# GRANITES IN TIN FIELDS OF EUROPE AND IN THE HIMALAYAS — a comparative study

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# Abstract

The Krušné hory-Smrčiny and Cornubian batholiths in Hercynian orogenic belt are well known tin provinces. Despite of their distant location (2000 km) and position in different tectonic zones (Saxothuringian zone and Rhynohercynian zone respectively) they show plenty of significant geological similarities. Both batholiths are nearly of the same age, size, shape, dimensions and orientation. They are characterized by steep sides and flat roof. Geophysical measures indicate etmolithic shape of both the intrusions. NW-SE trending wrench faults dislocate the batholiths into various domal plutons. In both batholith volcanic ejecta have been reported. In Cornwall they are beside the batholith while in Krušné hory-Smrčiny batholith they are intruded by the youngest phase of granites. The primary heat production and heat flow is estimated to be similar in both the provinces. The same can be said about the type and style of mineralization (greisen, veins, and stockworks of Sn ± W, ± Mo, ± Cu ores).

As far the granites are concerned, using statistical methods on geochemical data they have been classified into five groups (G1, G2, G3, G4 and G5). G2 to G4 are common types in both batholiths but G1 is absent in Cornubian batholith. Geochemically, the granites within their groups in both batholiths have similar range of variation for alumina balances, alkali ratios, alkali/calcium ratios, amount of dark mineral constituents, normative feldspars, and trace element distributions. They show remarkably similar degrees of differentiation and tectonic settings (syn-collision and/or post-orogenic).

Geochronologically, the emplacement of the granites in both the batholiths is almost simultaneous. At least, two phases of magmatism can be recognized with 10 to 25 Ma interval. The older phase of granites magmatism (330–300 Ma) produced the G1 and G2 granite which are mesocratic, tin barren, poorly differentiated and deeply eroded. The younger phase of magmatism (290 – 270 Ma) produced leucocratic, tin-bearing, metasomatised, strongly differentiated granites (G3, G4, and G5 granites), which are metasomatised and still uncovered at places. $^{87}Sr/^{86}Sr$ ratio varies in a common range corresponding to their crustal origin in both batholiths.

According to geomorphological, petrographycal and geochemical data of the granites in both batholiths, it is estimated that the magma might have formed at 700 – 900 $^{0}C$ & 8 kb P conditions and 600 – 700 $^{0}C$ & 2 – 2.5 kb P condition for their emplacement.

In the second part of the study, geochemical characteristics of the Hercynian tin-bearing leucogranites have been applied to estimate tin prospectivity of Himalayan leucogranites. It has been found that several geological and geochemical features are fully comparable ( *texture, color, mineral constituents, tectonic settings, alumina balance, alkali/calcium ratio, ferro-magnesium ratio, dark mineral constituents, Ba, Rb, Sr*, and others). However, there is contrast mainly in parameters, which are controlled by post-magmatic metasomatism (*alkali ratio, and free quartz)*.

The leucogranites in Himalayas, while holding the similar petrological feature as the leucogranites in Hercynian Europe, have no record on the tin mineralization. It may indicates that tin mineralization generally associates with the leucogranites but the leucogranite may not always hold tin mineralization. It seems that environment of magma generation (crustal thickness) is critical factor for tin prospectivity of a leugranites, rather than petrological and geochemical compatibility. It can be argued that the leucogranites in Himalayas have formed in very thick crust (60 – 70 km), whereas the leucogranite in Hercynian Europe have generated not more than 40 km thick crust. It may reflect that the source of tin and source of granitic magma may not coincide. It seems for fetch to conceive the school of thought, which believe that the tin is brought to the granitic magma from lower crust or upper mantle. This could be possible in the case of Hercynian orogeny where the crust was relatively thin – but in the Himalayan orogeny seems difficult for the leucogranite to assimilate deeply originated tin bearing fluid phase, as they have generated much higher from the level of lower crust or upper mantle. Hypothesis of tin metallogeny based on the thickness of Earth's crust is also supported by the fact that most of the tin fields of the world are located in crustal thin provinces. Alternatively it can be said that the parental rocks of Himalayan leucogranites were tin free or well refined, metal free undistinguished sediments.

The older Hercynian granites in Europe show significant similarities in chemical and petrographical features with the Almora granites in the Lesser Himalayas (*alumina balance, alkali/calcium ratio, ferro-magnesium ratio, dark mineral constituting elements, free quartz, alkali ratio, trace element distribution, initial Sr isotope ratio, REE distribution*). The source composition of Almora granites is more certain as they have brought up by several parallel upthrusts. The petrological and geochemical compatibility of the Almora granites with the Hercynian older granites favor the pelitic composition of source rock for later granite in Europe.

# CONTENTS

## PART I — GRANITES IN HERCYNIAN TIN PROVINCES

## PART II — GRANITES IN THE HIMALAYAS AND THEIR COMPARISON WITH HERCYNIAN GRANITES IN EUROPE

## SUMMARY

# PREFACE

Granite is a common rock type in the upper Palaeozoic Hercynian orogenic belt (Europe) and in the Tertiary orogenic belt of the Himalayas (north of the Indian sub-continent). In both the orogenic belts it has different significance. In Himalayas, it represents different types of tectonic environment and in Hercynian Europe, it stands for metallogenic prospectivity.

This study aims to focus attention on the geochemical comparison of the granites in Hercynian tin provinces with those of the Himalayas. Two granite belts of the Himalayas have been selected for this study, viz. 1– post-collisional, leucogranites of Vaikrita thrust sheet (20–30 Ma), and 2– Anatectic granitoids of Lesser Himalayas (1800 Ma and 550 Ma). Before this comparison, a correlation of the granites of the Krušné hory-Smrčiny Mts. tin province and the Cornubian tin province has done. Finally, the characteristic features of the tin-barren and tin-bearing granites of the Hercynian tin provinces are compared with the Himalayan granites.

A mini data bank has been prepared for the geochemical analyses of granites from SW England, NW Bohemia, and the Himalayas. It contains about 2000 published and unpublished analyses of the granitoids. The data of Himalayan granites are relatively less then for the Hercynian granites in Europe, therefore the results are still on the primary. For the correlation of granites, an empirical proposal for the classification of granites has been developed, using granite standards for particular features such as tectonics, metallogeny, nomenclature etc. making use of computer soft-ware (FoxPro, SC5 and Statgraphics).

The comparison of granites in Hercynian fold belt and the Himalayan fold belt may be of interest to the researchers, who are oriented toward understanding of the crustal evolution on global scale and also to geoscientists who are comparing of style of geological phenomenon in the earth's crust (magmatism, metallogeny and tectonics). The correlation of the Krušné hory-Smrčiny and Cornubian batholiths in the Hercynian fold belt may be useful for the granite petrologists and economic geologists.

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# PART I

# GRANITES IN HERCYNIAN TIN PROVINCES

## 1. Introduction

The Krušné hory-Smrčiny Mountains (Central Europe) and Cornwall (SW England) are well known tin provinces. They lie in the northern 'wing' of the Hercynian fold belt, which is comprised of two lithotectonic zones namely, the Rhenohercynian and Saxothuringian zones (Fig. 1). Cornwall is generally included in the Rhenohercynian zone, and the Krušné hory-Smrčiny Mts. belong to the Saxothuringian zone. Both provinces represent different lithotectonic settings but have similar features in their granites, for example; age of emplacement, metallogeny, and petrography. These have been discussed by many authors.

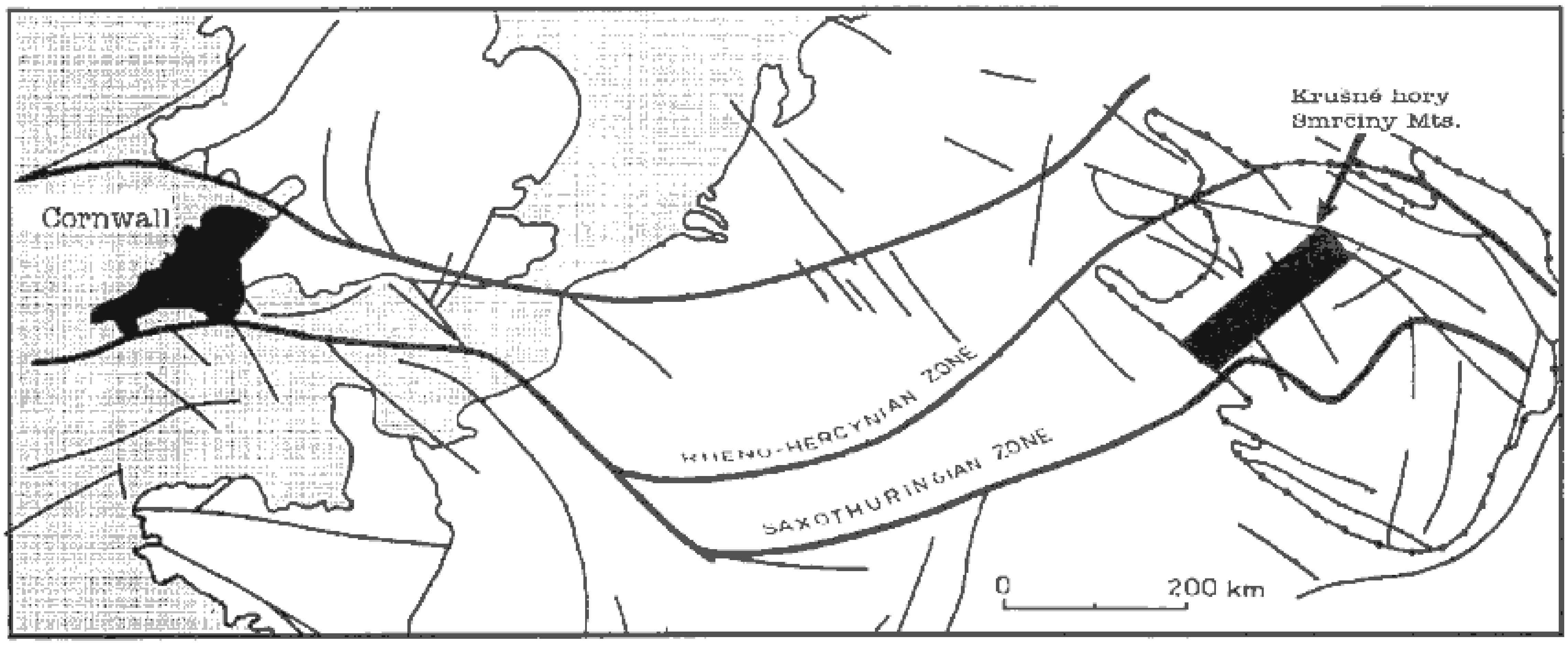

*Fig. 1 Location map of Krušné hory-Smrčiny and Cornubian batholiths in Hercynian fold belt.*

### 1.1 Krušné hory-Smrčiny Mts.

The Krušné hory-Smrčiny Mountains cover an area of about 8000 sq km, located in the northwestern part of the Bohemian Massif. The southeastern part of the mountains occurs in Czech Republic and the northwestern part occurs in Germany (the German Krušné hory Mts. are called as "Erzgebirge" and Smrčiny Mts. as "Fichtelgebirge"). This province is a rectangular-tabular in shape, which is bounded by the "Eger lineament" and the "Central Saxon lineament" in the SE and NW respectively (Fig. 2). It is extended to the NW-SE trending "Elbe lineament" in the northeast and to the "Franconian lineament" in the southwest. The Krušné hory-Smrčiny Mts. are underlied by a large granite batholith (Krušné hory-Smrčiny batholith). The Krušné hory-Smrčiny Mts. can be divided into four fault-based sectors.

**A– Northeastern sector**

This is bounded by Elbe line in the northeast and Flöha zone in the southwest. This sector comprises crystalline and metasedimentary rocks, which are intruded by the Hercynian acid plutonites (Fig. 3). Granite outcrops are generally small elliptical to semicircular in shape, and comprise the Niederbobrizch, Markersbach, Sadisdorf, Schellerhau, Altenberg, Cínovec-Zinnwald, Fláje, Krupka, and Telnice . This part is characterized by the presence of the Teplice caldron (Pälchen, 1968 and Jiranek, 1987), where volcanic ejecta are intruded by related granites.

**B– Central northeastern sector**

This is bounded by the Flöha zone in the northeast and the Jáchymov fault in the SW and comprises mainly crystalline and metasedimentary rocks, which are intruded by granites. The granites are not frequently exposed on the surface, but their presence has been proved by borehole investigations. Many granite cupolas have been verified by drilling and geophysical means (MAWAM map, 1974). The significant cupolas and outcrops are Hora sv. Kateřiny, Ehrenfriedersdorf, Annaberg, Ziegeberg, and Geyer (Fig. 3 and 4).

**C– Central-southwestern sector**

This part is bounded by the Jachymov fault in the northeast and the Mariánské Lázně fault in the southwest. This is intruded by the large "Karlovy Vary pluton". In the SE, the pluton is partly covered by Tertiary sedimentary basins in Sub-Krušné hory fault zone. Many satellite granite bodies are present around the main Karlovy

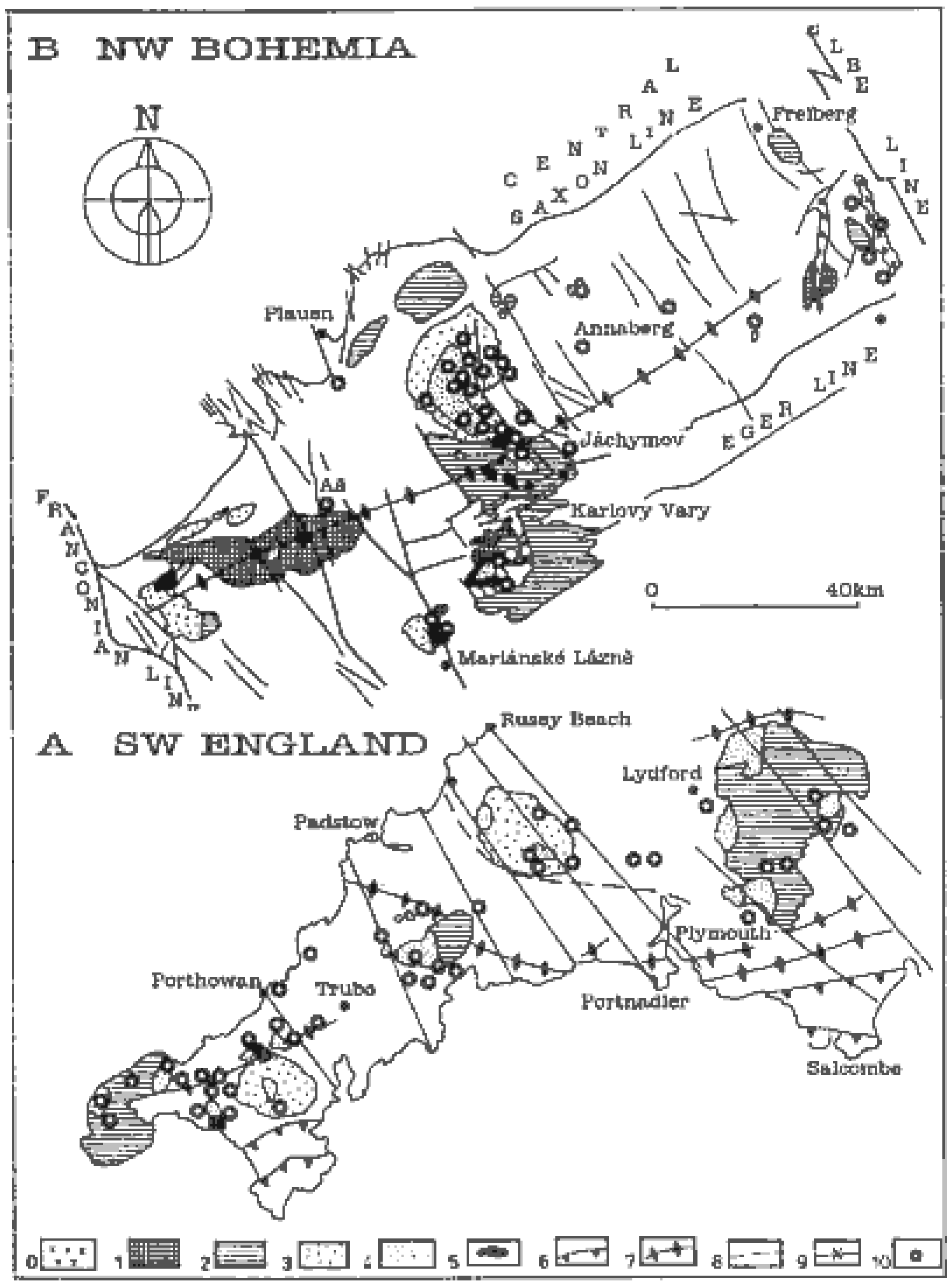

*Fig. 2. Map showing structures and distribution of tin deposits and granites in SW England and NW Bohemia, 0–granite porphyries, 1– G1 granites, 2–G2granites, 3–G3 granites, 4–G4 granites, 5–G5 granites, 6–Thrust plane, 7– Axis of anticline, 8–Line facing confrontation, 9–Axis of major synclines, 10– Tin deposits.*

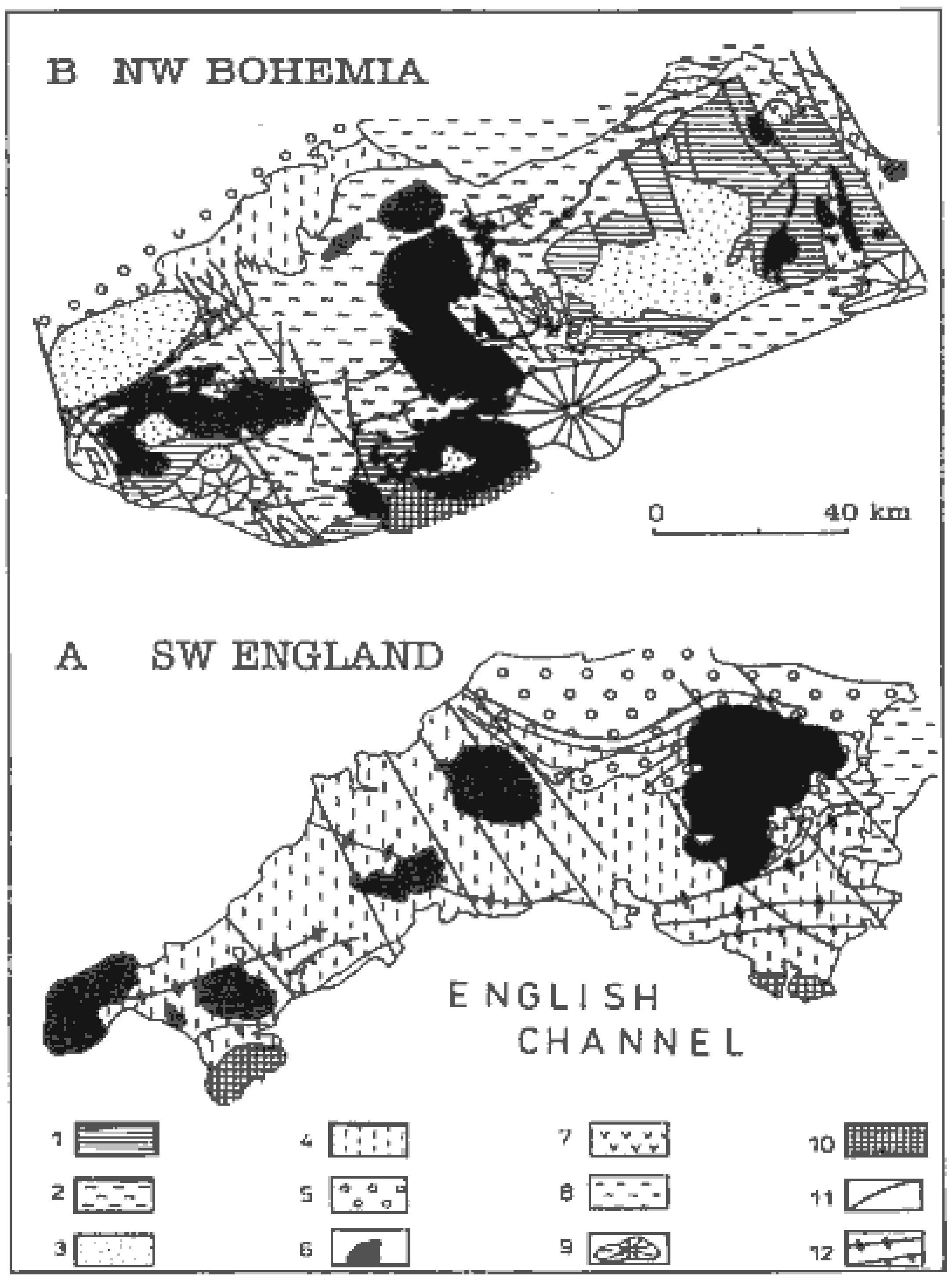

*Fig. 3. Simplified geological map of SW England and NW Bohemia, 1–Proterozoic gneisses, 2–Lower Palaeozoic schists and phyllites , 3–Cambrian–Ordovician orthogneisses, 4–Devonian greywacke and diabase, 5–Lower Carboniferous conglomerates and greywackes, 6–Granite outcrops (Permocarboniferous), 7–Up. Carboniferous–Permian acid volcanics, 8–Sedimentary cover, 9–Tertiary alkaline volcanic centers, 10–Cambrian-Ordovician metabasalts and metabasics, 11–Principal faults, 12–Axis of anticline.*

Vary pluton, e.g. Kirchberg, Bergen, Aue, Schwarzenberg, Blatná, Vykmanov etc. granites. The southern part of the pluton is represented by many small granite bodies e.g. Krudum, Kfely, Kynžvart, Lesný-Lysina (Fig. 4).

### D– Southwestern sector

This part lies between the Mariánské Lázně fault in the northeast and the Franconian lineament in the southwest. A major part of the granite body occur in Germany which is called as Smrčiny pluton. The literature indicate that this part has a different tectonic evolution from that of the Krušné hory Mts. However, the lithology around the main granite pluton is similar to that around the Karlovy Vary pluton. Moreover, the geochemical and petrographical studies indicate a close affinity between the granites of the Smrčiny and Karlovy Vary plutons (see Rajpoot and Klominský, 1992). The Smrčiny pluton is ornamented by two satellite granite bodies, viz. Waldstein and Kornberg (Fig. 4).

### Structures

The majority of the cross-faults trend NW-SE to E-W (see Hösel, 1972). Structurally, Krušné hory-Smrčiny Mts. form a large NE-SW trending anticline, with open warps of about 10 km wavelength. The warps might have developed as a result of emplacement of the Permo-carboniferous granites. Detailed structural and metamorphic study of the Krušné hory-Smrčiny Mts. is lacking. However, four phases of folding (= deformation) have been suggested in the crystalline rocks (Bankwitz and Bankwitz, 1982) and five phases of folding have been observed in the Smrčiny (Stettner, 1979 and Stein, 1986). The intrusion of granitic magma is supposed to have been emplaced during or after the waning stage of deformation. This province is characterized by deep-rooted lineaments, which have been recorded by geophysical studies. The main lineaments are the Central Saxon, Ohře (Eger), Labe (Elbe), and Franconian. The age of their development has not yet been confirmed but certainly they were reactivated during Mesozoic and Tertiary time. Many NW-SE trending parallel faults occur in this province (Fig. 2). The lateral displacement has not been precisely measured but as Fritz (1991) discussed dextral wrenching for their southeastern extension in Austria.

## 1.2 SW England

SW England includes Cornwall and Devon, which encompass

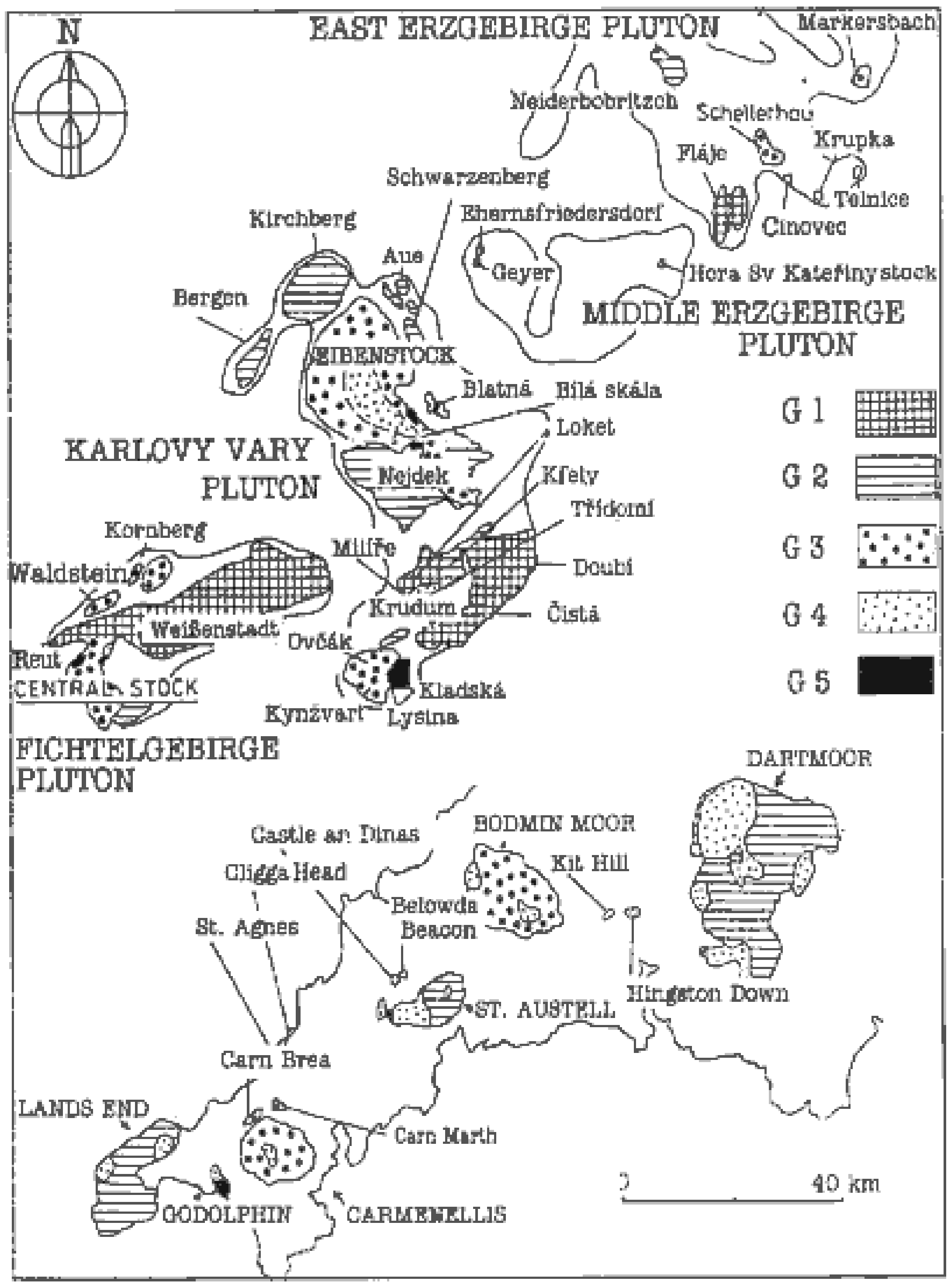

*Fig. 4. Granite distribution in SW England and NW Bohemia*

an area of about 6000 sq km. This is bounded by Atlantic ocean in the west, the Bristol channel in the north, the English channel in the south and by an arbitrary line from the Parrett estuary to Charmouth in the east. Structurally, SW England is characterized by repeated phases of the Hercynian folding, faulting and thrusting. As a whole, SW England forms a huge east-west trending syncline (Fig. 2). The southern limb of the syncline has locally developed parallel trending anticlines. The geotectonic setting of the area in the tectonic framework of Hercynian fold belt is still a matter of controversy. However, the whole of SW England is usually included in the Rhenohercynian zone (except for the Lizard Complex), perhaps because the lithostratigraphy satisfies the definition of the Rhenohercynian zone. However, at the same time the province can be included in the Saxothuringian zone, if magmatism and metallogeny are concidered (see Matthews, 1984 and Rajpoot, 1991).

Cornwall is characterized by two tectonic zones e.g. Caledonian and Armorican (Dearman, 1970, 1971; Simpson, 1969, 1971; Sanderson and Dearman, 1973; and others). According to the widely accepted, the Caledonian zone is roughly truncated along the southern edge of the Devonian Formations (Armorican zone). The Armorican orogeny of Permo-Carboniferous time was characterized by N-S compression, which has produced E-W trending structures (Fig. 2). Dominant folds are attributed to this event. Towards the end of the deformation, granitic magma was thought to have been intruded. As the granites crystallized and pressure relaxed, E-W trending normal faults developed. The north-westward wrench faults across SW England culminated in dexteral displacement of at least 21 miles (Dearman, 1964). The wrench faults are thought to be Tertiary (ibid). Removal of the wrench effect puts the south margin of the Dartmoor and Bodmin Moor plutons on the same lattitude.

## 1.3 Provincial stratigraphy

Stratigraphically, both the provinces have contrasting units. In SW England, the majority of outcrops are Devonian and Lower-Carboniferous, whereas in the Krušné hory-Smrčiny Mts., they are Devonian to Ordovician or older (Table 1). The grade of metamorphism reached up to granulite and eclogite facies in the Krušné hory-Smrčiny Mts., but the age of metamorphism is controversial. The metamorphism in Smrčiny Mts. coincides with the dominant second phase of folding (Excursion Guide, 1985), which is older then 330 m.y. In the Armorican zone of SW England, the absence of Hercynian high grade metamorphites and presence of marine sediments are in contrast with Krušné hory-Smrčiny Mts. However, a small locality of Ordovician-Silurian (?) rocks (Veryan series) does occur in the Caledonian zone (in the Lizard area) (Fig. 3).

### Volcanites

The volcanic associations in the Krušné hory-Smrčiny Mts. include acid to alkaline rocks, ranging in age from Devonian to Tertiary. In SW England, the two main groups of post-orogenic volcanic rocks are; -first, rhyolitic and rhyodacite lavas of possible Permian age that rest on deformed Devonian strata in the vicinity of Plymouth and -second, basaltic lavas and intrusives within the basal Permian (north and west of Exter, Exley and Stone , 1982).

### Lamprophyres

The lamprophyres can be seen in both provinces. In general, they are fault controlled and widely distributed (Krammer, 1976). It is generally agreed that lamprophyre emplacement is a separate event from granite emplacement. In the Krušné hory Mts., the lamprophyres are younger than the older granites (OIC) (Tischendorf, 1989) and in SW England, K-Ar dates give an age of 279 ± 6 Ma (Miller and Mohr, 1964). Petrographical and geochemical features of the lamprophyres of the Krušné hory-Smrčiny Mts. are like those of the lamprophyres in SW England. The age of their intrusion has not yet been precisely determined. However the formation of lamprophyres in both provinces seems to be simultaneous as they cross cut the Carboniferous rocks. Genetically, the lamprophyres could be related to mantle metasomatism (Dziedzic, 1986 and Krammer, 1988).

### Granite porphyries

These are common rock type in both provinces. In SW England, (locally called as elvan) they occur in the form of dykes of varing dimensions. The width varies from 1-2 m, exceptionally up to 15 m and the length ranges up to 15 Km. In the Krušné hory Mts., dykes of granite porphyry are widely scattered and in the eastern-central or north-eastern part, a large dyke crosscutting the Flaje granite is well known; they are wide upto 2 km and 30 km long (Fig. 2). In SW England they are younger than all the granites (269 ± 8 Ma, Hawkes et al., 1975), but in the Krušné hory Mts., they are older than the youngest phase of granites, as younger granites intrude the granite porphyries.

### Mineralization

Both these provinces are well known for tin-tungsten mineralization associated with the granites. Several types of ore mineral association are common in both the provinces, e.g. cassiterite-quartz, cassiterite-silicate, cassiterite-sulphides, cassiterite-silicate - sulphides. Many common modes of occurrence of tin and other ore minerals can be seen; examples include veins, veinlets, stockworks, pegmatites, greisens, breccias, and skarns. Beyond these similarities in the mineral deposits, the most remarkable contrast is in the physical relation between the majority of deposits and the granite bodies. In SW England, significant tin-tungsten deposits lie in the contact or exocontact zone of the granites, whereas in the NW Bohemia they are mainly confined to the endocontact zone of the granite bodies (Fig. 2).

*Table .1. A summary of stratigraphy in SW England and Krušné hory-Smrčiny Mts. (compiled from literature)*

| Age | Krušné hory-Smrčiny Mts. | SW England |
|---|---|---|
| Quarternary | Peat, alluvials | Beach sand, peat, alluvial |
| Mesozoic | Terrestrial sediments | Nodular chalk, l.st., grits, |
| Permian | Mainly acid volcanites | Red marl, breccia,, conglom., clay & basic, acid intrusive |
| Up. Carbon. | Conglomerates, psammites, shales | Bude sandstone, culm facies rocks |
|  | **Granites** | **Granites** |
| L. Carbon. |  | Mudstones with shales |
| Devonian | Volcano-sedimentary units, diabase | Shales, mudstone, s.st.l.st. conglomerates and calcareous rocks |
| Ordovician - Silurian | Quartzite, phyllite, graphite schist | Exotic blocks of quartzite, and l.st. in Devonian rocks |
| Cambrian | Quartzite, metacarb. rocks, graphite & mica, schists, fine grained, paragneisses, metagrew. & metabasites, Orthogneisses. | ? |
| Proterozoic | Lower monotonous group, paragneisses, quartzite, metabasites | ? |

l.st. – limestone

## 1.4 Morphology of the batholiths

### Relief

The maximum relief within the exposed granites in the Krušné hory Mts. is 1008 msl (in Nejdek-Eibenstock). In the Smrčiny Mts. (Smrčiny Mts.), it is 1024 msl. (in Central stock) and in the Cornubian batholith it is 470 msl. The greatest continuous vertical exposure is about 600 m in the Krušné hory Mts., 550 m in the Smrčiny Mts. Mts. and about 250 m in the SW England.

### Area and Volume

The total volume of granite to a depth of 6 km is estimated at about 120,000 km$^3$ for the Krušné hory-Smrčiny batholith and 68,000 km$^3$ (report, Camborne school of mines) or 41,000 km$^3$ (Willis-Richards and Jackson, 1989) for the Cornubian batholith. The total area of exposed granites in the Krušné hory-Smrčiny Mts. is about 1883 km$^2$ and in SW England about 500 km$^2$.

### Depth of the batholiths

Various authors have discussed the thickness of the granite plutons by interpreting the seismic and gravity measurements. In SW England, Brooks et al. (1984) and Doody (1985) have suggested three seismic reflectors at depths of 7-8 km (R1), 10-15 km (R2), and 27-30 km(R3). R1 is restricted to the interior of each of the major plutons, R2 is commonly defined as a mid-crustal reflector, which probably rises eastwards from Land's End to Dartmoor, and R3 is uniform throughout SW England. The average seismic velocity of the granites above the R1 reflector is about 6.0 km/sec, which decreases suddenly to about 5.6 km/sec, and increases again below R2 to about 6.5 km/sec. R2 is generally considered to correspond with the base of Cornubian batholith.

Recently, CEE project (University of München, Germany CREGU Nancy, France, and British Geological Survey, England) determined a 3D shape of the Smrčiny Mts. pluton using an iterative technique, which incorporates lateral facies changes (Guillet et al., 1985; Guinebertea et al. , 1987; Vignerese , 1988 and Audrain et al., 1989) the results are shown on a map indicating the depth contours ( Vigneresse op.cit.). According to this map the Smrčiny Mts. pluton reaches a depth of 8 km in the Central stock.

### Shape of the batholiths

Both the batholiths have distinct negative gravity anomalies. The -50 mgal gravity contour almost covers the present outcrops of the granites (Fig. 5).

Some authors have suggested an inverted 'L' shape of the Cornubian batholith (Brammall, 1926, and Edmonds et al., 1975), although others define other shapes. Tombs (1977) suggested that the Cornubian batholith is thinned from 20 km beneath Dartmoor to 10 km near Land's End. Tombs's suggestion does not fit with the heat flow pattern in SW England, proposed by Sams and Thomas-Betts (1986). From a N-S gravity profile across Bodmin Moor, Bott and Scott (1964) argued that the Bodmin Moor pluton has steeper sides and a nearly flat roof. A NW-SE trending fault along the northern margin of Bodmin Moor is described by Dearman (1964) suggests that the northern side of the Bodmin Moor pluton is steeper. It is difficult to estimate the shape of the batholiths, with a high level of confidence. However, the argument by Willis-Richards and Jackson (1989) and others for a steep-sided Cornubian batholith seems more logical. The shape of the basal part of the batholith is not clear. The Krušné hory-Smrčiny batholiths have generally been interpreted as wedge-shape, thinning towards the NW (Polanský, 1973). Recent geophysical investigations in the Smrčiny Mts. have been interpreted in new way which indicates that the Smrčiny Mts. pluton has a cone shape (Vigneresse et al., 1989).

Subsurface continuity between the plutons of SW England has been established by geophysical investigations. In Krušné hory-Smrčiny Mts., the subsurface continuity is proved by drilling as well as by gravity measurements. Both batholiths are characterised by dominant NW-SE trending post-emplacement faults. The movement along these faults is more lateral in SW England and relatively more vertical in the Krušné hory Mts.

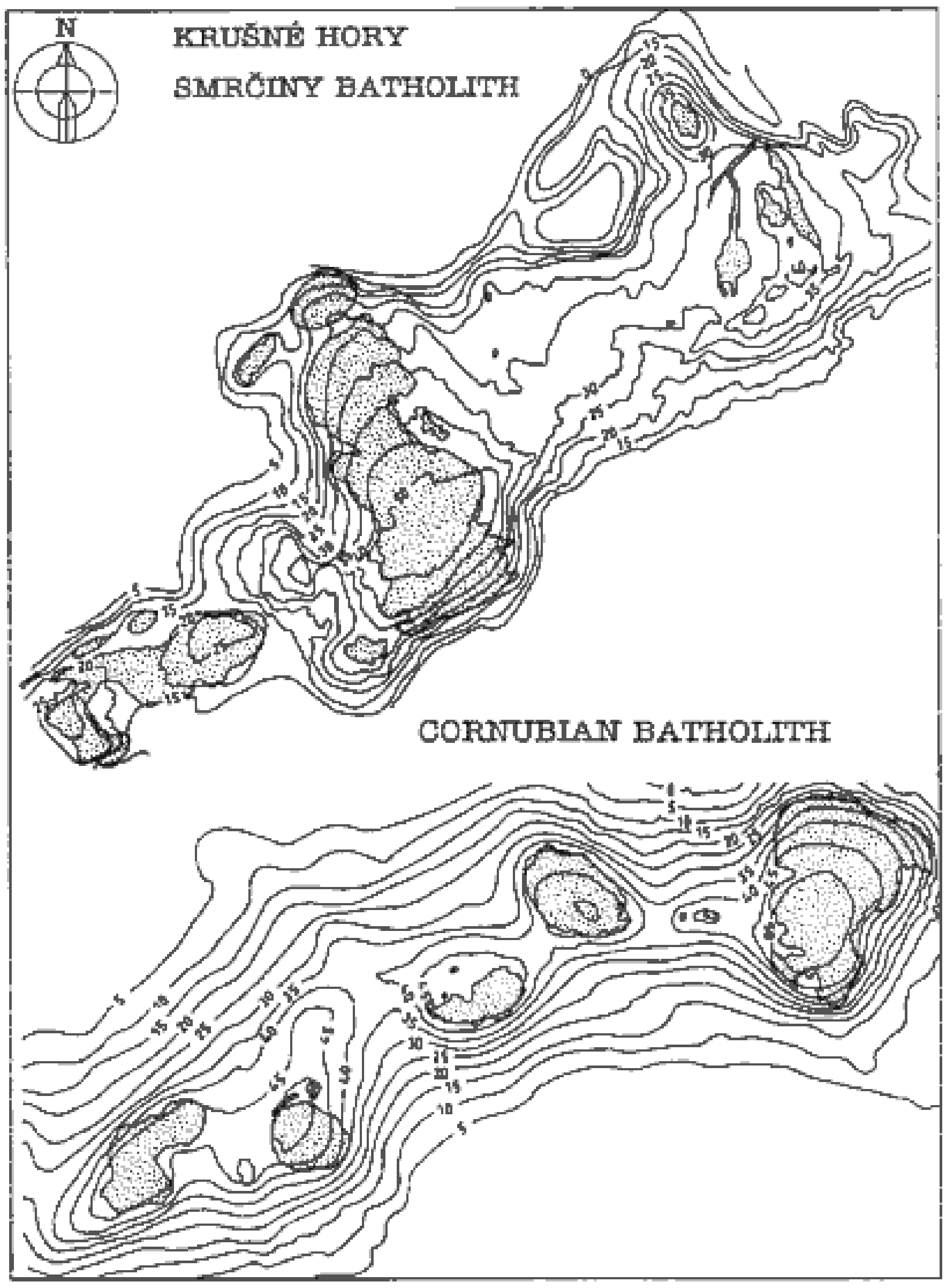

*Fig. 5. Bouger anomaly map of SW England (after Camborne school of mines) and NW Bohemia (compiled after Czech Geological Survey and Vigneresse p.c.)*

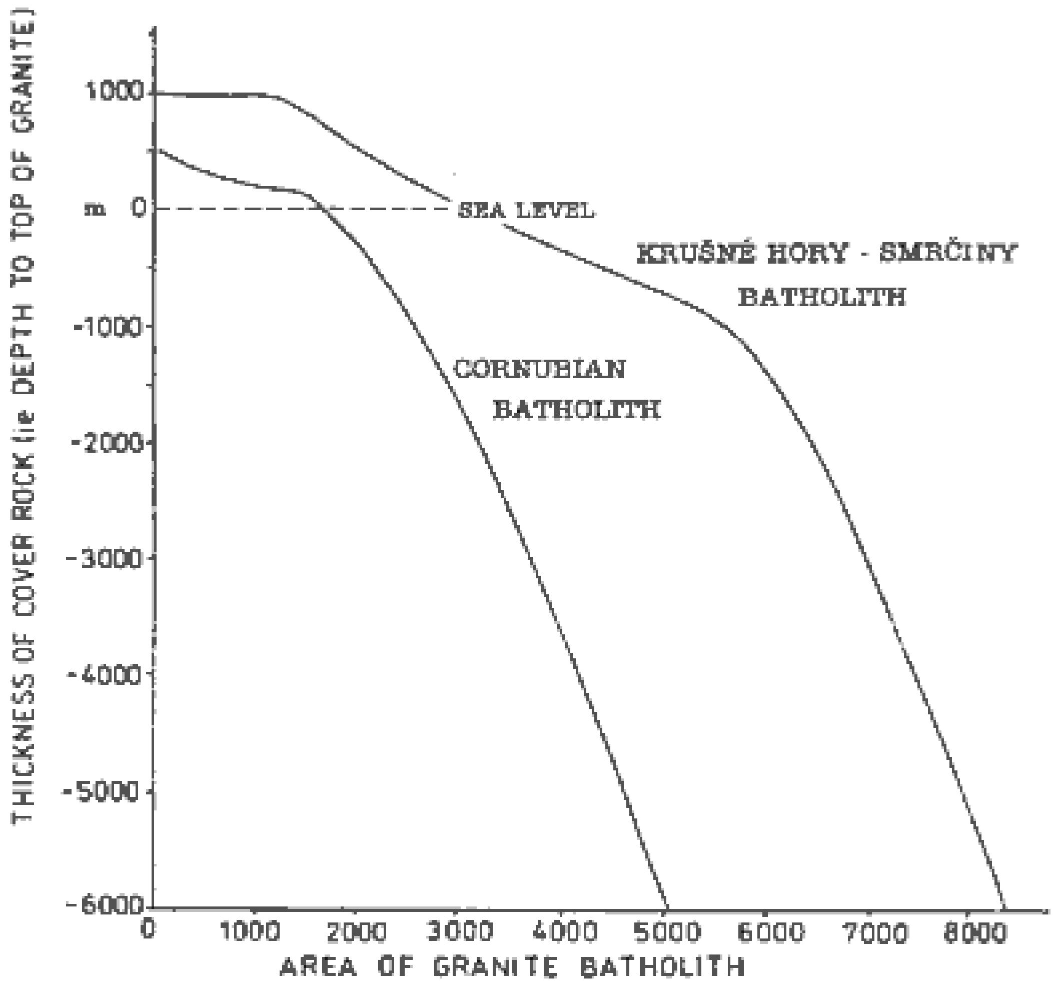

*Fig. 7. Area of batholith at different depth.*

From the various profiles across the Cornubian and Krušné hory-Smrčiny batholiths, it can be seen that the former is narrower than the latter. The Cornubian batholith forms a continunous line ridge dislocated by post emplacement NW-SE fault movements between the Dartmoor and Bodmin Moor plutons (Dearman, 1964). The Krušné hory-Smrčiny batholith also looks like a NE-SW trending ridge (Fig. 6), but in its central part (Karlovy Vary pluton) it appears to show a NW-SE axis perhaps due to local post-emplacement tectonism. The various plutons in the Cornubian batholith have been interpreted as having a flat roof (Exley and Stone, 1982 and Willis Richard and Jackson, 1989). A similar features (flat roof) can be seen in the Karlovy Vary pluton (Ne-

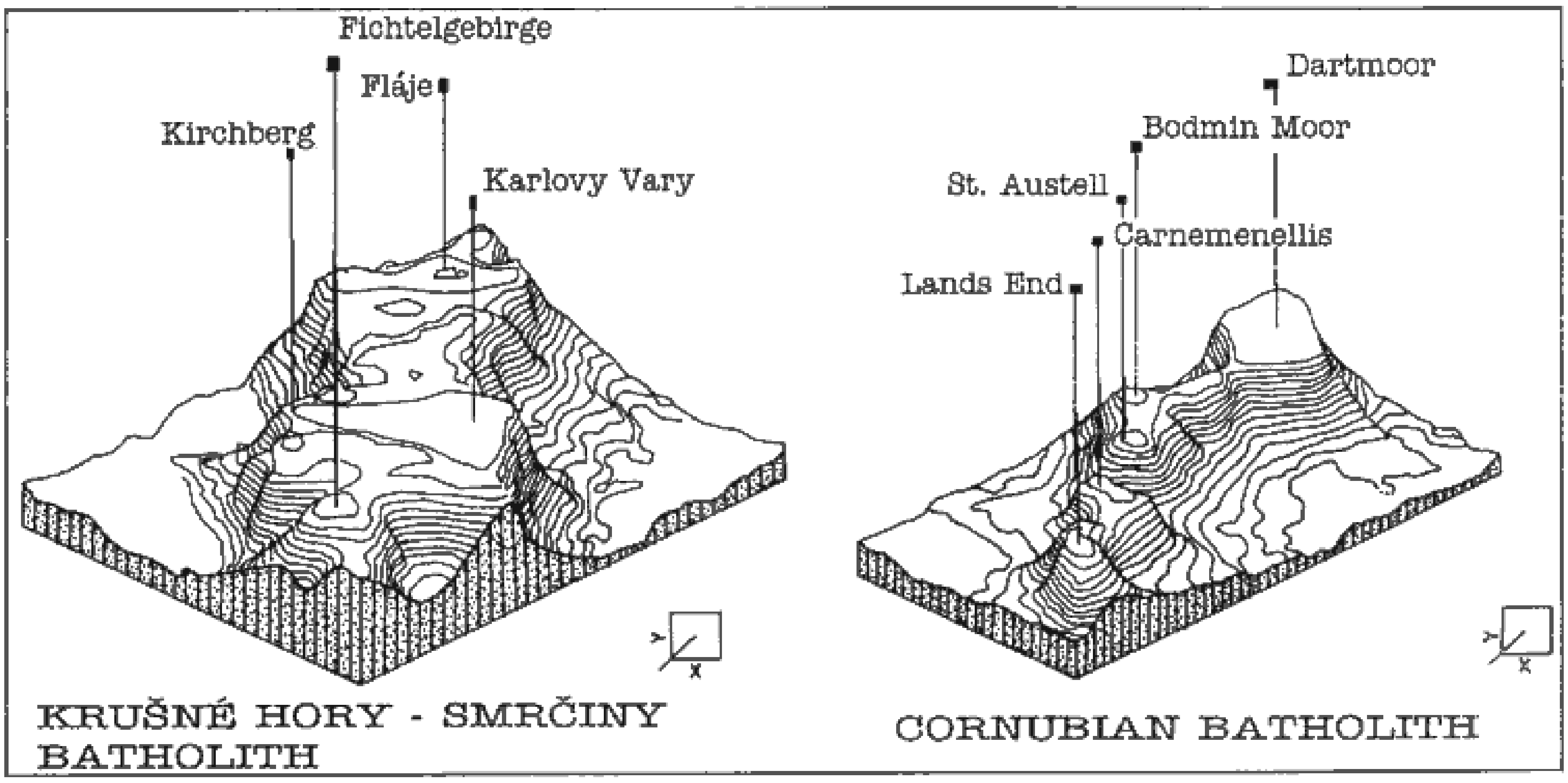

*Fig. 6. Isometric diagram of the space form of Cornubian and Krušné hory-Smrčiny batholiths*

jdek-Eibenstock part), where the present ground surface nearly follows the roof of the pluton.

The area of the batholith at different depths has been estimated in order to have an idea of the batholith in a vertical section (Fig. 7). It can be seen in the Fig. 7 that cupolas and elevations in the Cornubian batholith are better preserved than in the Krušné hory-Smrčiny batholith. This reflects the higher density of granite related-pegmatites and veins in the Cornubian batholith comparing with the same units in the Krušné hory-Smrčiny batholith.

## 1.5 Heat flow and heat production in NW Bohemia and SW England

Both provinces are characterised by high heat flow and heat production. In SW England, the Imperial College heat flow group and Francis (1981) have carried out many heat flow and heat production measurement, and in the Krušné hory-Smrčiny Mts., the Czech Geological Survey and Čermák (1984) have also made some heat flow investigations. These data and calculated data for heat flow and heat production are compiled in Fig. 8.

The following formulas are used for the calculation of heat flow (Q) and heat production (A)

$$Q = 26.6(+3.5)\mu W/m^2 + [15.6(+0.6)\ km \times A]$$

*(after Jolivet et al., 1989)*

$$A = 0.081(K_2O) + 0.261(U) + 0.072(Th)$$

*(Brich, 1954; Vigneresse et al., 1989)*

### Krušné hory-Smrčiny Mts.

The measured highest surface heat flow reaches up to 80 $\mu W/m^2$ (Čermák, 1984) and heat production reaches 3.6 $\mu W/m^3$ (Archive ČGU) in the Karlovy Vary pluton. Using the calculation methods above, the highest heat production reaches 6 $\mu W/m^3$ and heat flow reaches 120 $\mu W/m^2$ in the zinngranite (Smrčiny Mts. pluton), Eibenstock, and in Cínovec. In these granites, the average heat flow is calculated as 90 $mW/m^2$ and heat production 3.5 $mW/m^3$. The younger granites appear to have higher heat production and heat flow than the older granites.

### SW England

The heat flow values in the granites of SW England average about 120 $\mu W/m^2$, with the highest values just over 130 $\mu W/m^2$ in Land's End area. Heat flow decreases rapidly away from the granites into the slates and phyllites. The best estimate of the surface heat productivity of the SW England is an average somewhat in excess of 4.4 $\mu W/m^3$ that does not vary rapidly with depth. If it is assumed, as a working figure, that the average granite heat productivity is 5.0 $\mu W/m^3$, the country rock heat productivity 2.0 $\mu W/m^2$ and the granite thickness 14 km, then a heat flow anomaly of 42 $\mu W/m^2$ would be observed between the granites and country rocks. The possible cause for the contrast in the present heat flow and heat production is discussed later.

### Comtemporary fluid flow

In both provinces, hot ground water discharge can be seen. In SW England, the hot groundwater is saline and generally reported in tin mines in the N-NW flank of the Carnmenellis pluton (HDR, Geothermal Energy program, Burgess et al., 1982, Edmonds et al., 1984, 1986, 1988) at a depth of 256 to 820 m in deep mines (Camborne-Redruth area) and 150-400 m in the Wheal Jane Mine. In the Krušné hory Mts., hot water springs have been used in foothill zone (Karlovy Vary area) for several centuries. The maximum temperature of hot water in SW England measures upto 55$^0$C in the Wheal Jane mine and in the Krušné hory Mts. 71.4$^0$C at Vřídlo thermal spring (Karlovy Vary).

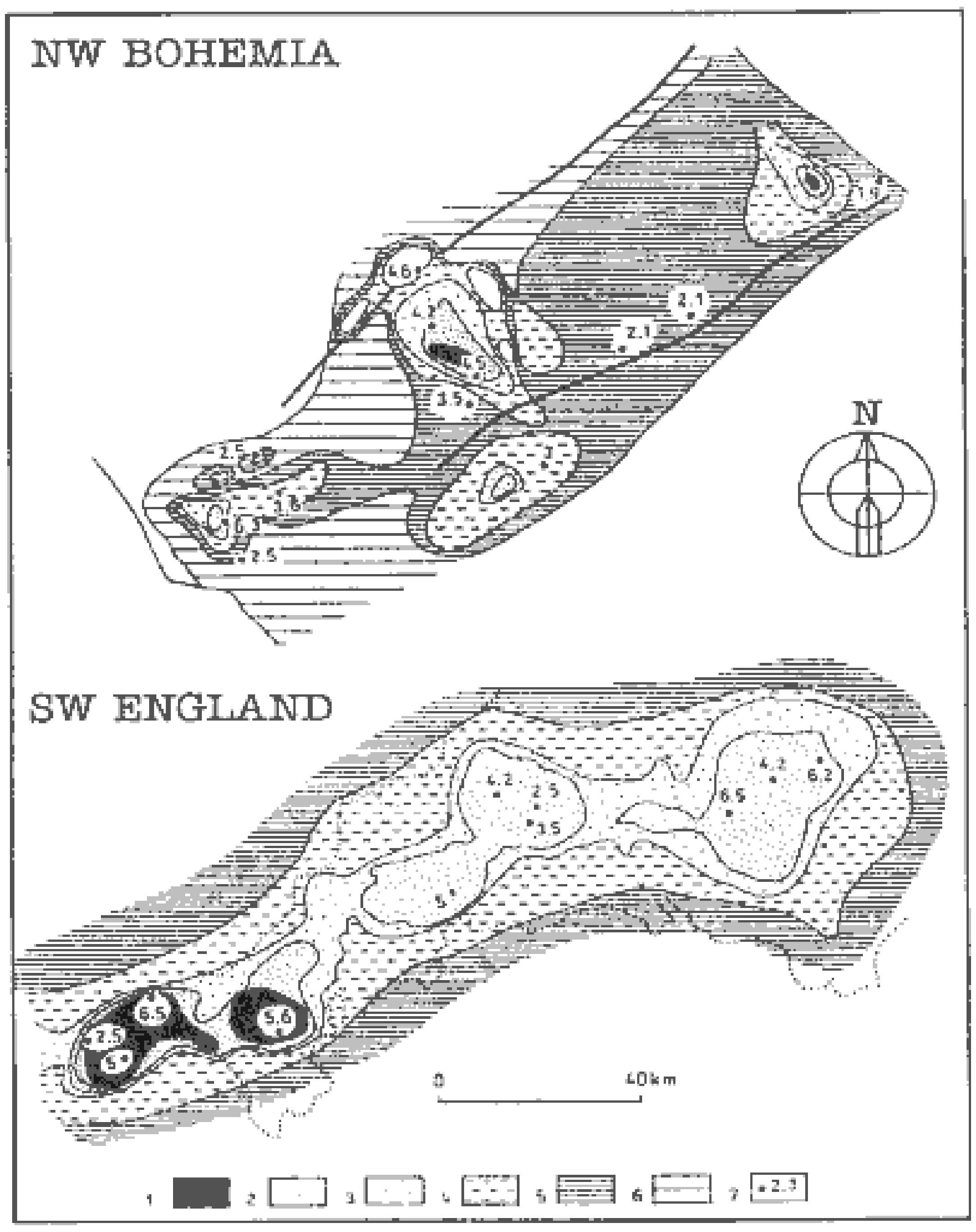

*Fig. 8. Heat flow (1-6) and heat production (7) in the SW England and NW Bohemia.*
*1 – 120 $\mu W/m^2$, 2 – 100-120 $\mu W/m^2$, 3 – 90-100 $\mu W/m^2$, 4 – 80-100 $\mu W/\mu^2$, 5 – 70-80 $\mu W/m^2$, 6 – 70 $\mu W/m^2$, 7 – i n $\mu W/m^3$*

## 1.6 Granite batholiths

Various isolated elongated or circular outcrops of granite are present in both provinces. Geophysical investigations and drilling data indicate that the exposed Hercynian granites in both provinces are linked at depth, so that the granite bodies as a whole can be called "batholiths". In the literature, some of the terms used for granite bodies are misleading, for example a small outcrop of granite within the older granites of Slavkovský Les Mountains is called the "Krudum massif". In present article, such terms are given below with the considered meaning.

*Massif:* A province having limited areal extent, considerable topographic relief and composed of crystalline gneisses and schists, (for example; Bohemian Massif),

*Batholith:* A large intrusive mass of acid igneous rocks (granitoid) situated in an orogenic belt characterized by sharp contact with country rock and elongated along the length of orogenic fold belt. (for example; Krušné hory-Smrčiny batholith)

*Pluton* : As in the sense of H.H.Read, e.g. a high level, cylindrical mass of granitic rock, which was emplaced at low temperature in a near solid state (for example; Dartmoor or Karlovy Vary pluton).

A comprehensive introduction to the significant granitic plutons and bosses in the batholiths is given in Table 2. The distribution of the granites shown in Fig. 4.

### Krušné hory-Smrčiny batholith

The batholith has been studied by several schools of workers (field has been limited to the political territory); the main references dealing with the granites on a regional scale are Hösel (1972), Lange et al. (1972), Richter and Stettner (1979), Štemprok (1986), Tischendorf (1989). The whole batholith can be divided into three parts viz. northeastern part, central part, and southwestern part. The largest granite outcrop is located in the central part of the batholith, i.e. the Karlovy Vary pluton, which lies across the border between the Czech Republic and Germany, together with the satellite bodies of Kirchberg, Bergen, Blatná etc. In the southeastern part of the Karlovy Vary pluton, isolated patches of contrasting younger granites can be seen, e.g. Krůdum and Kynžvart. In the northeastern part, the outcrops of granite are relatively small, the main ones are Niederbobrisch, Markersbach, Sadisdorf, Schelerhau, Altenberg, Cínovec-Zinnwald, Fláje, Preiselberg, and Telnice. In the southwestern part, a large hook shape outcrop of granites (Smrčiny Mts.) is exposed with two satellite bodies (Waldstein, Kornberg) (Fig. 4).

### Cornubian Batholith

The Cornubian batholith has been studied by many workers and relatively more information is available for the whole batholith. The following references review the granites of this batholith: Beer (1978), Hawkes and Dangerfield (1978), Dangerfield and Hawkes (1981), Stone and Exley (1982), Darbyshire and Shepherd (1985).

Principal granite outcrops are Dartmoor, Bodmin Moor, St. Austell, Carnmenellis, Tregonning-Godolphin, Land's End, and the Isles of Scilly. Small bosses occur around or between the larger bodies. They are Kit Hill and Hingston Down between Dartmoor and Bodmin Moor, Castle-an-Dinas and Belowda Beacon, north of Hensbarrow (St. Austell), and Carn Brea and Carn Marth north of Carnmenellis. Small isolated exposures of the Isles of Scilly are located 30 km southwest of Land's End. The underwater granite body of "Haig Fras" is located about 90 km WNW of the Scilly Isles. It is not yet certain whether it belongs to the Cornubian batholith or not.

## Table 2 : Summary on the Hercynian granite bodies in SW England and NW Bohemia

Cornubian batholith

| Pluton | Rock Types | | Area $km^2$ Aprox. | Country rocks | Metallogenic and distinct features | Main references | Age Ma. method. sources | Average chemical composition N = Number of samples; The values shown in brackets are coefficient of variation. Data are taken from the given references. |
|---|---|---|---|---|---|---|---|---|
| | Proposed Groups | Pre-existing Typology | | | | | | |
| DART MOOR | Group 3<br>Group 4 | Type B<br>(E.&S. 1982) | 244 | Mid. to Up. Devonian slates and volcanics in south and Low. to Mid. Carboniferous. slates volcanics turbidites and alkali basalts in north | Kaolinisation in SW area. Tungsten mineralization at Hemerdon and economic Sn-W mineralization in Tamar valley. G2 contains xenoliths. | Hawkes (1978);<br>Dangerfield (1981);<br>Brammall & Harwood (1932); Edmond et al (1968) | 280±1<br>Rb/Sr<br>D.& S.<br>(1985) | N= 27, $SiO_2$ *71.88* (3.06); $TiO_2$ *0.34* (58.37); CaO *1.21* (46.36); $Al_2O_3$ *14.2* (7.10); $Na_2O$ *3.19* (28.4); MgO *0.59* (74.54); $Fe_2O_3$ *0.45* (49.73); $K_2O$ *4.96* (24.17); FeO *1.78* (60.74); $P_2O_5$ *0.25* (45.29); MnO *0.08* (101.05) |
| BODMIN MOOR | Group 3<br>Group 4 | Type B (90%)<br>Type C (10%)<br>E.&S. (1982) | 78 | | Granodiorite inclusions are common. Some elvan quarry are important economically. | Edmondson (1972);<br>Ghosh (1927) | 287±2<br>Rb/Sr<br>D.&S.<br>(1985) | N= 16, $SiO_2$ *72.45* (1.80); MgO *0.36* (49.08); $TiO_2$ *0.22* (50.67); CaO *0.80* (38.45) $Al_2O_3$ *15.0* (3.53); $Na_2O$ *3.0* (57.04); $Fe_2O_3$ *0.52* (88.60); $K_2O$ *5.51* (14.28); FeO *1.02* (35.74); $P_2O_5$ *0.25* (31.42); MnO *0.10* (91.12); $Li_2O$ *0.03* (64.55) |
| St. AUSTELL | Group 2<br>Group 4<br>Group 5 | Type B (35%)<br>Type D (45%)<br>Type E (15%)<br>Type F (5%) | 32 | | Kaolinization of commercial importance in the center of pluton. Sn mineralization significantly rich. | | | N=22, $SiO_2$ *72.30* (3.53); $TiO_2$ *0.16* (76.07); $Al_2O_3$ *15.03* (8.3); $Fe_2O_3$ *1.9* (186.0); FeO *0.59* (101.3); MnO *0.02* (118.5); MgO *0.27* (105.9); CaO *0.98* (68.51); $Li_2O$ *0.06* (172.3) $Na_2O$ *3.14* (33.5); $K_2O$ *5.32* (46.5); $P_2O_5$ *0.18* (94.67) |
| CARNMENELLIS | Group 3<br>Group 4 | Type B (95%)<br>E.&S. (1982) | 50. | | Rich in economic minerals. Loads are distinct in northern exocontact | Al Turki (1972);<br>Ghosh (1934); Al Turki & Stone (1978) | 290±2<br>D.&S.<br>(1985), | |
| TREGONNING and GODOLPHINE | Group 4<br>Group 5 | Type C, 35%<br>Type E, 65%<br>E. & S. 1982 | 5 | | Tregonning granites are Li mica and Godolphin are two mica granites. | Stone (1975); Taylor and Wilson (1975) | | |
| LANDS END | Group 2<br>Group 4 | Type B (85%)<br>Type C (15%)<br>E.&S. (1982) | 73 | | Rich economic mineralization. Mineralization is mainly in north part. | Booth (1966); Booth and Exley (1987);<br>Jackson et al (1982);<br>Halliday (1980) | 268±1<br>D.&S.<br>(1985), | |
| SCILLI ISLES | | Type B, 90%<br>Type C, 10% | | Country rock not visible and granite seen only on Tresco and St. Mary island | Small islands connected to Land's End granite at depth | | | |

*E. & S. = Exley and Stone (1982), D. & S. = Darbyshire and Shepherd (1985)*

| Pluton | Rock Types | | Area km² Aprox. | Country rocks | Metallogenic and distinct features | Main references | Age Ma. method. sources | Average chemical composition N = Number of samples; The values shown in brackets are coefficient of variation. Data are taken from the given references. |
|---|---|---|---|---|---|---|---|---|
| | Proposed Groups | Pre-existing Typology | | | | | | |
| SCHELLERHAU | Group 3 | S1, S2 Seim et al.(1972) YIC 1 Tischendorf (1989) | 17 | Intruded in Teplice rhyolite and crystallines of Krušné hory Mts.. It is being interpreted as pluton in ring complex. Intruded in meta-sediments. | Two phases of granites are distinct. Topaz and fluorite are common minerals. Tin mineralization is significant. | Seim et al. (1982) | | |
| NIEDER-BOBRITZSCH | Group 1<br>Group 2 | OIC NB1 NB2 NB3 | 21 | Intruded in paragneisses and crystalline rocks. | The older granites are characterized by xenoliths of mafic rocks. Texture and colour index devide them in three types. | Gottesmann & Geisler (1988) | | N=4, $SiO_2$ *69.25* (4.51); MnO *0.05* (33.4); $Ti0_2$ *0.43* (32.48); MgO *1.09* (37.7); $Al_2O_3$ *15.01* (7.8); CaO *2.11* (38.88); $Fe_2O_3$ *1.4* (53.48); $Na_2O$ *3.43* (6.90); FeO *1.48* (25.81); $K_2O$ *4.61* (7.33) |
| CÍNOVEC | Group 5 | YIC | ~0.4 | It is a vertical intrusion in qtz. porphyry. Only top part of cupola is exposed. | The exposed granite is Li mica rich. Tin mineralization has been of commercial importance | Štemprok & Šulcek (1969); Gottesman (1962) | 298 K/Ar 290 K/Ar Tischendorf 1989 | N=17, $SiO_2$ *74.88* (2.82); MgO *0.15* (47.38); $TiO_2$ *0.10* (47.76); CaO *0.49* (47.12) $Al_2O_3$ *12.87* (9.6); $Na_2O$ *3.2* (43.14); $Fe_2O_3$ *0.61* (78.45); $K_2O$ *4.87* (13.54); FeO *0.81* (79.99); $P_2O_5$ *0.03* (45.12); MnO *0.09* (149.3); $Li_2O$ *0.20* (135.3) |
| KRUPKA - PREISELBERG | Group 5 | YIC | ~0.5 | A small cupola intruded in qtz. porphyry and granites | It is similar to Cinovec granites. comparises of Li mica granite and posses Sn-W mineralization. | Janečka & Štemprok (1969); Fiala & Pácal (1965) | | N=18, $SiO_2$ *73.65* (3.76); MgO *0.32* (119.9); $TiO_2$ *0.15* (103.38); CaO *0.69* (65.44); $Al_2O_3$ *13.8* (10.8); $Na_2O$ *3.18* (22.0); $Fe_2O_3$ *0.62* (71.40) $K_2O$ *4.26* (21.85); FeO *1.26* (73.13); $P_2O_5$ *0.12* (77.98); MnO *0.04* (55.33); $Li_2O$ *0.13* (91.84) |
| TELNICE | Group 1 | OIC | ~1 | It is a dome like intrusion in migmatites and paragneisses | Two types of granites are common. The pluton is characterised by pyrite and molybdnite mineralization | Chrt & Klomínský (1964) | | |
| FLÁJE | Group 1<br>Group 2 | Gebirge granites, (OIC) | 38 | Intruded in crystalline rocks. The granites are intruded by granite porphyry. | It comprises of two types of granites. Older one is more porphyritic then younger one | Sattran (1959, 1982) | older than 320 K/Ar. | |
| KIRCHBERG and BERGEN | Group 2 | OIC | 112 & 30 | These are adjacent bodies believed to be linked Nejdek-Eibenstock. Geochemically they are similar but petrographicaly they differ from one another. | These are characterised by similar features as granites of Nejdek older type. Bergen posses W mineralization | Baumann et al. (1964); Lange (1972); Mahfiouz (1971) | 323±5 Gerstenberg et al. (1984) | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| NEJDEK - EIBENSTOCK | Group 2,<br>Group 3,<br>Group 4,<br>Group 5 | OIC,<br>YIC,<br>YICm | 1081 | This is a largest pluton in the west Bohemian massif. It is intruded mainly in phyllitic rocks. The pluton is characterised by intrusion of subsequent phases. The axis of pluton crosscuts the axis of regional anticline. One of the significant feature is presence of roof pendants. | The Nejdek part of the pluton represent both older and younger granites and the Eibenstock part comprises the varies types of younger phase magmatism. Tin mineralization is of economic significant related to the younger granites. Tungsten mineralization is associated mainly with the older granites. | Absolonová (1972),<br>Absolonová & Klomínský (1971),<br>Lange (1972),<br>Štemprok (1986),<br>Tischendorf (1990) | | N=141, $SiO_2$ *72.76* (3.32); $TiO_2$ *0.31* (313.60); $Al_2O_3$ *13.86* (7.19); $Fe_2O_3$ *0.58* (55.82); FeO *1.34* (53.39); MnO *0.06* (71.79); MgO *0.47* (84.77); CaO *0.83* (69.98), $Na_2O$ *3.18* (27.62); $K_2O$ *4.75* (13.96); $P_2O_5$ *0.23* (48.96); BaO *0.03* (28.18); $Li_2O$ *0.09* *(290.70)* |
| KRUDUM | Group 4<br>Group 5 | YIC m<br>Milíře type<br>Čistá type<br>Třídomí type. | 27 | It is intruded in the metasediments and gneisess. Three local types of granites indicate their subsequent development of crystalization | It is comprises of highly metasomatised granites. Tin mineralization is significant in Horní Slavkov & Krásno area. associated with Čistá granite. | Jarchovský & Štemprok (1979)<br>Fiala and Zoubek (1963) | | N=10, $SiO_2$ *73.89* (1.51); MgO *0.18* (49.38); $TiO_2$ *0.17* (57.81); CaO *0.14* (73.54); $Al_2O_3$ *13.88* (4.2); $Na_2O$ *3.27* (8.55); $Fe_2O_3$ *1.41* (22.3); $K_2O$ *4.91* (7.20) $P_2O_5$ *0.25* (31.91); MnO *0.04* (39.06) |
| KFELY | Group 2<br>Group 3 | OIC Special facies granite OM | 25 | Granites are intruded in metasediments. The granites are intruded by granite porphyry | | Fiala (1968),<br>Jarchovský and Štemprok (1979) | | N=4, $SiO_2$ *74.04* (0.48); MgO *0.18* (17.57); $TiO_2$ *0.20* (4.81); CaO *0.14* (40.18); $Al_2O_3$ *13.92* (0.55); $Na_2O$ *3.18* (2.05); $Fe_2O_3$ *1.10* (3.40); $K_2O$ *4.81* (1.33) $P_2O_5$ *0.22* (24.35); MnO *0.02* (17.50) |
| LOKET | Group 1 | Loket type | | It is a oldest Hercynian granite in NW Bohemia, intruded in gneisses in Slavkovský les Mts. | Large porphyroblasts of twined K-feldspar. | Fiala (1968) | | N=7, $SiO_2$ *65.59* (4.27); $TiO_2$ *0.80* (24.45); $Al_2O_3$ *15.88* (5.14); $Fe_2O_3$ *0.89* (34.23); MnO *0.07* (10.88); MgO *1.45* (38.07); CaO *2.59* (25.41); $Li_2O$ *0.02* (37.8); $Na_2O$ *3.47* (8.13) $K_2O$ *4.12* (15.26); $P_2O_5$ *0.3* (13.03); $H_2O$ 1.11 (11.94) |
| WEIßENSTADT | Group 1 | G 1, G 1 B,<br>G 1 R, G 1 S | 310 | It covers the largest part of Smrčiny pluton. It is intruded in the metasediments of pre- to early - Hercynian orogeny. Granites in this region are usually defined as "altered granites". Weißenstadt granites are porphyritic whereas Hozmühl and Selb are fine grained. | It is comprises of different textural & colour varieties of granites. | Stettner (1958, 1964, 1977);<br>Vejnar (1960);<br>Richter and Stettner (1979) | 310 ± 14 Besang et al. (1979) | N=12, $SiO_2$ *67.10* (5.53); $TiO_2$ *0.76* (30.88); $Al_2O_3$ *15.04* (5.22); FeO *3.17* (28.67); $Fe_2O_3$ *0.82* (50.83); MnO *0.31* (267.93); MgO *1.51*; (54.71); CaO *2.45* (47.10); $Na_2O$ *3.26* (5.92); $K_2O$ *4.35* (10.13); $P_2O_5$ *0.33* (19.75); $H_2O$ *0.92* (32.51) |
| HOLZMÜHL | Group 2 | G 1 H | | | | | | N=3, $SiO_2$ *73.53* (.86) MgO *0.44* (26.42); $TiO_2$ *0.22* (30.85); CaO *0.99* (27.54); $Al_2O_3$ *14.4* (1.7); $Na_2O$ *3.40* (3.60); $Fe_2O_3$ *0.48* (6.09) $K_2O$ *5.14* (7.23); FeO *0.83* (17.66); $P_2O_5$ *0.21* (25.91) MnO *0.04* (22.27); $Na_2O$ *3.4* (3.60); $H_2O$ *0.57* (14.11) |

Krušné hory - Smrčiny batholith (cont.)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| SELB | Group 2 | G 1 S | | | | | | N=8, $SiO_2$ *73.55* (1.38) MgO *0.37* (39.39); $TiO_2$ *0.22* (42.01); CaO *0.82* (36.6); $Al_2O_3$ *14.4* (1.7); $Na_2O$ *3.58* (8.4); $Fe_2O_3$ *0.36* (69.4); $K_2O$ *4.88* (6.97); FeO *1.00* (23.09); $P_2O_5$ *0.27* (30.24); MnO *0.03* (25.60); $Na_2O$ *3.58* (8.4) $H_2O$ *0.70* (21.30) |
| REUT | Group 2 | G 1 R | | | | | | N=8, $SiO_2$ *69.37* (3.0) MgO *1.0* (28.01); $TiO_2$ *0.53* (36.07); CaO *1.73* (14.3); $Al_2O_3$ *15.2* (3.4); $Na_2O$ *3.45* (2.7); $Fe_2O_3$ *1.0* (49.35); $K_2O$ *4.72* (4.87); FeO *2.30* (31.27); $P_2O_5$ *0.30* (20.96); MnO *0.06* (22.82); $LiO_2$ *0.03* (64.79); $H_2O$ *0.83* (25.39) |
| WALDSTEIN (Randgranit, Kerngranit) | Group 2<br>Group 3 | G2, G3 | 22 | | | Goeman (1970, 1972, 1975) | 282± 1 Besang et al. (1979) | N=11, $SiO_2$ *75.01* (1.3); MgO *0.19* (35.57); $TiO_2$ *0.17* (23.93); CaO *0.56* (15.35); $Al_2O_3$ *13.5* (4.8); $Na_2O$ *3.0* (5.74); $Fe_2O_3$ *0.28* (70.2) $K_2O$ *4.92* (3.68); FeO *1.49* (11.00); $P_2O_5$ *0.18* (15.99) MnO *0.04* (25.83); $LiO_2$ *0.04* (23.62); $H_2O$ *0.35* (63.90) |
| KORNBERG (Randgranit, Kerngranit) | Group 2<br>Group 3 | G 2, G 3, G 3K | 22 | | | Goeman (1970, 1972, 1975) | | N=13, $SiO_2$ *74.99* (2.52); $TiO_2$ *0.21* (54.80); $Al_2O_3$ *13.25* (4.69); FeO *1.71* (38.11); Fe2O3 *0.24* (101.8); MnO *0.03* (34.49); MgO *0.24*; (74.40); CaO *0.63* (45.87); $Na_2O$ *3.13* (8.98); $K_2O$ *5.00* (7.71); $P_2O_5$ *0.23* (12.68); $H_2O$ *0.48* (51.64) |
| CENTR. STOCK (Zinngranit) | Group 3<br>Group 4<br>Group 5 | G 2, G 2/4, G 3 | 111 | This is truncated at Franconian line in west. Eastern part is bordered with orthogneiss | Tin mineralization occur in the eastern part and north central part | Herzberg (1976) | Zinngr. 280±4<br>Kerngr. 283±1<br>Besang et al. (1979) | N=40, $SiO_2$ *74.95* (1.6); MgO *0.17* (72.42); $TiO_2$ *0.15* (67.35); CaO *0.55* (41.27) $Al_2O_3$ *13.3* (5.9); $Na_2O$ *3.2* (14.7); $Fe_2O_3$ *0.20* (80.5); $K_2O$ *5.10* (0.57); FeO *1.45* (24.81); $P_2O_5$ *0.20* (23.46); MnO *0.03* (26.95); $LiO_2$ *0.06* (135) |
| KÖSSEINE (Kerngranit) | Group 2<br>Group 3 | G 2K, G 3K | | This the south extrem of Central stock exposure. Two kind of granites are distinct texturally | | Luczizky (1905); Richter & Stettner (1979) | 284±2.4<br>289±2.6<br>Besang et al. (1979) | N=9, $SiO_2$ *73.56* (2.4); MgO *0.51* (65.32); $TiO_2$ *0.39* (41.96); CaO *0.85* (39.13) $Al_2O_3$ *13.4* (5.5); $Na_2O$ *2.5* (21.2); $Fe_2O_3$ *0.43* (70.4); $K_2O$ *5.09* (6.70); FeO *2.46* (39.07); $P_2O_5$ *0.22* (19.72); MnO *0.04* (25.38); $LiO_2$ *0.02* (33.54); $H_2O$ *0.39* (58.01) |

# 2. Granites in Cornubian and the Krušné hory-Smrčiny batholiths

While both the batholiths Cornubian and Krušné hory-Smrčiny situated in differefent tectonic zones of Hercynian orogenic belt (e.g. Cornubian in Rhenohercynian and Krušné hory-Smrčiny in Saxothuringian zones). There are many similarities, for instance; shape and form of the batholiths, NW-SE trending wrench faults, presence of granite porphyries (but there is a difference in age of emplacement relative to the granites), age of emplacement, $^{87}$Sr/$^{86}$Sr ratio, associated mineral deposits, primary heat flow and heat production (Rajpoot, 1992). However, there are some differences in the construction of host rocks, order of abundance of some minerals, for example; tourmaline, topaz. In this chapter, mainly the geochemical characteristics of the various granites are discussed.

**Methodology**

*Whole rock chemical analyses of the granites considered in this study, include major and trace elements. The data have been stored in a local data bank. The data selected for this study are relatively compatible, although systematic sampling and analyses are needed for proper correlation. The geochemical analyses of granites from SW England were taken from Darbyshire and Sheppherd (1985). These were done by X-ray fluorescence spectrometry (MESA, Nottingham), for major as well as trace elements. The analyses of granites in the Czech part of the Karlovy Vary pluton were obtained from Absolonová (1971), and were done by AAS for major elements, while XRF and OES were used for the determination of trace elements. Similar techniques were adopted for the new analyses of 29 samples from the Slavkovský les Mts. The analyses of granites from the Smrčiny Mts. pluton are from Richter and Stettner (1979); these were done by AAS and XRF. Statistical summary of granite groups is given in Table 3.*

## 2.1 Granite typology

The granites of the Cornubian and Krušné hory-Smrčiny batholiths have been classified into several types by many authors (Table 4). Authors have emphasized different aspects of the petrology of the granites, for example; in the Krušné hory Mts., Lange et al. (1972) classified the granites into two major types, an Older Intrusive Complex (OIC) and a Younger Intrusive Complex (YIC), using relative age of emplacement as the prime factor. In the Smrčiny Mts. pluton, Richter and Stettner (1979) classified the granites as G1, G2 etc., based principally upon the petrogenetic sequence. In the Cornubian batholith, Dangerfield and Hawkes (1981) categorized the granites as 1A, 1B, 2B etc., based on K-feldspars and Li-micas. Exley and Stone (1982) classified the granites in the same batholith as Type A, Type B etc., using mainly textural features and mineralogy. For the comparison of granites in the Cornubian and Krušné hory-Smrčiny batholiths, it is essential to unify terminologies and principal factors for the classification of granites as far as possible. This is one of the aspects of this study. To obtain the fundamental types of granites, a statistical „Cluster analysis“ is applied. Rb, Ba, Sr, Zr, Sn, Rb-(Sr+Ba), Al-(Na+K+2Ca), Fe+Mg+Ti, Mg/(Mg+Fe), K/(Na+K), and (Na+K)/Ca parameters of 400 samples were processed by computer for cluster analysis. Two methods of cluster analysis have been used (Milligan, 1980). First; 'Average method', which indicate two main clusters of the granites (Fig. 9). The plots representing the clusters correspond with the broad classification of Lange et al. (1972) ( OIC and YIC granites). In fact, there are many subfacies of granites, which have been distinguished by Lange (ibid) and other authors. Second; „Seeded method“ to determine the subfacies in the broad types of granites. The initial seeds (granites used to designate a group or a subfacies) for the clusters were selected from the following localities in the Krušné hory Mts.

*Cluster 1* – Loket type, *Cluster 2* – Nejdek type, *Cluster 3* – Eibenstock type, *Cluster 4* – Blauenthal type, *Cluster 5* – Čistá type.

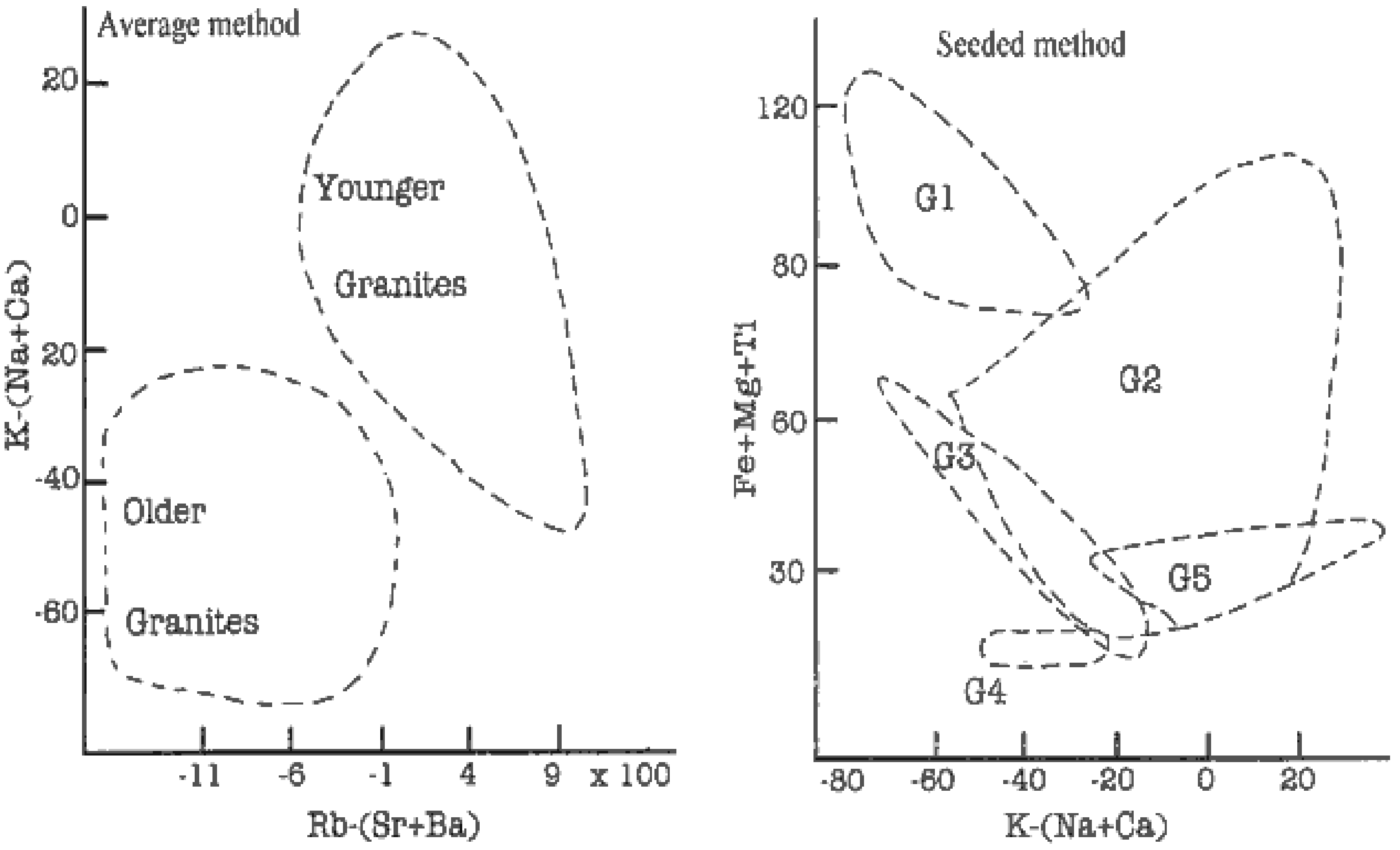

*Fig. 9. Geochemical clusters of granites in Cornubian and Krušné hory-Smrčiny batholiths*

## Table 3: Statistic summary of geochemistry of granite groups

| | Group 1 n=17. | | | | | | | | | Group 2 n=56 | | | | | | | | | Group 3 n=88 | | | | | | | | | Group 4 n=68 | | | | | | | | | Group 5 n=22 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Std. | Min. | Max. | C.V. | L.Q. | U.Q. | S.S. | S.K. | Mean | Std. | Min. | Max. | C.V. | L.Q. | U.Q. | S.S. | S.K. | Mean | Std. | Min. | Max | C.V. | L.Q. | U.Q. | S.S. | S.K. | Mean | Std. | Min. | Max. | C.V. | L.Q. | U.Q. | S.S. | S.K. | Mean | Std. | Min. | Max. | C.V. | L.Q. | U.Q. | S.S. | S.K. |
| $SiO_2$ | 68.43 | 2.12 | 62.75 | 72.3 | 3.09 | 67.5 | 69.73 | -.10 | 1.28 | 70.99 | 1.97 | 64 | 74.5 | 2.78 | 70.5 | 71.92 | -4.26 | 5.31 | 74.28 | 1.6 | 70.13 | 77.2 | 2.15 | 73 | 75.6 | -.66 | -1.48 | 74.12 | 1.17 | 70.24 | 76.4 | 1.58 | 73.2 | 74.9 | -1.23 | .88 | 74.02 | 1.47 | 71.1 | 76.53 | 1.99 | 72.97 | 75.1 | -.43 | -.43 |
| $TiO_2$ | .64 | .15 | .34 | .92 | 23.63 | .54 | .73 | -.19 | -.07 | .37 | .17 | .05 | 1.02 | 46.63 | .25 | .47 | 3.57 | 3.77 | .19 | .07 | .07 | .40 | 35.97 | .14 | .24 | 2.36 | .51 | .15 | .07 | .04 | .38 | 45.34 | .10 | .20 | 2.65 | 1.08 | .06 | .03 | .02 | .14 | 59.83 | .04 | .06 | 3.53 | 2.37 |
| $Al_2O_3$ | 15.01 | .56 | 13.70 | 16.55 | 3.72 | 14.6 | 15.3 | .86 | 2.26 | 14.5 | .52 | 13.60 | 15.80 | 3.61 | 14.1 | 14.8 | 2.15 | -.14 | 13.69 | .90 | 12 | 16.01 | 6.60 | 13 | 14.61 | .63 | -1.81 | 13.68 | .67 | 12 | 15.2 | 4.93 | 13.15 | 14.07 | .09 | -.23 | 14.21 | 1.00 | 12.23 | 16.11 | 7.03 | 13.8 | 14.72 | -.51 | .21 |
| $Fe_2O_3$ | .73 | .30 | .30 | 1.54 | 41.18 | .55 | .75 | 2.22 | 1.32 | 1.00 | .77 | .10 | 3.07 | 77.25 | .51 | 1.02 | 4.44 | 1.34 | .60 | .62 | .03 | 1.99 | 103.14 | .16 | .80 | 4.35 | -.66 | .96 | .67 | .04 | 2.88 | 69.51 | .39 | 1.51 | 2.00 | -.95 | .43 | .32 | .05 | 1.11 | 75.6 | .11 | .47 | 1.87 | .02 |
| FeO | 2.63 | .71 | 1.10 | 4.09 | 26.84 | 2.4 | 3.1 | -.93 | .59 | 1.95 | .81 | .28 | 4.1 | 41.69 | 1.36 | 2.3 | 1.01 | .25 | 1.45 | .42 | .40 | 2.81 | 28.93 | 1.20 | 1.70 | -.19 | 2.04 | 1.17 | .29 | .29 | 1.94 | 24.53 | .99 | 1.3 | -.99 | 1.99 | .80 | .27 | .25 | 1.2 | 33.67 | .57 | 1.01 | -.13 | -.67 |
| MnO | .06 | .01 | .04 | .08 | 18.56 | .05 | .07 | -.58 | -.45 | .06 | .01 | .03 | .09 | 23.09 | .05 | .06 | .53 | 1.16 | .04 | .01 | 0 | .08 | 36.73 | .03 | .04 | 3.07 | 2.39 | .04 | .02 | .02 | .09 | 43.42 | .03 | .04 | 4.30 | 4.09 | .05 | .02 | .03 | .10 | 44.33 | .03 | .06 | 2.28 | .86 |
| MgO | 1.21 | .29 | .59 | 1.99 | 23.99 | 1.15 | 1.32 | .12 | 2.16 | .72 | .38 | .14 | 2.35 | 53.09 | .47 | .87 | 5.66 | 8.1 | .26 | .11 | 0 | .54 | 44.21 | .17 | .33 | 1.50 | -.41 | .22 | .20 | .03 | 1.31 | 88.16 | .12 | .24 | 11.97 | 26.56 | .09 | .08 | .01 | .33 | 83.65 | .03 | .11 | 3.41 | 3.53 |
| CaO | 2.09 | .43 | 1.21 | 2.87 | 20.67 | 1.81 | 2.41 | -.21 | -.35 | 1.17 | .42 | .32 | 2.28 | 35.77 | .88 | 1.51 | .89 | -.64 | .63 | .20 | .11 | 1.12 | 31.34 | .51 | .77 | -.27 | .56 | .41 | .17 | .02 | 1.02 | 41.66 | .31 | .49 | 2.67 | 3.66 | .38 | .13 | .03 | .59 | 34.69 | .30 | .44 | -.73 | .78 |
| $Na_2O$ | 3.31 | .20 | 3.00 | 3.74 | 6.02 | 3.1 | 3.45 | .74 | -.70 | 3.3 | .34 | 2.5 | 4.08 | 10.32 | 3.18 | 3.49 | -1.34 | .53 | 3.08 | .35 | 2.13 | 4.1 | 11.45 | 2.9 | 3.25 | .68 | 1.23 | 3.12 | .33 | 1.78 | 4.04 | 10.72 | 2.97 | 3.26 | -.94 | 6.63 | 3.72 | .25 | 3.21 | 4.2 | 6.69 | 3.55 | 3.8 | .27 | 0 |
| $K_2O$ | 4.57 | .39 | 3.9 | 5.54 | 8.57 | 4.29 | 4.84 | .90 | .54 | 4.85 | .50 | 3.23 | 5.9 | 10.41 | 4.59 | 5.09 | -.92 | 1.67 | 5.12 | .51 | 3.2 | 6.82 | 9.93 | 4.85 | 7.38 | 1.20 | 6.71 | 4.89 | .35 | 3.50 | 5.78 | 7.06 | 4.69 | 5.03 | -1.04 | 5.25 | 4.54 | .37 | 3.89 | 5.36 | 8.18 | 4.32 | 4.77 | 1.05 | .41 |
| $P_2O_5$ | .30 | .07 | .18 | .45 | 22.03 | .25 | .36 | .52 | -.05 | .21 | .07 | .07 | .43 | 34.10 | .16 | .25 | 1.88 | 1.38 | .20 | .06 | .04 | .37 | 29.44 | .17 | .24 | .84 | 1.64 | .21 | .06 | .04 | .32 | 28.33 | .19 | .26 | -.68 | 2.98 | .28 | .15 | .02 | .55 | 53.57 | .15 | .35 | -.06 | -.59 |
| Ba | 887 | 253.8 | 500 | 1450 | 28.6 | 730 | 1020 | .85 | -.06 | 446 | 222.4 | 197 | 965 | 49.77 | 255.5 | 533 | 2.69 | -.46 | 184 | 121.1 | 30 | 680 | 65.55 | 97.5 | 227.5 | 6.19 | 7.76 | 125 | 95.59 | 5 | 328 | 76.41 | 45 | 181 | 7.42 | 14.11 | 50 | 61.17 | 2 | 204 | 121.8 | 5 | 50 | 2.73 | 1.77 |
| Rb | 199 | 33.8 | 121 | 249 | 16.94 | 180 | 231 | -.73 | -.29 | 302 | 84.44 | 183 | 655 | 27.96 | 242.5 | 335 | 5.01 | 5.98 | 445 | 91.7 | 280 | 680 | 20.57 | 385 | 482 | 2.59 | .77 | 556. | 153.9 | 210 | 890 | 27.67 | 424 | 670 | -.25 | .62 | 872 | 375 | 8294 | 1969 | 43 | 695 | 1456 | 1.35 | 1.27 |
| Sr | 242 | 51.96 | 150 | 349 | 21.43 | 205 | 270 | .21 | -.31 | 148 | 68.94 | 59 | 375 | 46.34 | 92.5 | 187 | 3.81 | 2.19 | 48 | 26.8 | 10 | 99 | 55.61 | 28.5 | 75 | 2.35 | -1.94 | 35 | 22.9 | 4 | 107 | 64.19 | 20.5 | 44.5 | 3.62 | 2.08 | 33 | 37.88 | 4 | 175 | 113 | 4 | 41 | 5.03 | 8.68 |
| Zr | 246 | 61.86 | 126 | 358 | 25.14 | 221 | 263 | -.24 | -.15 | 176 | 79.73 | 28 | 464 | 45.19 | 110 | 220 | 2.03 | 2.1 | 92 | 38.21 | 30 | 240 | 41.49 | 65.5 | 110 | 4.93 | 6.36 | 70 | 38.72 | 5 | 169 | 55.32 | 44 | 90 | 2.02 | .38 | 26 | 84 | 5 | 65 | 68.63 | 10 | 46 | 3.78 | 5.16 |
| Sn | 7 | 2.1 | 3 | 13 | 28.81 | 6 | 8 | 1.1 | 1.66 | 15 | 9.18 | 4 | 39 | 58.57 | 7 | 22.5 | 1.84 | -.81 | 16 | 10.41 | 0 | 79 | 62.92 | 11 | 22 | 11.04 | 29.18 | 28 | 14.04 | 6 | 71 | 49.35 | 19.33 | 33.5 | 3.41 | 2.54 | 25 | 7.78 | 13 | 45 | 30.03 | 20 | 30 | .87 | .98 |
| U | 4 | 1.39 | 0 | 6 | 34.45 | 3.4 | 5 | .66 | -.82 | 6. | 2.79 | 2 | 13 | 40.83 | 4.4 | 8.6 | .84 | -.95 | 9 | 4.83 | 2.9 | 29 | 51.58 | 6 | 12.25 | 5.28 | 5.62 | 18 | 7.86 | 4 | 41 | 42.28 | 14 | 22 | 2.06 | 1.86 | 10 | 8.66 | 2 | 26 | 85.24 | 2.5 | 19.55 | .89 | -.7 |
| Th | 31 | 7.5 | 17 | 48 | 23.79 | 28 | 33.5 | .28 | .72 | 21 | 7.48 | 9.8 | 57 | 34.53 | 17 | 24.1 | 3.61 | 8.72 | 15 | 8 | 2 | 43 | 53.16 | 11 | 16.7 | 6.87 | 6.82 | 11 | 4.66 | 4 | 24 | 40.6 | 8 | 15 | 1.51 | .67 | 8 | 6.77 | 2 | 22 | 81.33 | 3.9 | 15.5 | 3.87 | 5.66 |
| Mg/(Fe+Mg) | .4 | .04 | .31 | .51 | 10.46 | .37 | .41 | 1.75 | 1.94 | .33 | .07 | .22 | .53 | 22.62 | .26 | .37 | 1.85 | -.52 | .22 | .08 | 0 | .43 | 38.81 | .17 | .28 | .22 | -.24 | .19 | .1 | .04 | .59 | 50.39 | .14 | .22 | 5.54 | 7.9 | .13 | .09 | .02 | .36 | 69.55 | .04 | .18 | 2.11 | 1.13 |
| K/Na+K | .48 | .03 | .41 | .53 | 6.06 | .46 | .49 | -.82 | .36 | .49 | .04 | .38 | .59 | 9.1 | .47 | .51 | .93 | .12 | .52 | .04 | .36 | .65 | 8.06 | .5 | .55 | -1.66 | 4.21 | .51 | .03 | .44 | .62 | 5.69 | .5 | .52 | 1.73 | 4.05 | .45 | .03 | .4 | .51 | 6.98 | .43 | .46 | 1.23 | -.02 |
| Q | 151.3 | 16.79 | 103.1 | 181.3 | 11.1 | 147.7 | 158.6 | -1.93 | 2.43 | 170.9 | 17.37 | 122.5 | 210.6 | 10.17 | 292.4 | 351.2 | -.37 | .19 | 196.9 | 19.64 | 139.9 | 242.8 | 9.97 | 183.7 | 212.2 | -1.45 | .09 | 202.5 | 18.27 | 152.6 | 262.1 | 9.02 | 192.7 | 212.9 | 1.46 | 4.14 | .08 | 13.79 | 164.6 | 219.2 | 7.24 | 183.4 | 196.4 | .6 | .4 |
| K-(Na+Ca) | -46.9 | 17.26 | -75.3 | -10.9 | -36.7 | -61.4 | -36.7 | .46 | -.43 | -24.3 | 22.12 | -70.8 | 22.19 | -91.1 | -37.5 | -12.9 | .59 | -.67 | -1.53 | 18.19 | -64.9 | 52.27 | -1189 | -10.7 | 6.31 | -1.39 | 4.37 | -3.21 | 12.37 | -45.1 | 31.51 | -385 | -9.15 | 2.25 | -1.69 | 2.18 | -29.5 | 13.09 | -48.9 | -3.85 | -44.3 | -41.3 | -23.1 | 1.01 | -.2 |
| Fe+Mg+Ti | 83.96 | 18.73 | 43.92 | 126.2 | 22.3 | 71.08 | 92.75 | -.41 | .85 | 57.41 | 21.45 | 16.51 | 134.7 | 37.36 | 43 | 68.39 | 3.54 | 4.29 | 32.09 | 6.81 | 14.56 | 51.8 | 21.23 | 27.71 | 36.07 | 1.47 | 1.13 | 28.59 | 8.43 | 13.65 | 59.06 | 29.5 | 22.43 | 31.81 | 4.93 | 6.14 | 17.11 | 3.27 | 12.22 | 27.18 | 19.08 | 14.5 | 18.63 | 2.23 | 2.42 |
| Al bal | 15.72 | 10.39 | -16.5 | 30.46 | 66.08 | 9.98 | 21.72 | -2.3 | 2.89 | 32.98 | 16.7 | -19.2 | 80.47 | 50.65 | 22.34 | 41.3 | -1.24 | 2.52 | 37.56 | 16.66 | 5.96 | 80.91 | 44.35 | 27.34 | 48.78 | .95 | -.5 | 50.06 | 16.56 | 18.08 | 131.8 | 33.08 | 40.63 | 56.97 | 6.47 | 14.98 | 49.49 | 17.83 | 12.05 | 83.75 | 36.03 | 40.1 | 67.48 | -.1 | -.51 |
| (K+Na)/Ca | 5.8 | 1.56 | 3.77 | 9.75 | 26.93 | 4.67 | 6.24 | 2.43 | 1.48 | 11.73 | 5.41 | 4.84 | 34.9 | 46.11 | 7.74 | 13.74 | 5.78 | 8.13 | 22.38 | 18.05 | 10.31 | 132.2 | 80.66 | 15 | 22.65 | 19.12 | 51.86 | 34.63 | 28.32 | 12.83 | 233.2 | 81.78 | 24.07 | 38.71 | 21.8 | 77.88 | 50.76 | 77.33 | 21.19 | 393.9 | 152.3 | 27.92 | 44.58 | 8.37 | 19 |

Std. = Standard Deviation; Min. = Minimum; Max. = Maximum; L.Q. = Lower Quartile; U.Q. = Upper Quartile; S.S. = Standard Skewness; S.K. = Standard Kurtosis; Al bal. = Al-(Na+K+2Ca)

The first two clusters represent the older granites and last three clusters represent the younger granites. In the first cluster, granites from Cornubian batholiths are absent, otherwise all clusters include the granites from both the batholiths. The cluster analysis also reflected the tentative relationship among the pre- existing classification schemes in the given provinces ( Table 4).

*Table. 4. Relationship between present proposal and preexisting typologies.*

| Rajpoot (1992) | Cornubian batholith | | Krušné hory-Smrčiny batholith | | | |
|---|---|---|---|---|---|---|
| | Dangerfield & Hakes (1981) | Exley &Stone (1982) | Lange et al. (1972) | Chlupáčová (1974) | Richter & Stettner (1979) | Štemprok (1986) |
| Group 5 | 2A-Li | E-F | YIC 3 | Čistá Type | | Ym |
| Group 4 | 1A-Li | D | YIC 2-3 | R3-R4 | G4 | YIC 2-3 |
| Group 3 | 1C-2B-2C | B | YIC 1 | R1-R2 | G3 | YIC 1-2-Om- DG |
| Group 2 | 1A-1B-1C | B | OIC 1-2 | SH2-SH3 | G1R-G3K | OIC 2-3 |
| Group 1 | | A (?) | | SHs- SH1 | G1 | OIC 1 |

To determine the geochemical characteristic features of the granite groups, typical data for each group were scanned through various world wide used schemes for different aspects of petrology (summarised in Table 5). Following five groups of granite in the Cornubian and Krušné hory-Smrčiny batholiths are clear (Rajpoot and Klominský, 1993) (see Fig. 10).

GROUP 1 granites – are biotite or two-mica, coarse-grained porphyritic, undifferentiated, late-orogenic, tin barren, peraluminous, monzo - granodiorite. The G1 granites occur mainly in Karlovy Vary Pluton (Loket type), Eastern Krušné hory Mts. (Fláje type), Smrčiny Mts. pluton (Weißenstadt and Selb granites, see Fig 4).

GROUP 2 granites – are two-mica or bio.mus., coarse-to medium grained, poorly differentiated, post-tectonic tin-barren, peraluminous, monzo-syenogranites. The G2 granites occur mainly in Karlovy Vary Pluton (Nejdek granite), Smrčiny Mts. pluton (Waldstein granite, Kösseine-Kern granite, Reut granite), Cornubian batholith (St. Austell pluton, Land's End pluton, Bodmin Moor pluton, Dartmoor pluton) (Fig. 4).

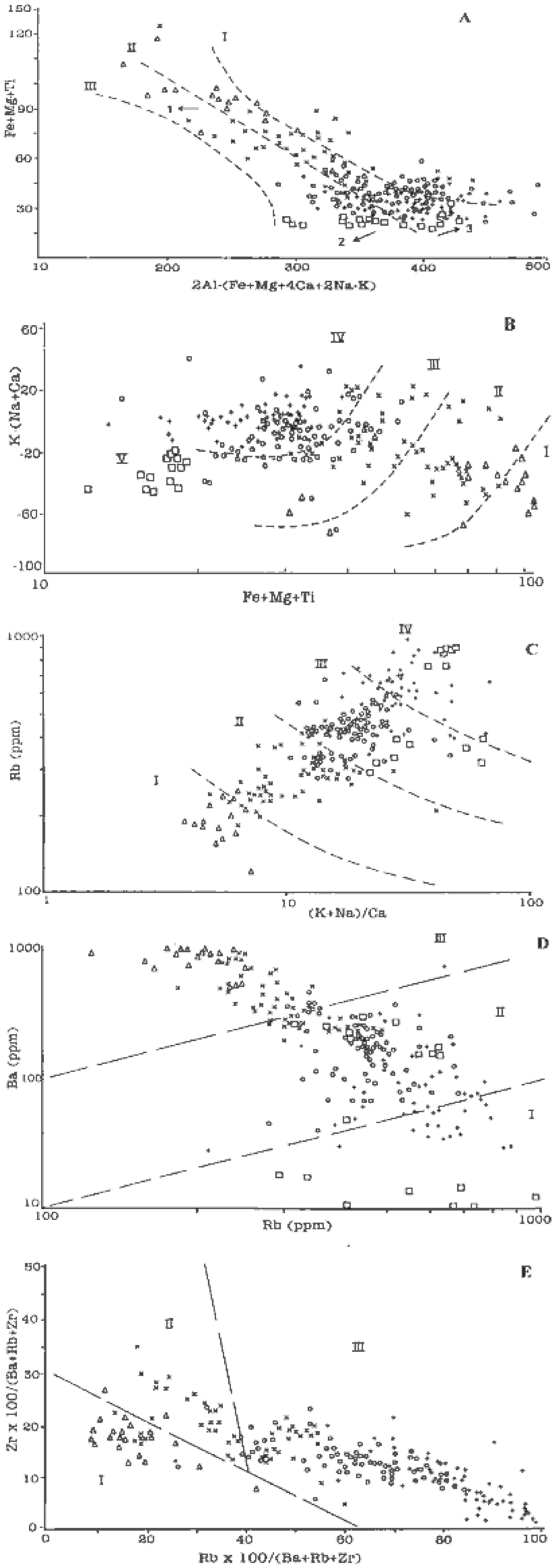

**Fig. 10.** *Classification of granitic rocks after Rajpoot (1992).*

*A; I – Aluminopotassic granite , II – Normal granite, II – Calcic or sodic granite –> 1 trend of altered granite, –> 2 trend of K-metasomatic or alumino silicate rich granite, –> 3 calcitized or albitized granite. B; 1 – Granodiorite, 2 – Monzogranite, 3 – Monzo-syenogranite, 4 – Syenogranite, 5 – Syenogranite. C; 1 – Highly differentiated granite, 2 – moderately differentiated granite. D; (after Olade, 1980) I – Tin mineralized granite, II – Stanniferous granite, III – Tin barren granite. E; I – Late-orogenic, II – Post-orogenic, III – Post-orogenic highly differentiated granite.*
*(triangle – G1, cross – G2, circle – G3, plus – G4 and box – G5)*

GROUP 3 granites – are two mica leucocratic, coarse or medium-grained moderately differentiated, post-orogenic, partly stanniferous, peraluminous, syenogranites. main occurences of G3 granites are Karlovy Vary Pluton (Eibenstock-Nejdek granite), isolated bodies of Cínovec, Kynžvart, Smrčiny Mts. (Kornberg granite, Kösseine-Rand granite, and Selb granite), Cornubian batholith (Cammenellis pluton, Bodmin Moor pluton, see Fig. 4).

GROUP 4 granites – are generally two-mica leucocratic, medium grained or fine grained, strongly differentiated, post-orogenic, stanniferous, highly peraluminous, syenogranites. The G4 granites occur mainly in Karlovy Vary Pluton (patches in Eibenstock granite), isolated bodies of Cínovec, Kynžvart, Kfely, Milíře, Třídomí; Smrčiny Mts. (Rand granite, and Zinngranite); Cornubian batholith (Land's End and Dartmoor and Bodmin Moor plutons, see Fig. 4).

*Table 5. Geochemical typology of granite groups various schemes.*

| | Group 1 | Group 2 | Group 3 | Group 4 | Group 5 |
|---|---|---|---|---|---|
| ***Nomenclature*** | | | | | |
| Hatchinson (1979) | Syenite | Syenite | Gd | Granite | Granite |
| Cox et al. (1979) | Gr-Gd | Gr-Gd | Granite | Granite | Granite |
| Middlemost (1985) | Granite | Granite | Granite | Granite | Granite |
| Le Matre (1989) | Gd | Gd | Mg | Mg | Mg |
| Debon & Le Fort (1983) | Adam | Adam | Granite | Granite | Granite |
| Jensen (1976) | CA Grd. | CA Gd | CA Ga | CAGa | CA Ga |
| Winchester& Flyod(1977) | Gd./Dio | Gd./Dio | Granite | Granite | Granite |
| Harpum (1963) | Adam | Adam | Granite | Granite | Granite |
| Rajpoot (1992) | Gd./Mg | Mg/Sg | Sg | Sg | Sg/Mg |
| ***Petrographic Types*** | | | | | |
| Peccerillo&Taylor(1976) | High K | High K | High K | High K | High K |
| Debon & Le Fort (1983) | T mica | T mica | Leuco | Leuco | Leuco |
| La Roche (1980) | Meso | Meso | Leuco | Leuco | Leuco |
| Ishihara (1977) | Mainly I | Mainly I | Mainly I | Mainly I | Mainly I |
| Irvine & Baragar (1971) | Sub-Alk | Sub-Alk | Sub-Alk | Sub-Alk | Sub-Alk |
| Chappell & White (1974) | S & I | S & I | S & I | S | S |
| Whalen et al. (1987) | OGT | OGT | FS | FS | FS |
| Bouseily&Sokkary(1975) | NG,AG | NG,SD | SD | SD | SD |
| Olade (1980) | Tin B | Stanif. | Stanif. | Tin min | Tin min |
| ***Tectonic discriminations*** | | | | | |
| Pearce et al.(1984) | VAG | VAG | SCG | SCG | SCG |
| Bathlor &Bowden (1985) | LOG | LOG | SCG | SCG | SCG |
| Maniar & Piccoli (1989) | IA/CA/ CC | IA/CA/ CC | POG | POG | RRG/ CEUG |
| Rajpoot (1992) | LOG | LOG | POG | POG | POG |
| Rajpoot (1992) | VPD | PD | MD | SD | MD/SD |

Abbreviations in Table 5:

*Gr* = Granite, *Gd* = Granodiorite, *Adam* = Adamellite, *CA* = Calc Alkaline, *Dio* = Diorite, *Mg* = Monzogranite, *Sg* = Syenogranite, *High K* = High Potassium, *T mica* = Two mica granites, *Leuco* = Leucogranite, *Meso* = Mesocratic, *Mainly I* = Mainly Ilmenite series, *Sub-Alk* = Sub-alkaline, *S & I* = I and S type, *OGT* = Unfractionated granite, *FS* = Fractionated granites, *NG* = Normal granite, *AG* = Abnormal granite, *SD* = Strongly differentiated granite, *Tin B* = Tin barren granite, *Stanif* = Stanniferous granite, *Tin min* = Tin mineralized granite, *VAG* = Volcanic arc granite, *SCG* = Syn-collision granite, *LOG* = Late orogenic granite, *IA/CA/CC* = Island arc/Continental arc/ Continental collision granite, *POG* = Post orogenic granite, *RRG/CEUG* =Rift related granite/ Continental epiorogenic uplift related granite, *VPD* = Very poorly differentiated, *PD* = Poorly differentiated, *MD* = Moderately differentiated, *SD* = Strongly differentiated

GROUP 5 granites – are lithium mica- and topaz- bearing, leucocratic, medium- or fine-grained, alkali-rich, moderate to strongly differentiated, post-orogenic, stanniferous, highly peraluminous, syeno-monzogranites. The main G5 granites are widely scattered in smaller outcrops or cupolas in these batholiths. For example, in the Karlovy Vary Pluton, (in small patches in Nejdek and Blatná), small isolated bodies are Čistá, Lesný-Lysina; Zinngranite in Smrčiny Mts. and Tregonian-Godolphin granite, St.Austell pltuon, Cligga Head granite in SW England.

## 2.2 Distinct petrographical features

### Zircon morphology

The morphology of zircons in the older (G1 & G2) and younger granites (G3, G4, & G5) have been studied by Kodýmová (1984, & pc). According to her, zircons in the older granites are subhedral in shape (Fig. 11a). Zircons in the younger granites are mostly euhedral and frequently show a significant overgrowth around earlier formed zircon (Fig. 11b). The shape of core or inner part of zircon in the younger granites is comparable to that in the older granites. The statistical analysis of 140 zircons from the older granites and 100 zircons from the younger granites was done following Pupin (1980) and Pupin and Turco (1972) methodology for zircon thermometry (Fig. 12).

The older granites have two peaks on the zircon thermometer. The first peak is represented by 31.4% of zircons at 850$^{0}$C and the second peak is represented by 42.85% of zircons at 650$^{0}$C temperature. It is calculated that zircons in the older granites were derived from a source rock at about 850$^{0}$C and had crystallized at *650*$^{0}$C. Most of the zircons (76%) in the younger granites show a temperature of crystallization at 650$^{0}$C.

### Triclinicity of K-feldspars

The structural state of K-feldspar in the Nejdek area (in the Karlovy Vary pluton) older and younger granites have been studied by Jiránek (1982). There, the older (G2) granites are spatially associated with younger (G3, G4 and G5) granites. An average triclinicity of K-feldspars in both older and younger granites is very low (Fig. 13). In this Fig., it is clear that statistically, the triclinicity of K-feldspars does not differ significantly in the older and younger granites. However, there are some "outliers" of triclinicity in both older and younger granites that plot higher than the upper quartile range. Older granites show a relatively lower triclinicity than the younger granites. Jiránek (1982) suggested that the lower tricilinicity in the older granites is due to the thermal influence of the younger intrusive granite and rapid cooling (Hall, 1966). The older granites are similar to the Lesser Himalayan granites in many geochemical and petrographical characters (discussed later), but there is a significant difference in triclinicity of the alkali feldspars. However, some "outlier" values have similar triclinicity. It supports the Jiránek (1982) suggestion that the alkali feldspars in these granites changed to a partial triclinic structure in the solid state during their development. Later on, the structure was changed to monoclinic due to the effects of hydrothermal solutions in the surrounding faults and fissures in the older granites and pressure associated with fault tectonics and autometamorphic processes in the younger granites (Jiránek, 1982).

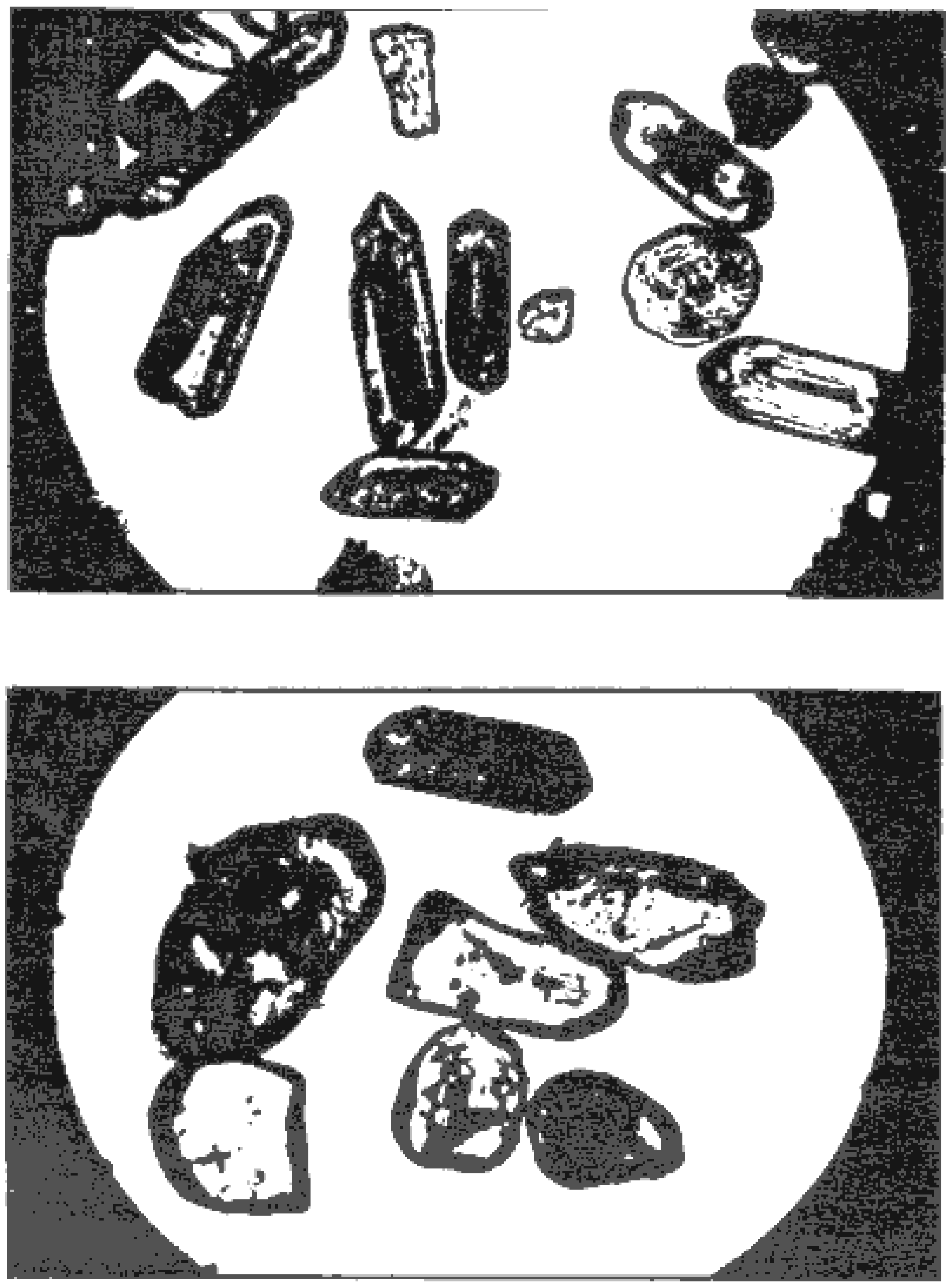

*Fig. 11. Zircon in the older and younger granites (Krušné hory Mts.)*

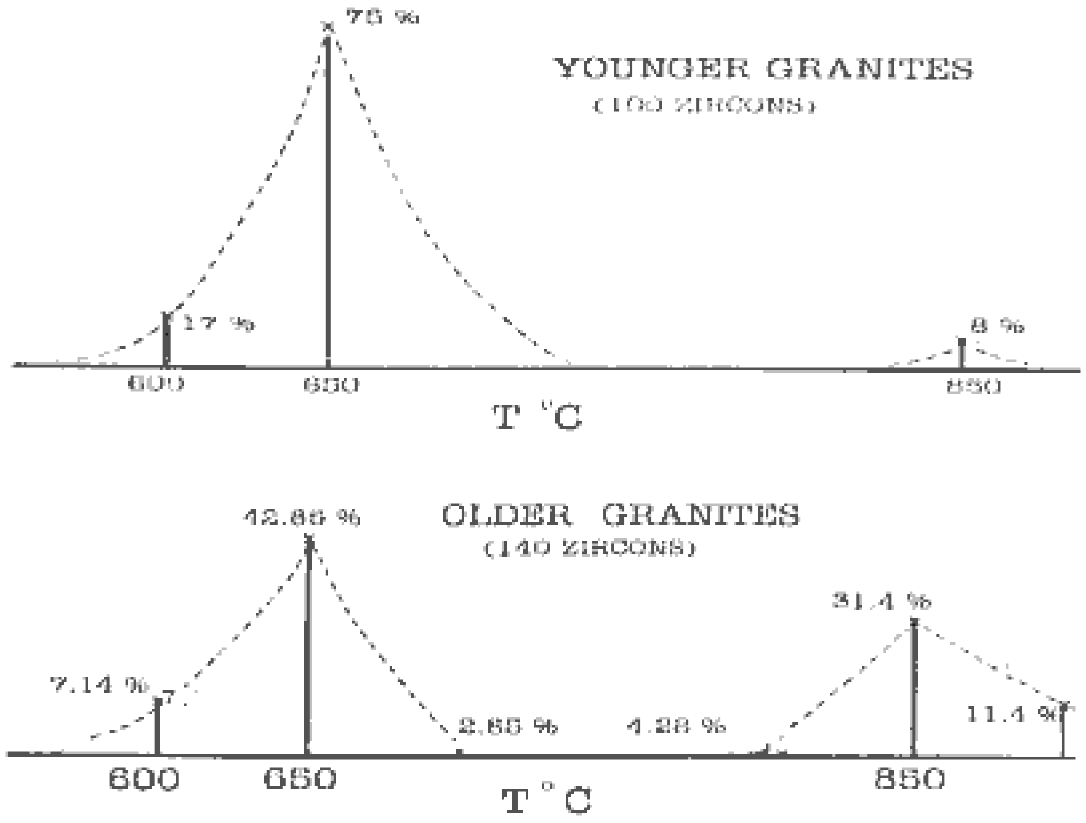

*Fig. 12. Frequency distribution of zircon on temperature scale after Pupin (1980) (data after Kodymová p.c.).*

### Restite minerals and xenoliths

In the older granites, hornblende, andalusite, cordierite, garnet, and biotite + muscovite are common accessory minerals, which occur as inclusions and/or occur in the intergranular space between feldspars and quartz. Smaller amount of these minerals occur in the younger granites. These minerals seems to be residual or 'restite' minerals derived from the partial melting of pelitic rocks (Exley et al., 1983). Geochemically some specific trace elements (Ba, Sr, V) are high in the older granites (discussed later). The higher abundance of these elements and restite minerals favour arguments that involve xenolith assimilation (contamination) in the older granites (Lister, 1984). Xenoliths of various dimension can be seen in both batholiths. The following sequence of development of xenolith in the G2 granites from margin to center has been proposed by Lister (1984) 1.- Foliated xenoliths, 2.- Unfoliated sediments, 3.- Feldspar bearing xenoliths. In both batholiths, roof pendants have been described in the younger granites (in the Cornubian batholith, Exley and Stone, 1982; and in the Karlovy Vary pluton, Klomínský and Absolonová, 1972). Such roof pendants are rare in the older granites.

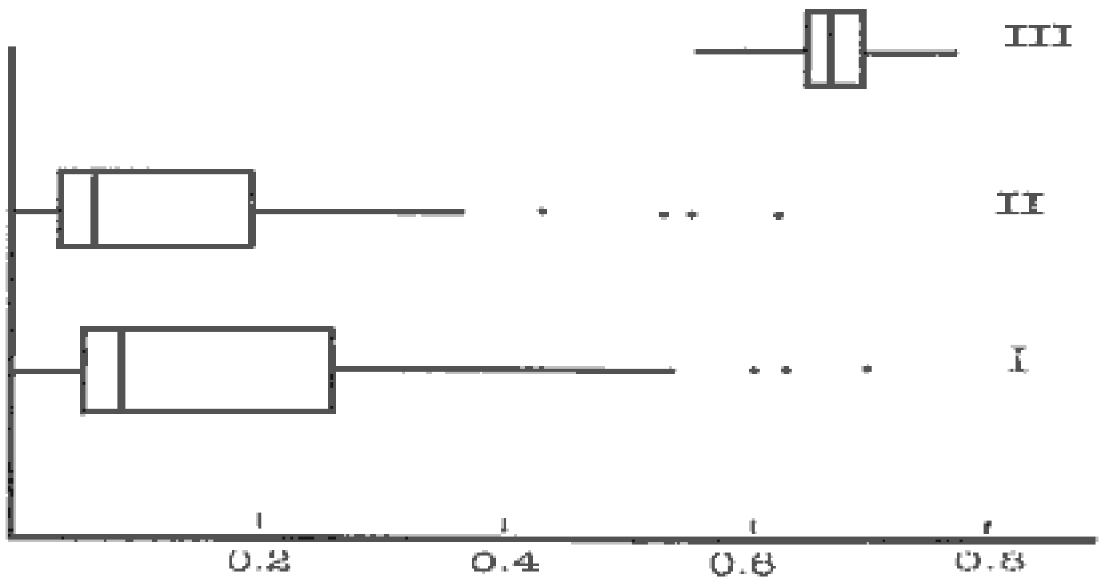

***Fig. 13.**. Box and whisker plots of triclinicity of K-feldspar in older* (I) *and younger* (II) *granites in Nejdek part of Karlovy Vary pluton, and of Lesser Himalayan granites* (III). *(data for Karlovy Vary pluton are after Jiránek, 1982; and for Lesser Himalaya after Rajpoot, 1988)*

*The Box and Whisker plot divides the data into four areas of equal frequency. The box encloses the middle 50%. The median is drawn as a line inside the box. The lines extend from each end of the box are called as "whiskers". The lower whisker is drawn from the first quartile to the smallest data point within 1.5 interquartile ranges. The upper whisker is drawn from the third quartile to the largest data point within 1.5 interquartile ranges. Data point beyond the whiskers are plotted individually (McGill et al., 1978 and Frigge et al. 1989).*

### Topaz

The presence of topaz in the younger granites was considered as an important factor for the discrimination of the younger granites from the older granites by previous authors (e.g. Zoubek, 1951), but in fact, its presence is not always confined to the granites of younger group. However, topaz frequently occurs in the younger granites. In the G4 and G5 granites, topaz occurs associated with K-feldspar and is replaced by quartz. This textural relation has been explained by following reaction (Stone, 1986).

(Orthoclase) (Topaz) (Qtz) (K+ions in solution)

$$2KAl_2Si_3O_8+2HF = Al_2SiO_4.F+5SiO_2+H_2O+K_2O$$

This reaction is similar to that of Glyuk and Anfilogov (in Bailey, 1977). If this reaction occurs, than the involvement of F released from the magmatic system during late-stage seems clear. There is some experimental evidence to indicate that F is retained in the magma in preference to the coexisting vapor phase (Koster and Wyllie, 1968; Wyllie and Tuttle, 1961 and Hards, 1976).

### Micas

Total mica content in the older granites (G1 and G2) varies from 8-13 vol% (exceptionally 19%) and in the younger granite (G3,G4

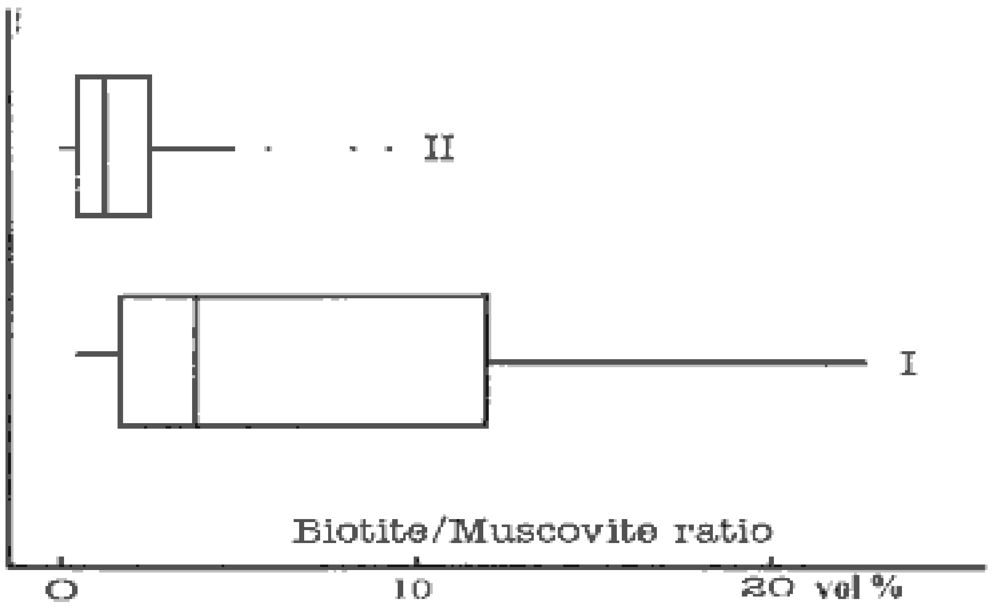

*Fig. 14. . Box and whisker plots for Biotite/Muscovite ratio in older (I) and younger granites (II) in Krušné hory-Smrčiny batholith.*

and G5) varies from 4-10 vol%. Biotite is usually more abundant in the older granites and varies from 3-20 vol%, with an average of 8 vol%. In the younger granites biotite (dark micas) varies from 1.5-6.5 vol% with an average of 3.5 vol%. Dark/white mica ratio varies from 1 to 25 vol% in older granites and has an average of 2.5%. In the younger granites, the ratio varies from 0 to 5% with an average of 1.2% (Fig. 14). The dark micas in the older granites are most probably biotite, as Li is deficient and Fe, Mg and Ti is higher in whole rock analyses.

### Textural relationships among Qt-Pl-Kf

In the older granites, inclusions of plagioclase, quartz, and biotite in the K-feldspar are generally observed, but inclusions of K-feldspars in plagioclase is rarely seen. Inclusions of quartz in K-feldspars is common but the reverse is rare except in granites close to the younger granites. In the Cornubian granites these features have been discussed in "Megacrystic biotite granites" by Exley et al. (1983). This sequence of crystallization corresponds with the experimental melting of natural rocks (Winkler, 1976). The inclusions of K-feldspar in quartz is a common feature in the younger granites, which may indicate late-stage grain enlargment. In the younger granites, growth of alkali feldspar and replacement of earlier formed plagioclase in both the batholiths has been discussed by several authors and is considered by some authors to provide evidence for alkali metasomatism and also to outweight the chemical and structural arguments in favour of an early magmatic origin (e.g. Kerrick, 1969 and de Albuquerque, 1975). The younger granites generally show the presence of drop-like quartz, which is generally absent in older granites.

## 2.3 Geochemistry

The oxides of major elements were recalculated to cationic proportions, to aid determination of the mineralogical significance of the granites (La Roche, 1976, 1986). Five cationic parameters that involve a complete representation of mineralogical characters of the granites were selected. The trace elements are discussed individually and recalculated Rb-(Ba+Sr) is also discussed. Box and whisker diagrams are used for statistical assessment of the comparison between granite groups and also for their representative geographically distinct granite bodies. As the G1 granites appear only in Krušné hory-Smrčiny batholith, their box and whisker diagrams are not shown the along with the other groups in Fig. 16, but they are shown separately in Fig. 17.

The alkali ratio (AR) is calculated as K/(Na+K) after Debon and Le Fort (1988). AR varies from sodic to potassic types in the given groups of granite (Fig. 15D). The G5 granites are "sodic" as a result of albitization in them. The G3 granites are "potassic" (AR=0.50), what favours the idea of potassium metasomatism. The rest of the granites (G1, G2 and G4) are *"sodi-potassic"* types ( AR= 0.45 – 0.50). Fig. 16 (A) indicates the variation in the alkali ratio between the different granites; The Cornubian G2 granites are more potassic than the G2 in Krušné hory Mts. (Nejdek older granites), but they are similar to the Smrčiny Mts. G2. The G1, G3 and G4 granites have insignificant differences of AR between the three bodies. The Cornubian G5 is more potassic than those of Krušné hory and Smrčiny Mts.. The G5 (so called '*albite Li- mica topaz granites*') in Cornubian batholith is more potassic than those of the Krušné hory-Smrčiny batholith. All types of granites in the Krušné hory and Smrčiny Mts. are similar in terms of alkali ratio.

### Alumina Balance [Al-(Na+K+2Ca]

Most of the granites are peraluminous (Fig. 15F). The G1 granites are 'low aluminous' (AB=10-20), G2 and G3 are 'moderate' (AB=20-40, and G4 and G5 are 'highly aluminous' (AB=40). Fig. 16 (C) indicates that all types of granite in the Krušné hory batholith are similar to the Smrčiny Mts. granites in terms of alumina balance, but the Cornubian G3 granites are more aluminous than the Smrčiny Mts. G3.

### Mg/(Fe+Mg)

The G1 and G2 granites lie between the range defined for magnesian association and ferriferous association (Fig. 15B). The G3, G4 and G5 are ferriferous. It can be stated that in general older granites are more magnesian than the younger granites. Fig. 16 (B) shows the variation in Mg/(Fe+Mg) ratio within the batholiths. The figure indicates differences between all three members (i.e. Krušné hory Mts., Smrčiny Mts. and Cornwall granites) in all groups except in G1. The G1 granites have the ratios that are similar in both the Smrčiny Mts. (Weißenstadt) and the Krušné hory Mts. (Loket and Flaje) (Fig.17). This geochemical disharmony among the plutons can be attributed either to the influence of host rock environment or different compositions of source rock.

### Alkali/Calcium ratio [(Na+K)/Ca]

The difference in ratio between older and younger granites is shown in Fig. 15C. Increasing AC ratio may represent progressive magmatic differentiation. Fig. 16 D shows the variation in the alkali/calcium ratio within the group. The figure indicates that all three granite provinces are broadly similar within their respective groups, except Cornubian G2 and G5 granite differ from the Smrčiny Mts. G2 and G5 but are similar to Krušné hory G2 and G5 respectively.

### Normative feldspars

The average CIPW normative feldspars (Table 1) show that G5 is richest in Ab (=35%), G3 is richest in Or (=33%), and G1 is richest in An (=10%). These observations correspond with other geochemical observations; for example, G5 is albite granite, G3 is K-metasomatised, and G1 is granodiorite to monzogranite. In

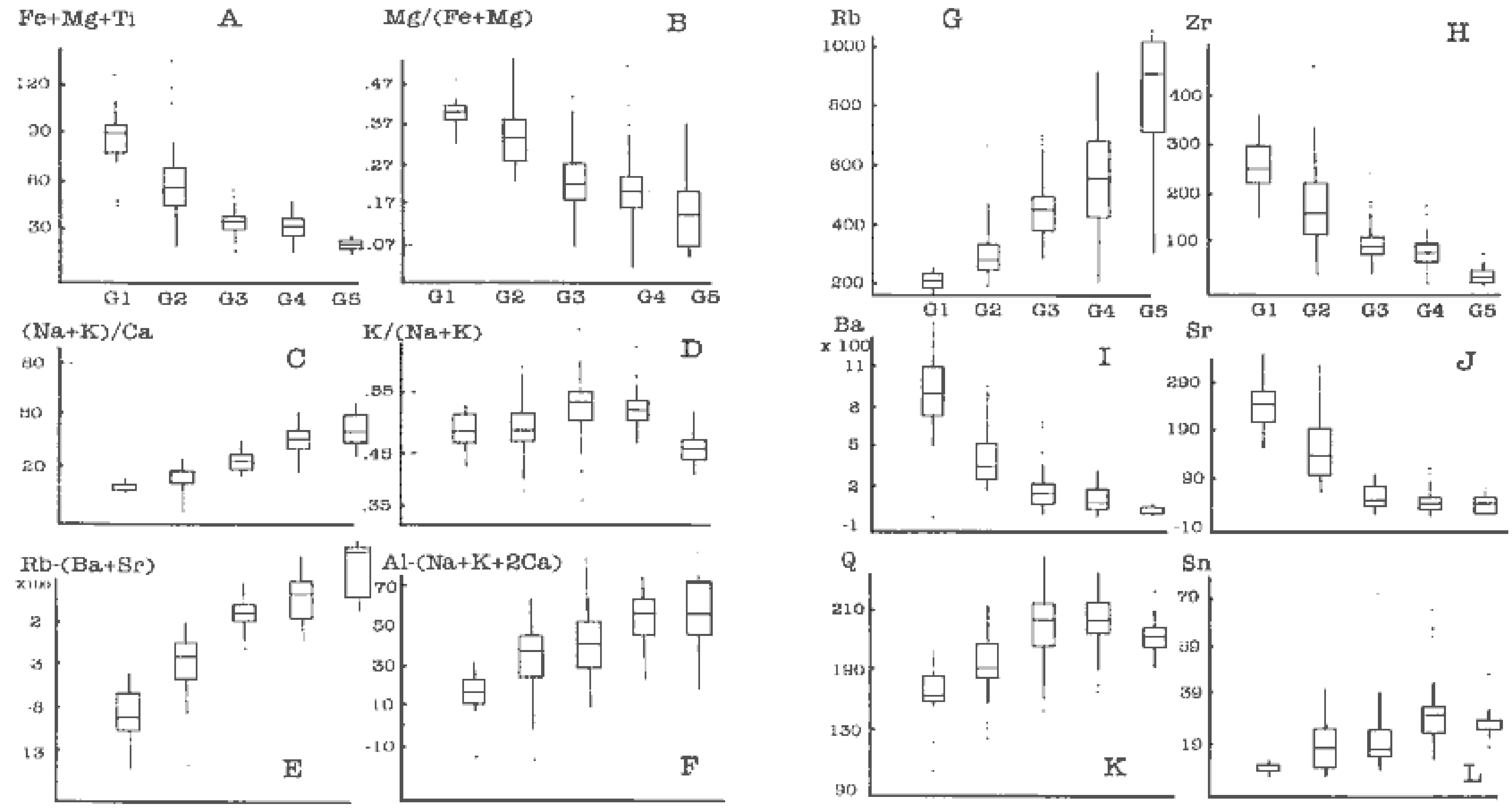

*Fig. 15. Box and whisker plots of cationic parameters and trace elements in individual group of granites (G1, G2, G3, G4, and G5).*

Fig. 11 (E, F, and G), it can be seen that normative Or behaves in a similar manner as the alkali ratio, and normative Ab is similar to the alkali/calcium ratio.

### Colour Index (Fe+Mg+Ti)

According to this parameter the older granites are 'mesocratic' and the younger granite are 'leucocratic' (Fig. 15). Fig. 16 shows the correspondence of colour index of individual batholith within granite groups except from Smrčiny Mts. G2, which does not correspond with Cornubian G2, and Weißenstadt G1 which does not corresponds with Fláje G1 granites (Fig. 17).

### Strontium

The G1 granites are significantly rich in Sr and do not correspond even with the G2 granites (Fig. 15). This may be difficult to explain, because the G1 and G2 granites have a close affinity to each other in many other respects. However, the older granites contain relatively higher concentrations of Sr than the younger granites. The younger granite groups have similar Sr concentrations that are much lower than those in the G1 and G2 granites. Fig. 16 (I) shows that the Smrčiny Mts. and Krušné hory members of G2 and G3 are similar but the G4 and G5 granites are different in Sr concentration. The Cornubian G2 and G3 granites differ significantly from G2 and G3 in the Krušné hory-Smrčiny batholith. The Cornubian G4 granites correspond with the G4 in Krušné hory Mts. The G5 granite in the Cornubian batholith differ from G5 in the Krušné hory-Smrčiny batholith.

### Barium

Ba has nearly same pattern in all groups as Sr and Zr (Fig. 15). Fig. 16 indicates that the Smrčiny Mts. G2 granites are abnormally high in Ba compared with the other granites. G3 granites have similar distributions of Ba in all batholiths. The G4 and G5 granites show significant difference between the Smrčiny Mts. and other batholith members as is shown by Sr. The Cornubian G5 contain high Ba and Sr than Krušné hory-Smrčiny G5 granites.

### Zirconium

Zr shows similar distribution in all groups as Sr and Ba, except that average Zr is very low in G5. The difference in Zr concentration between G3 and G4 is less than that of G4 and G5 (see Fig. 15). The box and whisker plots of Zr in different granite bodies could not be done due to a large number of missing values in the data set.

### Rubidium

Rb shows reverse behavior to Sr, Ba and Zr. In older granites Rb is lower than in younger granites. Among the younger granites, G3 and G4 show a considerable similarities in Rb, but G5 shows higher Rb than other groups (Fig. 15). Fig. 16 (J) show that Cornubian G2 contain considerably higher Rb than G2 in the Krušné hory-Smrčiny Mts. The Krušné Hory Mts. G3 contain relatively higher Rb than G3 in the Smrčiny Mts. and Cornwall. G4 granites in Smrčiny Mts. contains relatively higher Rb than the Cornubian G4, but is similar to G4 in the Krušné hory Mts. G5 do not show great differences, between the Krušné hory Mts. and Cornubian G5, except for a few representatives of Cornubian G5 which are slightly richer than the Krušné hory-Smrčiny G5.

### Rb-(Sr+Ba)

To check the status of the cationic "alkali/calcium ratio" parameter for magmatic differentiation, Rb-(Sr+Ba) was calculated. It is found that the older granites show negative values and the younger granites have positive values (Fig. 15). The trend of variation in is

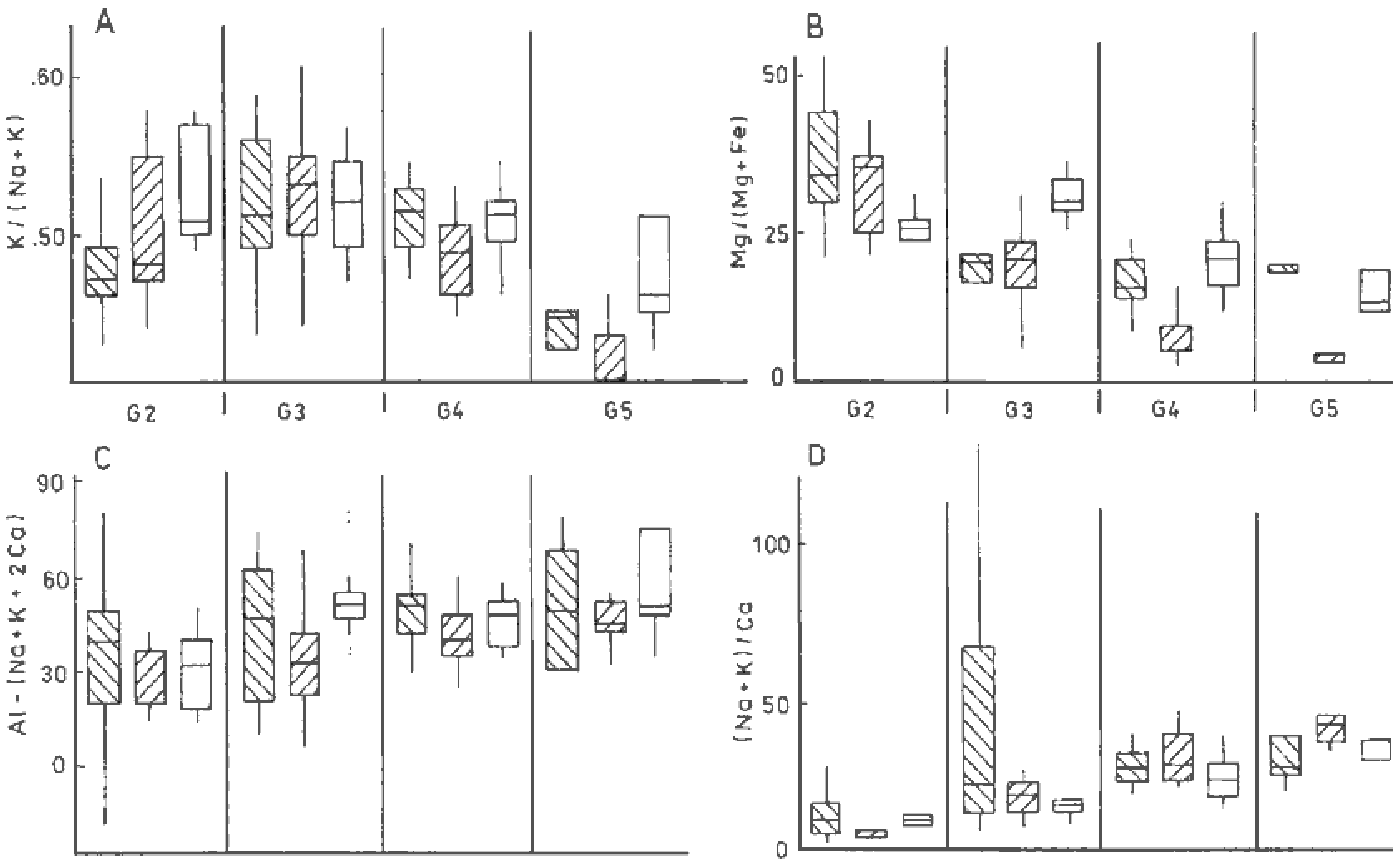

*Fig. 16. (A): Box and whisker plots of cationic parameters, normative feldspars and trace elements in the granites of Krušné hory Mts. (\\\), Smrčiny Mts. (///) and SW England (blank) granites*

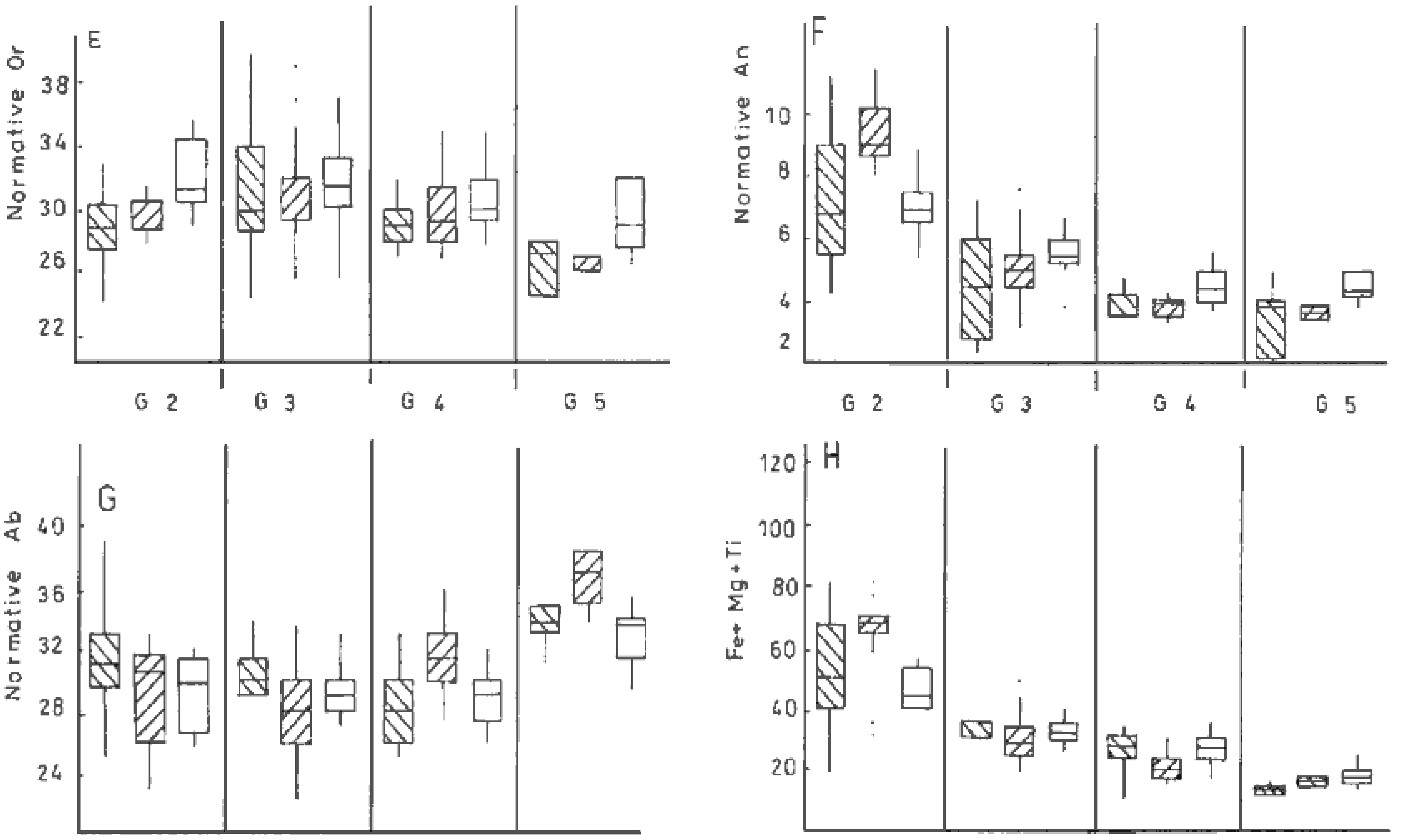

*Fig. 16(B). Box and whisker plots of cationic parameters, normative feldspars and trace elements in the granites (symbols as in Fig. 16A)*

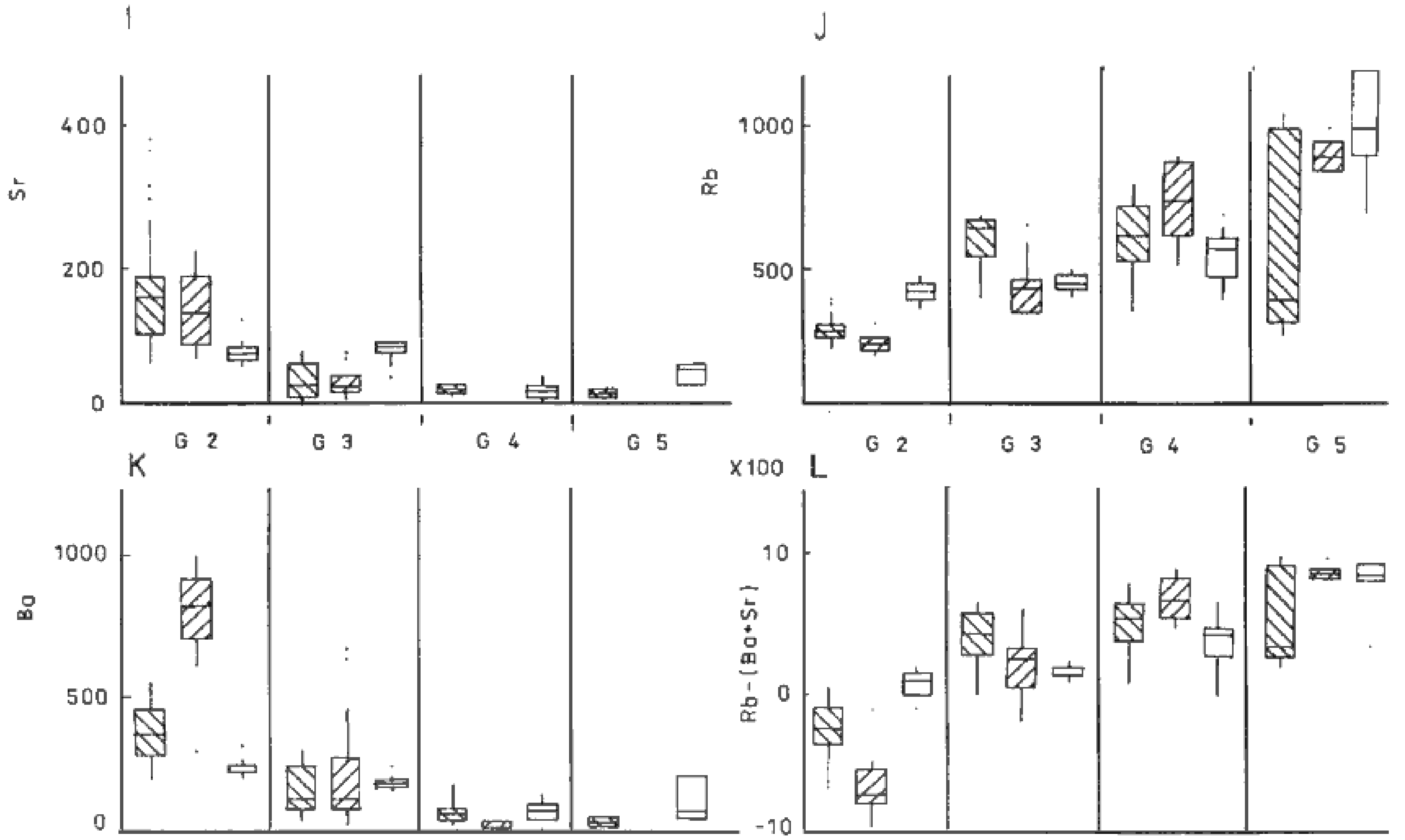

*Fig. 16(C). Box and whisker plots of cationic parameters, normative feldspars and trace elements in the granites (symbols as in Fig. 16A)*

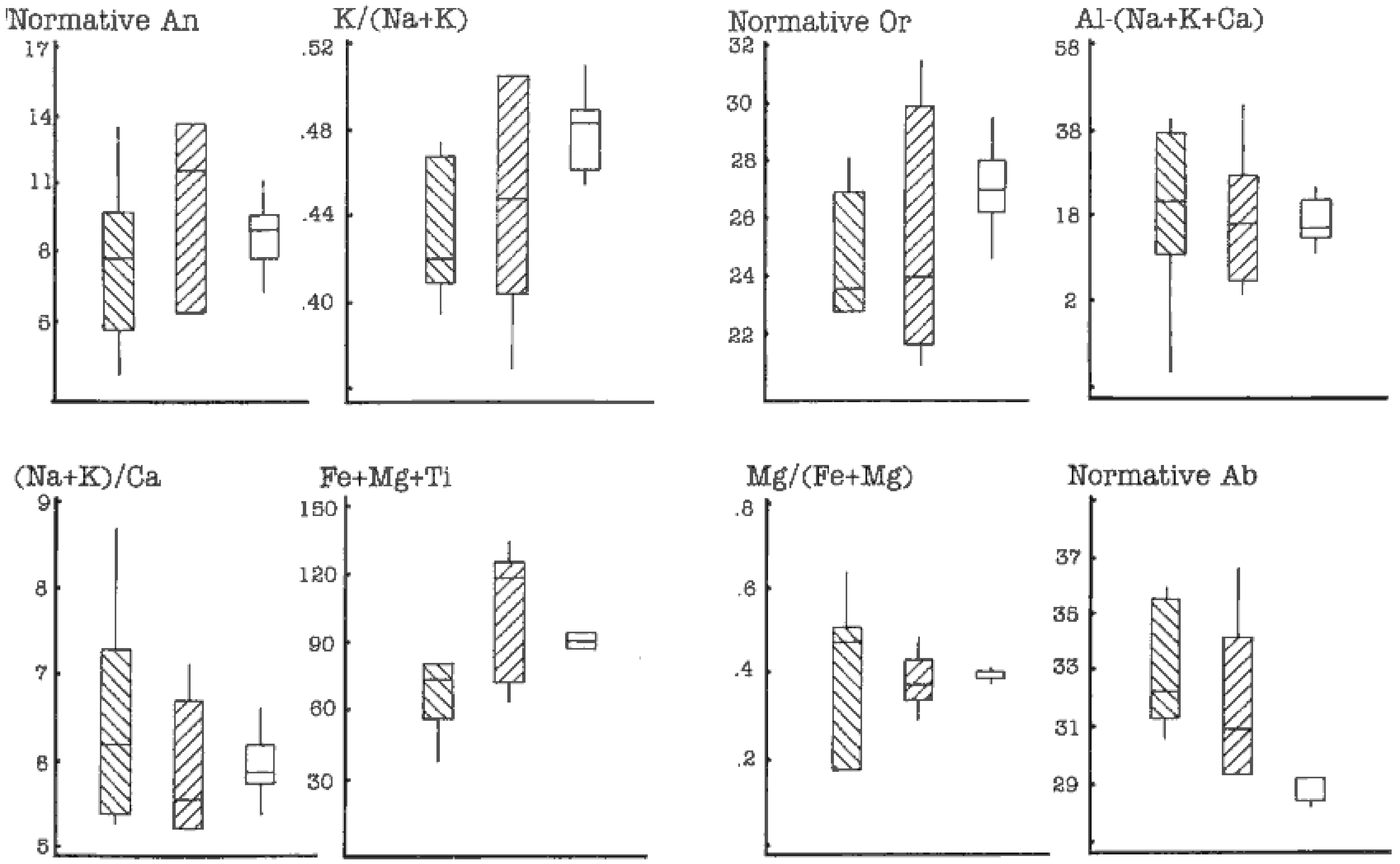

*Fig. 17. Box and whisker plots of cationic parameters in the G1 granites of Weißenstadt (\\\), Loket (///) and Fláje (blank).*

similar as trend in AC ratio. In general, this may verify the argument indicating the progressive magmatic differentiation from older to younger granites. But, if Rb-(Ba+Sr) is checked in older and younger granites seperately, than it can be seen that Rb-(Ba+Sr) is distinct in both granites. The Rb-(Sr+Ba) patterns of individual granite provinces in all groups are similar to the Rb patterns.

## 2.4 Definition of granite groups

In the Central Europe and SW England the granites are classified into following groups according to the major and trace element distributions.

### G1 granites

The G1 granites are characterized by the highest concentrations of $TiO_2$, MgO, $Al_2O_3$, (Fe+Mg+Ti), Mg/Mg+Fe ratio, normative An, Zr, Ba, Sr and Th. The granites are also characterized by relatively poor contents of $SiO_2$, alumina balance, free quartz, alkali/calcium ratio, Rb and Sn (Fig. 15). The G1 granites appear only in the Krušné hory-Smrčiny batholith. All cationic parameters indicate similarities among the G1 granites of Loket and Fláje, (in Krušné hory Mts.) and Weißenstadt (in Smrčiny Mts.) except for the dark mineral constituents (Fe+Mg+Ti), which are higher in the Weißenstadt than in the Fláje (Fig. 17, 18A). Normative An also differs in Fláje and Weißenstadt G1.

### G2 granites:

The G2 granites are characterized by relatively high concentration of $TiO_2$, MgO, $Al_2O_3$, Mg/Mg+Fe, normative An, Ba, Sr, Zr, and Th ( lower than the G1 granites) and relatively low (but higher then group 1 granites) $SiO_2$, alumina balance, alkali/calcium ratio, Rb and Sn (Fig. 15). The G2 granites occur in both batholiths and they are similar in all plutons in respect of alumina balance, dark mineral constituents and alkalis, but there are dissimilarities in the distribution of Rb, Sr and Ba (Fig. 18B). The dissimilarities can be attributed to different composition of source rock.

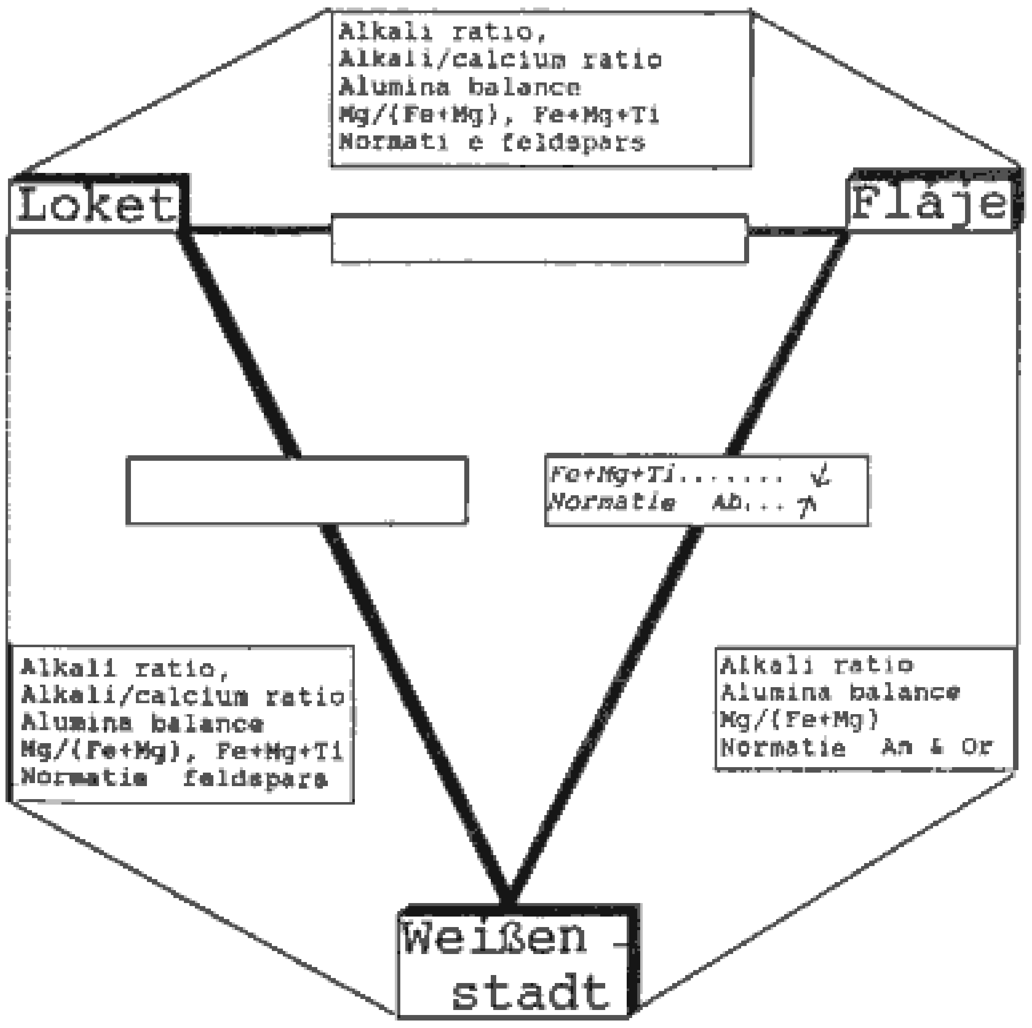

*Fig. 18(A). Relationship between the G1 granite. The parameters shown in inner boxes (connected by thick line) are not comparable between the relative provinces. Arrows indicate trend of increasing. The parameters in outer boxes are comparable between the provinces connected by thin line.*

### G3 granites

The G3 granites are characterized by relatively high values of $K_2O$, alkali ratio, and normative Or, and low values of $Na_2O/K_2O$, and $Al_2O_3$. The rest of the elements have concentration that lie between

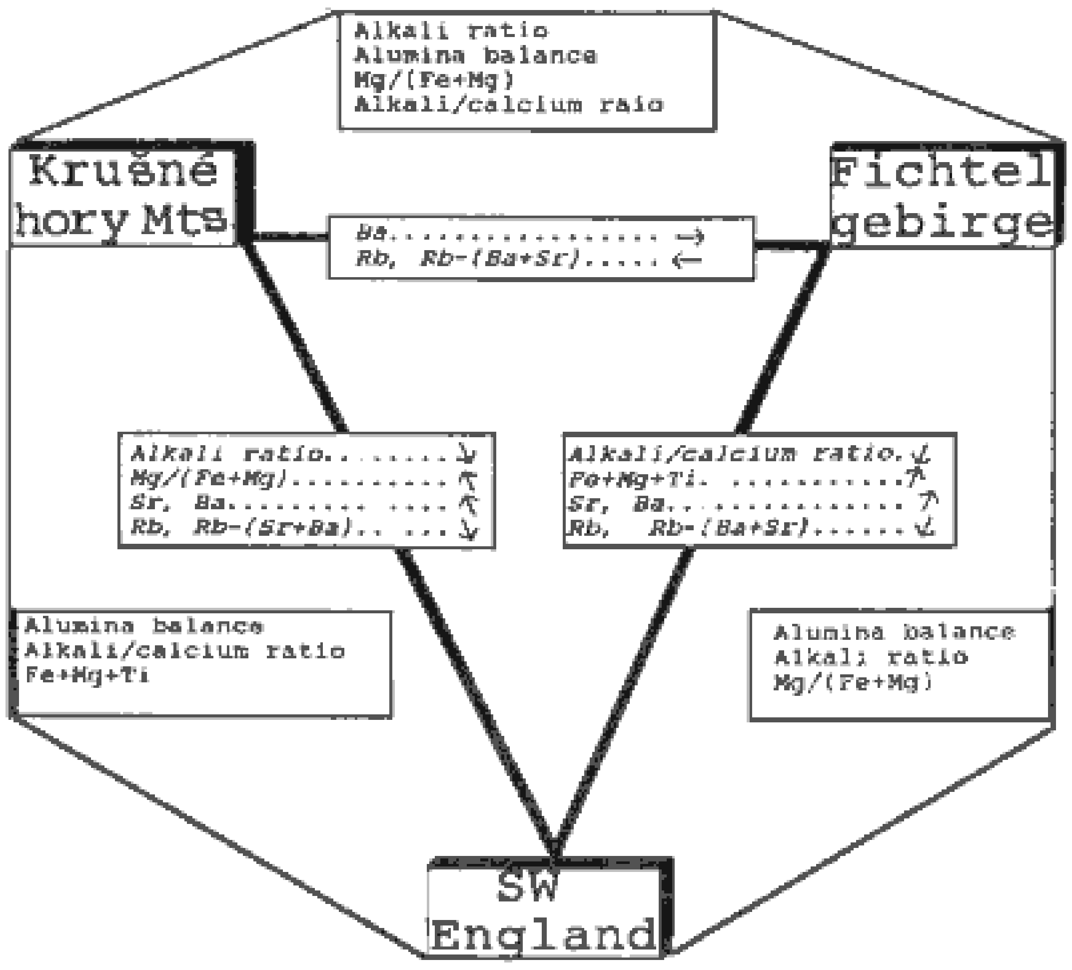

*Fig. 18(B). Relationship between the G2 granite. The parameters shown in inner boxes (connected by thick line) are not comparable between the relative provinces. Arrows indicate trend of increasing. The parameters in outer boxes are comparable between the provinces connected by thin line.*

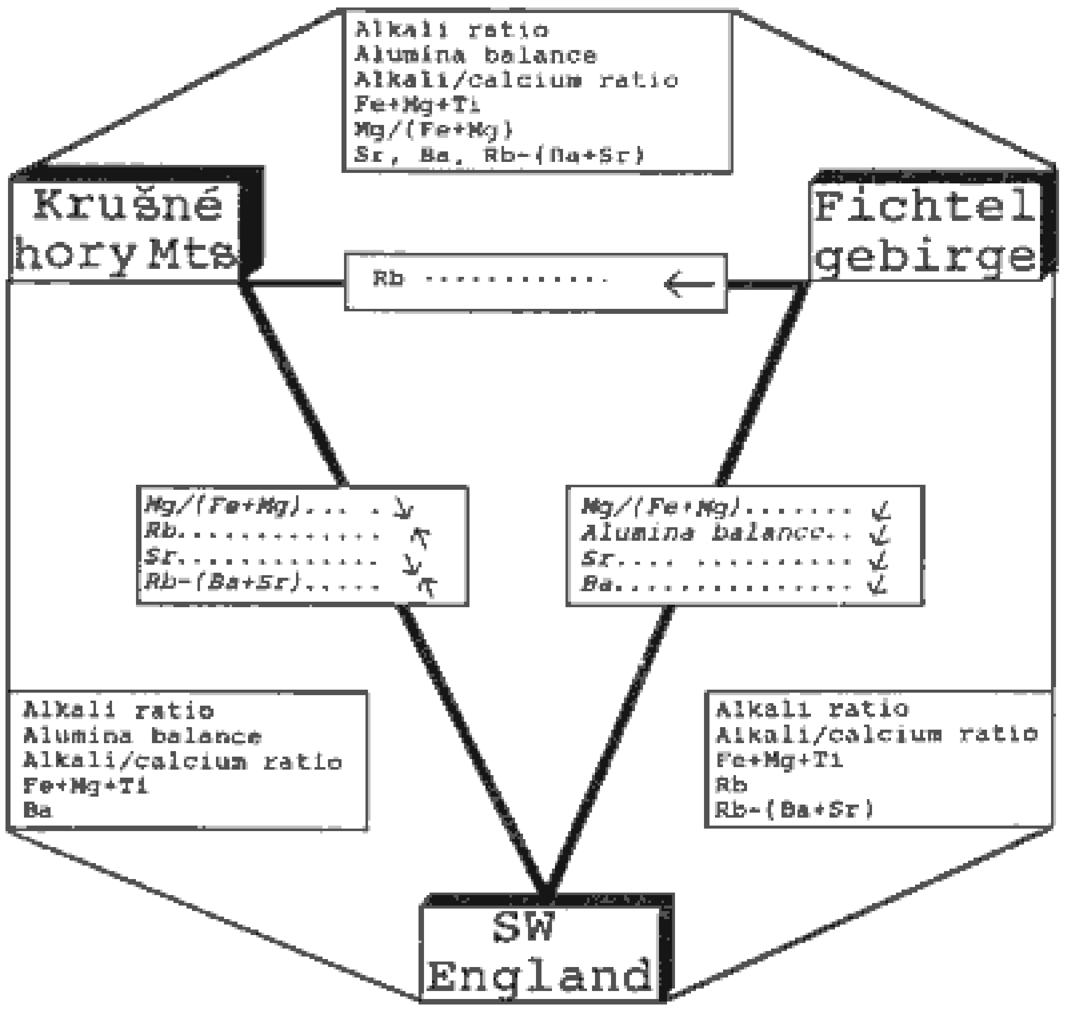

*Fig. 18(C). Relationship between the G3 granite. The parameters shown in inner boxes (connected by thick line) are not comparable between the relative provinces. Arrows indicate trend of increasing. The parameters in outer boxes are comparable between the provinces connected by thin line.*

the G2 and G4 granites although they are closer to the G4 granites than the G2 granites, except for alumina balance and Sn (Fig. 15). The G3 granites in all the granite plutons are similar in most of the cationic parameters except for Mg/(Fe+Mg) and Sr ratios, which are higher in the Cornubian granites. Rb is relatively higher in the Krušné hory batholith. Cornubian G3 is more aluminous than the Smrčiny Mts. G3 (Fig. 18C). The higher contents in Rb in the Krušné hory batholith may indicate higher degree of the differentiation. Higher magniferous nature (Mg/Fe+Mg) of Cornubian G3 granites may be problematic, but probably explain the great abundance of pelitic xenoliths in the Cornubian granites (Lister, 1984). The G3 granites of the Smrčiny Mts. and Krušné hory Mts. are remarkably similar. The phase of G3 granite formation in both batholiths seems to be syngenetic and simultaneous, as their geochronological data indicate about 290 Ma for G3 granites in both batholiths.

### G4 granites

In the G4 granites $SiO_2$, alumina balance, Rb, Rb-(Ba+Sr), and the alkali/calcium ratio are relatively higher than in the G3 granite but lower than in the G5 granites. On the other hand, dark mineral constituents, Mg/(Fe+Mg), alkali ratio, $TiO_2$, $K_2O$, normative An and Or, Ba, Sr, and Zr are higher than in G5 and lower than in G3 granites (Fig. 15). The G4 granites in Cornwall and in the Krušné hory batholiths are remarkably similar in all calculated geochemical parameters (Fig. 18D). The G4 granites in the Smrčiny Mts. differ from the Cornubian and Krušné hory G4 granites in terms of higher dark mineral constituents and Sr. This may reflect either relatively less differentiation or more contamination by host rock in the G4 granites in Smrčiny Mts. . In general, the G4 granites in all the batholiths are similar. Geochronologically they are slightly younger than the G3 granites.

### G5 granites

The G5 granites are characterized by the highest values of alkali/calcium ratio, $Na_2O/K_2O$ ratio, $SiO_2$, alumina balance, normative Ab, Rb, and Rb-(Ba+Sr) and the lowest value of $TiO_2$, $Na_2O$, Mg/(Fe+Mg), normative An, alkali ratio, Ba, Sr, Zr, and Th (Fig. 15). In the Cornubian batholith, the G5 granites are similar to the Krušné hory G5 in terms of alumina balance, and degree of differentiation but differ in terms of having higher alkali ratio, dark mineral constituents and Sr (Fig. 18E). This may indicate that the G5 granite in the Krušné hory Mts. are more albitized than in Cornwall. The higher Sr content in Cornwall may be due to contamination as previously mentioned. G5 in the Smrčiny Mts. is similar to the Krušné Hory G5 granites but differes slightly from Cornubian G5 in having lower alkali ratio, Mg/(Fe+Mg) ratio, Ba and Sr and higher alkali/calcium ratio. This may indicate that either the granites are highly differentiated or there was a phase of dominant alkali metasomatism. In general, albitization was more dominant in the Krušné hory-Smrčiny than in the Cornubian batholith, otherwise the G5 granites are more or less homogeneous in both the batholiths.

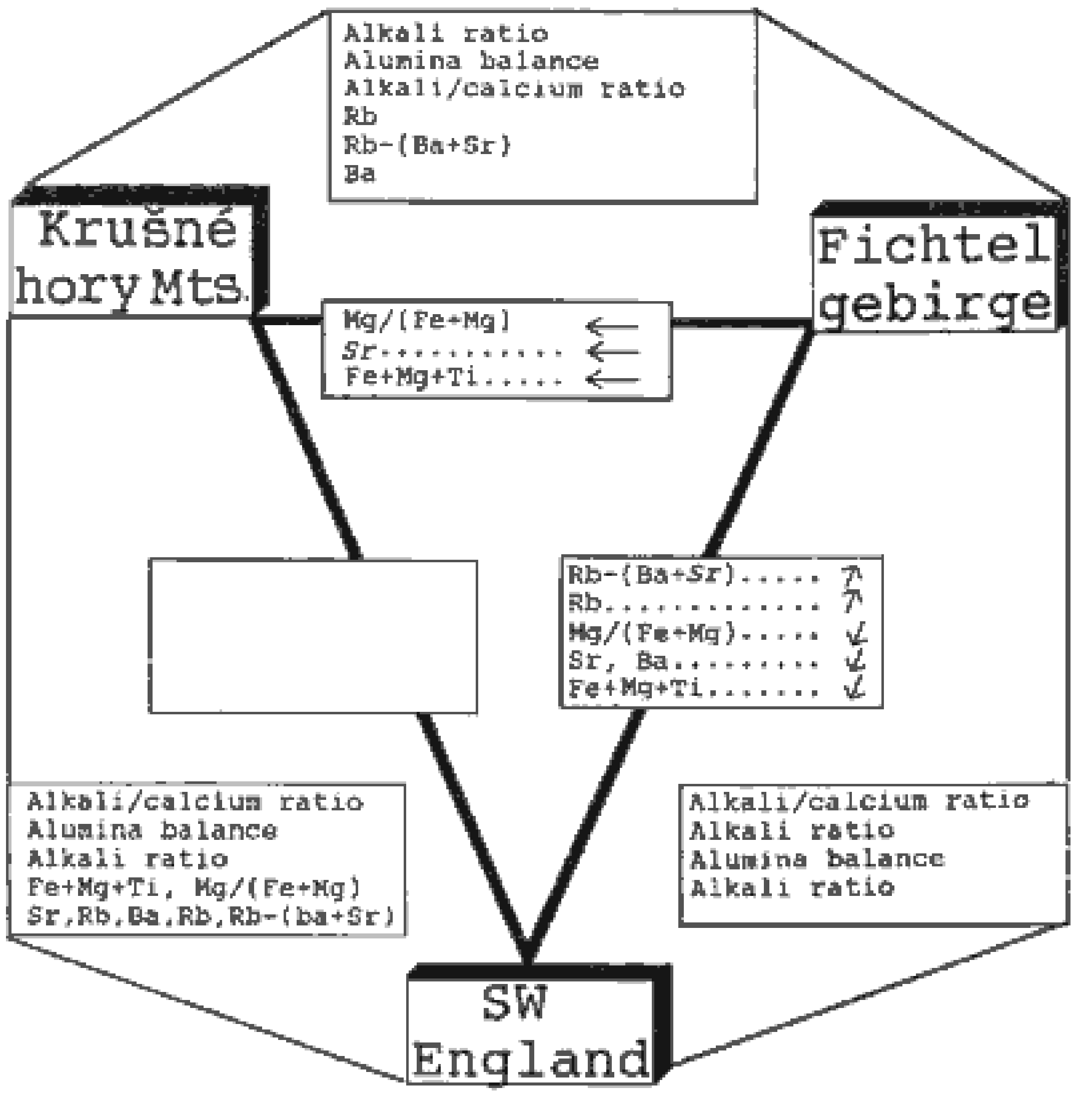

*Fig. 18(D). Relationship between the G4 granites. The parameters shown in inner boxes (connected by thick line) are not comparable between the relative provinces. Arrows indicate trend of increasing. The parameters in outer boxes are comparable between the provinces connected by thin line.*

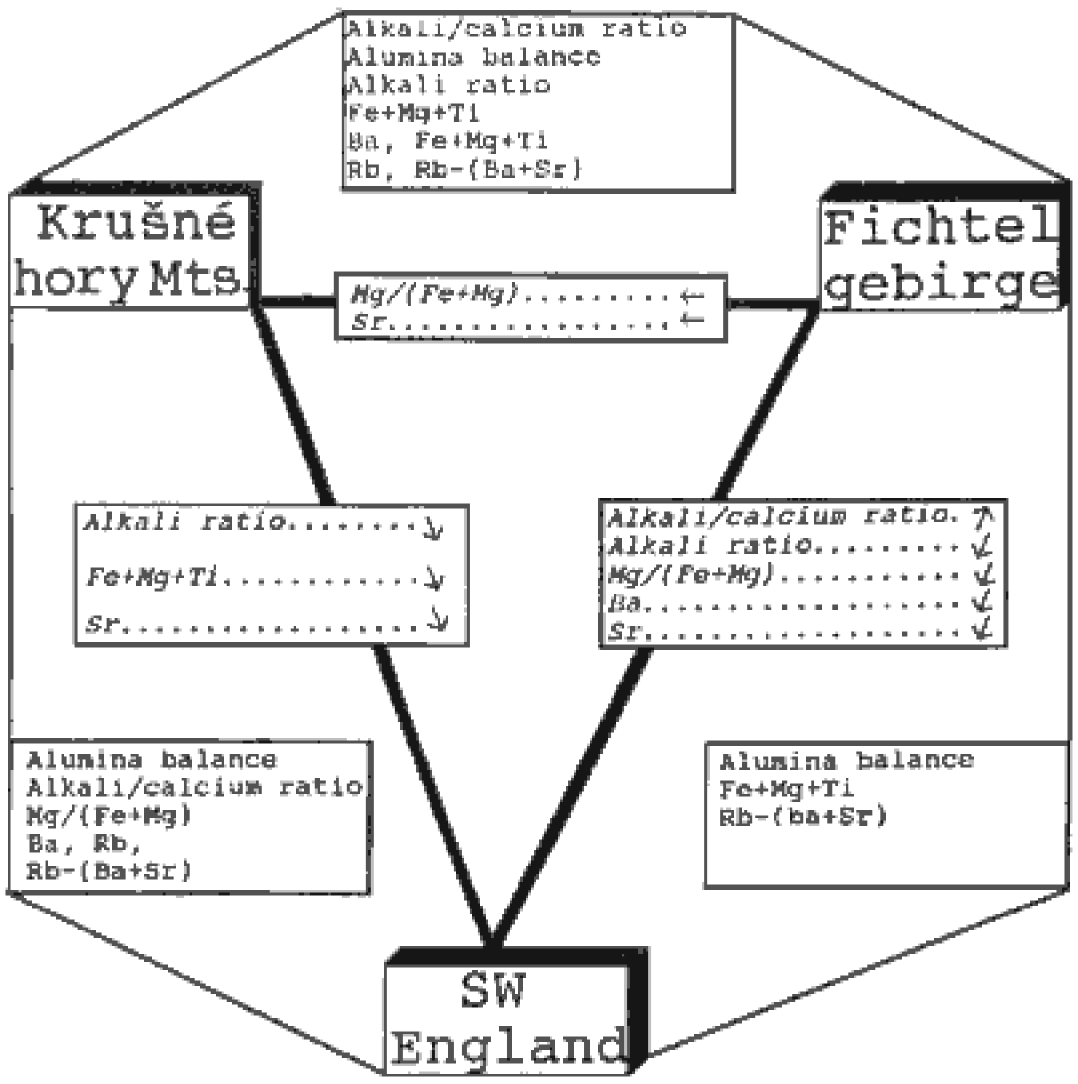

*Fig. 18(E). Relationship between the G5 granites. The parameters shown in inner boxes (connected by thick line) are not comparable between the relative provinces. Arrows indicate trend of increasing. The parameters in outer boxes are comparable between the provinces connected by thin line.*

# 3. Petrogenesis of granites

## 3.1 Differentiation and crystallization

In Rb/Sr vs Sr variation diagram (Fig. 19A), the G1 granites plot in the upper left corner and G5 granites plot in the lower right corner of the diagram. In general, it indicates an increasing order of magmatic differentiation from G1 to G5 granites but there is a slight shift in the regression line for older granites (G1 and G2) and younger granites (G3, G4, and G5). This may favour the arguments indicating that the older and younger granites are separate phases of granite magmatism. The G1 and G2 granites are close to the regression line whereas the G3, G4 and G5 granites are slightly scattered. This may indicates influence of the host rock or different composition of source rocks or some other factor. The dividing lines for high and low Ca and tin barren and tin bearing granites in Fig. 14A after Lehmann and Mahawat (1989), fit well with observations presented above, e.g. G1 and G2 granites plot in the field high Ca granite, and G3, G4, and G5 granites plot in the field of low Ca granites. The line dividing tin bearing and tin barren granite is not fully verified in the present case. In the Zr vs $TiO_2$ variation diagram (Fig. 19) positive correlation verifies progressive magmatic differentiation from G1 to G5 granites as it was already mentioned. In the Rb vs Ba variation diagram (Fig. 19) a negative regression line passes through G1 to G4 granites, but G5 do not correspond to this line, perhaps because G5 were highly influenced by a post magmatic fluid phase.

## 3.2 Tin metallogeny of granites

Some variation diagrams have been used by authors to discriminate tin-bearing from tin-barren granites. These variation diagrams, in fact indicate the status of magmatic differentiation, which is one of the most significant parameters in distinguishing the metalliferous granites. Lehmann (1982, 1985, 1987) emphasized that granites from various tin provinces show a positive linear correlation between log Sn vs log Rb/Sr diagram and negative linear correlation between log Sn vs $TiO_2$ (Fig. 19). He found that the Bolivian and Thailandian granites have wide range of variation of Rb/Sr ratio and contain low tin contents. The granites from the Cornubian and Krušné hory-Smrčiny batholiths have similar types of linear correlation (Fig. 19D & F). In Fig. 19(F), G3 granites plot close to the line of regression, whereas the plots of the other granites are more scattered. The G5 granites (which are practically related to tin deposits) plot below the regression line. A similar feature can be seen in the South-East Asian granites (Lehmann, ibid), where the highly differentiated granites are also characterized by low tin contents. This has been interpreted as removal of tin by fluid interaction (Lehmann and Harmonto, 1990). The removed tin might have been deposited in the fracture systems, in the cap mantle of the granite bodies (Tischendorf, 1989; and Hosking, 1964), which is a common type of deposits in both the batholiths examined here . In Fig. 19(D), two trends are observed. The first is represented by G3, G4 & G5 granites and the second by G1 & G2 granites. In Fig. 19 (J), Sn is plotted against Rb. In this variation diagram are some representatives of G2, which contain low Rb but relatively higher Sn content. Such representatives belong to the Nejdek granites, where the underlying G5 have apophyses in it. Possibly the tin was removed from the G5 granites during the fluid interaction and enriched in the surrounding G2. Such interpretations have already been made by Richter and Stettner (1979) and Štemprok (1986). In Fig. 19F, 1* indicates the average crustal composition ( see Taylor and McLennan, 1985), wich is close to the plots of G1.

## 3.3 Postmagmatic fluid phase

In order to determine the influence of a postmagmatic fluid phase, data are plotted in F vs Rb, F vs Sr and $TiO_2$ vs Li variation diagrams (Fig.19). F shows a positive correlation with Rb and a negative correlation with Sr. Similar to the F vs Sr variation diagram, Li shows a negative correlation with $TiO_2$. G1 granites plot in field of low differentiation and G4 granites plot in the field of highly differentiated granites. This supports the idea that F enrichement is most probably a consequence of magmatic fractionation. In places, F might be trapped in surrounding older granites. Such host granites indicate high F while containing low Rb/Sr, and Rb/Ba ratios ( dotted circle in Fig. 19).

Lange et al.(1972) have examined the behavior of potassium in Erzgebirge granites. They concluded that K increases from the older intrusive complex to the transitional granites (G3), and, in subsequent phases, it decreases to the highly metasomatic granites of the Younger Intrusive Complex (YIC). Similar observations are seen in Fig. 19 O&N, where K increases from Group 1 to Group 3 granites and than decreases from Group 3 to Group 5 granites. In most of the variation diagrams, the plots of the older granites lie close to the regression line, whereas the plots of the younger granites are scattered. This scattering of data may be due to the influence of postmagmatic processes. In Th vs U variation diagram (Fig. 19P) it is clear that Th is higher in older granites and U is enriched in the younger granites. U is almost constant in the older granites while Th varies, and in the younger granites Th is constant and U varies. Late phase granites (G5) show cumulative U. These observations may indicate different compositions of older and younger granitic magmas or some other feature.

## 3.4 Two phases of granite magmatism

The granites in both batholiths have been divided into two main suites (Older Granites and Younger Granites), which correspond to the typology proposed by Lange et al. (1972) for the Krušné hory granites. These two suites are characterized by distinct petrography, geochemistry, geochronology, field relationships, and associated metallogeny. The older and younger granites seem to represent two different events of granite magmatism during the waning stages of the Hercynian orogeny. These episodes are presently designated as 'first phase of granite magmatism' and 'second phase of granite magmatism'. The emplacement of granitic magma probably took place in several pulses. Two pluses in the first event and three pluses in the second event of magmatism could account for intrusion of G1 and G2, and G3, G4, and G5 respectively. It is important to note that G1 is absent in the Cornubian batholith, but the micro-granodioritic to micro-dioritic xenoliths in the G2 of Dartmoor may represent G1 in SW England.

The genetic relationship between the first and second phases of granite magmatism is not fully understood. However, definite intrusive relationships between the older and younger granites has been observed in the Karlovy Vary pluton, in several drilling projects (Škvor, 1975). In most cases, it is found that the older granites are underlain by the younger granites. This suggests that the older granites prepared the structural foundation and later the younger granites followed the feeder pipe and intruded the older granites. This may explain the small extent of contamination in the younger granites of the Karlovy Vary pluton. Geochronologically, Darbyshire and Shepherd (1985) indicated that the first dominant phase of granite magmatism in SW England appeared in 290 Ma and the second dominant phase appeared 10 Ma later. However, other authors believe that the first phase of granite magmatism took place prior to 300 Ma (see Adam, 1976; Hawkes, 1981). In the Smrčiny Mts., Besang et al. (1976) concluded that two different sequences of crystallization correspond geochronologically to the first and second phases of granite magmatism. Trace element geochemistry clearly favours the idea of two contrasting granite suites which correspond to the first and second magmatic events. But some elements show a gradual variation in their concentration from G1 to G5. These are Li, F, Sn, and B. In fact, these elements and their minerals are suitable for distinguishing the phases of granite formation. In both the batholiths, younger granites are emplaced into the older granites, so that the surrounding older granites are influenced by volatiles concentrated in the residual fluids of the younger granites. This is clear, from some samples of G2 granites lying in the contact zone of younger granites (G4 and G5) in the Nejdek part of the Karlovy Vary pluton, that these have high biotite/muscovite ratios, and concentration of Ba, Sr, Zr on the one hand and on the other hand high Li, Sn, and F. Such 'impure' granites generally join the clusters of first and second phase granites in variation diagrams. This hybridization can be interpreted as a result of a fluid interaction process (Štemprok, 1986, Lehmann, 1990). The assumption of two different phases of granite magmatism is partly favoured by geochronological data, which indicate about 10 Ma difference in the emplacement of older and younger granites (Tischendorf, 1989 and Darbyshire and Shepherd, 1985).

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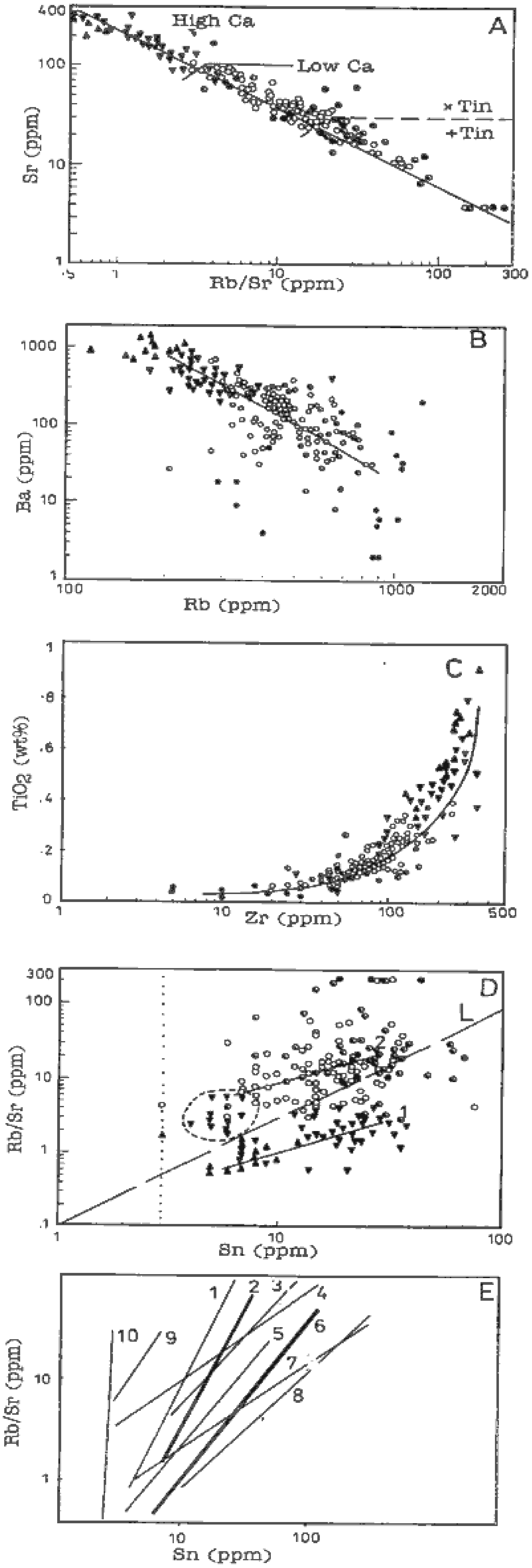
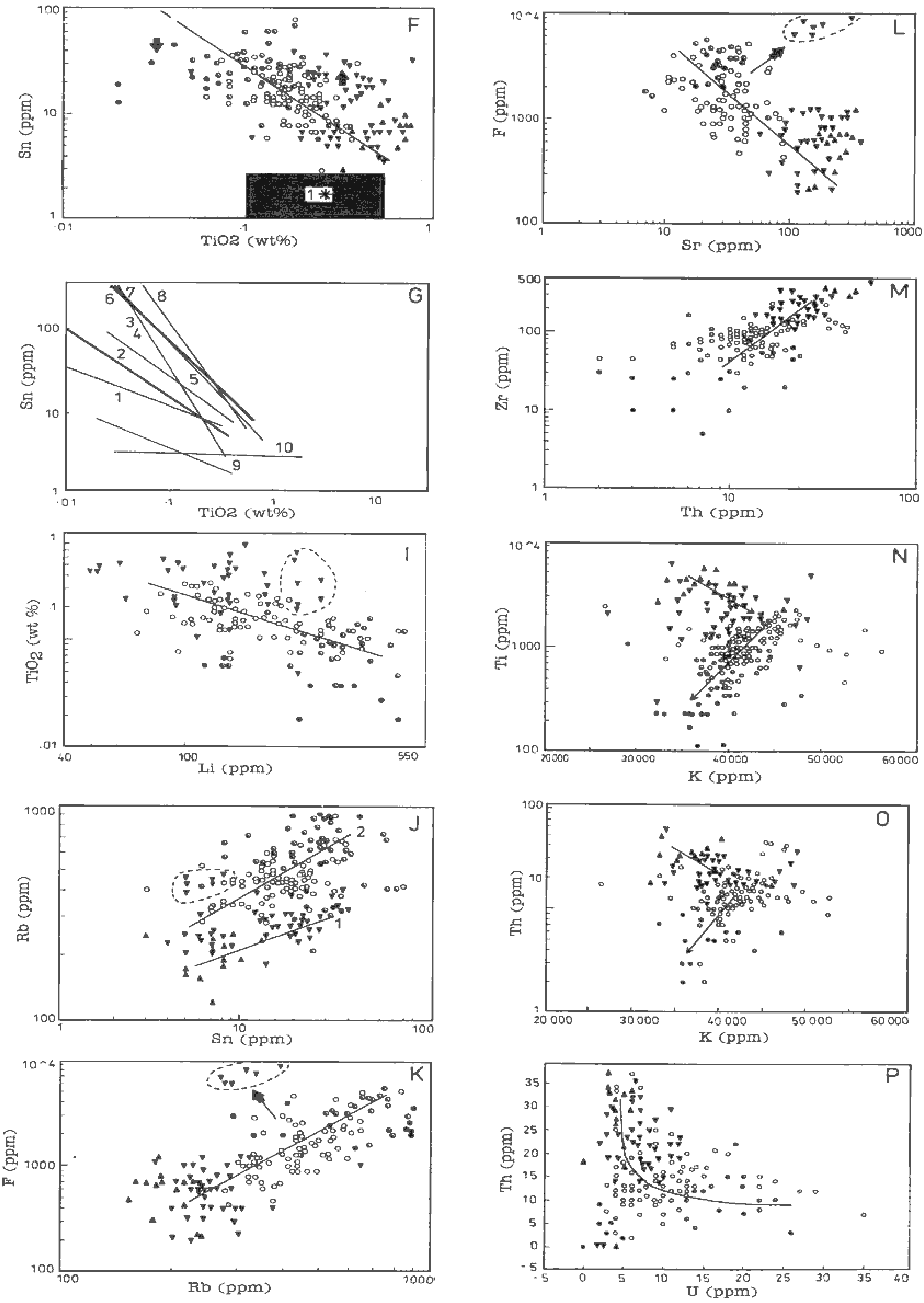


*Fig. 19. Variation diagrams. The lines in variation diagrams from A to P are not calculated regression line but they are visual fit lines except in Fig E and G. The dividing lines in A are after Lehmann (1990). Lines in A, B, and C indicate trend of magmatic fractionation. Dotted circle in D, F, I, J, K and L indicate older granite lying just above the younger granites in the Nejdek part of Karlovy Vary pluton. Solid arrow in F, K, L and M indicate change in relative parameter due to fluid interaction. In figure D, 1 and 2 indicate trend for older and younger granites respectively, and in L indicate a linear regression in Thailandian granites after Lehmann (1990). In L and N linear correlations for different tin provinces after Lehmann (1982). In figure E and G correlation lines represent following tin provinces (after Lehmann, 1982): 1-Blue Tier, Australia 2-Krušné hory Mts., NW Bohemia 3&4-Iberia, Portugal 5-Cordillera Real, Bolivia 6-Cornwall, England 7-Viseu, Portugal 8-Montebras, France 9-Sardegna, Italy 10-Cape. S.Africa. G1-up-triangle, G2-down triangle, G3-open circle, G4-half filled circle, G5- solid circle.*


F
Sn (ppm)
100
10
1
.01
.1
1
TiO2 (wt%)
1 *
G
Sn (ppm)
100
10
1
.01
.1
1
10
TiO2 (wt%)
1
2
3
4
5
6
7
8
9
10
I
TiO2 (wt %)
1
.1
.01
40
100
550
Li (ppm)
J
Rb (ppm)
1000
100
1
10
100
Sn (ppm)
1
2
K
F (ppm)
10^4
1000
100
100
1000
Rb (ppm)
L
F (ppm)
10^4
1000
100
1
10
100
1000
Sr (ppm)
M
Zr (ppm)
500
100
10
1
1
10
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Th (ppm)
N
Ti (ppm)
10^4
1000
100
20000
30000
40000
50000
60000
K (ppm)
O
Th (ppm)
100
10
1
20 000
30 000
40 000
50 000
60 000
K (ppm)
P
Th (ppm)
35
30
25
20
15
10
5
0
-5
-5
0
5
10
15
20
25
30
35
40
U (ppm)

## 3.5. Chronology of magmatic events

There are insufficient Rb/Sr ages of granites in the Krušné hory-Smrčiny batholith so that relative ages of emplacement of the granites in both batholiths is difficult to establish. However, Rb/Sr dates for granites in the Smrčiny Mts. pluton of Krušné hory-Smrčiny batholith and Cornubian batholith have been determined more systematically by Besang et al. (1976) and Darbyshire and Shepherd (1985) respectively. The available geochronological data for the granites are summarized in Fig. 20. The older granites (G1) in the Krušné hory-Smrčiny batholith has been dated as 325 ± 11 and 318 ± 5 Ma (Gerstenberger, 1987). Representatives of G2 granites in Cornwall (St. Austell and Dartmoor) and the Smrčiny Mts. (Randgranite) indicate ages varying from 290 to 280 Ma. The G3 granites in both batholiths have been dated between 288 and 275 Ma. The ages of G4 and G5 vary between 285 and 268 Ma. It is interesting that all representatives of the different groups of granite in both batholiths give nearly the same age, but some G4 and G5 granites show differences up to 20 Ma. G4 in the Land's End granite gives a younger age than the G4 Zinngranites in the Smrčiny Mts. The geochronological data for G4 and G5 granites in the Krušné hory-Smrčiny batholith are insufficient for comparison.

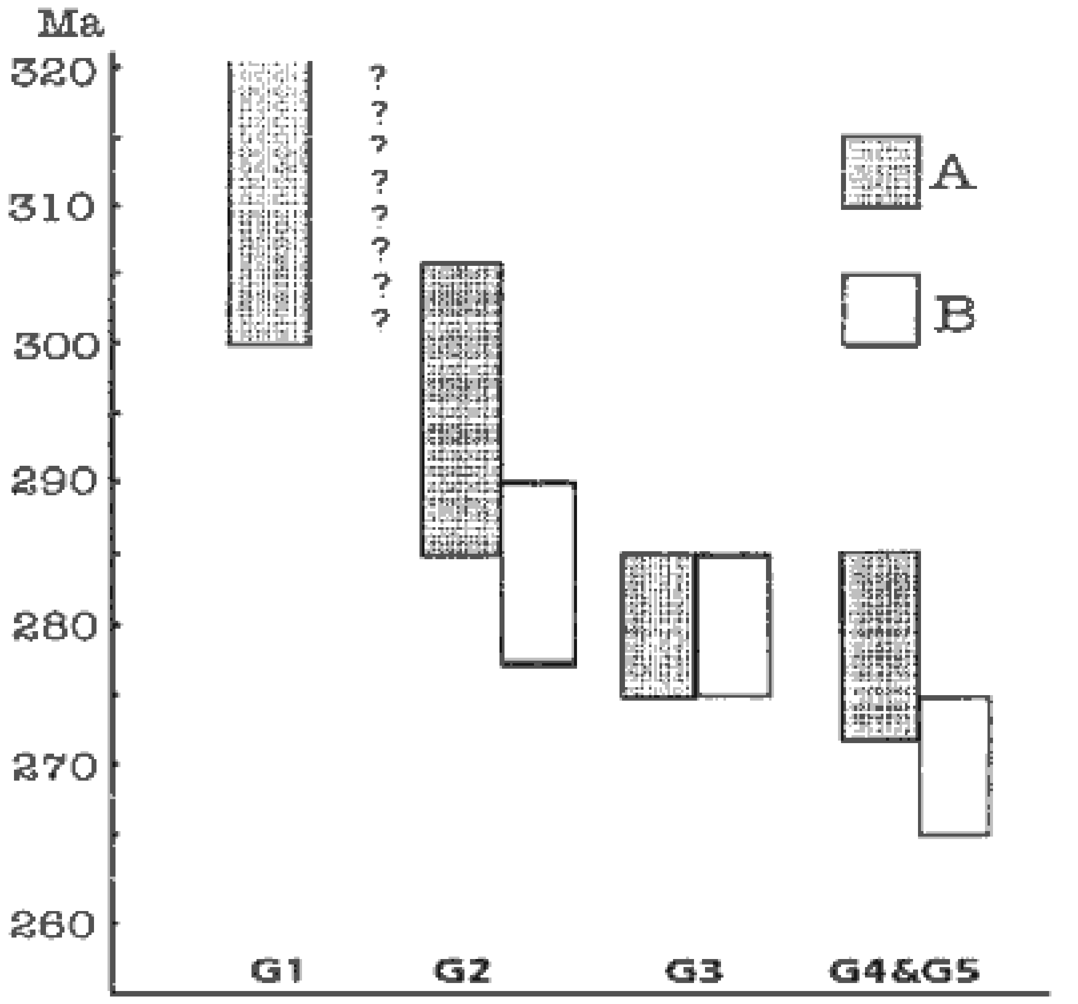

*Fig. 20. Age of emplacement of granites in Krušné hory-Smrčiny (A) and Cornubian (B) batholiths.*

# 4. Origin of granites

The problem of interpreting and commenting about the origin of granites is still in an elementary stage, though a lot of philosophical and experimental work has been done by many authorities (e.g. Sederholms, 1923; Buddington, 1933; Read, 1948; Grout, 1948; Goodspead, 1948; Tuttle and Bowen, 1958; Menhert, 1968; Winkler, 1979; Miyashiro, 1972; Green and Vsdausky, 1986; Brown, 1948; Ramberg, 1949; Wyllie, 1983; Mehnert, 1968; Didier et al., 1973; Raguin, 1965; Barker, 1981; Chatterjee and Strong, 1985; Strong et al., 1974; Clemens and Vielzeuf, 1987 and many others). Presently, some observations are discussed in an attempt to construct an image of the origin of granites in the batholiths studied here.

The seismic surveys in SW England and the Krušné hory-Smrčiny Mts. indicate the presence of a significant reflector at depths of 10 to 15 km. The MOHO discontinuity has been interpreted as occuring at a depth of 26 to 30 km. This may indicate that the source of magma occured between 15 to 26 km. According to Thomas (1989) and Tischendorf (1989) the magma for the older granites was generated at a minimum depth of 21.1 km and for the younger granites slightly deeper at 25 km. This estimate differs slightly from the estimate made by Charoy (1986) for Cornubian granites (about 17-19km).

The composition of the parental rock is controversial. Charoy (1986) suggested that the source rock for the Cornubian granites could be similar to 'Brioverian pelite'. Lehmann (1982) suggested that the $fo_2$ favour the enrichment of Sn in the residual liquid. Lehmann expected such an oxygen fugacity from the partial melting of a metasedimentary sequence of black shales and greywackes. The presence of biotite, garnet, cordierite, and andalusite restites may indicate a pelitic composition of the source rock.

The isotope measurements and petrography of the granites indicate that they are mainly S-type granites with an ${}^{87}Sr/{}^{86}Sr$ ratio 0.7086 (an average). But the ${}^{87}Sr/{}^{86}Sr$ ratio is exceptionally lower in the G 4 and G 5 granites of Altenberg (0.686) and Ehrenfriedersdorf (0.701) (in Tischendorf, 1989) (Fig. 21). This may indicates the participation of mantle material in the generation of granitic magma. Similar opinions have been proposed by many authors (e.g. Dham, 1985; Leeder, 1985; Schütze and Stiehl, 1985; and Stiehl et al., 1985). Gerstenberger et al. (1986) concluded that the younger granites were formed by mixing of 60-70 % of the mantle and 30-40 % of the lower crustal material, based on Sm-Nd measurement in the granites of the Krušné hory Mts. These observations were made in granites lying in a cauldron in the northeastern part of the Krušné hory-Smrčiny batholith, (Jiránek et al., 1987 unpublished report). In the western part of the batholith (Smrčiny Mts.), Sr ratio varies from 0.7,74 to 0,7177 in Smrčiny Mts. granites (Besang et al., 1976). Similar measurements of ${}^{87}Sr/{}^{86}Sr$ ratio have been obtained in Cornubian batholith (Darbyshire and Shapherd, 1985). These measurements can be interpreted in terms of the crustal origin of the granites, although higher ${}^{87}Sr/{}^{86}Sr$ ratios have been measured in truly anorogenic provinces e.g. Nigeria (van Breemen et al., 1975).

Petrographically, the first phase of granite magmatism shows crystallization of biotite later than quartz and K-feldspar (Ab/Kf/Qt/Bi). In the second phase, Ab/Kf/Bi/Qt have in addition crystallized later. In this order crystallization of biotite is of particular interest, because its stability relative to quartz and feldspars seems to be ruled by the water content of the magmatic system (Piwinskii and Wyllie, 1970; Piwinskii, 1973, 1975; and Maaloe and Wyllie, 1975). The actual position of biotite in the first phase is similar to that in the experimental results for the water undersaturated system. Rocks of similar composition have been produced at about 7 kb (27-28 km) and 800 $^{0}$C (Brown and Fyfe, 1970 and Fyfe, 1973). Similar, P-T conditions for the granites have proposed by Charoy (1986). Higher temperatures can be assumed for the formation of granitic magma in these provinces if they are derived by an orogenic crustal anatexis (Wedephol, 1991). Other experimental studies indicate the genesis of granite in water saturated system (e.g. Tuttle and Bowen, 1958, Luth et al., 1964 and Winkler, 1979). Petrographical and geochemical observations show that the initial melt for at least the older granites could have been generated in a water-undersaturated system. Recent experimental studies also verify this assumption (e.g. Johnson and Rutherford, 1989; Johannes and Holtz, 1991).

It is generally agreed that 4% $H_2O$ is essential to form 50% melt, which is able to rise in the crust. Johannes and Holtz found that a initial melt with 50% melt plus 50% quartz and feldspar would occur at 720 $^{0}$C to 920 $^{0}$C and 8 kb pressure, in a closed system. This temperature accords with zircon thermometry, which indicates 800 $^{0}$C for the initial crystallization of the melt in the older granites. The amount of melt at given P-T conditions would depend upon the availability of water (Johannes and Holtz, 1991), whose supply could be provided by the break-down of muscovites in a close system or from some external source.

In the later stages of the second phase of granite emplacement, an addition of a fluid to the solid to sub-solidus state of the granite melt might have occurred (Štemprok, 1986). The source of fluid, which gave rise to Sn and associated mineralization is not fully understood. There are two schools of thought pertaining the source of Sn in granites. First- Sn was derived from the source rock from which the magma was derived, and in the case of tin deposits associated with the granites, Sn was enriched sufficiently in the residual melt during crystallization. Second- Sn was brought to the magma by a fluid phase. In fact, both schools of thought are logical and confirm with some petrographical and geochemical evidence. It seems that geochemistry and/or petrography is unable to distinguish the differences. Perhaps, the alkali-rich fluid could have been derived from the lower crust or upper mantle (Groves and McCarthy, 1978; Chauris, 1977; Štemprok, 1977; Sainsbury et al., 1968; Barsukov and Dmitriev, 1972; Bernard, 1980; and others) or it might have been a residual liquid from the crystallization of the main phase of the granites (Bowen, 1945; Tuttle and Bowen, 1958; Plimer, 1980; Hesp and Varlamoff, 1977; Brunhamm and Ohmoto, 1980; Sattran, 1981; Lehmann, 1982 and others). It is important to consider, - is the amount of fluid derived as a residual liquid sufficient for the metasomatism of such a huge mass of granites ? If not, then from where has the fluid been derived ? A general observation of the world-wide distribution of tin metallogenic fields indicates that granites associated with mineralization are characteristically highly differentiated, high ${}^{87}Sr/{}^{86}Sr$ ratio, S-type, and peraluminous, leucogranites, occur in thin crustal provinces (30 to 40 km) (Table 6).

*Table 6. Crustal thickness under tin barren and tin bearing leucogranite provinces.*

| Crustal thin provinces (Tin bearing leucogranites) | | Crustal thick provinces (Tin barren leucogranites) | |
|---|---|---|---|
| Africa | (20-30 km) | Higher Himalaya | (65-70 km) |
| Hercynian Europe | (35-40 km) | Alps | (50-55 km) |
| SE. Asia | (25-30 km) | Tain Shan | (45-50 km) |
| E. Australia | (30-40 km) | N. Pamir | (65-70 km) |

The intrusion level of the older granites can be determined with less confidence than that of the younger granites, because the former are deeply eroded whereas the roof of the younger granites is still preserved. In general, the roof of the younger granites lies nearly parallel to the present surface at many places. The younger granites can be assumed to have been emplaced at a depth of between 3 and 6 km as the separation of fluid from melt and the precipitation of metal have been calculated as pressure decreased below 2 kb (Nakano and Urabe, 1989 and Candela, 1989). Thomas (in Tischendorf, 1989) has calculated that intrusion level of about 7 km for older granites and about 3 km for the younger granites in the Krušné hory-Smrčiny batholith (based upon fluid pressure calculations and the linear correction relation between Pws and H). Charoy (1986) estimated that the final crystallization of the early Cornubian magma (G2 or older granites) took place at about 650 $^0$C and 2-2.5 kb pressure, which corresponds to 7-9 km depth. Charoy's estimation is not inconsistent with Thomas's estimation for older granites in Krušné hory Mts. Flyod (1971) estimated that the load pressure in Land's End aureole was 1 kb or less, representing a depth of 2-4 km, and a similar depth was proposed by Allman-Ward et al. (1982) for the emplacement of the Wheal Remfry complex at St. Austell (younger granites). These estimations of depth for emplacement of younger granites in Cornwall are similar to Thomas's calculation for same in Krušné Hory Mts.

A tentative model for crystallization in the granites in the batholiths considered here is shown in Fig. 21. An initial melt is estimated at 920 $^0$C and 8 kb P with 4% $H_2O$. The melt fraction of magma, the water activity and the viscosity increases with decreasing pressure. The temperature slightly decreases to 700 $^0$C. The viscosity is approximately two orders of magnitude lower than it was at 900 $^0$C. This is related to the higher amount of water in the melt at low T (Johannes and Holtz, 1991). In the subsequent stage of magma development, an addition of fluid phase may occur at low P and T conditions, although not lower than as required for metasomatism (e.g. 400-600 $^0$C and 2-4 kb pressure, Ivanova and Naumov, 1983). If the followings could be accepted as facts, an approximate model for the evolution of the granites shown in the cartoon diagram (Fig. 22) can be considered:

- Base of older granites lying at a depth of 4-6 km.
- Base of younger granites laying at the depth of 14-15 km.
- 20-25 km depth for magma formation.
- Roof of younger granites nearly parallel to present surface.
- Younger granites are intruded into the older granites.
- Older granites are eroded to a deeper level and the younger granites are not yet fully exposed.
- Older granites emplaced at 330-331 Ma and younger granites emplaced at 270-290 Ma.
- 10 Ma interval between older and younger granite emplacement.

According to this model 6 to 10 km of crustal thickening might have occurred during 10 Ma of the late stage of the Hercynian orogeny, and the feeder pipe for the older granites was followed by the younger granitic magma.

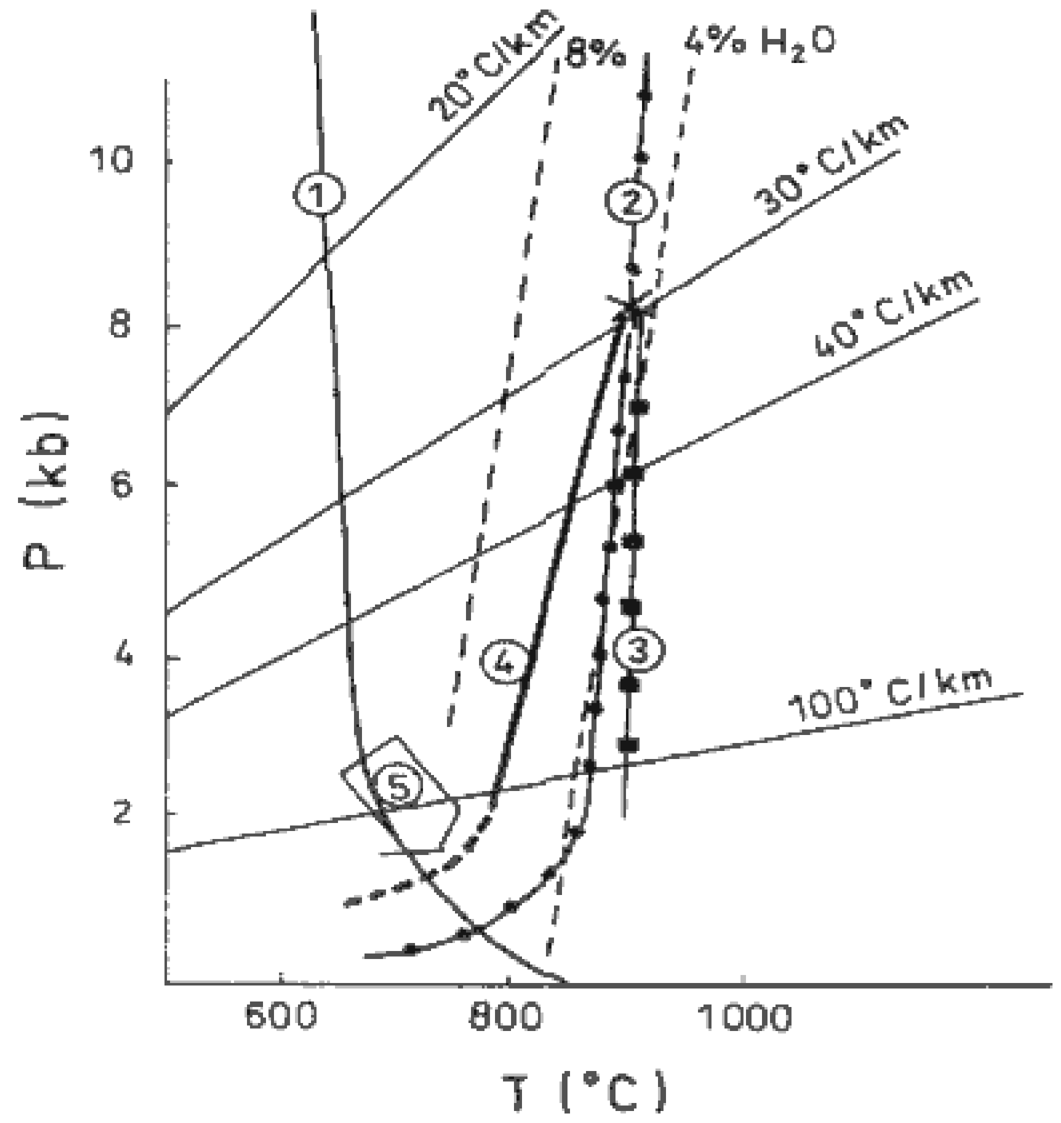

*Fig. 21. A tentative model for crystallization path of granitic magma in Cornubian and Krušné hory-Smrčiny batholiths: 1 – solidus of granite (Wyllie, 1977), 2 – liquidus curve of biotite (Burnham, 1979), 3 – crystallization path for haplogranites (Johannes and Holtz, 1991), 4 – crystallization path for granites in the Cornubian and Krušné hory-Smrčiny batholiths, 5 – addition of fluid phase to the younger granites. The geotherms are drawn after Reier (1968).*

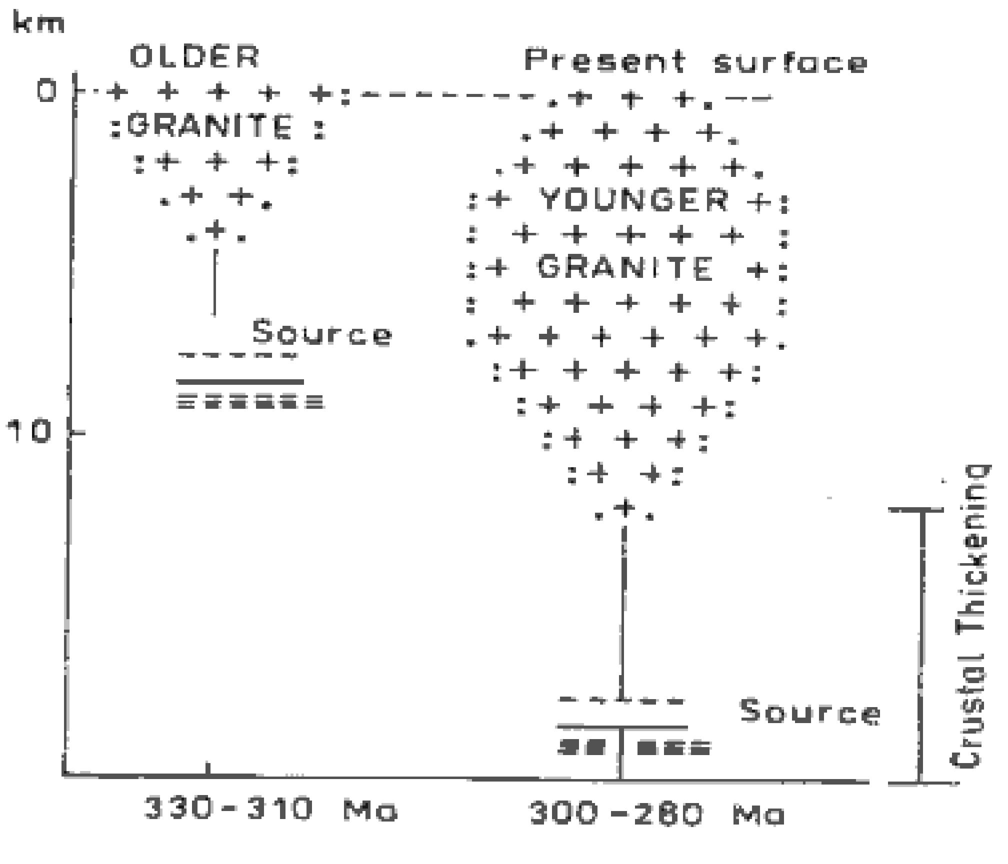

*Fig. 22. . Cartoon diagram showing an evolution of Krušné hory-Smrčiny batholith.*