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The Železné hory pluton and its mantle rocks

Železnohorský pluton a jeho plášť

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Abstract: Systematic mineral exploration in the Železné hory Mts. carried out for in more than two decades and completed in 1991 provided plentiful new information on the geological structure of the Železné hory pluton and its surrounding rock complexes. In this paper geotectonic position of the Železné hory pluton within the Bohemian Massif is characterized using data from regional geological studies and geophysical mapping. A detailed tectonic, magmatic and postmagmatic Variscan and post Variscan history of the Železné hory pluton is presented. A multiple-stage development is documented by geological, tectonic and petrologic studies. Rock classification is based on microscopic study and numeric treatment of 758 silicate analyses, 443 RFA trace element analyses and 137 INAA trace element analyses. An outline of ore deposits associated with the Železné hory pluton and their metallogenic classification are also given.

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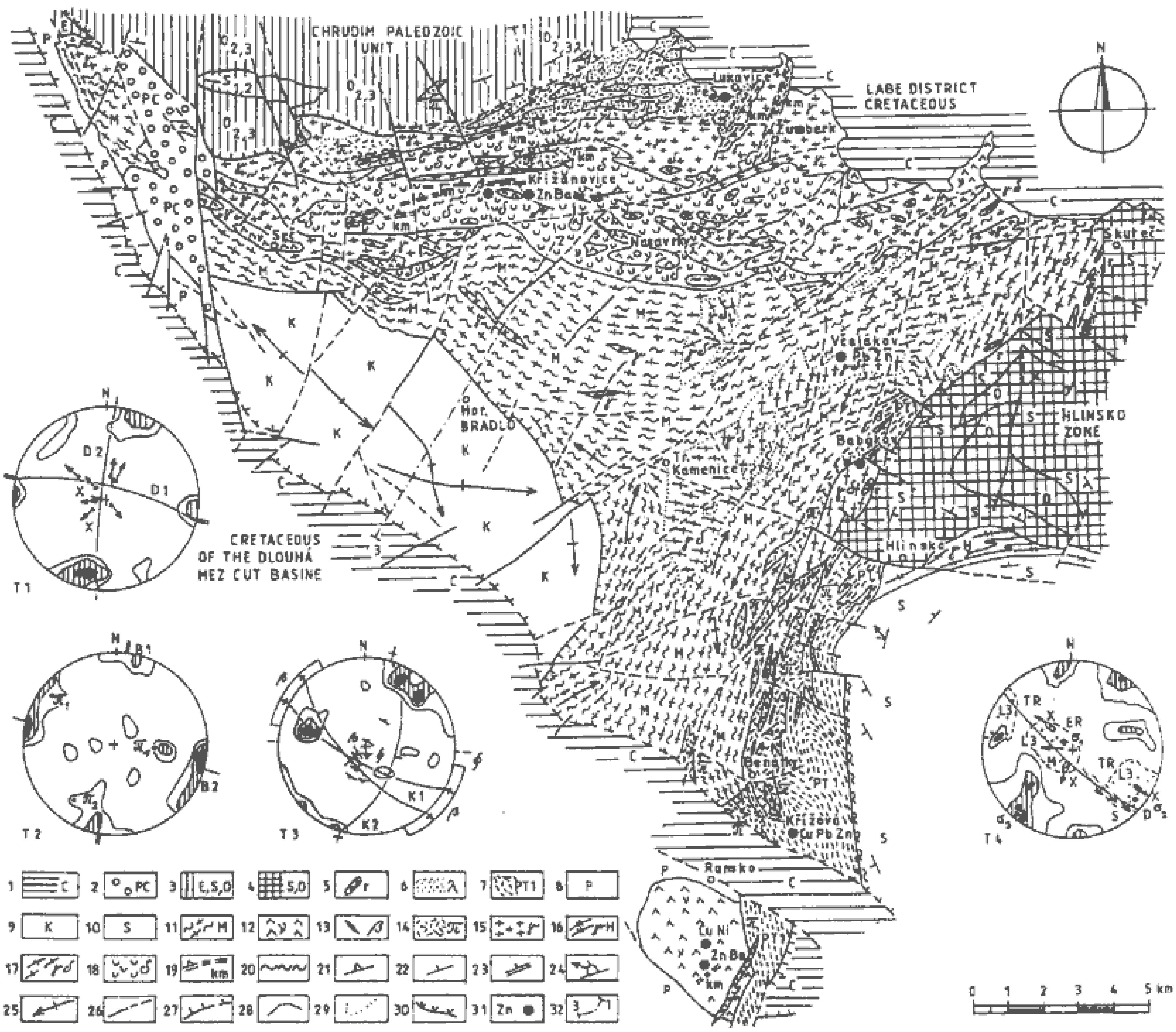
Introduction

During the last few decades our knowledge of the geological structure of the Železné hory Mts. region considerably improved. An effort to assess the economic ore potential of this region and to actually find new mineral deposits stimulated a number of regional geological, geophysical, geochemical, tectonic, petrological and mineralogical studies. Data generated by specialists from many institutions are scattered in various manuscripts, unpublished final project reports, diploma works and dissertations. In this paper we summarize and review contemporary literature on the geology of the Železné hory Mts. and the main results of our own work and the work of our collaborators M. Abraham, S. Březina, V. Cvejn, M. Kloz, Z. Procházka, J. Šura, K. Zídek, M. Žáček (Špaček et al. 1985, 1991). Also mentioned is the work of numerous research students from Charles University, Prague, Masaryk University, Brno and the Institute of Mining and Metallurgy, Ostrava (L. Harapád, J. Hiršl, M. Novák, Z. Pištora, T. Střelec, M. Šípek, J. Vostradovský and D. Tesařová). Basic information on magmatogenic formations of the Železné hory pluton, the Lukavice and Benátky belts and the crystalline mantle of the pluton can be found in Vodička (1950, 1966), Vachtl (1975), Vachtl and Knotek (1979), Minařík et al. (1983), Pošmourný et al. (1985), Žežulková (1988) and Rambousek (1989). Tectonic patterns of the Železné hory pluton and of the Proterozoic and Paleozoic rock suites of the Železné hory Mts. region were discussed by Máška (1962), Beneš (1963) and Vachtl (1979).

Simultaneously with a detailed exploration of the Zn, Ba ore deposit Křižanovice (Špaček et al. 1985, Drozen et al. 1987) and with further prospecting for mineral deposits in the Železné hory pluton and surrounding rocks, new regional geological, petrologic, tectonic and geophysical studies were caried out (Pošmourný et al. 1985, Žežulková 1988, Rambousek 1989, Dědáček et al. 1984, Sedlák et al. 1990). In addition to microscopic description of rock types, petrochemical data were processed in the Center of Applied Geochemistry, Jihlava using all major petrochemical classification systems. This enabled us to evaluate the degree of homogeneity of igneous rocks, and of metamorphites in the rock mantle, as well as their metallogenic specialization (Špaček et al. 1985, 1991). Here we mostly discuss Variscan intrusive and subvolcanic members of the Železné hory pluton, i.e. rocks easy to observe directly in the exposed central and southern part of the pluton, which are also important metallogenically.

The regional geological and geotectonic setting of the pluton

The Železné hory pluton is a complex of plutonic, volcanic and granitized rocks, formed in the tectonic crossing near the NE border of the core of the Bohemian Massif during Cadomian and Upper Variscan tectonic cycles. The pluton is situated in the eastern part of the region of the Železné hory Mts. and in the basement of the Labe river region between Týniště nad Orlicí, Hradec Králové and Chrudim.



1. Synoptical geological map of the Železné hory pluton with symbols of main ore deposits (modified from Špaček et al. 1991). Platform cover: 1 – Cretaceous of the Labe district and Dlouhá mez cut basin; 2 – Permocarbon of Kraskov. Central Bohemian region: 3 – Cambrian, Ordovician, Silurian in the Chrudim Paleozoic unit; 4 – Silurian-Ordovician of the Hlinsko zone; 5 – xenolites of contact hornfels in granodiorites of Skuteč type; 6 – metavolcanites of Ordovician age in Lukavice belt; 7 – Upper Proterozoic volcanosedimentary group of strata of the Hlinsko zone. Kutná Hora-Svratka region, crystalline complexes: 8 – Podhořany; 9 – Kutná Hora; 10 – Svratka; 11 – periplutonic migmatized and granitized equivalent of Pre-Variscan crystalline complex in crystalline mantle of the Železné hory pluton. Magmatic complexes of Pre-Variscan age: 12 – xenolites of basites and metabasites in tonalite body of Křižanovice type and ultrabasic rocks of the Ransko massif. Variscan magmatites of Železné hory pluton: 13 – basalt dykes; 14 – subvolcanites of rhyolite up to dacite composition in Lukavice and Benátky belts; 15 – granite of Křižanovice and Žumberk types; 16 – cataclastic granite of Hlinsko type; 17 – granodiorites to quartz diorites of Skuteč type; 18 – tonalite to quartz diorite of Křižanovice type. Postmagmatic metamorphism: 19 – zones of rocks reworked by kinetic and metasomatic processes. Structural elements: 20 – dislocation zones with mylonitization and hydrothermal alterations; 21 – cleavage in kinetically and metasomatically metamorphosed rocks; 22 – schistosity in sediments and foliation in metamorphites; 23 – primary foliation in volcanites of Lukavice belt; 24 – planar and linear fabric in tonalites of Křižanovice type; 25 – B axes of antiform and synform megafolds; 26 – faults; 27 – reverse faults; 28 – stratigraphic and intrusive contact; 29 – gradual petrological transitions; 30 – discordances; 31 – sulphidic ore deposits; 32 – geological cross section. T1 – Pole diagram of planar parallel fabric in tonalites of Křižanovice type. Maximal elongation of xenolites – X-axes and the main plans of ductile flow D1 and D2 are marked. No. 20, Contours, % 25, 10, 5. T2 – Pole diagram of planar parallel fabric in granodiorites of Skuteč type and foliation in xenolites of amphibolites and gneisses. The constructive axes of plicate deformations (π axes) and main systems of foliation B1 and B2 are marked. No. 30, Contours, % 17, 10, 3. T3 – Contact plans diagram of dykes and smaller bodies of Křižanovice type granite. The main systems K1 and K2 and dykes of basalts ß and lamprophyres φ are marked . No. 20, Contours, % 15, 10, 5. T4 – Pole diagram of cleavage – foliation F_3 in Křižanovice ore and dislocation zones. The lineation L_3, X–axes of boudinage in extension régime ER and translation régime TR, average dip and strike of baryte-sphalerite ore deposit Křižanovice D, its main (M) and secondary (S) morphological axis are marked; $\sigma_1, \sigma_2, \sigma_3$ normal strains of extension tectonic régime. N = 50, Contours, % 12, 8, 2.

Its surface area is about 600 km^2 (Vachtl 1979, Mísař et al. 1983, Fig. 1, Fig. 7).

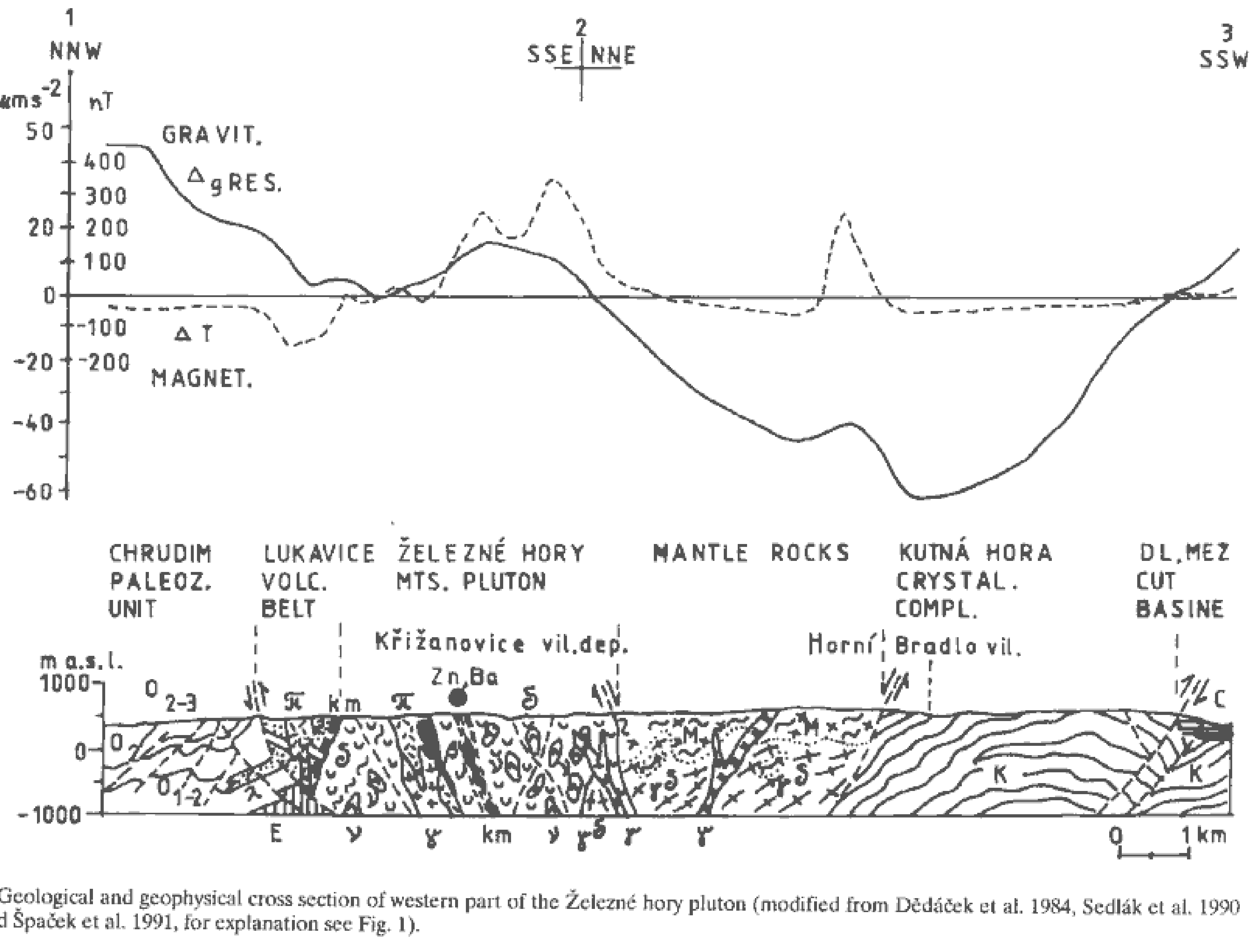
The northern exposed part of the pluton has an E-W zonal structure given by the shape and position of a tonalite body of the Křižanovice type, a granite body of the Žumberk type and volcanites of the Lukavice belt. In the eastern and south-eastern part of the Železné hory pluton granodiorites of the Skuteč and Hlinsko types and volcanites of the Benátky belt follow a NNE-SSW to NE-SW direction. This direction also prevails in the northern segment of the Železné hory pluton, which is covered by Cretaceous sediments. Another NW-SE structural system is situated in the southern part of the pluton. All these systems and their position in different parts of the pluton are apparent from magnetometric and gravity maps (Máška 1962, Dědáček et al. 1984, Ibrmajer, Suk et al. 1989, Sedlák et al. 1990).

The Cadomian members of the pluton, i.e., ultrabasic rocks of the Ransko Massif, basic rocks of the Svatý Kříž Massif, and granitoides of the Chvaletice Massif, are situated mostly at the southern, south-western and western margin of the pluton along the contact with Lower to Upper Proterozoic units (Vachtl 1979, Mísař et al. 1983). Granitoides of the Všeradov complex at the south-eastern margin of the pluton, classified by Vachtl (1975, 1979) as Cadomian members of the Železné hory pluton, represent, according to new geological and petrologic studies, multimetamorphosed orthogneisses. These rocks form a mantle of Middle Variscan granodiorites of the Hlinsko type and of Upper Variscan subvolcanic bodies of the Benátky type (Špaček et al. 1991, Fig. 1).

The central and northern part of the pluton is built by Lower to Upper Variscan magmatites with a tonalite (Křižanovice type), granodiorite (Skuteč type) and granite (Křižanovice and Žumberk type) composition. Subvolcanite rocks of a granitoid character are part of the linear Lukavice and Benátky belts near the northern and south-eastern margins of the pluton (Fig. 1).

Migmatized and granitized rocks of the crystalline mantle, belonging to the Proterozoic Kutná Hora-Svratka region, build the southern part of the pluton, on surface representing about 90 km^2. Granitoides of the Skuteč and Hlinsko types intrude into the rock mantle in the form of elongated digitations (Fig. 1).

The character of the contact of the Železné hory pluton with surrounding rock units varies considerably. Of a mostly intrusive character is the contact with Lower Paleozoic strata of the Hlinsko belt. The contact with the Chrudim Paleozoic coincides with a tectonic line of an overthrust, which is indicated by a strong gravity gradient between granitoid bodies of the Železné hory Mts. and a massive group of strata of the Chrudim Paleozoic (Sedlák et al. 1990, Fig. 2). The contact with the Lower Paleozoic vol-



2. Geological and geophysical cross section of western part of the Železné hory pluton (modified from Dědáček et al. 1984, Sedlák et al. 1990 and Špaček et al. 1991, for explanation see Fig. 1).

canogenic Lukavice belt in the North and with the Proterozoic of the Vítanov group in the south-east have the character of a geosuture healed by Upper Variscan volcanic and subvolcanic rocks (Vodička 1966, Vachtl 1975, Pošmourný et al. 1985).

In a geophysical model of the Bohemian Massif, this pluton is classified as part of the Železné hory block situated in the Barrandian-Železné hory zone which is characterized by a positive gravity anomaly. The Železné hory block is assumed to be a segment of a fossil geotectonic system of Proterozoic age (Vacek et al. 1983, Ibrmajer, Suk et al. 1989). This system was faulted and the resulting segments were transported mostly into the mobile Labe lineament of a NW-SE direction by later tectonic movements (Rajlich 1987).

Two different crustal blocks border on each other near the margin of the Železné hory segment. The first block is characterized by a positive gravity anomaly with splitted magnetic field and was formed by oceanic crust during the Cadomian cycle. The second block is characterized by a negative gravity anomaly with homogeneous magnetic field, and was formed by continental crust consolided in the Pre-Cadomian cycle (the sialic and simatic core type of Zeman 1978).

A network of deep-seated faults formed along block boundaries, known as the Labe and Přibyslav systems (Vondrová 1963, Blížkovský et al. 1975) or the Železné hory and Jihlava systems (Vachtl 1979). The mobility of deep-seated faults near the margin of the crystalline core of Moldanubicum (Zeman 1978) controlled Paleozoic sedimentation (Havlíček 1980), magmatic evolution and geological structure in the Variscan stage (Vachtl 1979) and also block segmentation during Saxonian tectogenesis (Malkovský 1980).

The Variscan stage of the Železné hory pluton

Magmatic development of the Železné hory pluton during the Variscan tectogenesis is characterized by several stages. Based on geological relationships and model age, tonalites of the Křižanovice type (Rb-Sr method, 483 ± 91 Ma, Scharbert 1987) and amphibole-biotite to biotite granodiorites and quartz diorites of the Skuteč type (K-Ar method, 332-336 Ma, Šmejkal 1960, 1964) are considered to be Early Variscan members. Cataclastic biotite granite of the Hlinsko type, porphyric biotite granite of the Žumberk types and biotite granite of the Křižanovice and Žumberk type (K-Ar method, 228 Ma, Šmejkal 1960, Rb-Sr method, 320 ± 4 Ma, Scharbert 1987) belong to the Late Variscan phase.

Subvolcanites of a dacite and rhyodacite composition, which form part of the Lukavice belt in the North and of the Benátky belt in the South-east, are probably Late Variscan (Fig. 1).

Position and petrology of individual rock types

Tonalites of the Křižanovice type

As seen from Fig. 1, tonalites form a body of an elliptical shape, 14 km in length and 3 km in width, elongated in the E-W direction. Geophysical mapping (Dědáček et al. 1984, Sedlák et al. 1990) and data from several boreholes suggest that the tonalite body with xenolites of basic rocks continues in the NE direction 4 km below the Cretaceous basin. The tonalite body has specific textural and structural features. Xenolites consisting of amphibolite gabbro, diorite, metagabbro to amphibolite but also of rocks of sedimentary origin (biotitic gneisses, quartzites and erlans) abound (Vachtl - Knotek 1979, Špaček et al. 1985, Drozen et al. 1987). Small bodies of biotite granite of the Křižanovice type and vein swarms of subparallel basalts intrude into the tonalites and their xenolites (Fig. 1). The size of xenolites varies from centimeters to several kilometers, but the shape is mostly the same, oval or strongly elongated, lenticular to tabular (Fig. 2). Anizometric xenolites have the shape of an index ellipsoid. Their main deformation plane XY is oriented subparallelly in the NW-SE and NE-SW directions with an abrupt dip 70–80° toward SW and SE. The rock fabric is documented (Fig. 1, T1) by a subvertical position of elongation axis X, by the shaping of tonalite in the régime of flow folding and its diapiric ascent (Špaček et al. 1985, Drozen et al. 1987). The position of tonalites in a zone of strong magnetic and gravity gradients (Dědáček et al. 1984, Sedlák et al. 1990, Fig. 2), the petrographic variety of xenolites, their anizometric form and anizotropic fabric, all suggest the influence of intensive deformations, which can be explained by the model of a deep-seated ductile shear zone (Ramsay 1980, Rajlich 1987).

The tonalites are medium to corse grained rocks of grayey colour, mostly strongly oriented. Some of them are porphyric. Corse grained plagioclase prevails over fine grained mixture of quartz and dark amphibole and biotite. Common accessory minerals are apatite, zircone, titanite, pyrite and magnetite, among secondary minerals epidote, sericite, chlorite and calcite predominate. In our geochemical data base tonalites represent a large data set petrologically relatively homogeneous. The data were plotted into graphs by De la Roche and Köhler-Raaz (Fig. 3).

In the Köhler-Raaz‘s diagram, the Křižanovice tonalites follow a differentiation line of calc-alkaline rocks (gabrodiorites to granodiorites) with a clear affinity to altered rocks.

The content of rare earth elements standardized to chondrites shows a continuous moderate decrease from light to heavy REE (Tab. 3). A positive europium anomaly was observed in several samples.

The position, shape and fabric of xenolites, as well as their petrologic character, were controlled by the tonalite intrusion of the Křižanovice type along a deep-seated shear zone. The gabbros, primarily prevailing in xenolites, were reworked into diorites and amphibolites and were refoliated near the margins.

The modal composition and chemism of xenolites studied in 29 samples from the Křižanovice ore zone is that of diorite (Špaček et al. 1991). The trace element compositions typical for both basic rocks (i.e., increased Cu, Cr, Ni, Co), and for sedimentary rocks (i.e., increased As, W) were determined in the metabasites of the Křižanovice ductile shear zone. This variable pattern of trace elements distribution as well as changes of characteristic element relationships suggest possible granitization of basic rocks (Burkov - Rundquist 1979). The plots show a decreasing content of REE element from LREE to HREE (Špaček et al. 1991).

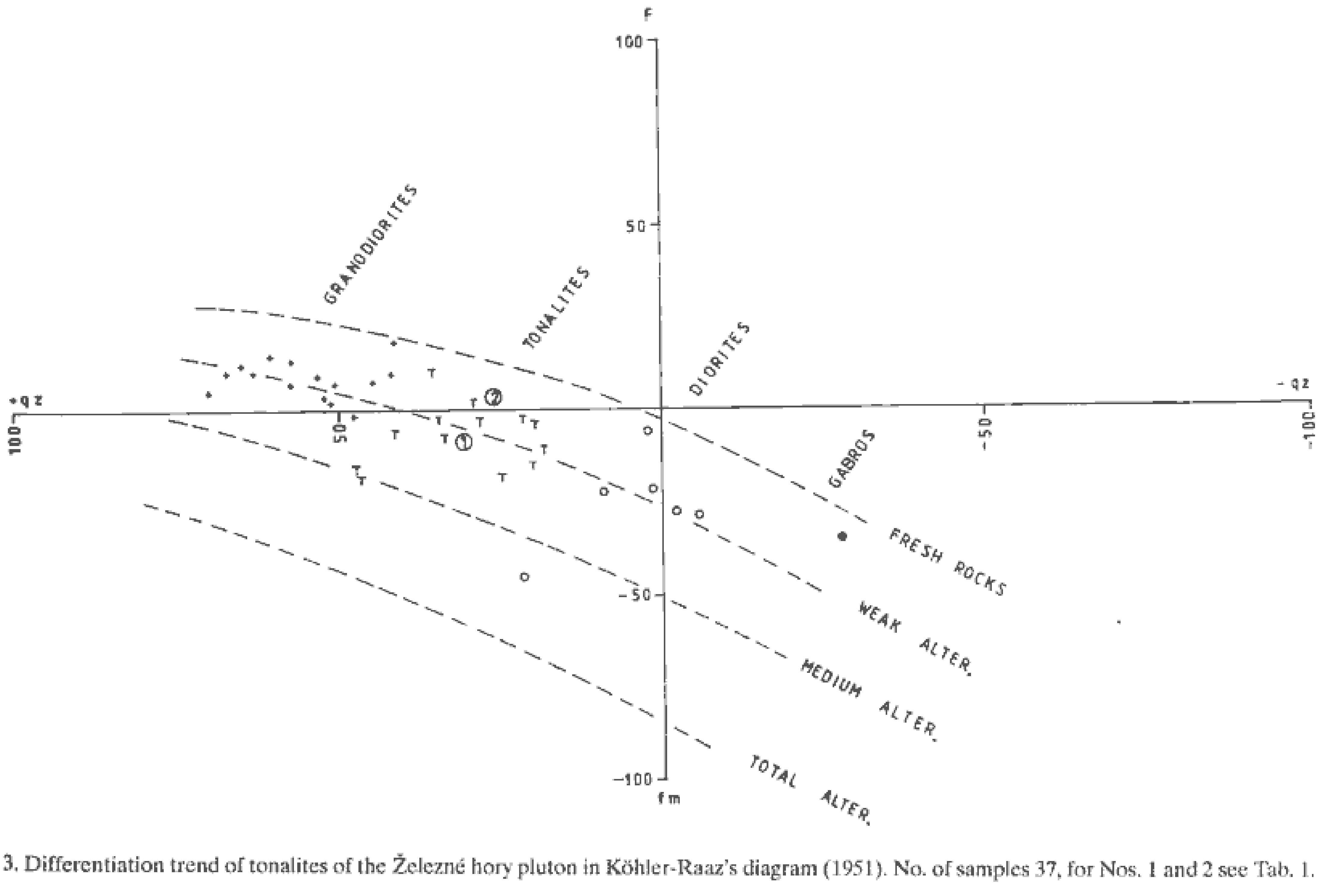
Skuteč type granodiorites

Amphibole-biotite and biotite granodiorites to quartz diorites of the Skuteč type form a few larger and several smaller bodies in the eastern and north-eastern part of the Železné hory pluton. These bodies are mostly elongated in the NE-SW direction. They intrude into migmatized and granitized rocks of the rock mantle and represent centers of ultrametamorphism, melting and homogenization. Close relations of these rocks to the crystalline mantle are documented by schlier and shoestring relics of amphiboles, gneisses and biotite cherts, embedded in granodiorites (active and abandoned quarries near Skuteč, Prosetín, Dachov, Miřetice and Trhová Kamenice – Špaček et al. 1991).

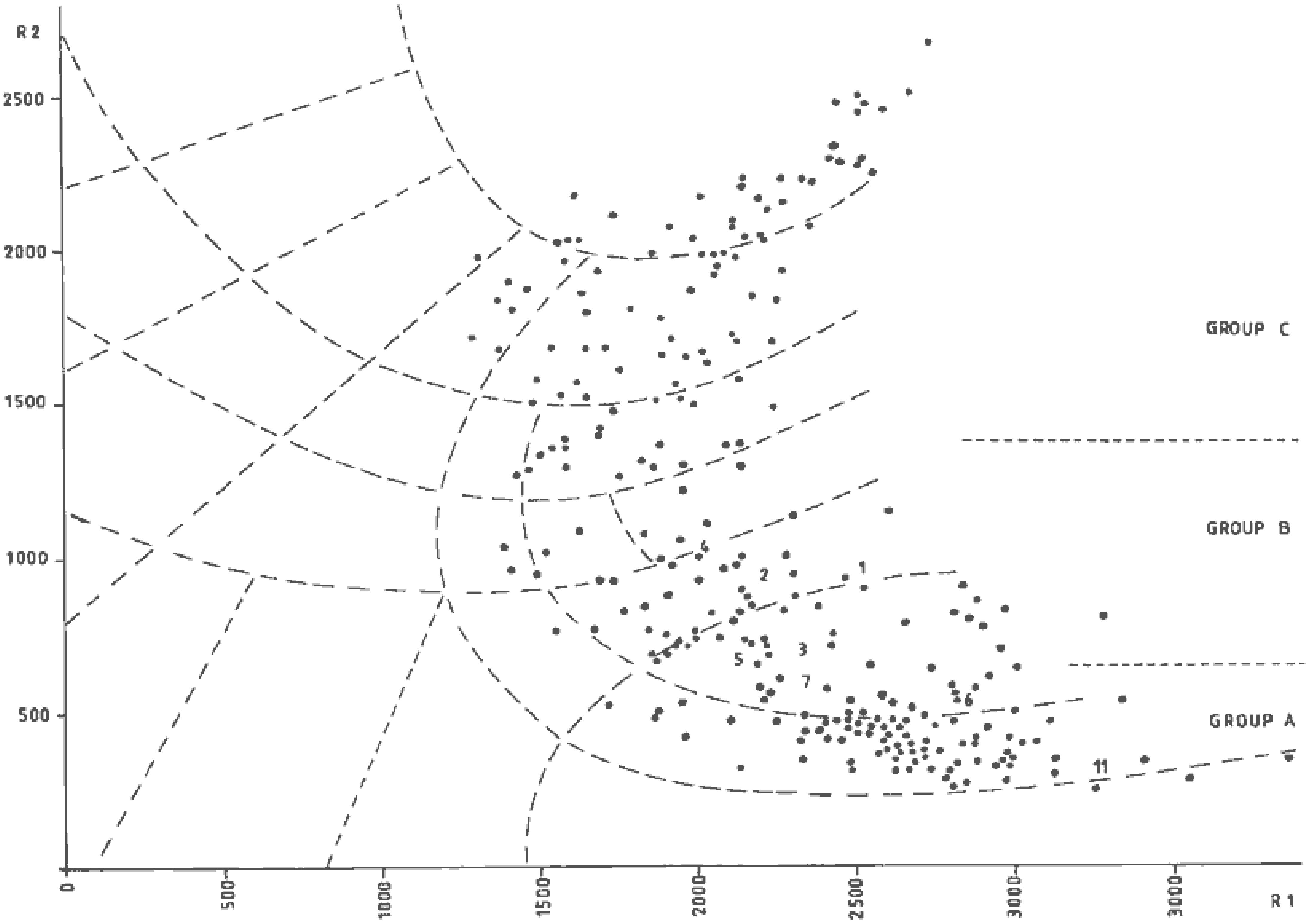
The foliation of inclusions and plane parallel fabric in granodiorites varies, nevertheless two main systems are the most important: B 1 of NNE-SSW and B 2 of WNW-ESE direction. Dipping of the foliation is much more uniform, mostly in the range of 70–85° (Fig. 1, T1). The inclusions undoubtedly represent relics of some steeply dipping monoclinal group of strata or, rarely relics of intensively compressed limbs. In granodiorites the componental movement was mostly steep as shown by the longer axis of lenticular relics and coincident with the dip of foliation. The granodiorite fabric and undoubtedly also the position and shape of granodiorite bodies depend on the fabric of metamorphic mantle rocks. Granodiorites have a copying rock fabric (Beneš 1963). Measurements of magnetic fabric led to similar conclusions (Hrouda - Chlupáčová 1980).

Granodiorite of the Skuteč type is fine to medium grained rock, grey, dark-grey to blue-grey in colour, mostly with indices of orientation or weakly oriented. Main minerals are acid plagioclase, quartz and, in most cases K-feldspar. Accessory minerals are apatite, magnetite, zircone, sericite, chlorite and calcite. The composition of leucocrate types is mostly granodioritic, melanocrate types pass into tonalites and exceptionally into diorites (Minařík et al. 1983, Fig. 4).

The variable petrologic character of granodiorites is illustrated by classification diagrams. Data points in the TAS diagram are concentrated in the field of dacitoides and continuously pass into the field of andesites and partially also into the trachyte and trachyandesite fields. In the graph according to Köhler-Raaz, the data points form a large cluster between diorites and granodiorites, with a clear tendency to altered types. The contents of REE standardized to chondrites continuously decrease from LREE to HREE (Špaček et al. 1991).



3. Differentiation trend of tonalites of the Železné hory pluton in Köhler-Raaz's diagram (1951). No. of samples 37, for Nos. 1 and 2 see Tab. 1.



4. Total graph of magmatic rocks of Železné hory pluton, according to De la Roche (1980). Number of samples 262, for numbers 1–11 see Tab. 1. R1 = 4 x Si – 11 (Na + K) – 2 (Fe + Ti); R2 = 6 x Ca + 2 (Mg + Al); Group: A – granites; B – granodiorites, tonalites, quartzdiorites; C – basic and metabasic rocks as xenolites in tonalites of Křižanovice type.

Biotite granites

Subvolcanic granites of the Křižanovice and Žumberk types represent a Late Variscan magmatic member of the Křižanovice ductile zone. In the western and central part of this zone near Seč and Křižanovice biotite granites form smaller bodies and very often intrude into tonalites, basic xenolites and mantle rocks in the form of dykes (Fig. 1, T3, Fig. 2, outcrops in the Chrudimka river valley under the Křižanovice dam). In the eastern part of the Křižanovice zone near Žumberk, a fractured massif representing the so called Žumberk variety is situated. Granites of the Žumberk type have rather a leucocrate and porphyric character (Rambousek 1989).

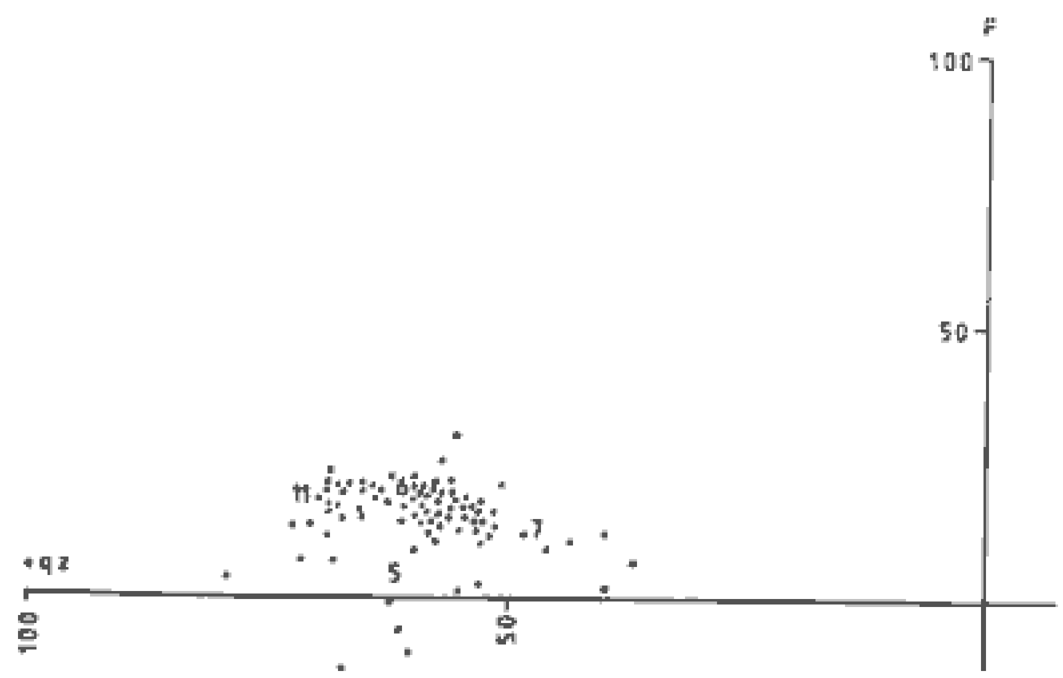
The Late Variscan granites are present in three textural types. The principal type is a uniformly grained granite reddish in colour. Its typical feature is micrographic structure (Vachtl 1975). The second type is represented by a porphyric facies with phenocrysts of feldspars. The third type is represented by a felsitic variety red to violet in colour with phenocrysts of quartz and feldspars. This type occurs near the margins of the granite bodies (for example near Práčov) and in the Lukavice belt, where it was kinematicaly metamorphosed together with volcanites of Ordovician age (Vodička 1966, Vachtl 1975).

The biotite granites are characterized by a balanced Na/K ratio. Data in the graph according to Köhler-Raaz fall in the field of alkaline-calcareous granites (Fig. 5).

The plot of REE contents standardized to chondrites shows a relatively sharp decrease from LREE to Eu (Tab. 3). A negative europium anomaly was observed in several granite samples.

Both K-metasomatism of dislocation metamorphites in tonalites and percolation of ore-bearing fluids through the Křižanovice-Samařov ore zone are connected with the magmatic activity of Late Variscan granites. Geochemical characteristics suggest that the biotite granite itself could not be the source of ore-bearing fluids (Fig. 5).

The granites are strongly enriched in typomorphic elements Ba, Pb, Rb, Sn and F, while depleted in Co, Cr and Zn (Tab. 2). Elevated contents of the first group of elements as well as a close positive correlation between Ba-F-Sn and Co-Cr-Zn suggest magmatic origin of Late Variscan granites of the Železné hory pluton (Burkov - Rundquist 1979).



5. Differentiation trend of granites of Křižanovice and Žumberk types of the Železné hory pluton in Köhler-Raaz's diagram (1951). Number of samples 88, for numbers 5–11 see Tab. 1.

Subvolcanites of the Lukavice and Benátky belts

Along the northern and south-eastern margin of the Železné hory pluton a belts up to 15 km long and 2 km wide are located formed by relatively thick layers, sills and smaller massifs of Late Variscan subvolcanites of dacite and rhyodacite-dacite composition. These rocks intruded into older (probably Ordovician) volcanites of the Lukavice group (Petříkovice and Lukavice type), into the epimetamorphosed Upper Proterozoic volcanosedimentary group of Vítanov and mantle rocks (Babákov and Benátky type). Conformable bodies and dykes parallel with bedding or foliation prevail (Fig. 1).

Primary foliation in unaltered volcanites of the Lukavice type of ENE-WSW direction with a dip of 35-45° to SSE is locally evident. The subvolcanites and volcanites of Early and Late Variscan age are mostly kinematicaly reworked into foliated porphyroides with a translation cleavage of mostly NNE-SSW direction and with a dip 35–60° to ESE (Fig. 1).

Late Variscan subvolcanites of the Petříkov and Lukavice type in the Lukavice belt are reddish and greenish in colour and contain phenocrysts. In nevaditic rocks phenocrysts were formed by more or less tarnished feldspars and rounded (magmaticaly eroded) grey or expressively blue quartz with size of 1–2 mm, exceptionally up to 9 mm. In the Benátky subvolcanite belt porphyric to nevaditic types also prevail with phenocrysts of quartz and feldspar. Felsitic types, sometimes with a small amount of phenocrysts, are less abundant. The subvolcanites form bodies with a NNW-SSE strike and dip 60° to WSW. The schistose porphyroides and sericitic schists with foliation of a dynamo-fluid character (strike NE-SW, dip 25–35° to SE and NW) had a source in zones faulted and metasomaticaly altered due to dynamic metamorphism. The porphyric types were found also near the eastern margin of the Ransko massif, in the form of swarms of parallel veins (Fig 1).

Kinematic metamorphism and metasomatic processes in the Lukavice and Benátky belts resulted in a very similar mineralogical and structural composition in older and younger phases of the volcanogenic rocks. The same development is evident in the marginal facies of the Křižanovice and Žumberk granite (Vachtl 1975, Pošmourný et al. 1985).

Petrologic evaluation of silicate analyses of 69 samples confirmed that in the Lukavice belt subvolcanites predominantly have a character of rhyolites while in the Benátky belt rhyodacites to dacites prevail (Špaček et al. 1991). Minor differences were observed in the alkali content. In the northern belt of Lukavice the composition of alkali is balanced while in the south-eastern Benátky belt Na_2O is dominant (Tab. 1).

Aplitic granite

In a belt of NE-SW direction between Včelákov and Prosetín, thin dykes of formed by aplitic granite and aplite are found. The rock is fine grained and white, light yellow and reddish in colour. Mafic minerals are rare. The mineral composition and structure of some types of the aplitic granite is similar to that of the Žumberk granite (Špaček et al. 1991).

Dyke-forming basic rocks

Older magmatic rocks of the Železné hory pluton and mantle rocks were intruded by dykes of basaltoids. The dykes occur in the ore-bearing Křižanovice zone and in the Lukavice and Benátky subvolcanite belts near the northern and south-eastern margins of the pluton. They form a system of parallel dykes with a length of up to 500 m and with a thickness up to 10 m, concordant with cleavage of porphyroids and sericitic schists (Fig. 1, T 3, Fig. 2).

The basaltoids are green-black to black. Their fabric is often porphyric, with a fine grained matrix. The main component is basic plagioclase, in some cases weakly albitized, and amphibole. Less abundant are magnetite, epidote, ore minerals and exceptionally quartz (epigenetic ?). As accessory minerals apatite, biotite, calcite and in some cases sulphidic minerals are very common. The dyke selvages are very often foliated and hydrothermaly altered. In the TAS graph according to Le Maitre, data points fall into the field of basalts and basaltic andesites (Fig. 6).

In the graph according to de la Roche, the same samples show a considerable scatter from the field of hawaiite through olivinic basalts to tholeiites, andesite-basalts and basalts. In the graph according to Köhler-Raaz these samples form a relatively homogeneous cluster in the field of gabbroids. A low oxidation degree seen in the graph according to Mueller-Saxena is typical (Špaček et al. 1991).

Lamprophyres

The dyke-shaped bodies formed by lamprophyres with a thickness of decimeters, steeply dipping and mostly of E-W strike, are the youngest magmatic rocks of the Železné hory pluton. Minettes, kersantites and spessartites are present in the dykes (Němec 1990).

Seven samples from the northern part of the Železné hory pluton were analyzed (Tab. 1). Data plotted in the TAS graph are dispersed in the field of trachybasalts and in fields

Table 1. Chemical composition of the base rock types of Železné hory pluton and its crystalline mantle (contents of rock-forming oxides in mass %)

rock No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
SiO_2	62.58	62.63	69.50	60.15	71.35	73.84	71.06	77.34	74.53	76.24	77.36	48.19	49.64	47.74	58.15	66.81	75.05	49.42	66.66	43.26	47.24
TiO_2	0.63	0.64	0.27	0.74	0.19	0.15	0.31	0.27	0.28	0.37	0.12	1.63	1.29	1.76	0.99	0.68	0.22	1.30	0.34	0.97	0.59
Al_2O_3	16.55	15.69	15.94	17.91	14.75	13.16	14.12	12.58	13.05	11.96	12.26	15.44	14.15	11.07	17.74	15.05	12.17	16.53	16.22	20.85	23.36
Fe_2O_3	3.78	0.85	0.63	1.46	0.93	1.60	1.50	1.07	1.15	3.59	0.83	8.34	3.51	3.44	1.34	1.57	0.37	4.25	3.84	6.86	3.63
FeO	2.99	3.50	1.25	3.49	0.51	0.50	1.44	0.31	1.04	0.29	0.27	5.91	3.42	4.68	7.10	3.13	1.40	7.34	0.50	4.03	3.24
MnO	0.13	0.08	0.03	0.09	0.02	0.01	0.01	0.02	0.04	0.01	0.07	0.22	0.01	0.14	0.12	0.07	0.03	0.22	0.26	0.38	0.12
MgO	2.05	2.32	0.67	2.29	0.73	0.53	0.79	0.41	0.51	0.43	0.21	5.11	7.57	10.38	3.56	2.22	1.60	4.65	2.37	6.64	3.87
CaO	4.95	4.80	3.27	5.27	1.16	2.32	2.68	1.50	2.06	0.83	0.65	8.96	5.95	8.32	1.08	2.58	0.48	7.30	1.64	7.56	13.05
K_2O	1.59	3.50	2.94	2.48	3.19	4.42	3.92	0.12	1.79	3.50	5.29	0.76	5.00	5.68	2.99	2.99	0.68	0.64	3.60	0.20	0.51
Na_2O	3.04	2.83	4.37	3.51	5.78	2.74	3.91	5.53	3.87	0.21	1.73	2.86	2.25	1.40	1.69	2.98	5.22	4.77	1.40	3.23	2.17
P_2O_5	0.15	0.40	0.14	0.33	0.25	0	0.11	0.10	0.10	0	0.21	0.17	0.61	0.13	0.29	0.33	0.05	0.42	0.08	0.02	0.14
CO_2	0.18	0.86	0.01	0.52	–	0	0	0.02	0.19	0	0.10	0.25	–	1.96	0.08	0.03	0.12	0.31	0.64	0.09	0.08
S	0.05	0.04	0.01	0.05	–	0.03	0.11	0.01	0.05	0.83	0.05	0.22	0.08	0.08	0.24	0.01	0.02	0.33	0.03	0.71	0.19
H_2O^+	0.95	0.90	0.69	0.79	0.75	0.36	0.64	0.45	1.04	2.02	0.42	1.73	2.01	2.68	3.16	1.12	2.38	1.37	2.04	5.09	1.13
H_2O^-	0.17	0.33	0.31	0.16	0.31	0.12	0.10	0.12	0.17	0.04	0.14	0.21	1.92	0.16	0.65	0.58	0.16	0.17	0.22	0.48	0.15
SUM	99.79	99.39	100.03	99.24	99.92	99.78	100.60	99.85	99.87	100.32	99.71	100.00	98.40	99.62	99.28	100.15	99.95	99.02	99.84	100.37	99.47

Železné hory pluton: tonalite of Křižanovice type: 1 – Křižanovice, borehole VKN-10a, deep 32.5 m; 2 – Seč, borehole MV-115, 15.5 m. Granodiorite up to quartz diorite of Skuteč type: 3 – Rohozná, borehole V-88, 14.8 m; 4 – Včelákov, borehole VČ-1, 100.2 m; Granites: 5 – Hlinsko type, quarry Hlinsko; 6 – Křižanovice type, borehole H-3, 78.0 m; 7 – Žumberk type, quarry Žumberk. Subvolcanites: 8 – Benátky type, Stružinec, borehole MV-150, 26.9 m; 9 – Babákov type, Babákov borehole MV-146, 10.0 m; 10 – Petříkovice type, borehole MV-28, 12.5 m; 11 – aplitic granite, Křižanovice, borehole VKN-10a, 31.6 m; 12 – basalt dyke, Křižanovice, borehole MV-2, 17.6 m; 13 – kersantite, Křižanovice, borehole VKN-30, 96.0 m; 14 – spessartite, Křižanovice, abandoned quarry near water dam. Rocks of pluton mantle: 15 – Kutná Hora Crystalline Complex, gneiss, Barovice, borehole MV-162, 12.0 m; 16 – Podhořany Crystalline Complex, gneiss, Podhořany, outcrop; 17 – Vítanov group of Hlinsko zone, dacite, Křížová, borehole VK-2, 46.7 m; 18 – metabasalt, Křížová, borehole VK-7, 159.0 m. Lukavice volcanic belt: 19 – metarhyodacite, Zabitý kopec, outcrop; 20 – metabasalt, Sychrov, outcrop. Basic rocks of Křižanovice ductile zone: 21 – amphibolic gabbro, Švihov, outcrop. Laboratories: Silicate analysis No. 5 – GÚ ČSAV, other analyses – ÚNS, Kutná Hora, RFA and INAA analyses – Geoindustria, Praha.

adjacent to the trachyandesite field. In the graph according to Köhler-Raaz, the samples concentrate in the field of non-altered basic rocks. The contents of REE standardized to chondrites show a strongly differentiated pattern characteristic by a steep decrease, from extremely high values of LREE to low values of HREE.

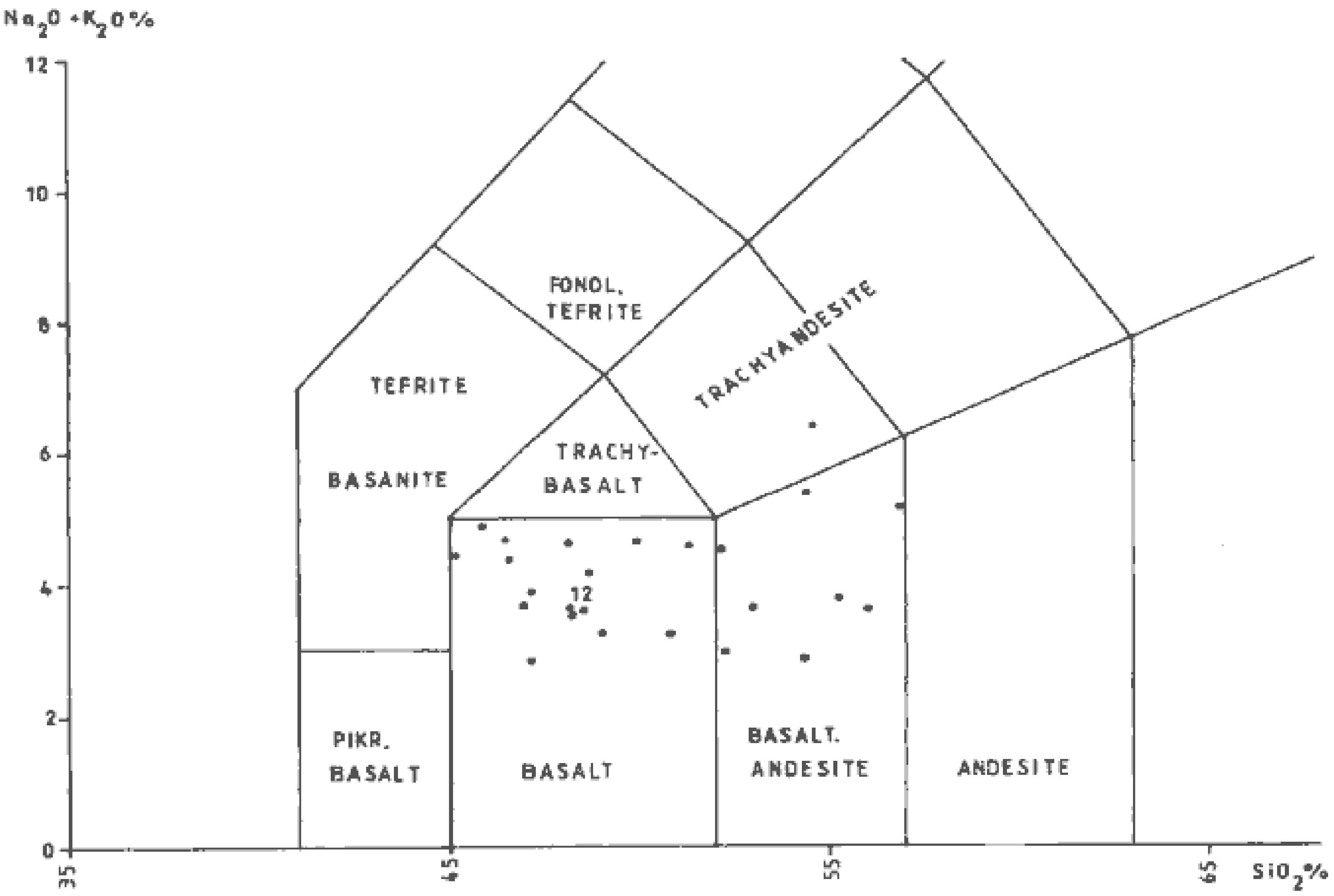
The crystalline mantle of the Železné hory pluton

A relatively continuous mantle is preserved in the southern part of the Železné hory pluton (Fig. 1). The mantle is built up by multimetamorphosed rocks of the Kutná Hora - Svratka Crystalline Complex. Sillimanite - biotite, biotite and chert gneisses (Tab. 1), orthogneisses, amphibolites, calc-silicate rocks and crystalline limestones are present in relics of different size and shape. The metamorphites, namely amphibolites and gneisses are migmatized and granitized in a various degree. Dark grey, fine grained rocks prevail, consisting of a mixture of biotite, amphibole, feldspar and quartz. The fabric is apparently parallel, isotropicaly grained and of a granitoid character. Migmatites very often exhibit a relics fabric of metasediments (Žežulková 1988). In the central part of the Železné hory pluton, the migmatites of ophtalmite, stromatite and nebulite structures locally pass very irregularly into oriented granodiorites and quartz diorites, preserving metamorphic fabric in relics (Fig. 1). As recent mapping suggests, migmatites of the Bojanov, Hluboká, Petrkov and Kvítkov and granodiorites of the Tábor and Petrkov types are part of the crystalline mantle of the pluton (in previous work by Vodička 1963 described as separate types).

Mantle migmatites to oriented granodiorites plot as granodioritic rocks with a predominance of Na_2O and K_2O in all used classification graphs (Špaček et al. 1991).

In the south-eastern part of the Železné hory pluton elongated bodies of coarse grained gneissic granite of the so called Všeradovy type with distinc orientation or an outright tabular character are present. According Vachtl (1975) these rocks belong to the Všeradovy volcano-plutonic formation of Cadomian age, together with subvolcanites of the Benátecká zone and Proterozoic of the Hlinecká zone. The results of exploration work north of Benátky show that the Všeradovy granite passes into migmatites, contains a layer of amphibolites and is intruded by irregular bodies of subvolcanites of the Benátky type and by dykes of leucocrate granites and diabases (Špaček et al. 1991). The Všeradovy granite is undoubtedly of pre-Variscan age but, unlike gneissic granites and orthogneisses of the Kutná Hora and Svratka Crystalline Complexes, does not belong to the granitized mantle of the Železné hory pluton. The subvolcanites of Benátky zone are the product of a tectonic zone active in Variscan orogeny, formed on the contact of Proterozoic of the Hlinsko zone with the granitized mantle of the Železné hory pluton (Fig. 1).

Based on 17 analyses, the Všeradov granite shows variable composition from Na-types to K-types. A prevailing albitic character of the Všeradov granite (Vachtl 1975, Minařík et al. 1983) was not confirmed by new analyses. In



6. Classification of basic dyke rocks of the Železné hory pluton in TAS diagram according to Le Maitre (1984). Number of samples 25, for number 12 see Tab. 1.

the Köhler-Raaz's graph, a cluster of points falls in the field of fresh to partially altered granites. In the TAS diagram data points are concentrated in the field of rhyolites (Špaček et al. 1991).

Basic rocks are abundant in the rock mantle complex. Together with migmatites and granitized gneisses they occur in two relatively continuous belts of NW-SE and NNE-SSW directions. From a petrologic point of view, the basic rocks correspond to amphibolic gabro with transitions to amphibolic diorite. Margins of the bodies very often show cleavage, the central parts are either isotropic or weakly oriented. Granitization of amphibolites and metabasites is manifested by gradual feldspathization with formation of dioritic rocks (Tab. 1). In the TAS diagram the majority of samples fall in the field of basaltic andesites, some plot into the field of basalts. In the Köhler-Raaz's graph data points fall into the field of gabro and some into the field of more acid rocks (Špaček et al. 1991).

Small blocks of marbles, calc-silicate rocks and biotite gneisses, occurring along the margin of the tonalite body of the Křižanovice type between Seč and Nasavrky (Fig. 1) represent probably equivalents of the Podhořany crystalline complex.

In the crystalline mantle of the pluton, the NW and NE branches were deliminated, resulting in the irregular arrangement of rock bodies. The rock branches converge in the south (Beneš 1963) and follow the direction of metamorphic foliation, lineation of crystallization and the main systems of fold B-axes. The prevailing direction in circle diagrams is NW-SE (B1 system) and NE-SW (B2 system). Subordinate directions are E-W and N-S. Statistically the B2 system is more significant (Fig. 1, T2). The fold character is clearly brachystructural. This is confirmed by inclination of B-axes of folds in the range 5–60°, as well as by reconstruction of brachy folds of a kilometer order in the surroundings of Trhová Kamenice (Fig. 1).

In the south-east the Železné hory pluton borders on Paleozoic rocks of the Hlinsko zone (Fig. 1). A folded group of strata of pelitic sediments was transformed to spotted shales and hornfels by thermic effects of the intrusive rocks. In addition, hornfels are migmatized in the form of bands, injections, and diffusive feldspathization in the contact periplutonic zone. The blocks of hornfels are very often enclosed as xenolites in granodiorites of the Skuteč type (Fig. 1).

Geotectonic development

Pre-intrusive stage

Extensive Pre-Cadomian crystalline units forming the Kutná Hora-Svratka region and volcanosedimentary Proterozoic complex of the Železné hory, both part of the Central Bohemian region, occur in the crystalline mantle of the Železné hory pluton (Figs. 1, 7). The regional Cadomian metamorphism and Variscan granitization processes strongly influenced, or totally smeared out, the primary geotectonic character of the Kutná Hora-Svratka region.

The geological units in central Bohemian region are products of Cadomian tectogenesis. It is possible to distinguish a nearly complete Cadomian geotectonic cycle, the product of which is the oceanic type (Fig. 7). The sedimentary volcanic complexes with bimodal volcanism

Table 2. The content of trace elements in rocks of Železné hory pluton and its crystalline mantle (RFA method, element content in ppm, for explanations see Tab. 1)

rock No.	1	2	3	4	6	7	8	9	10	11	12	13	15	16	17	18	19	20
As	–	10	–	8	–	–	2	2	22	–	2	5	2	2	5	6	10	31
Ba	1570	1420	795	1173	2154	1816	30	572	1146	–	378	3902	709	637	149	161	1312	5
Bi	–	10	10	10	10	5	16	10	6	–	–	–	10	10	25	10	1	–
Cd	–	10	10	10	–	–	10	10	–	–	–	–	10	10	–	10	–	–
Co	3	–	–	–	–	–	–	–	–	–	11	18	–	–	–	–	–	–
Cr	–	–	–	–	–	–	–	–	–	–	26	59	–	–	28	–	–	–
Cu	52	13	2	5	–	–	2	2	306	27	96	–	71	21	1	28	–	9
Ga	10	–	19	–	4	10	–	15	8	1	7	5	–	–	13	–	10	16
Mo	–	5	5	5	–	–	5	5	2	–	3	–	5	5	–	5	–	2
Nb	7	10	13	12	6	8	10	10	12	8	3	13	9	12	12	2	10	6
Ni	39	26	7	24	–	–	2	2	2	26	51	45	108	32	–	13	1	5
Pb	20	31	36	13	–	–	5	5	7	153	–	–	5	5	6	5	–	184
Rb	28	–	66	–	–	124	–	24	92	90	–	88	–	–	25	–	96	236
Sb	14	–	–	–	–	–	–	–	–	19	19	–	–	–	4	–	–	–
Sn	–	5	5	5	–	–	5	5	4	–	–	–	5	5	3	5	–	–
Sr	458	314	255	543	189	749	168	179	78	267	316	1447	204	193	90	381	47	276
W	1	10	10	10	–	–	10	10	16	–	2	–	10	10	–	10	–	17
Zn	57	60	31	93	–	–	2	28	8	21	104	–	103	43	12	58	–	488
Li	9	–	–	–	4	30	–	–	–	4	13	20	–	–	–	–	16	–
Zr	217	–	89	–	121	50	–	134	96	42	101	288	–	–	174	–	154	383
F	2300	–	–	–	1400	–	–	–	–	300	500	2000	–	–	–	–	1000	–
Y	–	28	17	27	–	–	23	24	18	–	–	–	27	26	–	24	–	21

Table 3. REE and other trace element contents in rocks of Železné hory pluton and its crystalline mantle (INAA method, element content in ppm, for explanation see Tab. 1)

rock No.	1	3	6	7	9	11	13	17	19	21
La	37	3	25	43	2	10	146	25	33	13
Ce	76	4	42	80	4	19	309	40	69	24
Sm	5	4	1	4	4	1	19	0.4	5	2
Eu	1	1	0.6	1	1	0.5	5	1	1	0.8
Tb	–	–	–	–	–	–	1	–	–	–
Yb	3	0.1	–	2	0.3	–	2	3	2	2
Lu	0.3	0.1	0.2	0.3	0.4	–	0.3	0.6	0.4	0.2
U	–	–	4	5	–	5	–	–	4	–
Th	11	12	23	23	6	19	24	4	14	2
Rb	36	<3	89	136	<3	111	37	22	136	–
Cs	3	4	2	2	0.1	–	4	2	1	4
Hf	6	0.3	4	5	0.6	2	7	4	4	3
Sc	17	5	1	7	8	2	20	9	12	32
Ta	–	0.5	–	–	0.5	–	–	–	–	–
Co	13	0.3	1	3	0.4	1	25	2	5	22
Cr	–	0.2	–	–	–	–	–	61	–	–
Au	–	0.2	–	–	0.2	–	–	–	–	–
Sb	–	0.1	–	–	0.2	–	–	–	7	–

developed in the environment of a marginal sea. In the Chvaletice-Sovolusky Proterozoic basin basic volcanism (Fiala 1979), and in the Hlinsko zone acid volcanism (Pošmourný et al. 1985, Špaček et al. 1991) prevailed. The Chvaletice granodiorite massif, the basic massif of Svatý Kříž and the ultrabasic massif of Ransko intruded in the last phases of the Cadomian cycle (Mísař et al. 1983). Folding associated with low-grade metamorphism (up to greenstone facies) took place at the end of the Cadomian cycle (Vendian). Metamorphism and deformation processes affected rock sequences of the Cadomian as well as Pre-Cadomian cycle. Uplift, denudation and deposition of molasse sediments followed in Middle Cambrian.

Intrusive stage

The Variscan cycle brought about strong rebuilding of the crust, formed during Pre-Cadomian and Cadomian. Geotectonic activity dynamically affected linear zones where tectono-magmatic reactivation followed by recycling of Pre-Variscan crust had been taking place. The reactivation was bound to the Železné hory Mts. system of deep zones (intersecting the Labe and Jihlava zones – Máška 1962, Vachtl 1979), which are manifestations of a first order tectonic structure in the contact of Cadomian and Pre-Cadomian crust blocks (Fig. 7).

The magmatic activity, i.e., production of magma in deep parts of the crust, was followed on the one hand by extension, uparching and uplifting of crustal blocks, on the other hand by dowthrow and accumulation of Ordovician, Silurian to Devonian(?) clastic sediments in the Chrudim

(Fig. 2) and Hlinsko basins. Based on the differences between the Paleozoic units of Chrudim (Barrandian development) and Hlinsko (Saxoturingian development), it seems that the geotectonic setting probably had the character of a rift zone combined with a transform fault (Ramberg 1978, Fig. 7).

The rift structure of E-W direction and the transform fault of N-S direction stimulated intrusive and effusive activity. Bimodal, probably Ordovician, volcanism of the Lukavice belt can be viewed as an initial near surface manifestation of the rift structure. The Late Variscan tonalite bodies of the Křižanovice type and gabbroid members of the Ransko massif are considered to be deep products of this rift structure. The expressive anizotropic fabric of the Křižanovice tonalite and Ransko gabbros with abundant petrologically varied xenolites suggests the formation of intrusive bodies in a regime of ductile flow and their active intruding through the crust.

The formation of Middle Variscan granitoid bodies was affected by structures of the Pre-Cadomian crystalline mantle. Granodiorites of the Skuteč and Hlinsko type, mostly forming elongated bodies near the NE and SE margin of the Železné hory pluton, have a character of digitations of a deeper laying massif into the mantle rocks. The anizotropic inner fabric of granodiorites demonstrates that the bodies were formed under close interaction with mantle complexes (Beneš 1963, Hrouda - Chlupáčová 1980, Figs. 1, 2).

Late Variscan volcanomagmatic activity can be seen in the Lukavice and Křižanovice belts near the northern margin and in the Benátky belt near the eastern margin of the Železné hory pluton and Ransko massif (Fig. 1). The shallow intrusive biotitic medium grained granites and their marginal porphyric facies are developed in the northern part of this belt, while in its south-eastern part subvolcanic rhyolites to dacites are present. The typical structural feature of these belts is their linearity subordinated to main tectonic directions of the Železné hory pluton. The position of these belts indicates a long-term persistence of volcanomagmatic centers.

Late Variscan magmatism was terminated by dyke intrusions of aplites, aplitic granites, bazaltoids and lamprophyres.

Post-intrusive stage

The Labe and Přibyslav deep zones, according to models of shear deformations belonging to the system of conjugate R and R' shears (Ramsay - Huber 1987), iniciated magmatic and volcanic activity at the beginning of Variscan reactivation. These zones were transformed into crush zones during the postmagmatic stage and in shallower segments of the crust; the brittle shear, normal-fault and translation-fault deformations were concentrated there, followed by hydrothermal metasomatic and metallogenic processes. The zones of dislocation metamorphism are conform to the belts of Late Variscan rhyolite and rhyolite-dacite magmatism (Figs. 1, 7).

The rocks in crush belts were dynamically transformed into kataclasites, mylonites and blastomylonites. The processes of dislocation metamorphism created favorable physico-chemical conditions for infiltration metasomatism.

Porphyroides and sericitic schists were formed from the dislocation metamorphosed rocks, followed in the next stage by metasomatic quartzites, these representing an environment favorable for crystallization and accumulation of sulphide ore mineralizations.

The main structural elements of the crush belts are represented by cleavages, lineations of various types, shear folds and various forms of fracture tectonics. The Křižanovice-Samařov crush and ore belts were formed in the setting of a shear zone during a normal-fault tectonic régime, i.e., in a zone of uparching and spreading of the crust. The younger phase of deformations took place under the dynamic régime of translation-faulting (Špaček et al. 1985, Drozen et al. 1987, Fig. 1, T4).

The Variscan cycle came to an end by molasse sedimentation of Carboniferous-Permian age. Relics of these sediments were found in the Železné hory Mts. region near Kraskov west of Seč (Mísař et al. 1983, Fig. 1).

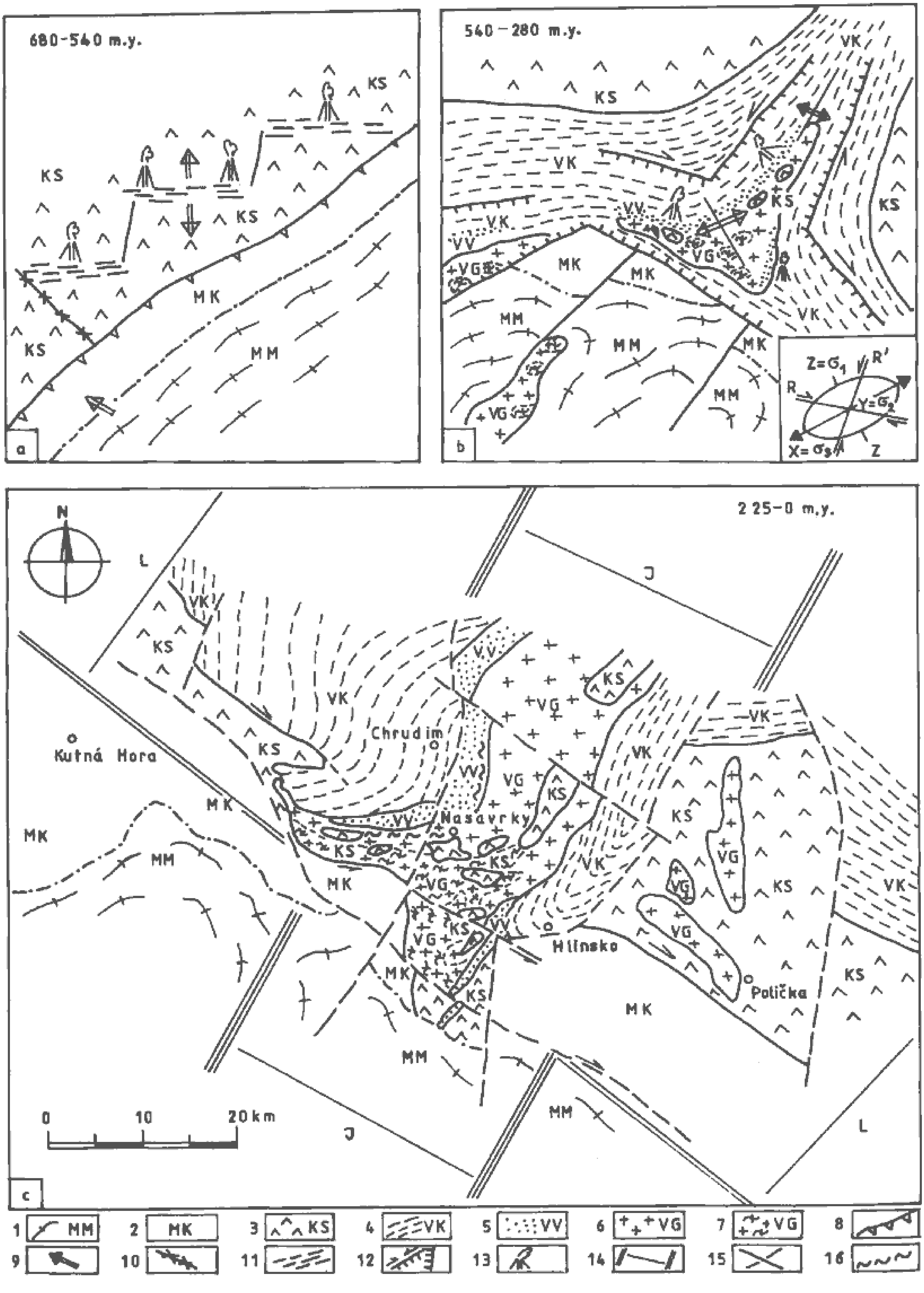
The geotectonic systems R and R' (Labe and Jihlava systems), pre-conditioning Variscan reactivation, maintained their mobility for a long period of time. In the Post-Variscan epoch, right-slip faults and partially normal faults continued to develop in the Labe zone. The uplift of the Železné hory pluton and Saxonian block, segmentation of Pre-Cadomian, Cadomian and Variscan structural levels and Cretaceous cover is apparent together with movements in the Jihlava zone (Figs. 2, 7).

Based on extensive geological and comparative studies, it is possible to conclude that the base dynamic and kinematic Variscan development of the Železné hory pluton corresponds to a model of right-slip faulting with the main tensile stress in the NE-SW direction. The conjugated shears R and R' mainly took place during the Variscan reactivation of the Železné hory Mts. region under the conditions of dilatation, dragging and translation (Ramsay - Huber 1987). These lines and their crossing became the main centers and belts not just of volcanism and magmatism, but also of postmagmatic kinetic metamorphism, metasomatism and block faulting (Fig. 7).

Metallogenic outline

The most important base metal ore deposits of the Železné hory Mts. region and abundant ore indices are bound to processes of the Variscan tectono-magmatic reactivation. The dynamic processes of high energy caused regeneration of older ore accumulations and generated ore fluids, bound to the intermediate to acid magmatism of the Železné hory pluton (Bernard - Pouba 1986).

The ore deposits and disseminated mineralizations are located in deep zones and belts of both granitoid magmatic activity and postmagmatic deformations and metasomatism near the northern and south-eastern margin of the Železné hory pluton and partially also in its mantle (Fig. 1). Accumulation of ore minerals took place after the



680-540 m.y.
KS
MK
MM
a
540 – 280 m.y.
KS
VK
VV
VG
MK
MM
Z=σ1
R'
R
Y=σ2
X=σ3
Z
b
2 25–0 m.y.
N
L
J
VK
KS
VV
VG
Chrudim
Kutná Hora
MK
MM
Nasavrky
Hlinsko
Polička
0
10
20 km
c
1 MM
2 MK
3 KS
4 VK
5 VV
6 VG
7 VG
8
9
10
11
12
13
14
15
16

rock environment was predisposed by dynamic metamorphism and metasomatism.

Ore deposits Samařov and Křižanovice are located in the zone of kinematic metamorphites and metasomatites, which originated mostly by reworking of tonalites and their xenolites and partly by reworking of the Křižanovice granites. This belt is 6 km long with a thickness of up to 340 m, NW-SE to WNW-ESE direction and a dip of 70–85° to SW and WNW (Fig. 1, T4). The main type of mineralization is represented by a metasomatic barite-sphalerite massive ore forming body of lenticular shape with the axis abruptly dipping to the NW. As secondary minerals a pyrite-sphalerite-chalcopyrite assemblage in nests, patches and stringers is present (Drozen et al. 1987). The barite-base metal mineralization shows paragenetic relations to the Late Variscan granite magmatic complex. Mineral assamblages within the Křižanovice ore deposit were formed probably as a result of multiphase development of a hydrothermal-metasomatic system in the zone of a deep-seated fault (Drozen in Špaček et al. 1985, Kloz 1986). Isotopic analyses of lead in galena from the Křižanovice deposit exhibit little variability. The results suggest that this lead belongs to the orogenic, little differenciated type. (Patočka et al. 1984, Kloz 1986).

Pertold and Suk (1986), Drozen et al. (1987) and Hladíková et al. (1988) interpreted massive barite-sulfidic ores of the Křižanovice deposit as a metamorphosed and metasomatically influenced stratiform ore deposit of a volcano-sedimentary series.

The Lukavice ore deposit and occurrences near Bítovany and Trpišov form impregnations and small accumulations of pyrite with traces of Cu, Zn, Pb sulphides, located in zones of metamorphosed acid volcanites of the Lukavice belt affected by kinematic and metasomatic metamorphism. The zones, tens to hundreds of meters thick, are of NNE-SSW direction with a dip of 65° to ESE. The isotopic composition of lead in galena and of sulphur in pyrite suggests a deep source of the Lukavice mineralization (Patočka et al. 1984, Pošmourný - Hladíková 1989).

The ore deposits Včelákov, Horní Babákov and Ransko-Obrázek are situated in the south-eastern volcanomagmatic belt of the Železné hory pluton. The small ore deposit Včelákov with Fe, Cu, Zn, Pb sulphides is located in an altered tectonic zone of NNW-SSE direction intersecting granodiorites and quartz diorites with xenolites of gabbros and gabbro-amphibolites (Vodička 1957, Holub 1978). A scheelite mineralization with Fe, As, Cu sulphides typical of granitoid magmatism was found in quartz veins and greisens near Horní Babákov. The veins and accompanying greisens form several zones of NW-SE direction with a dip of 70° to SW in biotitic granodiorite of the Hlinsko type (Vachtl - Štemprok 1961, Hájek 1971). The scheelite mineralization in the form of incrustations in fissures is abundant in granitoids of the Skuteč type and in mantle rocks in the larger area near the SE margin of the Železné hory pluton (Novák - Vostradovský 1985, Špaček et al. 1991).

The economically significant ore deposit Ransko-Obrázek with a massive sphalerite-barite mineralization and disseminated Fe, Cu, Mo, Pb sulphides is located in hydrothermally-altered metasomatic quartzites, associated with quartz diorites of the Ransko massif. The moderate dipping lenticular ore bodies of ENE-WSW to NE-SW direction with a dip of 30° to NE are bound to rupture systems (Holub 1978). The dynamic and metasomatic alterations of diorites took place in several phases resulting in a distinct mineral and geochemical zoning (Němec - Holub 1980).

The Fe, Pb, Zn, Cu sulphide mineralization occurs also in the form of irregular stringers and impregnations in small lenses of marbles and erlans, situated in the crystalline mantle of the pluton south-west of Křižanovice. The age of this ore occurrence has not been determined. It is assumed to be either an older mineralization regenerated in Variscan or a Variscan postmagmatic product (Špaček et al. 1991).

Sporadic inclusions of native Au were found in sulphidic ores of the Ransko, Křižanovice and Křížová deposits by microscopy. Therefore sulphide ores can be considered to be one of primary sources of gold in placers.

A Mo, Cu, Fe, As assemblage occurring as fracture incrustations in granodiorites of the Skuteč type and granites of the Žumberk type is connected with granodiorite magmatism.

Small indices of Fe, Cu, Pb, Zn, Ag ± F, occurring in fissures in granodiorites of the Železné hory pluton and in metamorphites of its mantle, and rarely accompanied by uranium minerals, have been attributes to the Upper Variscan to Lower Cimmerian phase (Špaček et al. 1991).

Conclusions

1. The evolution of the Železné hory pluton can be divided into three phases: the phase of Early-Variscan tonalite, Middle Variscan granodiorite and Late-Variscan granite.

7. Model of geotectonic development of the basement of the north-eastern margin of the Moldanubian core.
a) Cadomian cycle with a character of oceanic divergent border near the margin of Pre-Cadomian continental plate, formed by undifferenciated crust. b) During Cadomian cycle the consolidated crust was reactivated by Early up to Late Variscan orogenesis. Lower Paleozoic basins were formed and both volcanic and magmatic activity were initiated during the régime of continental rift. Under the condition of crust extension in the NE-SW direction mostly conjugated shears R and R' were active during Variscan reactivation. The relics of Pre-Cadomian and Cadomian structural levels were assimilated in Variscan granitoids. c) Saxonian block dislocation of basement of Central Bohemia, Kutná Hora-Svratka and Moldanubian regions.
Stratigraphic-litology units: Precadomian stage: 1 – Moldanubian region, PT1 (?), 1100 Ma (?); 2 – Kutná Hora-Svratka region, upper level, PT2 (?), 1100–680 Ma. Cadomian stage: 3 – Central Bohemian region, Eocambrian to Lower Cambrian, 680–540 Ma. Variscan stage: Central Bohemian region, Upper Cambrian to Lower Carboniferous, 540–280 Ma; 4 – clastic sediments; 5 – volcanogenic groups of strata; 6 – granitoid complexes; 7 – migmatized and granitized Prevariscian mantle complexes. Structural symbols: 8 – subduction zone; 9 – direction of movement of litospheric plates; 10 – transform fault; 11 – ocean ridge with tholeiitic magmatism; 12 – rift valley; 13 – Cadomian tholeiitic and Variscan rhyolite-dacitic volcanism; 14 – zones of deep seated faults of Pre-neoid stage, L – Labe, J – Jihlava; 15 – main faults of Neoid stage; 16 – zones of dislocation metamorphites and metasomatites.

These phases are dependent on recurrent tectonic activity in the deep-seated Labe and Jihlava systems. The tectonic development was controlled by horizontal right-slip faulting and tensile stress of NE-SW direction. The deformation maximum was concentrated in the system of conjugated shears R and R', in NNE-SSW and NW-SE directions. Both systems can be seen in the arrangement of foliations and folds in the pluton mantle, in anizotropic structures of granodiorites of the Skuteč type, in the rock fabric of tonalites of the Křižanovice type, its xenolites and in belts of rhyolite and rhyolit-dacite volcanism. The structure of the post-intrusive crush and of the metasomatic Křižanovice and Ransko-Včelákov zones is also subordinated to a shear deformation of the normal-fault and slip-fault type. Deformation in the Labe and Jihlava systems continued during Saxonian tectogenesis, resulting in the formation of ramp valleys and horsts, restricted by faults.

2. Geotectonically the Železné hory pluton can be classified as marginal (Chain 1974) because of its formation on the contact of blocks with the crust partly of continental, partly of oceanic type. With regard to the strongly anizotropic rock fabric, the plutonic, subvolcanic and volcanic members of the Železné hory pluton belong heterogeneous bodies with different fabric (Beneš 1974).

3. All types of intrusive rocks, typical of the calc-alkaline series were observed in the Železné hory pluton. This assemblage is characteristic for a geochemically more mature crust of active continental margins – crust partly recycled during some older stage of development (Jakeš 1984).

4. Based on assemblages of major and trace elements we assume a common magmatic origin of the Lukavice and Benátky Late Variscan subvolcanic and volcanic belts located near the northern and south-eastern margins of the Železné hory pluton.

5. Based on structural, petrological and metallogenic studies we conclude that tectonic and hydrothermal processes continued during the postmagmatic evolution. These processes were concentrated in the crush zones near the northern and south-eastern margins of the Železné hory pluton, where dynamic and metasomatic reworking of rocks and deposition of sulphide ore mineralization took place. The important deposits of base metals are related to the processes of Variscan tectono-magmatic reactivation. The dynamic and metasomatic processes initiated regeneration of Pre-Variscan ore deposits as well as formation of new ore deposits, typical of granodiorite massifs. The ore mineralizations have the same location near the northern and south-eastern margins of the Železné hory pluton and Ransko massif, as belts of the Late-Variscan magmatic activity and of dynamic and metasomatic changes in plutonic and volcanic rocks.

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Železnohorský pluton a jeho plášť

(Résumé anglického textu)

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1. Granitoidní železnohorský pluton variského stáří se formoval na křížení hlubinné zóny labské a jihlavské na styku dvou kontrastních korových bloků – prekadomského s kůrou kontinentálního typu a kadomského s kůrou oceánického typu. Variské pochody měly charakter tektonomagmatické reaktivace provázené recyklací prevarisky konsolidované kůry. Variský i postvariský geotektonický vývoj Železných hor lze objasnit modelem pravostranného horizontálního posunu s hlavním tahovým napětím směru SV–JZ. Struktura měla pravděpodobně charakter kontinentálního riftu. V rozložení vulkanismu a magmatismu a postmagmatické dislokační metamorfóze a metasomatóze a platformní kerné segmentaci se uplatňovaly hlavně konjugované střihy R a R' směru SZ–JV a SSV–JJZ.

2. Magmatismus železnohorského plutonu byl polyfázový – staro- až mladovariský. Nejstaršími jsou tonality vázané do křižanovické duktilní zóny a obsahující velké množství převážně bazických xenolitů. Hlavní masu tvoří středně variské granodiority typu Skuteč. Nejmladšími jsou biotitové žuly křižanovické a žumberecké a žíly aplitů, bazaltoidů a lamprofyrů. S mladovariskými žulami jsou v úzké spojitosti subvulkanity ryolitového až dacitového složení, které tvoří zóny při s. a jv. okraji plutonu.

3. Krystalinické a sedimentární jednotky obou korových bloků – krystalinikum kutnohorské a podhořanské, sedimentárně vulkanické proterozoické souvrství vítanovské skupiny a staropaleozoické souvrství vítanovské a lukavické skupiny a flyšové sedimenty hlinské zóny byly periplutonicky granitizovány a kontaktně metamorfovány. Jednotky zůstaly zachovány jako plášť anebo xenolity a relikty. Plášťové jednotky mají nehomogenní vrásovou stavbu uspořádanou do dvou větví. Formy granodioritových intruzí železnohorského plutonu se do značně míry přizpůsobují vrásové stavbě krystalinického pláště.

4. V postmagmatickém vývoji hrála významnou roli petrogenetickou a metalogenetickou dislokační metamorfóza a hydrotermální metasomatóza vázaná do regionálních pásem střižné deformace při s. a jv. okraji plutonu. Pásmo křižanovické a lukavické a ransko-včelákovské se shoduje s hlavními centry ryolitového až dacitového vulkanismu a ukazuje na dlouhodobé působení R a R' střihů v labském a jihlavském hlubinném systému.

5. Hlavní polymetalická sulfidická ložiska i rozptýlená mineralizace jsou uložena v pásmech Ca-Na magmatismu a vulkanismu při s. a jv. okraji plutonu. Ke koncentraci rudních minerálů došlo až v prostředí připraveném dynamicky metamorfně a hydrotermálně metasomaticky v pásmu křižanovicko-samařovském a ransko-včelákovském. Jako výplně puklin v granodioritech a žulách jsou zastoupeny typomorfní asociace pro granitoidní masivy – greisenová se scheelitem a molybdenitová.

Vysvětlivky k tabulkám

1. Chemismus základních horninových typů Železnohorského plutonu a jeho pláště (oxidy v hmot. %).
Železnohorský pluton: tonalit typu Křižanovice: 1 – Křižanovice, vrt VKN-10a, hl. 32,5 m; 2 – Seč, vrt MV-115, hl. 15,5 m. Granodiorit až křemenný diorit typu Skuteč: 3 – Rohozná, vrt V-88, hl. 14,0 m; 4 – Včelákov, vrt VČ-1, hl.100,2 m. Granity: 5 – typ Hlinsko, lom Hlinsko; 6 – typ Křižanovice, Křižanovice vrt H-3, hl. 78,0 m; 7 – typ Žumberk, lom Žumberk. Subvulkanity: 8 – typ Benátky, Stružinec, vrt MV-150, hl. 26,9 m; 9 – typ Babákov, vrt MV-146, hl.10,0 m; 10 – typ Petříkovice, vrt MV-28, hl. 12,5 m; 11 – aplitická žula, Křižanovice, vrt VKN-10a, hl. 31,6 m; 12 – žilný bazalt, Křižanovice, vrt MV-2, hl. 17,6 m; 13 – kersantit, Křižanovice, vrt VKN-30, hl. 96,0m; 14 – spessartit, Křižanovice, opuštěný lom u hráze přehrady. Plášť plutonu: 15 – kutnohorské krystalinikum, rula, Barovice, vrt MV-162, hl. 12,0 m; 16 – podhořanské krystalinikum, rula, Podhořany, výchoz; 17 – vítanovská skupina, dacit, Křížová, vrt VK-2, hl. 46,7 m; 18 – metabazalt, Křížová, vrt VK-7, hl. 159,0 m. Lukavické pásmo: 19 – metaryodacit, Zabitý kopec, výchoz, 20 – metabazalt, Sychrov, výchoz; 21 – amfibolické gabro křižanovické duktilní zóny, Švihov, výchoz. Laboratoř: Silikátová anal. č. 5 – GÚ ČSAV, ostatní anal. ÚNS, Kutná Hora, anal. RFA a INAA Geoindustria, Praha.

2. Obsah stopových prvků v horninách železnohorského plutonu a jeho pláště (metoda RFA, obsah prvků v ppm, legenda viz tab. 1).

3. Obsah vzácných zemina stopových prvků v horninách železnohorského plutonu a jeho pláště (metoda INAA, obsah prvků v ppm, legenda viz tab. 1).

Vysvětlivky k obrázkům

1. Přehledná geologická mapa železnohorského plutonu s vyznačením hlavních rudních ložisek (upraveno podle map in Špaček et al. 1991). Platformní pokryv: 1 - křída labské oblasti a prolomu Dlouhé meze; 2 – kraskovský permokarbon. Středočeská oblast: 3 – kambrium, ordovik, silur chrudimského paleozoika; 4 – silur až ordovik hlinské zóny; 5 – xenolity kontaktních rohovců v granodioritu typu Skuteč; 6 – metavulkanity ordovického stáří v lukavickém pásmu; 7 – svrchněproterozoické vulkanosedimentární souvrství hlinské zóny. Kutnohorsko-svratecká oblast, krystalinikum: 8 - podhořanské, 9 - kutnohorské; 10 – svratecké; 11 – periplutonicky migmatitizované a granitizované ekvivalenty prevariského krystalinika v plášti železnohorského plutonu. Magmatické komplexy prevariského stáří: 12 – xenolity bazitů a metabazitů v tělese tonalitu typu Křižanovice a ultrabazika ranského masivu. Variský magmatismus železnohorského plutonu: 13 – žíly bazaltu; 14 – subvulkanity ryolitového až dacitového složení v pásmu lukavickém a benáteckém; 15 – žula typu Křižanovice a Žumberk; 16 – kataklastická žula typu Hlinsko; 17 – granodiorit až křemenný diorit typ Skuteč; 18 – tonalit až křemenný diorit typ Křižanovice. Postmagmatické proměny: 19 – zóny hornin přepracované dynamicky a metasomaticky. Strukturní prvky: 20 – poruchová pásma provázená drcením a hydrotermální alterací; 21 – kliváž v dynamicky a metasomaticky porušených horninách; 22 – vrstevnatost v sedimentech a břidličnatost v metamorfitech; 23 – primární foliace ve vulkanitech lukavického pásma; 24 – plošně a lineárně paralelní stavba v tonalitu typu Křižanovice; 25 – osy B antiformních a synformních megavrás; 26 – zlomy; 27 – přesmyky; 28 – kontakty stratigrafické a intruzivní; 29 – petrografické přechody; 30 – diskordance; 31 – sulfidická rudní ložiska; 32 – geologický řez. Diagram: Tl: Póly plošně paralelní stavby v tonalitu typu Křižanovice. Vyznačeno max. protažení xenolitů – osy X a hlavní roviny duktilního toku D1 a D2. Měř. 20, % 25, 10, 5. T2: Póly plošně paralelní stavby v granodioritu typu Skuteč a foliace v reliktech amfibolitů a rul. Vyznačeny konstruktivní osy π plikativních deformací a hlavní systémy foliaci Bl a B2. Měř. 30, 17, 10, 3. T3: Kontaktní plochy žil a menších masívů žuly typu Křižanovice. Vyznačeny hlavní systémy Kl, K2 a žíly bazaltu β, lamprofyru φ. Měř. 20, % 15, 10, 5. T4: Póly kliváže – foliace F_3 v křižanovickém dislokačním a rudním pásmu. Promítnuty: lineace roztažení L_3, osy budin X v režimu extenzním ER a translačním TR, průměrný směr a sklon baryt-sfaleritového ložiska Křižanovice D, jeho morfologická osa hlav-ní M, vedlejší S; $\sigma1$ $\sigma2$ a $\sigma3$ normálová napětí extenzního tektonického režimu. Měř. 50, % 12, 8, 2.

2. Geologický a geofyzikální řez západní částí železnohorského plutonu (upraveno podle dokumentace in Dědáček et al. 1984, Sedlák et al. 1990 a Špaček et al. 1991, legenda shodná s obr. 1.)

3. Diferenciační trend tonalitů železnohorského plutonu v diagramu podle Köhlera a Raaze (1951), vzorků 37, č. 1, 2 viz tab. 1.

4. Souborný graf magmatických hornin železnohorského plutonu podle De la Roche (1980), vzorků 262, č. 1 až 11 viz tab. 1.
$R1 = -4xSi - 11(Na + K) -2(Fe + Ti)$; $R2 = -6xCa + 2(Mg+Al)$; skupina: A – žuly; B – granodiority, tonality, křemenné diority; C – bazity a metabazity jako xenolity v tonalitu typu Křižanovice.

5. Diferenciační trend žul typu Křižanovice a Žumberk železnohorského plutonu v diagramu podle Köhlera a Raaze (1951), vzorků 88, č. 5 až 11 viz tab. 1.

6. Klasifikace bazických žilných hornin železnohorského plutonu v diagramu podle Le Maitre (1984), vzorků 25, č. 12 viz tab. 1.

7. Model geotektonického vývoje fundamentu severovýchodního okraje moldanubického jádra. a) Kadomský cyklus charakteru oceanického divergentního rozhraní při okraji prekadomské kontinentální desky tvořené nediferencovanou kůrou. b) Kůra konsolidovaná v kadomském cyklu byla reaktivována staro- až mladovariskou orogenezí. V režimu kontinentálního riftu se tvořily staropaleozoické pánve, oživoval vulkanismus a magmatismus. V podmínkách rozpínání kůry ve směru SV-JZ se při variské reaktivaci uplatňovaly hlavně konjugované střihy R a R'. Ve variských granitoidech byly asimilovány relikty prekadomského a kadomského patra. c) Saxonská kerná segmentace fundamentu středočeské, kutnohorsko-svratecké a moldanubické oblasti.
Stratigraficko-litologické jednotky: epocha prekadomská: 1 – moldanubická oblast, PT 1 (?), 1 100 Ma (?); 2 – kutnohorsko-svratecká oblast, svrchní patro, PT 2 (?), 1 100–680 Ma. Epocha kadomská: 3 – středočeská oblast, eokambrium až spodní kambrium, 680–540 Ma. Epocha variská: Středočeská oblast, svrchní kambrium až spodní karbon, 540–280 Ma. 4 – klastické sedimenty; 5 – vulkanogenní série; 6 – granitodní komplexy; 7 – migmatitizované a granitizované prevariské plášťové komplexy. Strukturní značky: 8 – subdukční zóna; 9 – směr pohybu litosférických desek; 10 – transformní zlom; 11 – oceanický hřbet s tholeiitovým magmatismem; 12 – riftový příkop; 13 – vulkanismus, kadomský tholeiitový, variský ryolit-dacitový; 14 – zóny hlubinných zlomů předneoidní epochy: L – labská, J – jihlavská; 15 – hlavní zlomy neoidní epochy; 16 – zóny dislokačních metamorfitů a metasomatitů.