



11b. Rb vs. Zr relation in granitoids. 1 – Čistá granodiorite; 2 – fenites s.l. of lower degree; 3 – fenites s.l. of higher degree; 4 – biotite ultramylonite syenite fenites; 5 – nonfenitized dyke rocks; 6 – muscovite granite "Černá kočka" Hill (SE-rim of the Čistá granite; 7 – post-fenitic granodiorite porphyrite dykes; 8 – aplites (fenitization free); 9 – Petrohrad subtype of granite; 10 – Tis-subtype of granite; 11 – strongly albitized granodiorite (Čistá body); 12 – slightly albitized granodiorite (Čistá body); 13 – fenitized granodiorite porphyrite dykes.





12. Pattern of chondrite normallized REE-values (after Nakamurą 1974). The average values of rock types are used for:

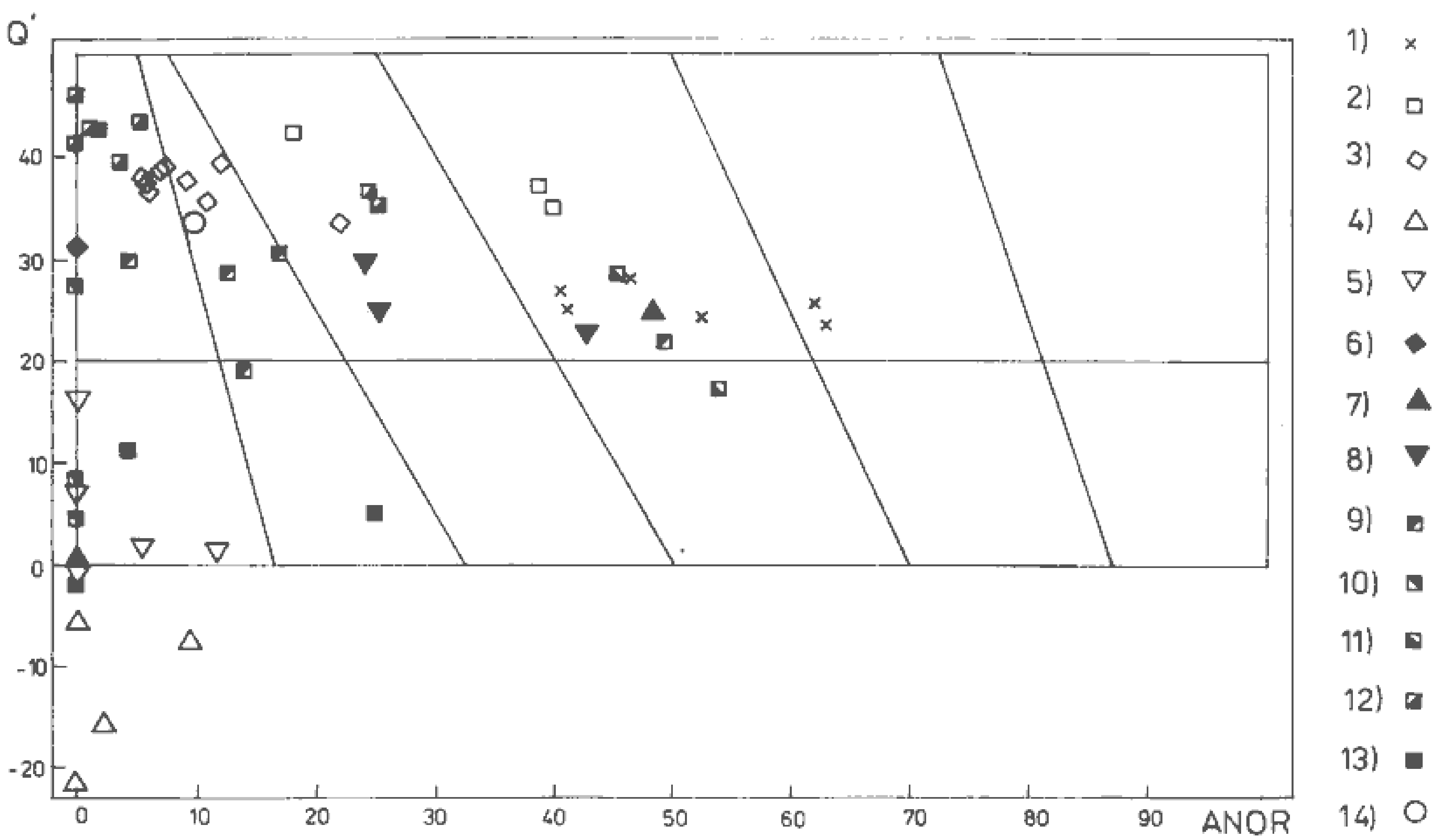
a) – main intrusive bodies of the Čistá-Jesenice pluton. 1 – Čistá granodiorite; 2 – Petrohrad subtype of granite; 3 – Tis-subtype of granite; 4 – nonfenitized aplites; 5 – postfenitic muscovite granite ("Černá Kočka" Hill).

b) – fenites s.l. from the vicinity of Hůrky. 1 – fenites s.l. of lower degree; 2 – fenites s.l. of higher degree; 3 – Ultramylonite biotite fenites; 4 – Petrohrad subtype of granite (added for comparison).

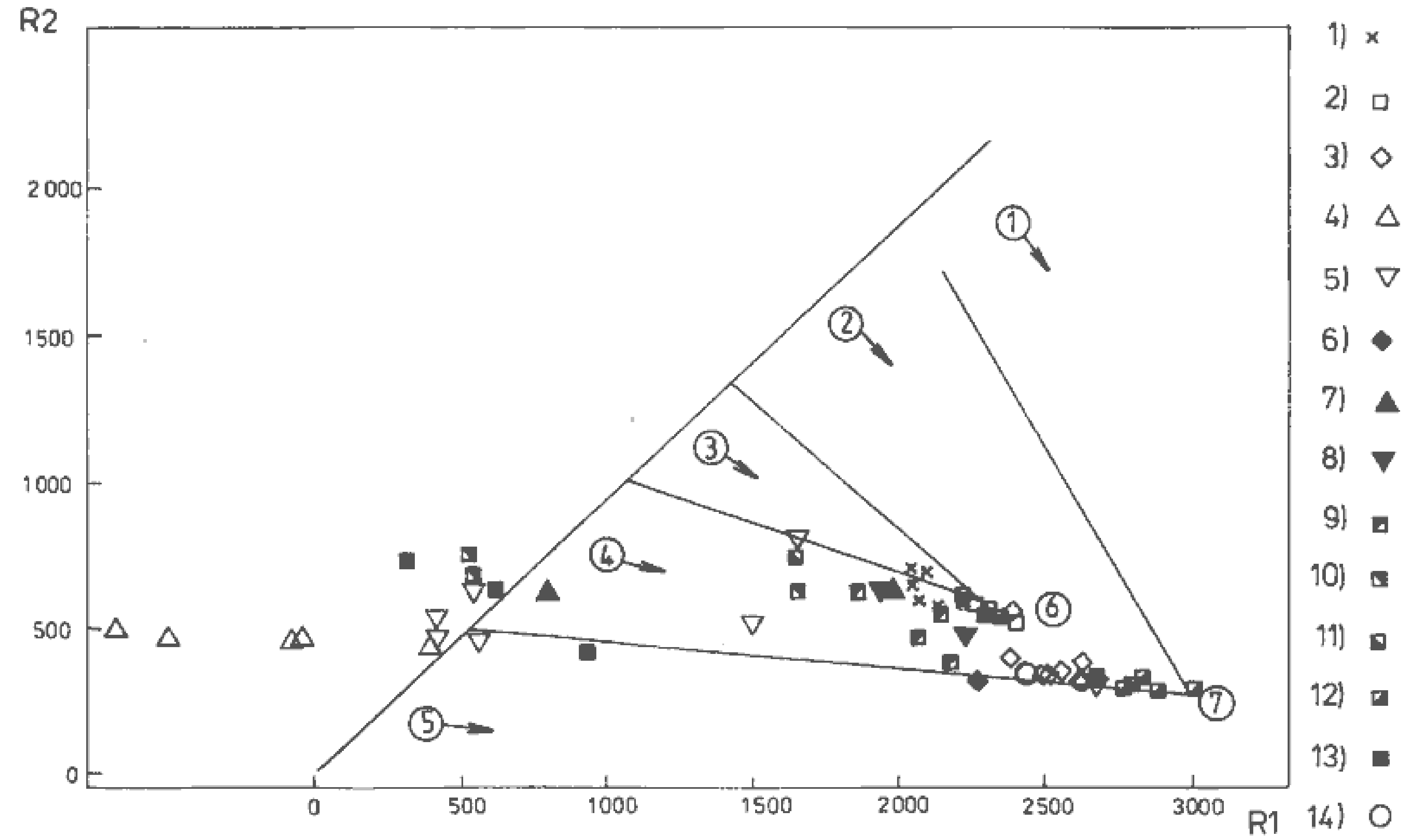
c) – feldspathized rocks s.l. from the vicinity of Hůrky. 1 – Čistá granodiorite (non-feldspathized); 2 – strongly albitized granodiorite (Čistá body); 3 – slightly albitized granodiorite (Čistá body); 4 – post-fenitic granodiorite porphyrite (added for comparison).

d) – aplite and fenitized granodiorite porphyrites from the vicinity of Hůky. 1 – aplites; 2 – fenitized granodiorite porphyrites.

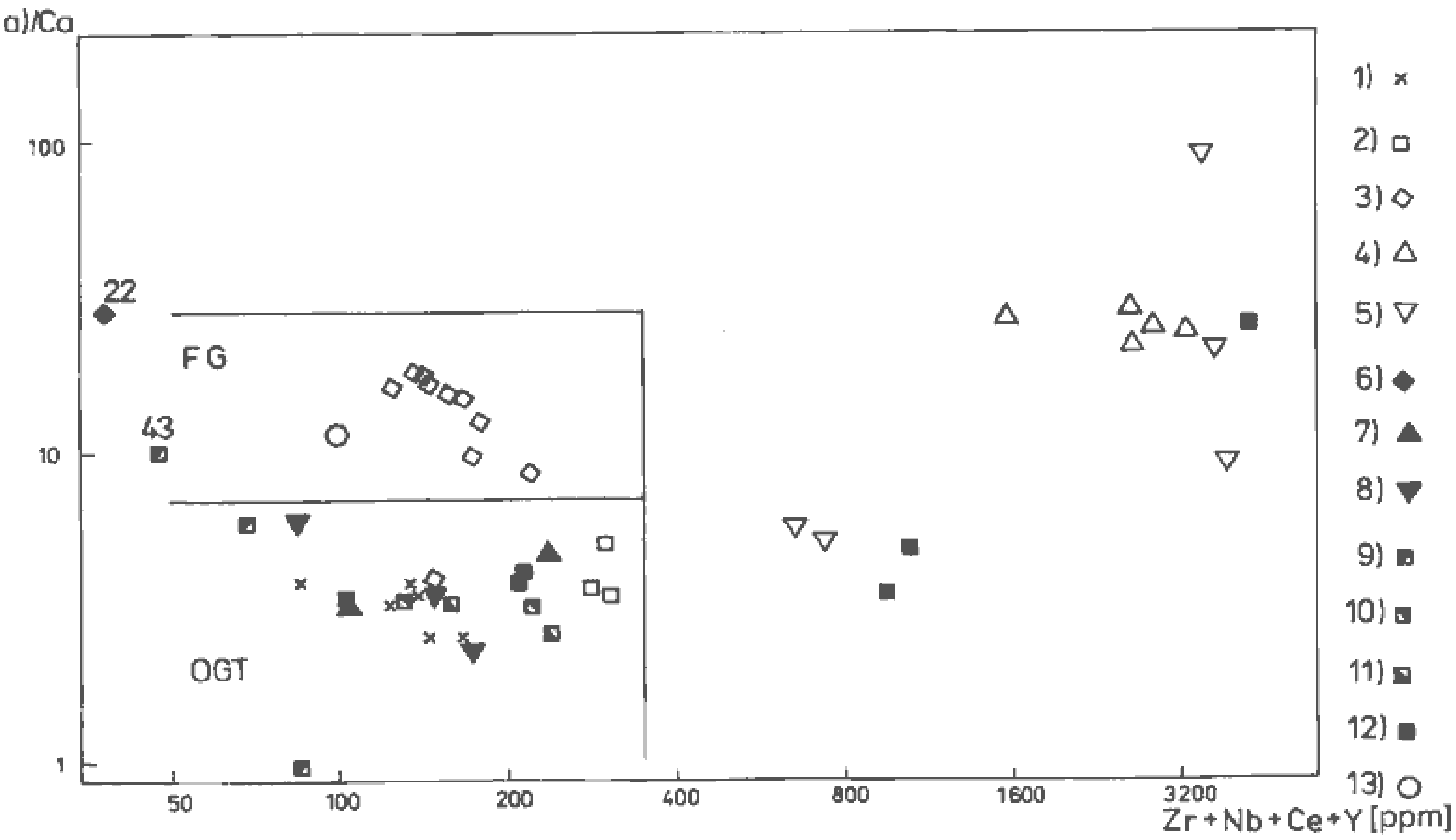
c) – post-fenitic muscovite granite ("Černá kočka" Hill) and dykes of post-fenitic granodiorite porphyrites and aplites. For comparison values of the Petrohrad granite subtype are plotted. 1 – post-fenitic granite (anal. No. 22); 2 – post-fenitic granodiorite porphyrites; 3 – aplites; 4 – Petrohrad subtype of biotite granite.



13. Classification of the rock types of the Čistá-Jesenice pluton in the Q-ANOR diagram of Streckeisen - Le Maitre (1979). Q = 100 Q/(Q + Or + Ab + An); ANOR = 100 An/(An + Or).
1 – Čistá granodiorite; 2 – Petrohrad granite subtype; 3 – Tis granite subtype; 4 – fenites s.l. of lower degree; 5 – fenites s.l. of higher degree; 6 – post-fenitic muscovite granite ("Černá kočka" Hill); 7 – post-fenitic granodiorite porphyrite dykes; 8 – fenitized granodiorite porphyrite dykes; 9 – strongly albitized granodiorite (Čistá body); 10 – slightly albitized granodiorite (Čistá body); 11 – fenitization-free dyke rocks; 12 – Rumburk granite of the Lusatian pluton; 13 – biotite ultramylonite fenites; 14 – aplites.



14. The Batchelor R.A. & Bowden P. (1985) – de La Roche R1-R2 multicationic diagram. R1 = 4Si – 11(Na + K) - 2(Fe + Ti); R2 = 6Ca + 2Mg + Al. The fields for the source trend during orogenic cycle (numbers in circles): 1 – mantle fractionates; 2 – pre-plate collisions; 3 – post-collision uplift; 4 – late-orogenic; 5 – anorogenic; 6 – syn-collision; 7 – post-orogenic. For other explanations see Fig. 13.



15. The Zr+Nb+Ce+Y vs. (K + Na)/Ca, Whalen et al. (1987) discriminant diagram for A-type granitoids: OGT = filed for I-, S- and M-type granitoids; FG = field for fractionated I-type granitoids; fenites plot mostly outside these fields. 1 – Čistá granodiorite; 2 – Petrohrad granite subtype; 3 – Tis granite subtype; 4 – fenites s.l. of lower degree; 5 – fenites s.l. of higher degree; 6 – post-fenitic muscovite granite ("Černá kočka" Hill); 7 – post-fenitic granodiorite porphyrite dykes; 8 – fenitized granodiorite porphyrite dykes; 9 – strongly albitized granodiorite (Čistá body); 10 – slightly albitized granodiorite (Čistá body); 11 – non-fenitized dyke rocks; 12 – biotite ultramylonite fenites; 13 – aplites.

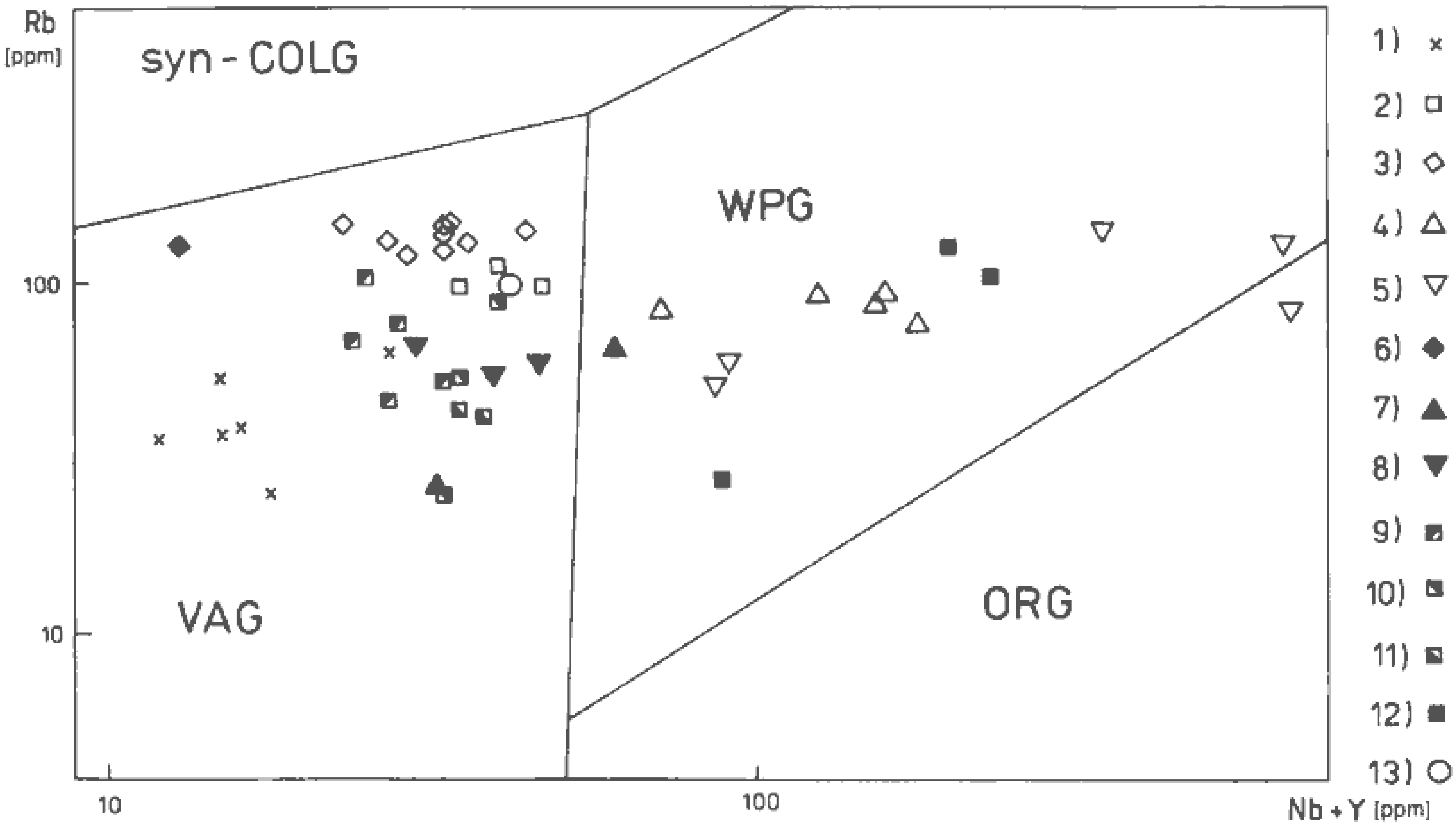
intrusion the most effective elements are Rb, Y (Yb), Nb (Ta). Contents of Y (Yb) and Nb (Ta) are assumed to be independent on alteration. According to Pearce et al. (1984): "...this projection plot yields complete separation of the VAG-field (volcanic arc granites) and WPG-field (within plate granites). The discrimination line between WPG-field and ORG-field (ocean ridge granites) could be overlapped by both types caused by WPG from attenuated continental lithosphere" (i.e. overlap below the dashed line in the plot Y vs. Nb; Fig. 16a)"...because the influence of Rb-inclusions in K-feldspars of LILE-rich rocks facies should separate the VAG-field from syn-COLG-field (syn-collision granites) (or ORG-field from WPG-field resp.) and thence the values from attenuated continental lithosphere can be little more shifted below the dashed line of the field WPG, the graph (Nb+Y)/Rb carries most of the discriminant power." (Fig. 16b).

All granites and granodiorites and associated "non-metasomatized" dykes plot into the fields of the VAG + syn-COLG (Y vs. Nb) or VAG [(Nb+Y)/Rb], but the distinct grouping of each of the rock types is evident. The lowest values of the Čistá granodiorite of all types involved, apparently suggest its derivation from a high-fractionated and HFSE-depleted mantle (or lower crust) source of cumulate character. The plot of muscovite granite with tourmaline proves (similar to the other diagrams) its relatively

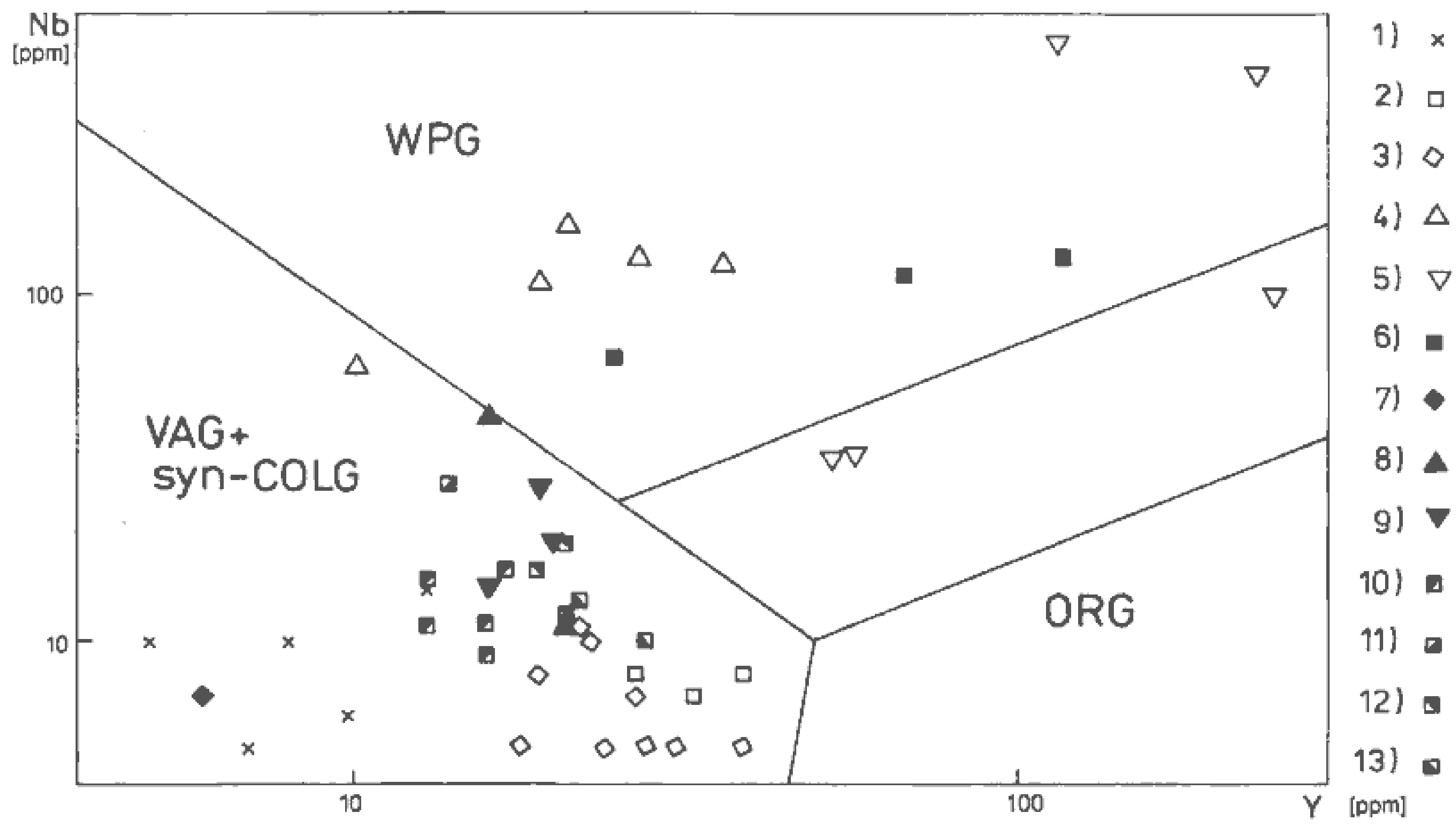
Table 4. Distribution of REE, Ta and Hf contents in heavy-mineral fractions of fenites s.l. from the vicinity of Hůrky

Rock group minerals	La [ppm]	Ce [ppm]	Nd [ppm]	Sm [ppm]	Eu [ppm]	Gd [ppm]	Yb [ppm]	Hf [ppm]	Ta [ppm]
nepheline syenite al, pc, zr, af, px, e	2 133 b.f.	3 459 b.f.	5 459 h.f.	186 h.f.,	15 b.f.,	50 l.f.	656 h.f.	13 958 h.f.	50 h.f.
syenite fenite al, pc, zr, af, px, ph, e	12 620 b.f.	27 768 b.f.	19 327 h.f.	1 918 b.f.	172 b.f.	760 l.f.	1141 h.f.	8 551 h.f.	376 b.f.
albitite fenites al, pc, zr, af, mz, e	5 446 l.f.	8 850 l.f.	3 288 l.f.	303 l.f.	21 l.f.	14 l.f.	1279 h.f.	13 902 h.f.	222 b.f.
ultramylonite fenite al, pc, zr, af, ph, mz, e	2 670 l.f.	6 038 l.f.	2 346 l.f.	374 l.f.	30 l.f.	260 h.f.	728 h.f.	12 969 h.f.	260 h.f.
granodiorite porphyrite al, pc, zr, mz, e	1 958 b.f.	2 963 l.f.	1 169 b.f.	177 l.f.	22 l.f.	103 l.f.	136 h.f.	1 074 h.f.	142 h.f.

Minerals as likely concentrators are as follows: af – arfvedsonite, al – allanite, e – eudialyte, mz – monazite, pc – pyrochlore, ph – phlogopite, px – pyroxene (aegirine-augite), zr – zircon, l.f. – light fraction, h.f. – heavy fraction, b.f. – both fraction.



16a. The Nb+Y vs. Rb, Pearce et al. (1984) discrimination diagram for granites from various geotectonic positions: syn-collision (syn-COLG), volcanic arc (VAG), within plate (WPG) and ocean ridge (ORG) granites. 1 – Čistá granodiorite; 2 – Petrohrad granite subtype; 3 – Tis granite subtype; 4 – fenites s.l. of lower degree; 5 – fenites s.l. of higher degree; 6 – post-fenitic muscovite granite ("Černá kočka" Hill); 7 – post-fenitic granodiorite porphyrite dykes; 8 – fenitized granodiorite porphyrite dykes; 9 – strongly albitized granodiorite (Čistá body); 10 – slightly albitized granodiorite (Čistá body); 11 – non-fenitized dyke rocks; 12 – biotite ultramylonite fenites; 13 – aplites.



16b. The Y vs. Rb, Pearce et al. (1984) discrimination diagram. 1 – Čistá granodiorite; 2 – Petrohrad granite subtype; 3 – Tis granite subtype; 4 – fenites s.l. of lower degree; 5 – fenites s.l. of higher degree; 6 – biotite ultramylonite fenites; 7 – post-fenitic muscovite granite ("Černá kočka" Hill); 8 – post-fenitic granodiorite porphyrite dykes; 9 – fenitized granodiorite porphyrite dykes; 10 – strongly albitized granodiorite (Čistá body); 11 – aplites; 12 – slightly albitized granodiorite (Čistá body); 13 – non-fenitized dyke rocks.

independent source. Syenitic fenites and zircon -rich biotite (phlogopite) ultramylonites both exhibit features of A-type granites and in the diagram (Fig. 16b) both plot into the WPG-field. High Nb, Y and Rb as well as Zr+REE contents together with higher amount of alkalies (Na»K predominance) are assumed to be derived from UP-mantle partial melts enriched in HFSE. The alkali-rich melts are suggested to be derived from primary magmas occurring along the assumed 15% partial melting line.

The values of (Nb+Y)/Rb (Fig. 16b) of both the Tis and Petrohrad (Jesenice) granite types plot into the VAG-field. The relative abundance of Rb, could imply the selective additional introduction of Rb (probably from subduction components introduced into the upper mantle/lower-crust region). The crustal source could be quartz diorites and graywackes and its melting yields high Rb-magmas. The theoretical magma derivation from the substratum of graywacke composition (with minor metabasalt/quartz diorite lenses) seems to be in a good agreement with Rb-contents of both the source rocks and granites of the Čistá-Jesenice pluton.

The post-collision granites plot into the VAG-field of the diagram. Granites of the Čistá-Jesenice pluton plot into the VAG-field and this fact corresponds with a probable mechanism of the intrusion event, i.e., pulsing introduction of magma masses into the postorogenic environment of very low metamorphosed rock sequences of the Teplá-Barrandian Late Proterozoic in the period of Early Paleozoic, most likely in Late Cambrian or Early Ordovician (c.f. granite intrusion into the Bechlín diorite body, Be-1 borehole, Cháb 1968, 1975).

3.3. Ree distribution in fenites and feldspathized rocks

The regional geochemistry project (Čadková et al. 1984) and the latest structural borehole H-28, (Kopecký Jr. 1990) have yielded the complete REE values for all fenitized rocks.

REE, Th, U, Hf and Ta contents were also determined from mineral (both heavy and light) fractions of fenites and feldspathized rocks and relative volumes of individual minerals were assessed (Hoffman and Trdlička 1988).

Individual minerals were determined by RTG-methods. In Tab. 4, likely REE-concentrators in mineral fractions are given:

The prevailing amount of an individual element is bound either in the light fraction (l.f.) or in the heavy fraction (h.f.) or the element is equally distributed in both fractions (b.f.).

La, Ce and Nd are mainly concentrated in allanite and in the phlogopite-rich bands of arfvedsonite fenites. Arfvedsonite, aegirine-augite and phlogopite in biotite-phlogopite ultramylonitic fenites seem to be the main mineral-concentrators of Gd and Eu. Pyrochlore is the only mineral-concentrator of Ta. Hf (as well as Th, Zr and U) is exclusively contained in zircon and monazite; Yb concentrates in monazite and eudialyte.

According to bulk analyses of fenitized rocks the LREE/HREE ratios increases in the final stage of fenitization. The maximum bulk contents of REE (reaching 1770 ppm) are in aegirine-cancrinite and nepheline syenitic fenites and in hornblende-biotitic ultramylonitic fenites. LREE/HREE ratio in albitites and fenites of the Čistá massif and those in ijolite-carbonatite complexes are analogous. The enrichment in LREE is characteristic for the late stage of ijolite-derived metasomatism, i.e. for the highly differentiated melts enriched in volatiles. High contents of REE were also found in the fenitized stripes of (pre-fenitic) dykes of granodiorite porphyrites.

3.4. C and O isotopic composition of fenites

Isotopic compositions of carbon and oxygen in biotite-phlogopite-carbonate streaks of fenites and younger carbonate veinlets in fenites were reported by Kopecký et al. (1987): "In the biotite-rich sövitic types of fenites that originate in the ultramylonite zone there are syngenetic streaks of white coarse grained carbonate parallel to the foliation of the rock and containing larger crystals of biotite, molybdenite, apatite, titanite, allanite and arfvedsonite. The studied carbonates from fenites and feldspathized granodiorite form four basic genetic groups: 1) syngenetic streaks, 2) metasomatic impregnations, 3) dyke breccias and 4) join veinlets. In conformity with the results of petrographic study, assumed origin and isotopic composition, nine genetic groups of carbonates can be distinguished".

The great variability of $\delta^{18}O$ and $\delta^{13}C$ values even within a single mineralogical type testifies to highly variable conditions of dissolving CO_2 and HCO_3^- in water. With the exception of one sample from borehole H-26, the isotopic composition of carbonates belongs neither to primary igneous carbonatites, nor intrusive association carbonatites or near-surface association carbonatites.

Closest to the C and O isotopic composition of primary igneous carbonates are syngenetic carbonate streaks in biotite-rich sövitic syenite fenites. The brecciated carbonate streaks and patches mineralized by sulfides in the feldspathized granodiorite on the radial faults of the Čistá structure, have composition close to intrusive association carbonatites, corresponding to later stage low-temperature carbonatite dykes from ijolite-carbonatite complexes (Kopecký et al. 1987).

4. The ore potential of the pluton

According to archive documents, the oldest exploration works were carried out on Au and Ag ores near the village of Hůrky, strating in the 16th century.

The objects of occasional exploration were mostly hydrothermal quartz veins with base metal ores. Kratochvíl (1958) mentioned several locations of base metal mineralizations of Ag-bearing galena, Au-bearing pyrite, arsenopyrite, sphalerite and rarely molybdenite (formerly "bournonite"), mostly in quartz veins described from several localities.

More recently exploration of ore mineralizations in the vicinity of the Čistá granodiorite massif was carried out by

Klomínský (1962). He described these deposits as belonging to an Au-Fe-quartz formation type with quartz veins bearing pyrite, molybdenite, sphalerite, galena and also a new Bi-Pb mineral - heyrovskite with the empirical formula $Pb_{4.98}(Ag,Cu)_{0.42}Bi_{2.60}S_{9.00}$ (Klomínský et al. 1971).

Klomínský (1962) described occurrences of quartz veins with molybdenite, pyrite and galena mineralizations near the village of Libyně, a quartz vein mineralization with pyrite, and heyrovskite near the village of Kralovice, a disseminated sulfide mineralization NW of the village of Kralovice and a vein, barite mineralization near the village of Otěvěky.

All these occurrences and formerly mined deposits are genetically associated with the final stage of the Variscan magmatism in this region (Klomínský 1962) .

The most recent investigation of the ore bearing potential in the vicinity of the Čistá massif was carried out by Kopecký (1982, 1983, 1985). A sulphidic molybdenite mineralization was found, spatially and genetically connected with alkaline metasomatism. As seen in the molybdenite disseminated ores are closely related to the final stage of Na-fenitization. Molybdenite replaces mostly arfvedsonite and biotite. The richest molybdenite accumulations are in the biotite-rich bands of biotite ultramylonites.

Kopecký (1982, 1983) calculated for the sector "Hůrky-north I" reserves of 6.278 Mt of 0,1 % Mo-ores and for the sector "Hůrky-center" a quantity of 5.0 Mt of 0.15 % Mo-ores. To the molybdenite mineralization the highest contents of Zr (up to 0.2 %) as well as REE, Nb, Ta, Y are closely related (the four last mentioned components occur exclusively in ultramylonites and rheomorphic syenites).

Crystalochemical studies on the position of Re (Te, Se) in molybdenite from fenites were carried out by Drábek et al. (1989a, 1989b, 1993). Very low contents of Re (1 to 4 ppm), Te (3 to 27 ppm) and Se (48 to 52 ppm) were found. Re, Te and Se isomorphously replaced Mo and S, respectively. These low contents indicate homogeneous (isomorphic) distribution of Re in the crystal lattice of molybdenite. The $\delta^{34}S$ values in MoS_2 obtained from fenites (from -0,7 ‰ up to +0,5 ‰) are very homogeneous and according to Hladíková (in Drábek et al, 1989a) indicate a deep (upper mantle/lower crust) source of molybdenite sulphur.

New evaluations of the ore potential of Mo-ores (Chrt and Jurák, 1990) arrived at higher reserves without economic rentability. The Mo-mineralization is inhomogeneous and Mo-enriched segments form spatially isolated cylindric bodies. The accompanying components (i.e. Zr, REE,Y) are present in an unfavorable form and scarcely can ameliorate economic rentability.

Kopecký (1985) described some other mineralizations, which are genetically connected with the carbonatite-ijolite metasomatism:

A Pb-Zn-Cu sulfide mineralization of highly differentiated carbonatite source, later in succession, was found in borehole H-25 in the albitized and feldspathized biotite granodiorite E of the village of Hůrky (Kopecký and Drábek 1983, Drábek 1983).

A uraninite vein mineralization was found in the borehole H-25 (202.3-202.45m) in a veinlet together with calcite, sphalerite, chalcopyrite and galena in mylonitized and hydrothermally altered granite and aplite (Kopecký 1983). This mineralization is localized on the radial Hůrky fault. Quartz and biotite are replaced by albite, K-feldspar and sericite (and/or calcite).

5. Discussion and conclusions

The Čistá-Jesenice pluton, exposed as several seemingly isolated bodies, continues below the platform cover (Upper Cretaceous, Upper Carboniferous and Permian) to the NE and in the vicinity of Roudnice n. L.-Bechlín plunges into the Upper Proterozoic basement. The extent of the pre-Carboniferous outcrops of the Čistá-Jesenice pluton is estimated to be 1000 km^2. The pluton is monotonous in composition, formed by biotite (+/- hornblende) granite to adamelite, could be subdivided into 2–3 subtypes.

The body intruded into slightly to medium metamorphosed Upper Proterozoic sediments of an asymetrically anticlinorial structure with a slightly inclined SE-limb. The fold axis plunges moderately to NE and consequently the outcropped part of the pluton represents its apical part. Its shape, inferred from gravitational pattern as well as from boreholes is assumed to be that of a flatted body with vertical extent of 2–3 km, most likely an asymmetrical ethmolite (Klomínský 1965) with root zone situated SE-E-wards (Fig. 3).

In paleogeographical interpretations of the Central Bohemian region a continental "dry land" character is assumed for the period of Middle Devonian (Givet) to Late Carboniferous (Westphalian B/C) when the first continental (fresh water) sediments transgressed from NE toward SW. Consequently, for a long period of time (65 Ma) no sedimentation was documented in this region. According to Holub et al. (1991) the absence of sediments in this period may have two reasons:

(1) No material sedimented in this period, or
(2) Rare and discontinuous sedimentary cover was removed soon after deposition.

The hiatus was probably caused by Variscan orogenesis. The Late Carboniferous sedimentation is interpreted as a postorogenic molasse sequence.

The Čistá-Jesenice-(Louny-Martiněves) pluton (emplaced most likely during Late Cambrian), must have been exposed very rapidly by erosion during Late Paleozoic. In Late Carboniferous (Westphalian B/C), the first platform molasse sediments transgressed towards SW after the termination of Variscan events. In this period humid climate prevailed and the occurrences of abundant Late Carboniferous arcose sediments resulted from erosion of long exposed parts of the pluton.

For explanation of the geochemical and space variability of the Čistá-Jesenice pluton five principal stages in its development are suggested:

(1) Emplacement of the pluton (in Late Cambrian)
(2) Intrusion of the Čistá granodiorite with associated dyke swarms (in Late Silurian in a chain of events closing the Barrandian Paleozoic Basin)

(3) Alkaline metasomatism s.l. and Mo-Zr mineralization (in Late Devonian or Early Carboniferous ?)
(4) Intrusion of post-fenite dyke rocks
(5) Hydrothermal vein mineralizations (most probably Late Variscan and/or post-Variscan).

It is evident that during Early Carboniferous the pluton rose from the surrounding landscape as a mountain range and possibly as an island separating the evolving Late Carboniferous sedimentary basin into two segments.

The intrusion of the Čistá-Jesenice pluton occurred within a contemporaneous extension of the surrounding rock environment and along a pull-apart opening segment of the Barrandian Upper Proterozoic. As the tectonic precursor we propose a WSW-ENE-running shear zone which was probably reactivated by some Early Paleozoic event.

The intrusion could have continued subsequently step by step (without magmatic assimilation of mantle rocks) into the folded, subsequently opening anticlinorial structure (Brun et al. 1990).

As seen in boreholes Be-1 (Bechlín) and Mt-1 (Martiněves) during consolidation granites registered a weak regional deformation event. The final shape, a flattened ethmolite, resulted from both the anticlinorial opening and an oriented stress field during emplacement.

The Čistá granodiorite body geochemically differs from other granitic rocks of the Čistá-Jesenice pluton. The Čistá granodiorite evolved in a different tectonic regime. The strong negative gravitational anomaly partly shifted NE-wards has been interpreted as a NE-inclined cylindric stock body plunging beneath and parallel with the bottom of the already existing granite pluton (Klomínský 1961b). The massif has some features of granitoids derived from source "contaminated" by Upper Mantle material.

Excellent dimensional orientation of magnetite in the Čistá granodiorite body is evidenced by a high degree of anisotropy of magnetite and by preferred orientation of biotite leaves and lensoidal aggregates of light minerals. These features reflect the structure of marginal portion of the body which had been formed earlier. This pattern of magmatic anisotropy was interpreted as an effect of combination of both shear and pure shear deformation in the penetrating and solidifying granitoid mass (Chlupáčová et al. 1975).

In the most-recent structural study (Schulmann et al. 1992) the marginal structural features are interpreted as magmatic foliation parallel to the shape of the stock resulting from intense deformation under conditions of subsolidus. This conclusion corroborates earlier interpretations of Chlupáčová et al. (1975) concerning foliation of magnetite aggregates. This preferred orientation is best developed at the E-margin of the Čistá granodiorite body. The most intense deformation is concentrated into the NE-SW trending shear zone, which is assumed to be a sinistral strike slip comprising a component of normal fault. The polyphase emplacement of the Čistá granodiorite body was most probably made possible by an extensional movement along this shear zone.

The geochemical properties together with the geophysical and structural characteristics of the Čistá granodiorite reflect deep-seated (mantle derived ?) magmatic source. The rock chemistry also represents a low differentiated source (Rb > Sr). The positive Eu-anomaly indicates feldspars of the cumulate origin.

The NE-SW trending shear zone along the SE-margin of the pluton spatially relates to a similar structure recently described from the borehole Mt-1 near Martiněves (Kopecký 1993). Both mylonitization and fenitization of biotite granite of the Tis type are introduced by a cataclasis of mineral grains and newly-formed biotite, alkali amphibole (arfvedsonite), partly depleted and recrystallized quartz and newly-formed abundant zircon and apatite.

This newly described occurrence of alkaline metasomatosis in borehole Mt-1 represents a slightly more developed equivalent of Na and K fenitization known from the vicinity of the village Hůrky.

A similar phenomenon was described on fenite xenoliths (together with alkaline syenites and sövites) from the Tertiary diatreme of the Košťál Hill near Litoměřice (Kopecký 1967; the first such occurence in the Bohemian Massif).

Aside from the above discussed characteristics of the Čistá-Jesenice pluton, unambiguous temporal and genetic relations among individual rock types and intrusive bodies remain unsolved. Due to the lack of more reliable isotopic (Rb/Sr etc.), geochemical (from the covered part of the pluton) and mineralogical data further genetic interpretations are scarcelly possible.

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Čistecko-jesenický pluton v západních Čechách: geochemie, geologie, petrofyzika a rudní potenciál

(Resumé anglického textu)

LUBOMÍR KOPECKÝ, Jr. - MARTA CHLUPÁČOVÁ - JOSEF KLOMÍNSKÝ - ADOLF SOKOL

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Čistecko-jesenický pluton se vyskytuje jako oválné protažené těleso v tepelsko-barrandienském krystaliniku (bohemiku) Českého masivu. Je převážně pouze z granitu tiského typu, který intrudoval do otevřené antiklinoriální struktury hornin svrchního proterozoika, a to nejspíše koncem kambria nebo začátkem ordoviku a vytvořil tak zploštělý ethmolit.

Nejspíše během devonu byl tento granit při svém jv. okraji proniknut pněm čisteckého granodioritu a rojem žilných hornin, které jsou prostorově téměř výlučně vázány na okolí granodioritové intruze. V období devonu a svrchního karbonu byl pluton postupně obnažen a jako horský hřbet zpočátku částečně rozděloval formující se svrchnokarbonskou kladensko-rakovnickou pánev. Celá oblast plutonu byla vystavena silnému větrání a odnosu horninového materiálu.

Patrně začátkem karbonu byla kontaktní zóna mezi kruhovou intruzí granodioritu čisteckého pně a starší intruzí čisteckého granitu drcena a mylonitizována a postižena procesem fenitizace – Na-alkalické metasomatózy – za vzniku souboru fenitů a reomorfních syenitových fenitů a alkalického kankrinit-nefelinického syenitu. S tímto procesem, prozatím téměř ojedinělým v Českém masivu, je spojen celkem unikátní výskyt molybdenitové a zirkonové mineralizace spolu s vysokými obsahy prvků lehkých vzácných zemin.

Ve westfalu C a D postupuje nová platformní pánevní sedimentace, jejíž produkty zakryly převážnou část plutonu. Na dnešní povrch tak pluton vystupuje jako několik izolovaných těles (tiské, jesenicko-oráčovské, petrohradské a čistecké).

Obě tělesa – jak hlavní ethmolitická intruze žuly tiského typu, tak peň čisteckého granodioritu – se vzájemně liší jak svými geofyzikálními projevy, tak i strukturními a geochemickými charakteristikami.

Vysvětlivky k obrázkům

1. Přehledná skica geologické situace výchozových partií čistecko-jesenického plutonu zkompilovaná podle geologických map Klomínského (1966), Kopeckého st. (1987), Fediuka (1993) a Blažka a kol. (1993). Názvy jednotlivých granitových těles (čísla v kroužku): 1 – oráčovské; 2 – tiské; 3 – jesenické; 4 – čistecký granodiorit, muskovitický granit tělesa "Černá kočka". Horninové typy: 1 – fylity a metadroby středočeského svrchního proterozoika; 2 – metabazalty; 3 – biotitický granit tiského typu; 4 – biotitický granodiorit čisteckého pně; 5 – mylonitové zóny s fenitizací s.l.; 6 – turmalinický muskovitický granit typu "Černá kočka"; 7 – platformní sedimenty svrchního karbonu a permu; 8 – zlomy; 9 – petrografické přechody; 10 – hlavní antiklinoriální struktury svrchnoproterozoického krystalinika.

2. Mapa předkarbonského podkladu a strukturní pozice čistecko-jesenického plutonu. 1 – fylity a metadroby svrchního proterozoika; 2 – metabazalty; 3 – diorit bechlínského tělesa; 4 – biotitický granit až adamelit čistecko-jesenického plutonu; 5 – biotitický granodiorit čisteckého pně; 6 – fenity s.l. a mylonitové zóny; 7 – muskovitický granit s turmalínem typu "Černá kočka"; 8 – zlomy; 9 – hlavní strukturní vrty, které pronikly až do krystalinika v podloží platformních (povariských) sedimentů (je označen horninový typ a údaj o nadmořské výšce, tj. kde byl ve vrtu zastižen); 10 – izohypsy nadmořských výšek předkarbonského reliéfu.

3. Podélný (A–A') a příčný (B–B') řez přes pluton, ze kterého vyplývají vzájemné prostorové vztahy mezi intruzivními tělesy (situace řezů je vyznačena na obr. 2). 1 – povariský platformní sedimentární pokryv; 2 – zlomy, mylonitizace a s ní spjatá fenitizace s.l.; 3 – biotitický granodiorit čisteckého pně; 4 – biotitický granit čistecko-jesenického plutonu; 5 – diorit bechlínského tělesa; 6 – fylity a metadroby barrandienského svrchního proterozoika; 7 – metabazalty; 8 – svory, pararuly a ortoruly saxothuringika (na SZ od litoměřického zlomu); 9 – zlomy; 10 – strukturní vrty.

4. Souhrnná skica hlavních granitoidních těles Českého masivu (podle Klomínského a Dudka 1978). A – severní zóna prevariských intruzívních komplexů; B – plutonické horniny bloku moravika. 1 – granitické masivy Smrčin a Krušných hor; 2 – lužický pluton (granitoidové masivy Krkonoš, Jizerských hor a Lužických hor); 3 – čistecko-jesenický pluton; 4 – středočeský pluton; 5 – nasavrcko-skutečský pluton; 6 – centrální moldanubický pluton.

5. Geologická situace okolí čisteckého granodioritového pně (podle Klomínského 1966 a Kopeckého st. 1985). 1 – fylity a metadroby svrchního proterozoika; 2 – metabazalty; 3 – biotitický granit; 4 – biotitický granodiorit čisteckého pně; 5 – kruhové kuželové zlomy a zóna fenitizace s fenity s.l.; 6 – turmalinický muskovitický granit typu "Černá kočka"; 7 – svrchnokarbonské pískovce a konglomeráty; 8 – radiální zlomy čisteckého pně; 9 – přechody mezi fenity s.l. a granitem; 10 – antiklinoriální struktury barrandienského svrchního proterozoika.

6. Schematický řez fenitovou zónou poblíž obce Hůrky (podle Kopeckého 1985). 1 – biotitický granodiorit pně čistecké intruze; 2 – slabě kataklastický drcený a albitizovaný biotitický granodiorit pně čistecké intruze; 3 – kataklastický drcený biotitický granit tiského typu II. stadia fenitizace; 4 – biotitický granit tiského typu (nemylonitizovaný); 5 – kataklastický biotitický granit tiského typu I. stadia fenitizace; 6 – biotitický ultramylonit nejvyššího stadia fenitizace vzniklý z biotitického granitu tiského typu; 7 – zlomy.

7. Obraz magnetické anizotropie čisteckého granodioritu (Chlupáčová et al. 1975). Hlavní směry susceptibility na jednotlivých lokalitách: 1 – maximální susceptibilita; 2 – střední susceptibilita; 3 – minimální susceptibilita; velké kružnice – magnetická foliace.

8. Rozložení magnetické susceptibility ve fenitech. Levá strana: histogram podle Chudáčka et al.(1983). a – fenitizované granity a ultramylonity II. stupně; b – c – slídnaté fenity a ultramylonity III. stupně; d – albitity. Pravá strana – histogram sestrojený s pomocí dat Jelena a Rackové (1972): e – fenitizované granity I. a II. stupně; f – slídnaté fenity a ultramylonity II. stupně; g – slídnaté fenity a ultramylonity III. stupně; h – nefelinické syenity IV. stupně.

9. Tíhový obraz čistecko-jesenického plutonu (s použitím map Bouguerových anomálií v měřítku 1 : 200 000 – Ibrmajer et al. 1965). 1 – proterozoické horniny; 2 – tiský granit; 3 – čistecký granodiorit; 4 – svrchnokarbonské a křídové sedimenty; 5 – terciérní sedimenty; 6 – terciérní vulkanity; 7 – izolinie g(m.s-2); 8 – předpokládaný rozsah čistecko-jesenického plutonu v podloží karbonských sedimentů (podle Klomínského 1966); 9 – předpokládaný rozsah plutonu v hloubce –1300 m pod úrovní mořské hladiny (podle Dobeše a Polanského 1967).

10. Magnetický obraz čistecké struktury a rozložení U a Th na povrchových výchozech dle leteckého geofyzikálního měření (Gnojek et al. 1982). a – mapa ΔT [nT] anomálií, měřených na výškové hladině 80 m nad terénem; b – ΔT anomálie přepočtené na výškovou hladinu 400 m nad terénem; c – distribuce obsahů U [ppm] získané měřením na výškové hladině 80 m nad terénem.; d – distribuce obsahů Th [ppm].

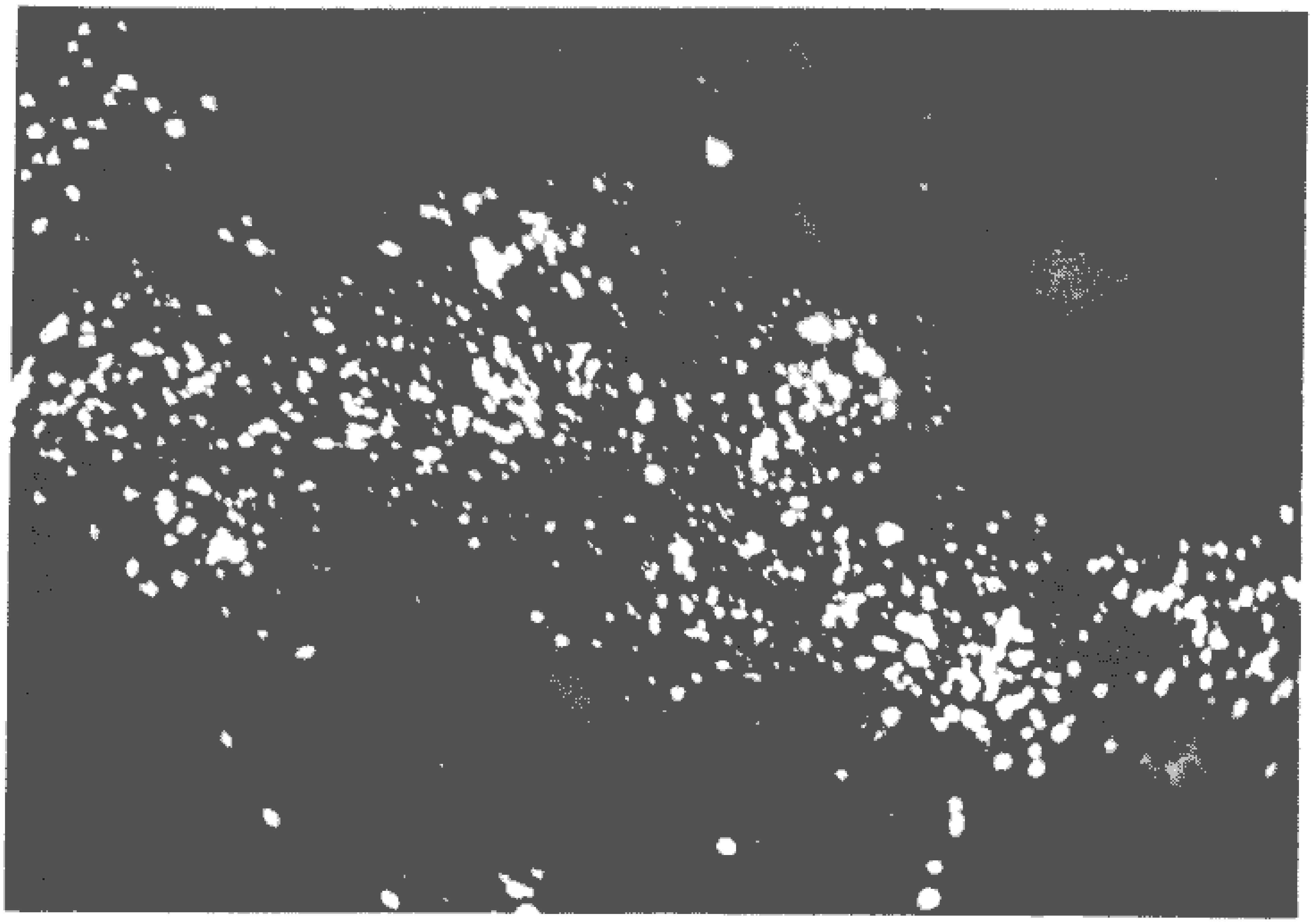
11a. Vzájemné vztahy mezi obsahy Rb a Sr v granitoidech. 1 – granodiorit čisteckého pně; 2 – petrohradský subtyp granitu čisteckého plutonu; 3 – tiský subtyp granitu čisteckého plutonu; 4 – fenity s.l. nižšího stupně fenitizace; 5 – fenity vyššího stupně fenitizace; 6 – postfenitický muskovitický granit typu "Černá kočka"; 7 – postfenitické žíly granodioritových porfyritů; 8 – žíly fenitizovaných granodioritových porfyritů; 9 – silně albitizovaný granodiorit čisteckého pně; 10 – slabě albitizovaný granodiorit čisteckého pně; 11 – aplity (nefenitizované).

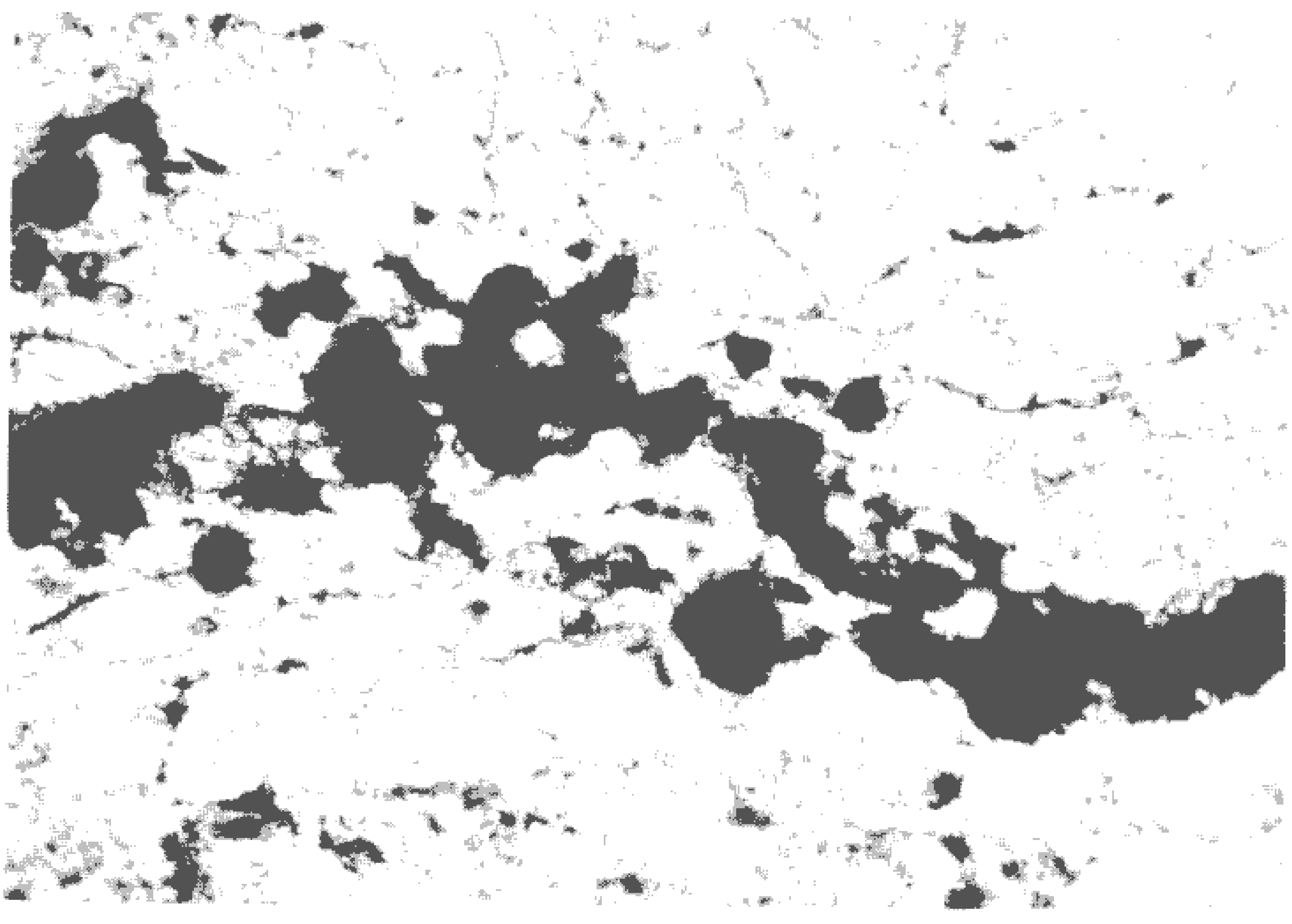
11b. Vztahy Rb vs. Zr v granitoidech. 1 – čistecký granodiorit; 2 – fenity s.l. nižšího stupně fenitizace; 3 – fenity s.l. vyššího stupně fenitizace; 4 – biotitický ultramylonitový syenitový fenit; 5 – nefenitizované žilné horniny; 6 – muskovitický granit "Černá kočka" (jv. okraj čisteckého granitu); 7 – postfenitické granodioritové porfyrity; 8 – nefenitizované aplity; 9 – petrohradský subtyp granitu; 10 – tiský subtyp granitu; 11 – silně albitizovaný granodiorit čisteckého pně; 12 – slabě albitizovaný granodiorit čisteckého pně; 13 – fenitizované žíly granodioritových porfyritů.

12. Normalizované křivky REE (podle Nakamury 1974) zprůměrovaných hodnot jednotlivých horninových typů pro:
a – hlavní intruzivní tělesa granitoidů čistecko-jesenického plutonu: 1 – čistecký granodiorit; 2 – petrohradský dílčí typ granitu; 3 – tiský dílčí typ granitu; 4 – aplity nepostižené fenitizací; 5 – postfenitický muskovitický granit (typ "Černá kočka");
b – fenity s.l. z okolí Hůrek: 1 – fenity s.l. nižšího stupně fenitizace; 2 – fenity s.l. vyššího stupně fenitizace; 3 – ultramylonitové biotitové fenity; 4 – petrohradský dílčí typ granitu (připojen pro porovnání).
c – feldspatizované horniny s.l. z okolí Hůrek: 1 – granodiorit čisteckého pně (nefeldspatizovaný); 2 – silně albitizovaný granodiorit čisteckého pně; 3 – slabě albitizovaný granodiorit čisteckého pně; 4 – postfenitický granodioritový porfyrit (připojen pro porovnání).
d – aplity a fenitizované granodioritové porfyrity z okolí Hůrek: 1 – aplity; 2 – fenitizované granodioritové porfyrity.
e – postfenitický muskovitický granit ("Černá kočka") a postfenitické granodioritové porfyrity a aplity. Pro porovnání jsou připojeny údaje petrohradského dílčího typu granitu: 1 – postfenitický granit (anal. č. 22); 2 – postfenitický granodioritový porfyrit; 3 – aplity; 4 – petrohradský dílčí typ biotitického granitu.

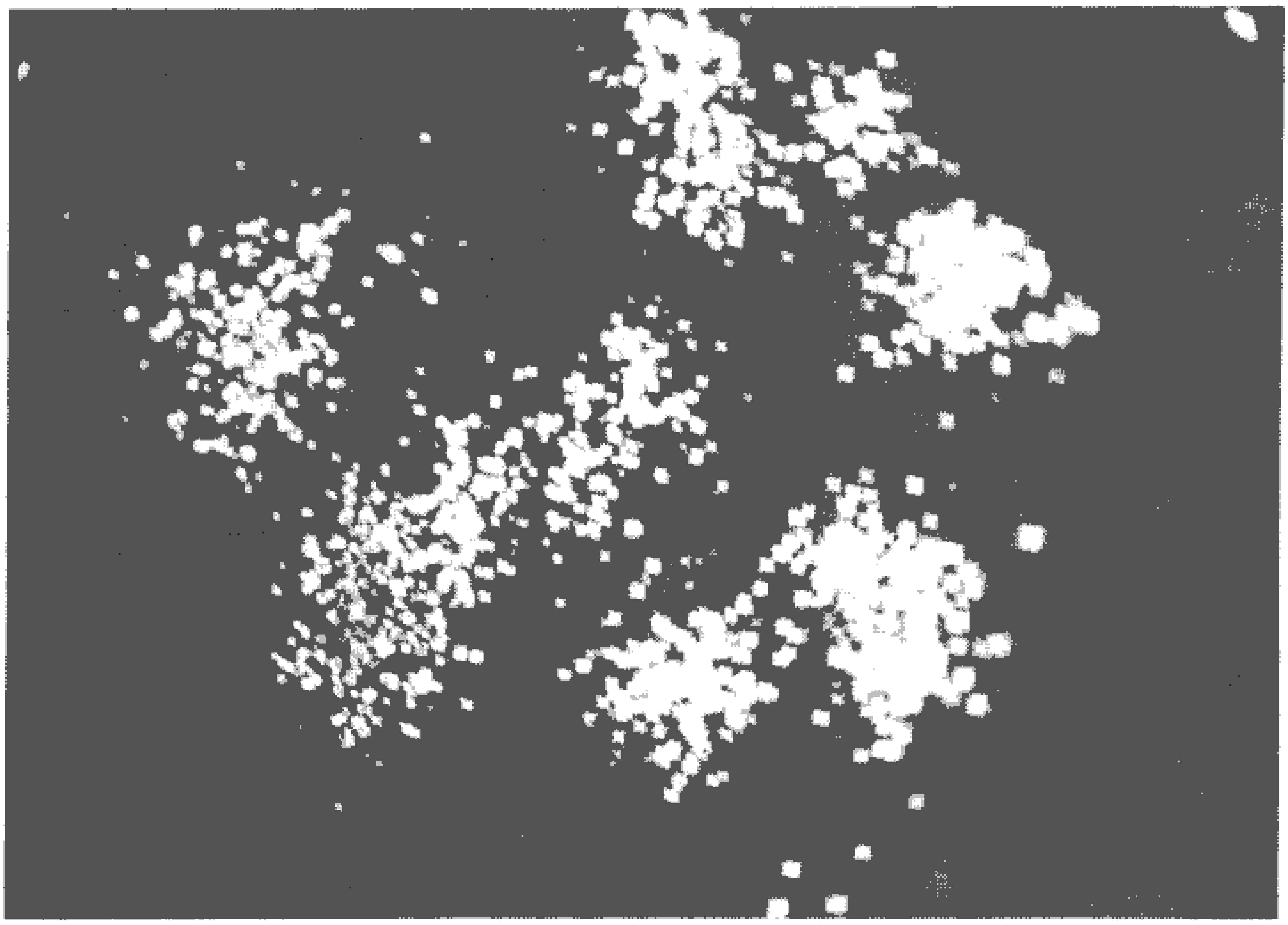
13. Klasifikace horninových typů čistecko-jesenického plutonu v diagramu Q-ANOR, podle Streckeisena a Le Maitra (1979): Q = 100 Q/(Q + Or + Ab + An); ANOR = 100 An/(An + Or). 1 – granodiorit čisteckého pně; 2 – petrohradský dílčí typ granitu; 3 – tiský dílčí typ granitu; 4 – fenity s.l. nižšího stupně fenitizace; 5 – fenity s.l. vyššího stupně fenitizace; 6 – postfenitický muskovitický granit ("Černá kočka"); 7 – žíly postfenitických granodioritových porfyritů; 8 – fenitizované granodioritové porfyrity; 9 – silně albitizovaný granodiorit čisteckého pně; 10 – slabě albitizovaný granodiorit čisteckého pně; 11 – nefenitizované žilné horniny (bez rozlišení); 12 – rumburský granit lužického plutonu; 13 – biotitové ultramylonitové fenity; 14 – aplity.

14. Diagram R1-R2 de La Roche (podle Batchelora a Bowdena 1985). R1 = 4Si - 11(Na + K) - 2(Fe + Ti); R2 = 6Ca + 2Mg + Al. Jednotlivá pole představují zdrojové oblasti magmatu během orogenetického cyklu (čísla v kroužcích): 1 – deriváty a produkty frakcionace svrchního zemského pláště; 2 – intruze v období před kolizí; 3 – intruze v období po kolizi a po výzdvihu; 4 – intruze v závěru orogenetického cyklu

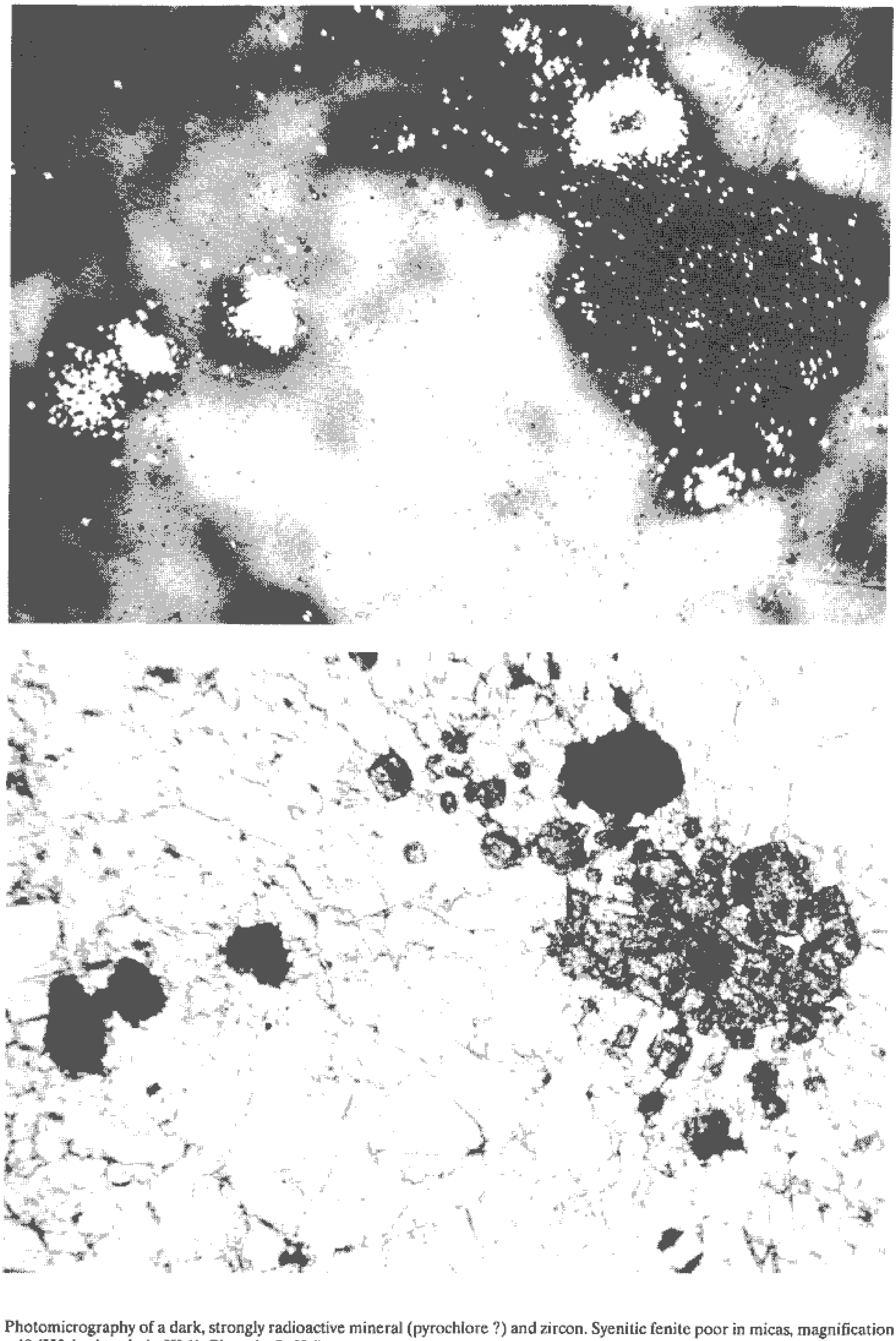




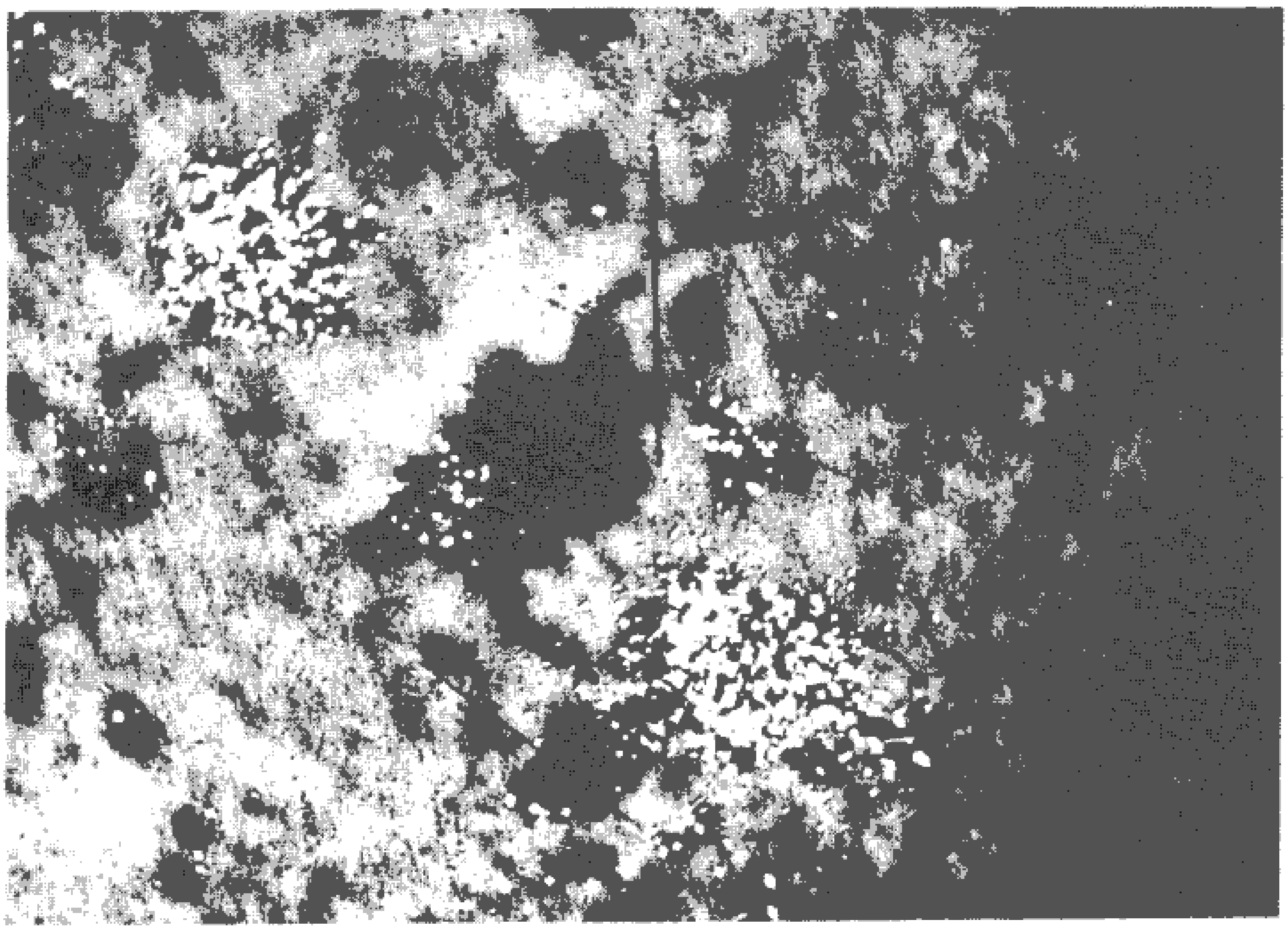
Autoradiogramm of thin section. Radioactive accessories. Crushed syenitic fenite, magnification x 70 (Hůrky, borehole JK-1). Photo by L. Kašparec.

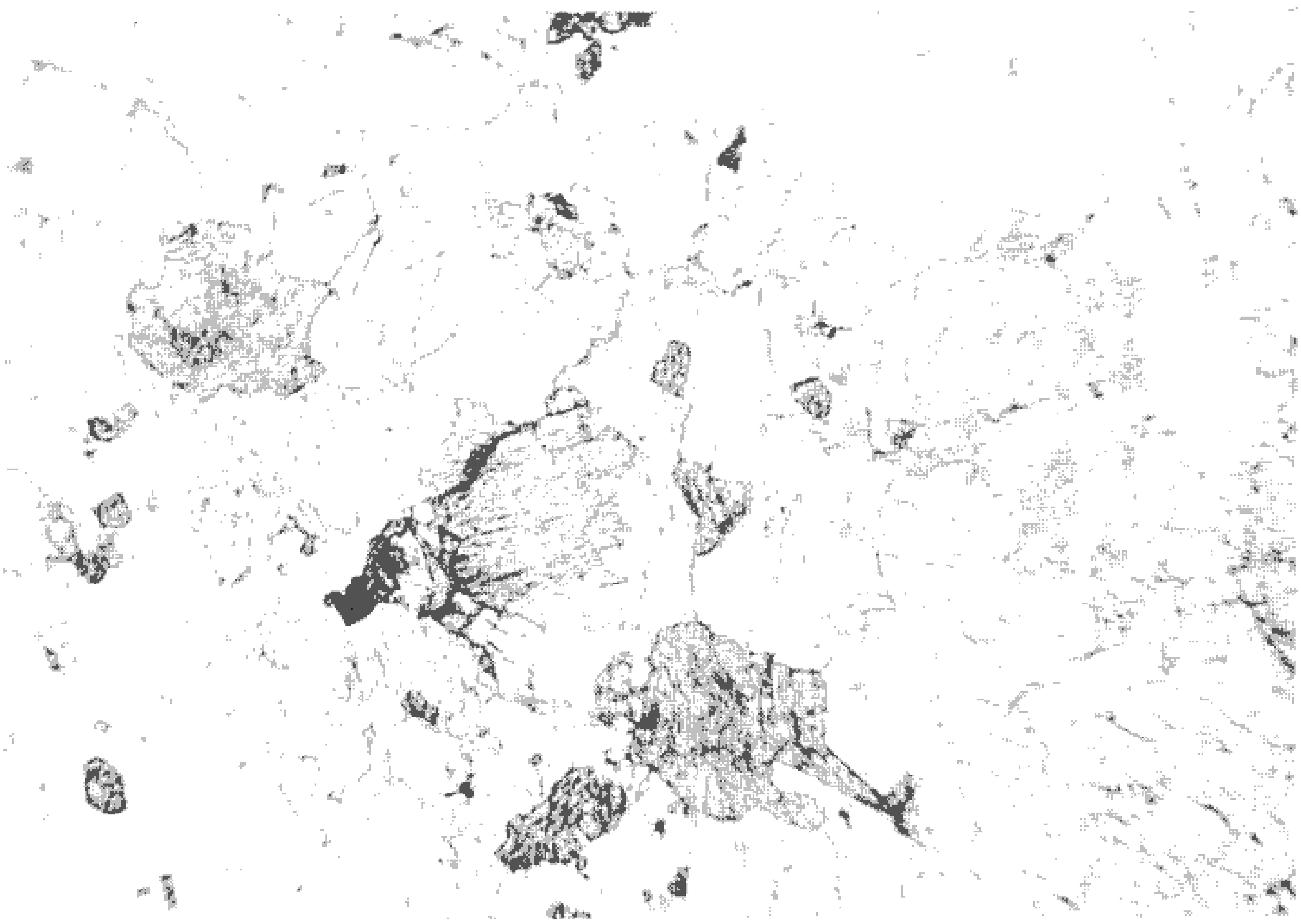


Photomicrography of strongly radioactive grain filling of intergranular space. Syenitic fenite poor in micas, magnification x 70 (Hůrky, borehole H-9). Photo by L. Kašparec.



Photomicrography of a dark, strongly radioactive mineral (pyrochlore ?) and zircon. Syenitic fenite poor in micas, magnification x 40 (Hůrky, borehole JK-1). Photo by L. Kašparec.





Photomicrography of eudialyte. Rheomorphic aegirine-cancrinite-nepheline-syenite, magnification x 40 (Hůrky locality). Photo by L. Kašparec.

("pozdně orogenní"); 5 – anorogenní intruze; 6 – intruze tzv. synkolizní; 7 – intruze v postorogenním období.
Vysvětlivky symbolů viz obr. 13.

15. Diskriminační diagram Zr+Nb+Ce+Y vs. (K + Na)/Ca), dle Whalena et al. (1987) vytvořený pro A-typy granitů: OGT = pole pro I-, S- a M-typy granitů; FG = pole pro výrazně frakcionované I-typy granitů; fenity se většinou zobrazují mimo vymezená pole. 1 – granodiorit čistecké intruze; 2 – petrohradský dílčí typ granitu; 3 – tiský dílčí typ granitu; 4 – fenity s.l. nižšího stupně fenitizace; 5 – fenity s.l. vyššího stupně fenitizace; 6 – postfenitický muskovitický granit ("Černá kočka"); 7 – žíly postfenitických granodioritových porfyritů; 8 – žíly fenitizovaných granodioritových porfyritů; 9 - silně albitizovaný granodiorit; 10 - slabě albitizovaný granodiorit; 11 – žilné horniny nepostižené fenitizací; 12 – biotitový ultramylonitový fenit; 13 – aplity.

16a. Diskriminační diagram Nb+Y vs. Rb, podle Pearce et al. (1984) pro identifikaci granitů z různých geotektonických prostředí: synkolizní granity (syn-COLG), granity vulkanických oblouků (VAG), vnitrodeskové granity (WPG) a granity oceánských hřbetů (ORG). 1 – granodiorit čisteckého pně; 2 – petrohradský dílčí typ granitu; 3 – tiský dílčí typ granitu; 4 – fenity s.l. nižšího stupně fenitizace; 5 – fenity s.l. vyššího stupně fenitizace; 6 – postfenitický muskovitický granit ("Černá kočka"); 7 – žíly postfenitických granodioritových porfyritů; 8 – žíly fenitizovaných granodioritových porfyritů; 9 – silně albitizovaný granodiorit čisteckého pně; 10 – slabě albitizovaný granodiorit čisteckého pně; 11– žilné horniny nepostižené fenitizací; 12 – biotitové ultramylonitové fenity; 13 - aplity.

16b. Diskriminační diagram Y vs. Rb podle Pearce et al. (1984). 1 – granodiorit čisteckého pně; 2 - petrohradský dílčí typ granitu; 3 – tiský dílčí typ granitu; 4 – fenity s.l. nižšího stupně fenitizace; 5 – fenity s.l. vyššího stupně fenitizace; 6 - biotitický ultramylonit; 7 – postfenitický muskovitický granit ("Černá kočka"); 8 – žíly postfenitických granodioritových porfyritů; 9 – žíly fenitizovaných granodioritových porfyritů; 10 – silně albitizovaný granodiorit čisteckého pně; 11 – aplity; 12 – slabě albitizovaný granodiorit čisteckého pně; 13 – žilné horniny nepostižené fenitizací.

Vysvětlivky k tabulkám

1. Hlavní epochy v magmatickém vývoji čistecko-jesenického plutonu interpretované na základě dat K-Ar.

2a. Petrofyzikální vlastnosti tiské žuly z oblasti Čisté (propočteno s užitím dat Chlupáčové, 1970). N – výpočet vzorků, p – statistický parametr, M – aritmetický průměr, D – standardní odchylka, Dg – zrnitostní hustota, Db – celková hustota, Pef – porózita, κ – magnetická susceptibilita.

2b. Petrofyzikální vlastnosti granodioritu pně čistecké intruze (podle Bartoška et al. 1969 a Chlupáčové et al. 1975). Vysvětlivky viz tab. 2a.

2c. Distribuce Th, U a K ve fenitech od Hůrek u Čisté z tiské žuly. AM – aritmetický průměr, GM – geometrický průměr; statistické hodnoty pro vrt JK-1 (sv. od Hůrek) byly propočteny s užitím dat Chlupáčové a Šťovíčkové (1971) a korigovány pomocí standardů laboratoře v Brně od r. 1972, měřených spektrometrií gama.

3. Chemické složení hlavních horninových typů čistecko-jesenického plutonu. AT – tiská žula (j. část tělesa u Tisu); AJ – žula z tělesa u Petrohradu; AC – granodiorit čisteckého pně z jz. části tělesa; B – granodiorit čisteckého pně z centrální části tělesa; FUB – biotitický ultramylonitový syenitový fenit (vrt H-13, hl. 37,5 m); PFG – muskovitická žula s turmalínem typu "Černá kočka" z jv. okraje čisteckého masivu; F3 – III. až IV. stadium fenitizace albititového mylonitu s arfvedsonitem (vrt H-28, hl. 105,7 m); BA3 – silně albitizovaný granodiorit (vrt H-28, hl. 423,9 m); n.d. – neanalyzováno.

4. Distribuce prvků vzácných zemin, Ta a Hf ve frakcích těžkých minerálů horninových šlichů z fenitů s.l. z okolí Hůrek. Akcesorické minerály, ve kterých se přednostně koncentrují výše uvedené prvky, jsou tyto: af – arfvedsonit, al – allanit, e – eudialyt, mz – monazit, pc – pyrochlór, ph – flogopit, px – pyroxen (egirínaugit), zr – zirkon, l.f. – v lehké frakci, h.f. – v těžké frakci, b.f. – v obou frakcích bez výrazných preferencí.

Vysvětlivky k přílohám

I. Autoradiogram výbrusu. Radioaktivní akcesorie, mylonitizovaný syenitový fenit, Hůrky, vrt JK-1, zvětšení 70x. Foto L. Kašparec

II. Mikrofotografie silně radioaktivních intergranulárních výplní. Slídami chudý syenitový fenit, Hůrky, vrt H-9, zvětšení 70x. Foto L. Kašparec

III. Mikrofotografie tmavých silně radioaktivních minerálů (pyrochlóru? a zirkonu). Slídami chudý syenitový fenit, Hůrky, vrt JK-1, zvětšení 40x. Foto L. Kašparec

IV. Mikrofotografie eudialytu. Reomorfní egirinický kankrinitický nefelinitický syenit, Hůrky, zvětšení 40x. Foto L. Kašparec

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