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A COMPARISON OF THE KRUŠNÉ HORY-ERZGEBIRGE (CZECH REPUBLIC - GERMANY) AND CORNISH (UK) GRANITES AND THEIR RELATED MINERALISATION

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The mining regions of the Krušné hory-Erzgebirge (Czech Republic - Germany) and of SW England (UK) are components of the northern branch of the European Variscides. They both have complex metallogenesis associated with granite batholiths of approximately similar size formed from the multiple injection of magma pulses at a high crustal level. Whereas the Krušné hory-Erzgebirge batholith and the Fichtelgebirge pluton include more primitive members, the Cornubian batholith is composed almost exclusively of more evolved granites with Rb over 300 ppm and low Sr. In the Krušné hory-Erzgebirge batholith these are comparable with the granites of the Younger Intrusive Complex. The chronometric interval of granite emplacement in the Krušné hory-Erzgebirge (KE) is broader, from about 330 to 290 ma, than that of the Cornish granites between 300 and 275 ma.

The Cornubian metallogenic province has been more productive of tin and copper than the KE province which produced more uranium and silver and, in recent years, much fluorite. However, the overall metallogeny characterized by Sn-W-Cu-As-Zn-Pb granite-related assemblages and epithermal Pb-Ag-U-Mn associations is similar in both the provinces. The Cornubian batholith can be characterized as B-enriched in contrast to the F-enriched granites of the KE, where greisen assemblages are typical of post-Variscan mineralisation. The classical Cornish type of vertical mineral zoning is poorly developed in the KE province, though there are lateral variations between the eastern and western parts of the batholith on a broad scale. In contrast the mineral zones of the Cornubian province are localized and may involve telescoping within lode complexes. Whether the similarity in the metallogeny of both the regions is the consequence of a number of coincident factors or of one major difference remains a matter of speculation. It has been repeatedly emphasized by workers in both the provinces that the metal enrichment can be explained by a mantle input to granitic sources either through mafic melts of mantle origin or by mantle fluids. The effect of meteoric waters on epithermal metallogenesis in the KE province has not been so far proved; this is in contrast with the Cornubian province where the effect of brines of meteoric origin on ore genesis has been indicated by isotopic data.

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INTRODUCTION

The polymetallic Cornubian (Cn) and Krušné hory-Erzgebirge (KE) metallogenic provinces include some of the most productive mining districts of Europe. Comparison of their geological and metallogenic features has challenged a number of workers. Key contributions include stratigraphy (Hendricks 1937), metallogeny (Berg, 1927, Shcheglov, 1968) and granite petrology (Rajpoot and Klominsky, 1993).

Mining and exploration for ores in the 18th and 19th centuries coincided with the birth of geology as science. Both the provinces provided data and interpretations from which some of the present theories of granite-related metallogenesis have been developed. The KE became a standard place for the concept of mineral "formations" worked individually in the Freiberg district in Saxony and the name "greisen" for the alteration accompanying tin-bearing veins derived from this province is now used worldwide. In Cornwall the observation of the vertical change of the lodes from copper downwards into tin (Collins 1912) led to the concept of metalliferous zoning, later elaborated into a general scheme of zoning around granite bodies by Emmons (1924).

GEOGRAPHY

The KE is a mountain ridge in the border area between the Czech Republic and Germany which extends SW to Smrčiny Fichtelgebirge (Figure 1). The granite outcrops lie between about 500 m and 1000 m above sea level, and have been penetrated by drilling to a depth of 1596 m at Cinovec (Zinnwald).

In SW England the granite outcrops extend from about 470 m AOD in the Dartmoor pluton to sea level. A drill hole was sunk to about 2600 m in the Carnmenellis granite of West Cornwall for geothermal exploration.

GEOLOGICAL INTRODUCTION

The Palaeozoic rocks of south west England are the low-grade metamorphosed components of an orogenic belt up to 1000 km wide which originated by the Late Palaeozoic collision of Laurasia and Gondwana (Ziegler, 1982, Badham, 1982). The outcrops of the pre-Mesozoic basement in the northern branch of the European Variscides (Rhenides) were interpreted as distinct zones by Kossmat (1927) (Rhenohercynian, Saxothuringian and Moldanubian) on the basis of their sedimentary, structural and metamorphic history (Figure 2), or partly continuous by Franke (1989). The continuity of these zones was doubted by Matthews (1977) and Badham (1982). Holder and Leveridge (1986) found criteria for the continuity of the Rhenohercynian zone on the basis of similarities in tectonic evolution of SW England, the Rheinisches Schiefergebirge and the Harz.

The Bohemian Massif along with the Armorican Massif is within the crystalline core of the Variscan chain (Figure 2) (Saxothuringian and Moldanubian zones) whereas the Rheinisches Schiefergebirge and SW England occur in a more external flysch-type Rhenohercynian zone.

The envelope of the Krušné hory-Erzgebirge - Smrčny-Fichtelgebirge (KESF) batholith comprises crystalline rocks ranging in age from Upper Proterozoic to Ordovician arranged in a NE trending anticline. The Upper Proterozoic is represented in the East by monotonous gneisses (metagreywackes) overlain by paragneisses and micaschists with limestones, amphibolites and quartzites of the Přisečnice (Pressnitz) group. In the central KESF these are intruded by premetamorphic apparently Cadomian granitoids ("red gneisses"). The overlying Klinovec (Keilberg) group of presumed Cambrian age comprises uniform micaschists pushing upwards into a Cambrian - Ordovician sequence with mica schists and phyllites containing amphibolites and limestone intercalations.

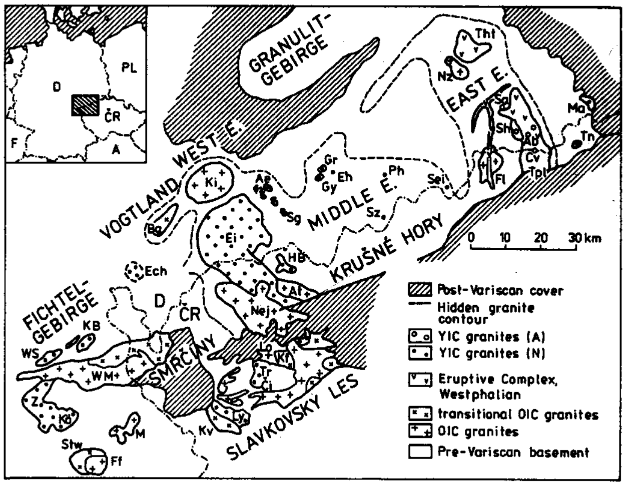

Figure 1. Sketch map according to Förster and Tischendorf (1994) showing the regional distribution of Variscan postkinematic silicic plutonic and volcanic rocks in the Erzgebirge -Krušnné, hory, Vogtland, Fichtelgebirge/Oberfalc - Smrčiny, and Slavkovský les (Kaiserwald) areas. Legend: Fichtelgebirge/Oberfalz - Smrčiny: WM - Weissenstein-Markleuthen, WS - Waldstein, KB - Kornberg, Z - Zentralmassiv, Kösseine, STW - Steinwald, Ff - Friedenfels, M - Mitterteich; Vogtland: Ech - Eichit, Bg - Bergen, Western Erzgebirge - Krušné hory: Ki - Kirchberg, Ae - Aue, Sg - Schwarzenberg, Ei - Eibenstock, Nej - Nejdek, At - Abertamy, HB - Horni Blatná, Middle Erzgebirge - Krušné hory: Gy - Geyer, Gr - Greifensteine, Eh - Ehrenfriedersdorf, Sz - Satzung, Ph - Pobershau, Sei - Seifert; eastern Erzgebirge - Krušné hory: Nz - Niederbobritsch, Fl - Fláje, Tn - Telnice, Ab - Altenberg, Sa - Sadisdorf, Cv - Cinovec, Ma -Markersbach, Tht - Tharandt, Tpl - Teplice; Slavkovský les: Lo - Loket, Kf - Kfely, Tr - Třidomi, Ci - Čistá, Ly - Lysina, Kv - Kynžvart.

	Krušné hory (Erzgebirge)	**SW England**
Age	340-290 ma.	300-270 ma.
Underground size	8,000 km^2	6,000 km^2
Thickness	8 - 12 km	10 - 15 km
Outcrop size	1,880 km^2	cca 800 km^2
Number of plutons	4	6
Number of outcrops	25	18
Heat flow	up to 80 mW/m^2	up to 130 mW/m^2
Heat production	3.6 μW/m^3	6.0 μW/m^3
Intrusion depth	2 - 3 km	2.5 - 4 km
Extrusive rhyolites	present	weakly developed
Lamprophyres	present	present
Differentiation ranges	Gabbro/Diorite to granite	granite

Table 1. Granite batholiths (compiled according to the data by Stone and Exley, 1985, Rajpoot and Klominský, 1993, Chesley et al., 1993, Halls, 1994 and C. Tomek, pers. communication, and own data).

In the north western part of the KESF the country rock consists of phyllites, mica schists and quartzites with metabasites and skarns near the basal part of the succession. Eclogites, granulites and garnet peridotite occur in the lowermost part of the Přisečnice group (Carswell and O'Brien, 1994).

The crustal structure of the KE is characterized (Bankwitz and Bankwitz, 1994), by an overall acid crust with the absence of substantial mafic intrusions or mafic restites. It is seismically stratified by megashear bands rather than by lithostratigraphy, and has a clear structural unconformity in the lower crust and evidence of the nappe structure mainly in the East. Several NE-SW trending lineaments extend to Moho levels (Trumbull *et al.,* 1994).

The granites in Cornwall and Devon have intruded a weakly regionally metamorphosed sequence of folded and faulted marine mudrocks, siltstones and sandstones of Devonian to Carboniferous age enclosing basic eruptives and carbonates (Halls 1994). The wave of Variscan deformations started in the south and progressed northwards to terminate in the Late Carboniferous. In the south the rocks are heavily cleaved, tightly folded and affected by major northward directed thrusts. The folding in the north is more open and upright except along the southern and northern margins of the Culm synclinorium. In contrast to the KE anticline, SW England is built up by a major syclinal system with general E-W trend of fold axes and anticlines in the southern limb. A thin-skinned thrust and nappe tectonic concept is accepted for the Cornubian province when upper Palaeozoic rocks became detached from their basement and pushed northwards (Shackleton *et al.,* 1982). This did not result in any marked thickening of the crust as no substantial uplift occurred to the end of Carboniferous (Watson *et al.,* 1984). In the east the upper Palaeozoic rocks are unconformably overlain by gently dipping unmetamorphosed Permo-Triassic sediments (Willis-Richards and Jackson, 1989).

KRUŠNÉ HORY-ERZGEBIRGE AND FICHTELGEBIRGE-SMRCINY

The KE batholith along with the Smrčiny-Fichtelgebirge pluton is a north-east trending granitoid body cropping out in an area of about 8,000 km^2 (Figure 1). The KE batholith itself is divided into the deeply eroded Western pluton, less exposed Middle pluton and intermediate level Eastern pluton. The Western pluton was split into its KE part to the north-west (Nejdek - Eibenstock) and Slavkovský les part to the south-east (Figure 2) by a major fault zone active in the Tertiary which formed piedmont basins.

CORNUBIAN BATHOLITH

The Cornubian batholith extends from the eastern contact of the Dartmoor granite to the Isles of Scilly, a distance of about 180 km with a width of about 40 to 60 km; it is exposed in 5 major plutons (Stone and Exley, 1985, Willis-Richards and Jackson, 1989, Halls, 1994). The essential characteristics of granites in the two provinces are given in Table 2.

Comubian	Fichtelgebirge	Krušné hory-Erzgebirge
Stone and Exley (1985)	Richter and Stettner (1979)	Štemprok (1986)
Type/name (granite)	**Symbol/name**	**Symbol/name**
A/ basic microgranite?	G1/	OIC/
	gabbrodiorite	gabbrodiorite
	granodiorite	quartz diorite
	porph. biotite	biotite granite
	granite	(monzogranite)
	G1S/	OIC - Om-TR/
	two mica granite	two mica granite
		Teplice rhyolite
		granite porphyry
A/ basic micrograpnite?	G2/ marginal	YIC, IM/ marginal,
	fine-grained	porphyritic
	porphyritic	microgranite
B/ coarse-grained	G3/ biotite or	YIC/ biotite or
megacrystic	two mica granite	two mica granite
biotite	(syenogranite)	(syenogranite)
C/ fine-grained		
biotite		
D/ megacrystic Li mica	G4/tin granite	YIC, Ym/Li mica
E/ equigranular Li mica	biotite or Li	YIC, Ym/Li mica
	mica granite	albite granites
F/ fluorite granite		

Table 2. Comparison of the granitic sequences of the Cornubian batholith, Fichtelgebirge pluton and the Krušnné hory/Erzgebirge batholith

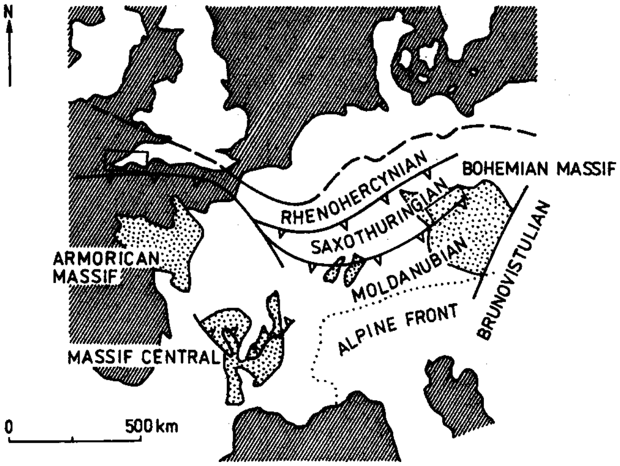

Figure 2. Schematic representation of orogenic zones in the northern branch of European Variscides from Štipská and Schullann (1994) based on Franke (1989) with the marked location of the SW England and Krušnné hory - Erzgebirge, Fichtelgebirge-Smrčiny metallogenic provinces (boxes).

In both the provinces the large plutons are accompanied by a number of small cupolas which are commonly strongly mineralized. The Cinovec, Preisselberg, Krásno, Altenberg granites in the KESF batholith (Figure 1) and St. Michael's Mount, St Agnes and Cligga Head in Cornwall (Hosking 1964) are examples.

GRANITES

The granites in the KEFS batholith have been studied by modern methods since the middle of the 19th century, when the concept of two granite series was introduced (Laube, 1876). Later these were classified as Older (OIC) and Younger (YIC) Intrusive Complexes (Lange *et al*, 1972, Štemprok, 1986). In the Fichtelgebirge more recent work by Richter and Stettner (1979) presented a modern petrological classification differentiating 4 granite groups (G1 to G4) and a number of more mafic precursors. Such granitoid precursors were identified among the granites of the Slavkovský les where the separation of the granites into two contrasting series has been considerably modified by Fiala (1968). This work differentiated the granites with transitional geochemical features. Similar intermediate petrochemical properties were found in porphyritic microgranites also classified as marginal granites (Štemprok, 1993a) which commenced the cycle of the YIC granites. A special type is represented by the lithium mica granites developed in some internal margins of YIC granites (Štemprok, 1986); for these a magmatic versus metasomatic origin has been discussed (Štemprok, 1986, Breiter *et al*., 1991). A gradual transition from zinnwaldite into protolithionite granite was identified at Cinovec (Zinnwald) (Rub *et al*, 1983) by a deep drill hole (Štemprok and Šulcek, 1969).

Sequential classification has not been so strictly observed in the Cornubian batholith, where the granites have been essentially classified according to their textures and micas (Dangerfield and Hawkes, 1981, Stone and Exley, 1985). A large part of the Cornubian granite batholith is formed of coarse-grained biotite-muscovite granite (type B) with about 2 cm euhedral and subhedral feldspar phenocrysts. In addition in smaller amount fine-grained biotite granite is represented (type C). Lithium granites occur as megacrystic (type D) and equigranular (type E) lithium granites (Stone and Exley, 1985) in the Tregonning and Godolphin pluton and in the western part of the St Austell pluton (Stone 1992). Fluorite granites (type F) occur to a very limited extent in association with the lithium mica granites.

The horizontal structure of the KE batholith can be defined as NE trending complex of OIC granites (Figure 4) cut across by YIC granites along essentially NW striking lineaments. The lithium mica granites probably represent the postmagmatically altered apical contact parts of the YIC granites and may well be arranged in NW trending ridges in the Eastern pluton and a bow-shaped lineament in the Western pluton (Štemprok, 1986). If we apply this type of interpretation to the Cornubian batholith the Tregonning-Godolphin granite could mark the apical, more evolved part of the Western compartment, and the western portion of the St Austell granite the more evolved part in the Eastern granite compartment.

A proposal for the correlation of the types of the granites in both the provinces is given in table 2. Equivalents of the OIC granites of the KEFS batholith are apparently missing from the Cornubian batholith (Rajpoot and Kominský, 1993). Also the more mafic precursors like gabbrodiorites and granodiorites are absent in Cornwall and Devon, though their presence may be suggested by the widespread xenoliths of basic microgranite (type A of Stone and Exley, 1985). The YIC granites may well be correlated with the B and C type granites of the Cornubian batholith, and the zinnwaldite and protolithionite granites of the KE province with D and E types of Cornish granites. There are no fluorite-bearing granites in the KEFS batholith so far known.

The Cornubian granites are classified on the basis of their petrochemical and isotopic composition with S-type, peraluminous granites, (Darbyshire and Shepherd, 1985, Stone and Exley, 1985, Willis-Richards and Jackson, 1989). The KE batholith granites appear to have the same characteristics (Štemprok, 1986) even if the YIC granites in Eastern pluton are closer to the A-type granites (Breiter *et al*, 1991). The OIC granites corresponding to the less evolved granites (adamellites) cannot be classified unambiguously either with S- or I-type granites (Tischendorf and Förster, 1990, Förster and Tischendorf, 1994; Štemprok, 1986). The granites of the KE batholith of both the complexes have the properties of the ilmenite series granites (Ishihara, 1977) as also supported by the measurements of their magnetic susceptibility (Štemprok, 1993, Förster and Tischendorf, 1994) which is comparable with the values of the Cornish granites (Willis-Richards and Jackson, 1989).

GRANITE PORPHYRIES

There is a substantial representation of rhyolitic magmatism synchronous with the granite emplacement in the Eastern pluton of the KEFS batholith. Whereas in Cornwall and Devon the felsite dykes, 'elvans', clearly postdate the emplacement of the granites (Darbyshire and Shepherd 1985), the granite porphyry in the KE province is more primitive in composition (see further) and in the Eastern pluton is intruded (Štemprok, 1986) by the granites of the YIC, e.g. at Altenberg and Preisselberg (Figure 1). There is also a certain temporal link between the mineralization and the emplacement of the elvans in the Cornubian batholith which is not so clearly manifested in the KEFS batholith. An exception is breccia pipes linked to the extrusion of rhyolites and intrusion of granite porphyries of the younger YIC granites in the Eastern pluton (Seltmann, 1994).

GRANITE GEOCHEMISTRY

The evolution of granites within the batholiths can be followed from geochemical (Lange *et al*. 1972, Tischendorf and Förster, 1990, mainly for the German part of the province; Fiala 1969, Štemprok, 1986 and Breiter *et al*., 1991 for the Czech part). The geochemistry of the Fichtelgebirge-Smrčiny granite pluton was characterized by Richter and Stettner (1979) and Štemprok (1992). The general geochemical characteristics of the Cornubian granites were presented by Stone and Exley (1985) and by Darbyshire and Shepherd (1985).

From the numerous possible ways of correlation of chemical compositions between the granites of these two provinces the A/ CNK versus SiO_2 and Rb/Sr plots have been selected for this study. The averaged values of many analyses were used from Štemprok (1986) for the KEFS batholith, and from Stone and Exley (1985) and Darbyshire and Shepherd (1985) for the Cornubian batholith.

The first plot (Figure 5) shows that the low silica members of the batholiths are represented in the KEFS batholith only in the OIC granites whose A/CNK values are close to, but below, 1.1. The YIC granites are distinctly higher in silica (about 73% SiO_2) and above 1.1 A/CNK; this shows some S-type characteristics. The Cornish granites are a little lower in silica than most of the YIC KE granites but distinctly higher than OIC granites. This supports the petrology-based conclusion that only the YIC granites of the KEFS batholith are comparable with the Cornish granites. The granite feldspars in both provinces are K_2O predominant; albitic varieties with Na_2O predominant or K_2O -Na_2O equivalent are exceptional.

In the Rb/Sr diagram (Figure 6) the negative Rb - Sr correlation is apparent. The granites of the YIC of the KEFS batholith are lower in Sr but higher in Rb than most of the Cornish granites. The Cornish granites mostly exceed 300 ppm Rb which has been empirically shown in the KEFS batholith to be the best limit between the OIC and YIC granites (Štemprok, 1986). The diagram shows a high degree of granite evolution shown by the values of Rb approaching or exceeding 1000 ppm Rb in both provinces.

GEOCHRONOLOGY

The Rb/Sr isotope data for the granites of the KE batholith by Gerstenberger (1989) gave the interval of emplacement for OIC granites of 336 - 309 ma and for the YIC of 333 - 301 ma. These results cannot distinguish an interval between the intrusion of OIC and YIC granites within the error of determination. These and recent data by Gerstenberger (Forster *et al.*, in press, Seltmann - pers. communication) are given in Table 3 supplemented by the data by Velichkin *et al* (1994) and by unpublished data of Bendl (personal communication).

The large scatter of the geochronological data in the YIC granites is considered to be due to a pronounced hydrothermal overprint leading to the addition of Rb and the loss of Sr (Gerstenbeger, 1989), and also by the incorporation of asynchronous granites in the data set. The geochronological data available before 1994 were interpreted by Förster and Tischendorf (1994) as giving ages of 330 - 320 ma for OIC granites and 315 - 290 ma for YIC granites.

Recent data on the granites do not justify a clear temporal separation of the granitic complexes. Paleontological evidence on plant relics gave a Westphalian C to D age (M. Simunek, oral communication) for the Teplice rhyolite which is postulated to originate in the time between the intrusion of the OIC and YIC granites. Three biotite separates from the granite porphyry have been analysed by Ar/Ar method (Seltmann and Breiter - in preparation) which is later than the rhyolite show plateau ages 307 - 309 ma. Thus, also the granite porphyry is according to R Seltmann (personal communication) using the synoptic time scale of Henning (1989, 1995) of Westphalian C to D age, following shortly after the origin of the Teplice rhyolite.

Granites of the Older Intrusive Complex				
Symbol	**pluton**	**locality**	**age m. a.**	**reference**
OG 1/2	Western E.	Eibenstock - Nejdek	324±12	Gerstenberger (1989)
OG 2/3	Western E.	Kirchberg	315±6	Gerstenberger (1989)
Kil-	Western E.	Kirchberg	309.4±3.8	Gerstenberger in Förster
				et al.
Ki2/3	Western E.	Bergen	313±7.4	Gerstenberger in Förster
				et al.
OG	Eastern E.	Niederbobritsch	317±4	Gerstenberger (1989)
G1	Fichtel-		326.4±2.1	Carl and Wendt (1993)
G-1R	gebirge			
G-1S				
Granites of the Younger Intrusive Complex				
YG 1/2	Western E.	Eibenstock	313±5	Gerstenberger (1989)
YG3	Western E.	Eibenstock	321±12	Gerstenberger (1989)
Ei1	Western E.	Eibenstock	305±4	Velichkin et al (1994)
Ei2	Western E.	Eibenstock	299±6	Velichkin et al (1994)
YI	Western K. h.	Karlovy Vary	305±10	Bendl (1994)
IM	Western K. h.	Bilá Skála	317±10	Bendl (1994)
YG	Middle E.	Ehrenfriedersdorf	318±4	Gerstenberger (1989)
YG	Middle E.	Pobershau-Satzung	305±7	Seifert (1994)
YG	Eastern E.	Altenberg	305±3	Gerstenberger (1989)
G2-G3	Fichtelgebirge		305±3	Carl and Wendt (1993)
G4	Fichtelgebirge		289±2	Carl and Wendt (1993)

Table 3. Geochronological data from the Krušnné hory/Erzgebirge granite batholith (Rb/Sr measurements)

Data from the Fichtelgebirge - Smrčiny by Carl and Wendt (1993)

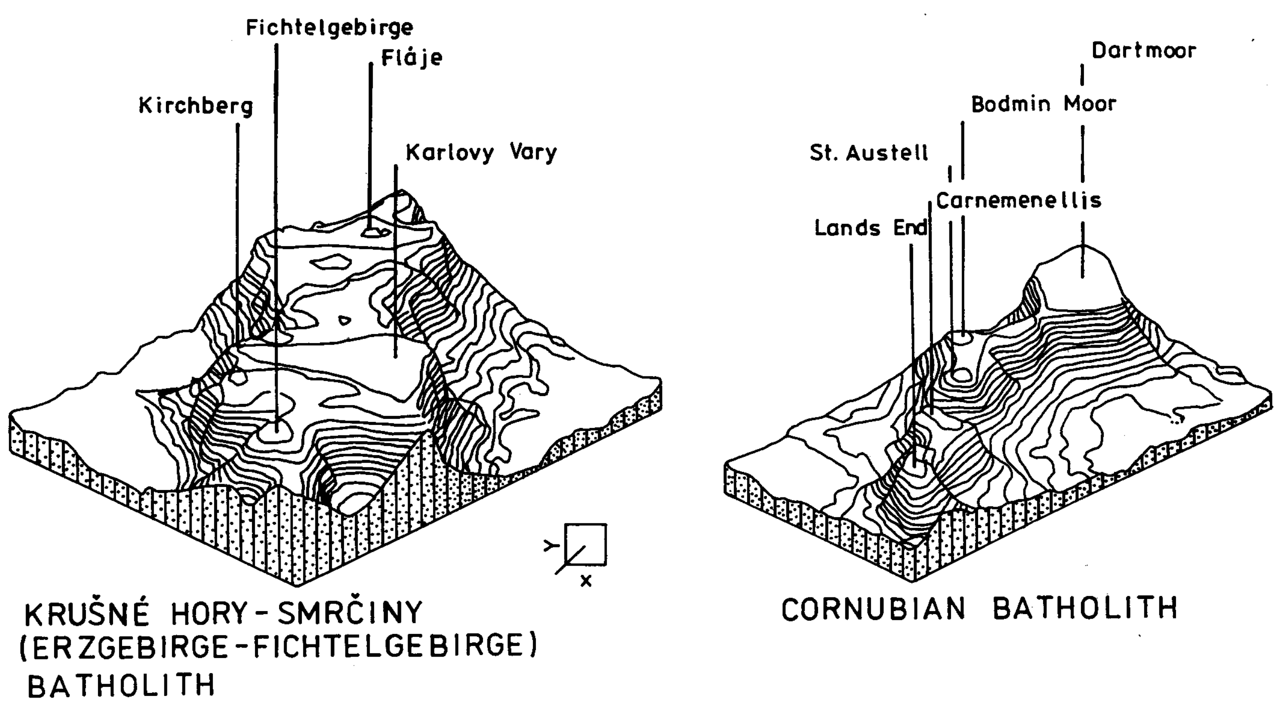

Figure 3. Isometric diagram of theforms of the Krušnné hory - Smrčiny (Erzgebirge- Fichtelgebirge) and Cornubian granite batholiths according to Rajpoot and Klominský (1993) based on the gravity data.

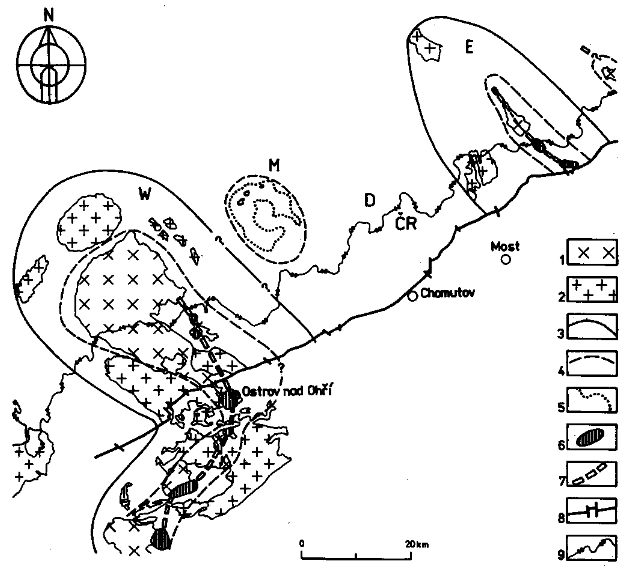

Figure 4. Magmatic zoning of the Krušnné hory - Erzgebirge granite batholith according to Štemprok (1986) with the differentiation of the granites into the OIC, YIC and Li-mica granites in three plutons (W - Western, M - Middle, E - Eastern). The lithium mica granites follow the margins of the apical parts of the batholith of the YIC granites.

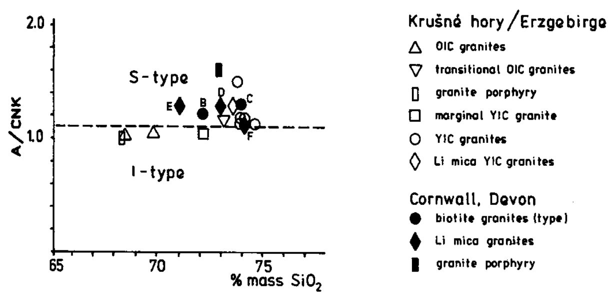

Figure 5. The A/CNK (A - molar Al_2O_3, C- molar CaO, N = molar Na_2O and K- molar K2O) versus SiO2 of the averaged granite compositions from the Krušné hory - Erzgebirge batholith Štemprok 1986) and from the Cornubian batholith (Stone and Exley 1985, the types marked with letters). The diagram shows the presence of less evolved OIC granites and granite porphyry in contrast to the more evolved YIC granites of the Krušnné bog - Erzgebirge batholith and most of the Cornish granites.

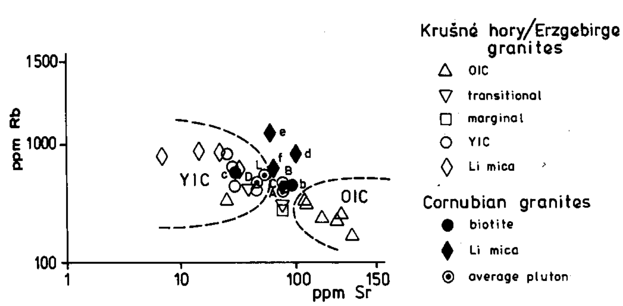

Figure 6. The Rb versus the Sr diagram of the granites of the Krušnné hory - Erzgebirge granite batholith (Štemprok 1986) and of the Cornubian batholith showing averaged data for the plutons from Darbyshire and Shepherd (1985). (L - *Land's End, D - Dartmoor, B - Bodmin, C - Carnmenellis) and from Stone and Exley (1985), averaged types in small letters.*

are in better agreement with the geological interpretation in that the equivalent of the OIC granites G1 granite was dated at 326 ± 2 ma and the possible YIC equivalent granites at 305 ± 3 ma (G2 and G3) and 289 ± 2 ma (G4) (Table 3).

The age determination of the Cornish granites has produced more consistent data. The Rb/Sr data measured by Darbyshire and Shepherd (1985) gave the interval of the emplacement of the granites between 280 - 270 ma and for the main stage of Sn-W-Mo mineralization 270 ma. These data were interpreted in terms of a more or less synchronous formation of the Cornish granites batholith.

Chesley *et al.* (1993) and Chen *et al.* (1993) interpret their isotopic data in terms of an autonomy of the plutons in age of their emplacement and subsequent evolution. The dating by U/Pb method on monazites and xenotimes indicate that the magmatism extended from 300 ma (Hemerdon granite) to 275 ma (Land's End granite) (Chesley *et al.* 1993). No major hiatus and no systematic relation between the age of a pluton and its location within the batholith could be discerned. Independence of the evolution of the plutons was demonstrated also by Clark *et al.* (1993) who found that the Cornubian batholith was emplaced diachronously from about 293 ma to about 275 ma over an interval of about 20 ma.

On the basis of petrochemistry Förster and Tischendorf (1994) in the same line of reasoning treat each of the plutons in the KE batholith as an intrinsic or autonomous unit and not as part of the homogenous series (Trumbull *et al.* 1994) however, isotopic data for this interpretation are still not available.

The granites in the KE and in the Fichtelgebirge - Smrčiny and Cornwall and Devon were thus emplaced at different times in the Late Palaeozoic. The Cornish granites within a 20 my interval starting with the Stephanian B whereas those in the KESF batholith over a 40 my interval starting in the Namurian A, according to the synoptic time scale proposed by Henning (1989, 1995).

MINERALIZATION

Ore types

The ore deposits associated with the KEFS batholith are essentially of Sn and W, and are related to the granites and their contacts. They can be classified as skarns, stockworks, veins, and sheeted greisens (Figure 7). In the Cornubian batholith the mineralization is also developed as skarns, sheeted veins (Sn-W) and lodes (Sn-Cu-As) striking essentially ENE-WSW (Jackson *et al* 1989), whereas 'crosscourses' mainly bearing Pb-Zn-Ag-F mineralization strike N-S (Scrivener *et al*, 1994). Pegmatites described from both provinces are of minor importance. Chesley *et al.* (1993) distinguished four stages of mineralization associated with the Cornubian batholith: 1) skarns, 2) pegmatites and sheeted greisen bordered veins, 3) Sn-bearing polymetallic fissure veins, 4) late polymetallic sulphide veins. Such stages of mineralizations can be identified also in the KE metallogenic province (Tischendorf *et al.* 1989).

A formational classification based on the Russian classifications was used by Štemprok (1980) to distinguish between cassiterite-quartz (wolframite-quartz) formation equivalent to stage 2, very typically developed in the KE, and cassiteritesilicate-sulphide formations typical of Cornwall and Devon (stage 3) which is but weakly developed in the KEFS batholith. The former is characterized mainly by the greisen style of alteration (Li-mica or muscovite bearing) whereas the latter one by the complex tourmaline-chlorite infillings and alterations accompanied by sulphides in veins. Even if both these styles are present in both the regions, their massive predominance is a remarkable difference notably the high copper-arsenic productivity of the Cornish cassiterite-silicate-sulphide formation and tin productivity of sheeted greisens in the KE metallogenic province.

Pb-Zn-Ag mineralization occurs in the KE province in the Freiberg ore district in separate multistage "ore formations" (pyritic, Zn-Sn-Cu, Pb, sulphidic redeposition and Ag, (Tischendorf *et al.*, 1989).

The Freiberg "formations" could be correlated with stages 3 and 4 in Cornwall (Chesley *et al.,* 1993) but without tourmaline in stage 3 veins and alteration. Uraninite-bearing veins which are typical of the Western pluton of the KE province, in association with dolomite and calcite, are rare in the Cornubian province. Fluorite mineralization is strongly represented in the envelope of the KEFS batholith and is characterized by Tischendorf *et al.,* 1989 as fluorite-quartz, fluorite-hematite-barite and fluoritebarite-galena types. It is assumed that fluorite deposition extended into the Mesozoic and Tertiary as indicated also in the Cornubian province.

The models which are traditionally used to explain the origin of the granite-related deposits (Figure 8) as summarized by Štemprok and Seltmann (1994) were used differently by various authors. Primary residual liquids below the cusps (Hosking, 1964) of the granitoid batholith and the development of emanative centers within the batholith (Dines, 1956) were employed to elucidate the origin of fluids by crystallization from granitic magma in the Cornubian batholith. A similar model was accepted by Tischendorf in the Erzgebirge to postulate the accumulation of incompatible elements by

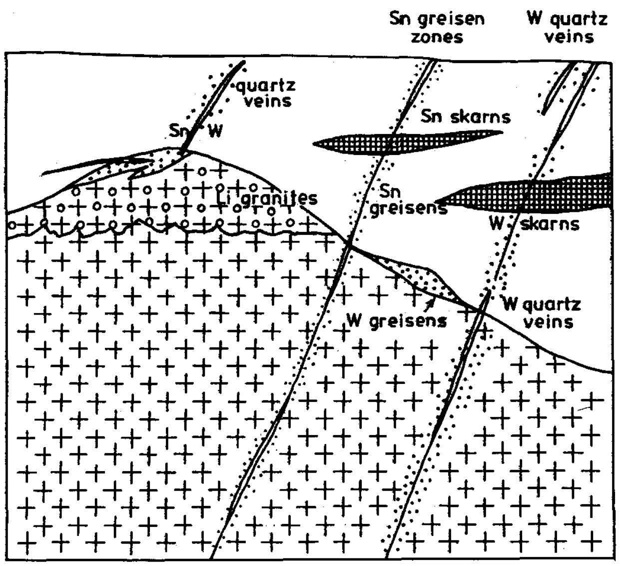

Figure 7. Schematic representation of the spatial association of the main types of tin and tungsten deposits with the YIC granites of the Krušné hory - Erzgebirge batholith (from Štemprok 1993b).

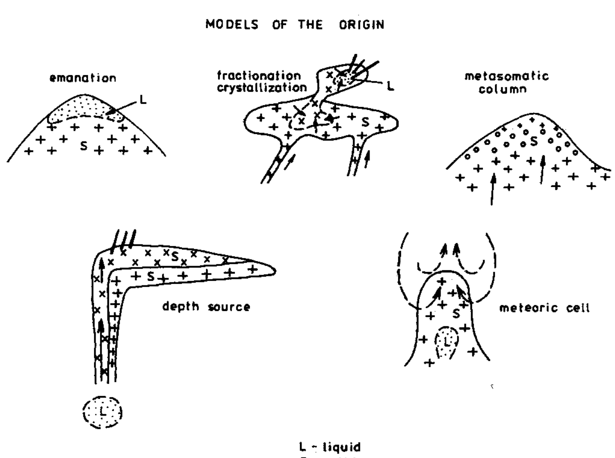

Figure 8. The scheme of the genetic models of the granite-related ore deposits from Štemprok and Seltmann (1994). The preferred models are those of fractional crystallization differentiation and the depth source model (magmatic models), eventually in combination with the meteoric cell model.

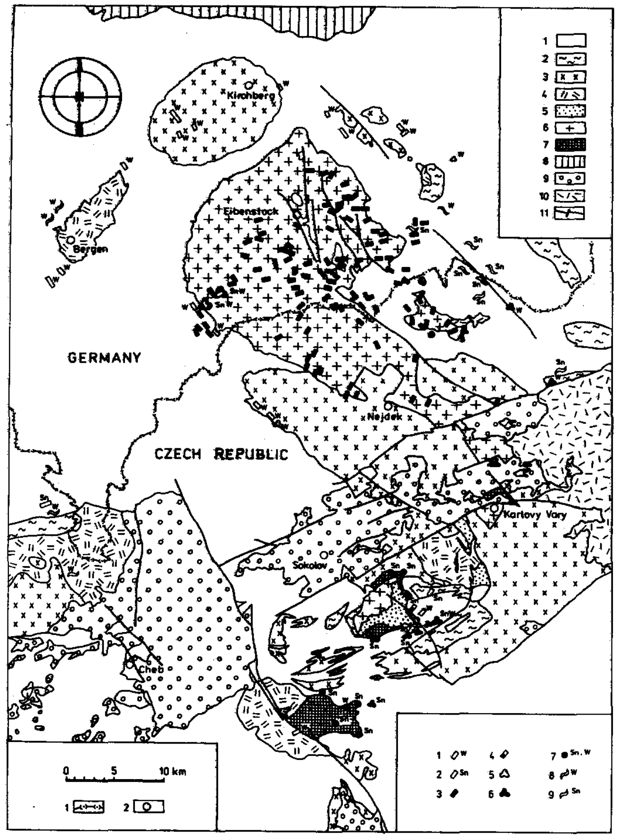

Figure 9. The geological and metallogenic map of the Western pluton based on the metallogenic map 1:200,000 (Wasternack et al., 1974). Metallogenic explanations: 1- wolframite-bearing quartz veins, 2 - cassiterite-bearing quartz veins, 3 - Joint controlled greisens with cassiterite and wolframite, quartz veins with wall rock greisens (cassiterite and wolframite), quartz stockworks, 6 - greisen lenses and pipes at the granite contact, 7 - pervasive greisen showings, 8 - skarns with scheelite, 9 - skarns with cassiterite. Geological explanations: 1 - crystalline basement, 2 - "Red Orthogneiss", 3 - OIC granites, 4 - transitional granites, 5 - granite porphyries and porphyric microgranites, 6 - YIC granites, 7 - lithium albite granites, 8 - mollasse deposits of the Upper Carboniferous and Permian, 9 - basin infillings of Upper Cretaceous and Tertiary, 10 - Tertiary volcanis and their tuffs, 11 - faults (from Štemprok 1993b).

fractional crystallization of granitic magma in the upper parts of the pluton to produce granite-related deposits.

Štemprok (1993b) used the observation about extensive distribution of muscovite-rich fissure-controlled greisens in the Western pluton of the KEFS batholith (Figure 9) to estimate of the depth of the source of magmatic ore-bearing solutions which developed in the middle or lower crust. This is explained by the model of a deep seated source (Figure 8) where metal enriched melts with fluids accumulated (Figure 10) between the source of granitic magmas and the granite batholith by the process of thermogravitational differentiation (Štemprok, 1993b).

Models suggesting a major participation of meteoric waters in the origin of the granite-related ore assemblages have been applied to the Cornubian province (e.g. Moore 1979). An alternative combining the effect of juvenile with meteoric waters (Jackson *et al.,* 1989) has also been suggested. These have never received support in the KE province except to explain the origin of some young fluorite mineralization (Čadek in Tischendorf 1989) or remobilization in the uranium-bearing vein deposits.

For the KE province there has not been any systematic dating of the mineralization such as for Cornwall, where the data shows considerable variation. In west Cornwall (Clark *et a1.*,1994) have demonstrated that the time between the granite emplacement and the main stage of Sn-Cu is 1-3 ma, while (Jackson *et al.,* 1989) and (Chesley *et al.,* 1993) postulate the origin of the Sn-Cu lodes up to 15 to 20 my after granite emplacement. For crosscourse mineralisation in the Tamar Valley in Devon, Scrivener *et al.* (1994) have demonstrated a Triassic age of 263 ± 3 my), which is consistent with the observations and interpretation of the KE metallogenic province for similar post-Variscan assemblages (Tischendorf *et al.,* 1989).

The abundant presence of F minerals in the ore-bearing assemblages of the KE batholith and common tourmaline in the Cornubian province makes it possible to characterize the former geochemically as typical fluorine province in contrast to the boron province of SW England.

METAL AND MINERAL PRODUCTIVITY

The metal and mineral production given in Štemprok and Seltmann (1994) supplemented by the data for Cornwall and Devon in Table 4 shows the total production of the two regions since historical records. The Cornubian province has been by far richer in tin and copper compared to the KE province. On the other hand the KE has been more productive in fluorite and uranium ores. It is interesting to note that the production of lead and zinc were on relatively similar levels, however, the KE province has been richer in silver mostly associated with these metals. A marked difference can be noted in the presence of the Bi-Co-Ni arsenide assemblages which led to the sporadic production of these metals in the KE province whereas their production was very small in the Cornubian province.

Metals (minerals)	Krušné hory/Erzgebirge	Cornwall
tin	300	1,500
lead	300	250
zinc	150	96.5
silver	10	0.23
silver ore		2
uranium	130	2
fluorite	2,000	10
barite	900	450
bismuth, cobalt, nickel	15	0.5
arsenic (oxide)	500	250
tungsten (oxide)	27	5.6
molybdenum	7	no data
copper	25	2,000
antimony ore	2.5	1

Table 4. Estimated metal (mineral) production from the Krušné hory/ Erzgebirge batholith and the Cornubian Provinces (in thousand metric tons, from Štemprok and Seltmann (1994), supplemented by the data by Bristow (1993).

MINERAL ZONING

Metalliferous zoning may be observed as vertical changes in mineral content of steep veins or in changes of the, horizontal distribution of mineral assemblages. The latter is relevant to the present treatment. The Cornubian province is characterized by the presence of deep structures extending from the granite to the country rock with change of metal assemblages. Thus Davison (1927) distinguished 5 mineral zones and Hosking (1964) 7 mineral zones following the surface of the granite batholith. Dines (1956) showed the distinction between areas of Pb-Zn-Ag-Ba mineralization in N and NW trending crosscourse structures and the chief regions of Sn-Cu-As-Zn mineralization in ENE trending lodes which contributed to the concept of mineral zoning.

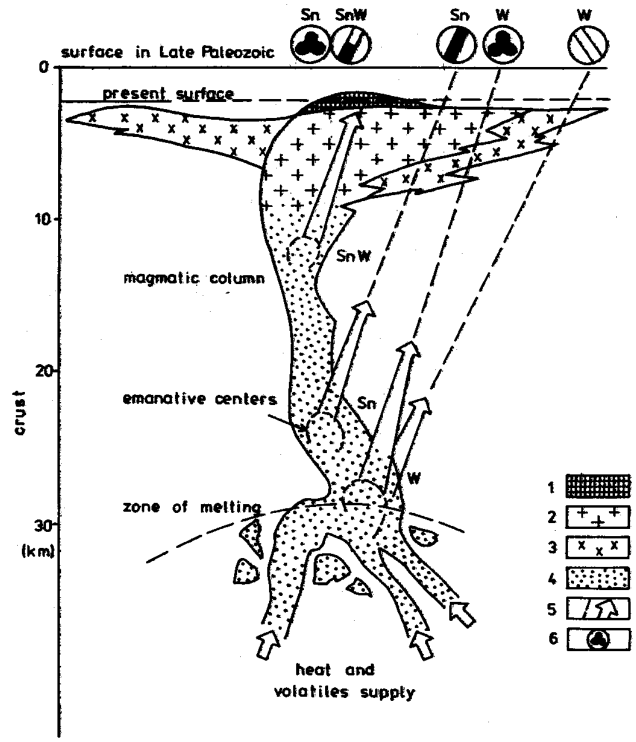

Figure 10. Schematic diagram showing the concept of the thermogravitational differentiation of a magmatic column in the middle and lower crust producing specialized high tin and high tungsten silicate melts from Štemprok (1993b).

The deep mineralized structures with tin and tungsten ores are essentially missing in the KE granite batholith and thus the validity of the classical zonal pattern with the temperature induced metal zones was doubted by Berg (1927) and Štemprok (1982).

The horizontal distribution of the metalliferous zones in the KE granite batholith was described by Štemprok and Seltmann (1994) (Figure 11) where the tin zone follows the main course of the partly hidden KEFS batholith whereas the tungsten zone is irregularly developed around the NW portion of the Western pluton. There is a very limited molybdenum zone in the Eastern pluton, from which sparse molybdenite mineralization in Telnice and Krupka is known. The uranium zones follow the deep lineaments along the NE margin of the Western pluton and continue southwards to the Bory massif outside the KE metalliferous province.

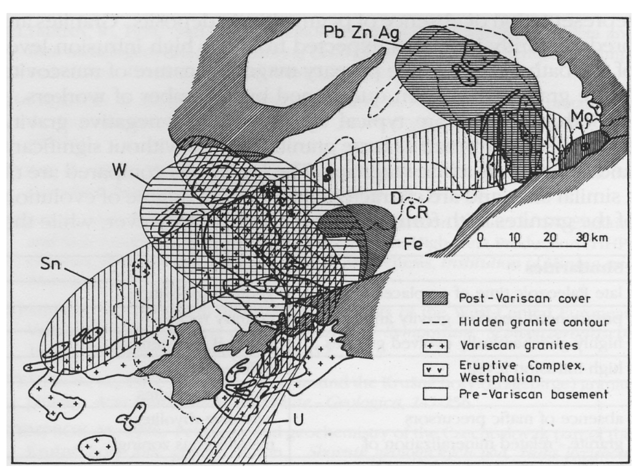

Figure 11. Horizontal zoning of some metals in the main granite related mineralizations in the Krušné hory - Erzgebirge, Fichtelgebirge - Smrčiny batholith region from Štemprok and Seltmann (1994).

The Pb-Zn-Ag zone is strictly limited to the Freiberg district far distant from the contact of the YIC granite except for unimportant Pb-Zn assemblages associated with the Western pluton.

In the Cornubian batholith the same picture can be suggested from the data of Willis-Richards and Jackson (1989) and Halls (1994) on the production of tin, copper and zinc in Southwest England (Figure 12). The tin zone overlies the outcrops of Land's End and Carnmenellis plutons and extends northwards to the eastern compartment. There it is broader covering the outcrops of the St Austell, Bodmin and Dartmoor pluton outcrops. The copper zone is limited to the northern area of the Carnmenellis plutons. The copper zone coincides with tin zone in the eastern compartment of the batholith. The zinc zone is very limited to the western compartment and weakly developed in the eastern one.

The classical explanation of metalliferous zonation by gradual cooling of the solutions away from the granitic contact (Dines, 1956) has been abandoned by most of the workers in both the regions and the idea of a multistage introduction of solutions into the joints and fissures of granites and country rock has been substituted (Garnett, 1965, Štemprok, 1982).

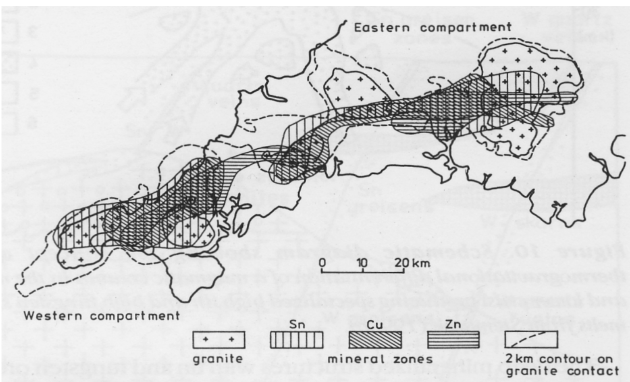

Figure 12. Horizontal zoning of some metals in the main granite-related mineralizations of the Cornubian batholith as based on the data on metal productivity by Willis-Richards and Jackson (1989).

DISCUSSION

The essential similarities and differences of the two region are summarized in Table 5; they occur separately within the Variscan belt in different geotectonic settings, and appear not to be strictly dependent on the zonal structure of the orogenic belt.

The two mining regions belong to the type of Sn and W provinces with the absence or only weak development of W-Mo associations. Both the regions are characterized by a low representation or absence of pegmatitic tin deposits. Granites are predominantly biotite as expected from the high intrusion level of the batholiths, and the primary magmatic nature of muscovite in the granites has been questioned by a number of workers.

Both the areas are typical by pronounced negative gravity anomalies interpreted as large granitic masses without significant underplating by mafic magmas. The batholiths compared are of a similar size, and are characterized by a high degree of evolution of the granites with formation of Li-F types. However, while the Cornubian province includes more evolved granitic types, the KE granite province includes more primitive granite members and their more mafic precursors. Extensive bodies of rhyolite so abundant in the KE province and neighbouring areas are weakly developed in SW England and they are present only as relics.

Similarities	Differences
late Paleozoic time of emplacement	geotectonic setting
pronounced negative gravity anomaly	country rocks
highly geochemically evolved granites	F and B geochemistry
high intrusion level	differentiation
	ranges of granites
absence of mafic precursors	extrusive rhyolites
granite - related mineralization of	metalliferous zoning
Sn, W, Cu, Pb, Zn, Ag, Ba and F	metal proportion
	kaolinization within the granites

Table 5. Differences between the Cornubian and Krušné hory-Erzgebirge granite batholiths

There is a significant difference between these two provinces in the major geochemical pattern. Whereas the Cornubian batholith region is characterized by an overall presence of tourmaline in alteration zones and the vein fillings it is relatively sparse in the Western pluton of the KEFS batholith. Tourmaline is completely lacking in the Eastern pluton. In contrast there is abundance of fluorine-bearing minerals in most of the greisens in the KE granite batholith region and a large amount of fluorite in post-Variscan veins. This contrast shows that in both areas conditions were established which led to the formation of highly evolved granites with similar large-scale postmagmatic mineralization, irrespective of whether fluorine or boron were abundant. Thus these elements may appear as incidental and not as the elements decisive for the specific features of the granite-related metallogeny.

It is improbable that a small scale geotectonic evolution involving only the upper crust could be responsible for such a variety of mineral assemblages, large volumes of granitic magmas and intense postmagmatic alterations such as those observed in the KE and Cornubian metallogenic provinces. It has been repeatedly emphasized in both the provinces (e.g. Watson *et al*., 1984, Dahm *et al*., 1985) that a mantle contribution can be responsible both for the introduction of incompatible elements into the crust via mafic magmas or mantle fluids. There is still little evidence on the exact mechanism of how the addition and concentration of metals from the granitic system occured, whether by fractional crystallization differentiation, thermogravitational differentiation or leaching of metals from solid granites or country rocks. The preferred models, however, in both provinces involve magmatic fluids with some participation of meteoric waters.

Despite the marked differences in the lithology of granite envelopes in both provinces the mineral content of granite-related metallogeny is very similar and is characterized by the SnW-Cu-Zn-Pb-Co-Ni-As-Ba-F geochemical association. It is very probable that the sedimentary lithology of the source areas was responsible for the specific spectrum of metals in the mineralizing systems. However, the differences in the province lithologies can account for the differences in quantitative proportion of metals. Thus, the predominance of copper in the Cornubian province could suggest the participation of mafic rocks in the process of granite genesis, and the large amount of B involving assimilation of sedimentary rocks. The abundance of F in the metallogeny of KE province could, on the other hand, account for a more pronounced participation of mantle fluids in the granite genesis.

It is also poorly known whether the KE and Cornubian metallogenic provinces formed as a result of a number of coinciding events or whether it was a single one which determined the specific features of granitic magmatism and associated metallogeny. The comparison of the provinces will hopefully encourage answers to these questions by a similar treatment of data and their interpretations. In this respect the comparison of both the provinces still offers a wide field of stimulus and ideas.

CONCLUSIONS

The KE and SW England metallogenic provinces despite a wide spatial separation represent a similar development of Late Paleozoic granitic magmatism within the northern branch of the Variscan belt of Europe. Both provinces are characterized by crustal sources of granitic magmatism influenced possibly by mantle contributions. The differences in lithology of the source areas were probably responsible for various representation of B, F, C and U in the provinces, and their participation in postmagmatic mineralization. The timing of the ore-bearing magmatism in both the regions in Late Paleozoic is very close, but apparently not contemporaneous which may be due to a different geotectonic setting of the regions.

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