Monograph Series on Mineral Deposits **31**: 97–129; Gebrüder Borntraeger, Berlin–Stuttgart 1994

The association between granites and tin-tungsten mineralization in the eastern Krušné hory (Erzgebirge), Czech Republic

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Abstract

Greisen tin and tungsten deposits occur in the eastern Krušné hory (Erzgebirge) in spatial association with a partially hidden Krušné hory (Erzgebirge) granite batholith of Variscan (330–295 m.y.) age emplaced within a crystalline complex. Numerous drill holes to a depth of 650 to 800 m between Cínovec and Krupka determined the underground surface of the granites of the Younger Instrusive Complex of the Krušné hory batholith and made it possible to distinguish two partially hidden granite plutons. The Cínovec granite pluton is formed by lithium-albite granite underlain by protolithionite porphyritic medium-grained granite probably equivalent to the Schellerhau medium-grained granite (II). The Krupka pluton is composed of biotite microgranite and medium-grained biotite granite underlain by lithium-albite granite.

The greisen deposits are associated with the endocontact zone of granite elevations of lithium-albite granites (Cínovec, Preisselberg II) and with stockwork-type deposits in the envelope of biotite granites (Preisselberg I). The deposits are formed by quartz veins with cassiterite and wolframite and by greisens composed of zinnwaldite (protolithionite), quartz and topaz. The greisen deposits mined until recently are low-grade with Sn and W contents between 0.1 and 0.3 %. The mineralization is distinctly epigenetic towards the granites in the elevations of the plutons. These elevations were strongly affected by metasomatic processes among which albitization and greisenization played the essential role. It is postulated that the solutions responsible for ore mineralization and deuteric alterations were derived from deeper sources related to the origin of granite magmas below the space of present elevations.

Introduction

The eastern Krušné hory (Erzgebirge) is a classic area for tin and tungsten mineralization associated with granite, for example the deposits of Cínovec (Zinnwald) and Krupka (Graupen). These deposits were mined since medieval times and have been examined scientifically from the beginning of the last century.

The new period of mining and intense exploration since World War II has brought numerous new data on the tin and tungsten mineralizations and on related granites, but opened new problems of their genetic interpretation emanating from a large amount of field and analytical data. The present paper reviews earlier studies of these deposits and granites published in Czechoslovakia during the last thirty years and interprets some new data derived from the exploration of hidden tin and tungsten greisen ore deposits. It compares the results and interpretations with data on the Altenberg and Sadisdorf deposits in the German part of the province.

0341-6356/94/0031-0097 $ 8.25

Geological setting

The eastern Krušné hory on Czech territory is composed of a metamorphic complex of orthogneisses and paragneisses of presumed Proterozoic age and of phyllites and epiamphibolites of Lower Paleozoic age. The crystalline rocks were intersected by an extrusive, partly intrusive complex of rhyolites, dacites and ignimbrites and tuffs with arkosic and

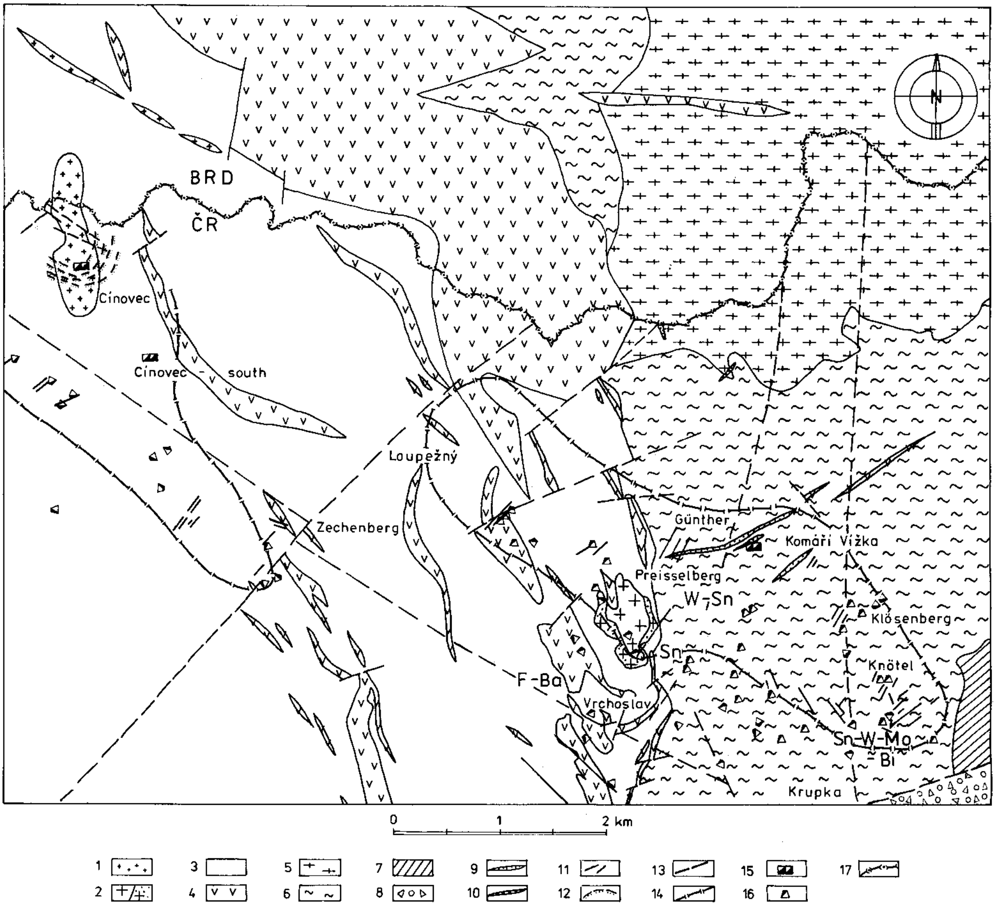

Fig. 1. Geological map of the area of Cínovec and Krupka in the Czech part of the eastern Krušné hory compiled from the geological map 1 : 25 000 by J. Jiránek & P. Schovánek (Geol. Survey, Prague); ore deposits according to Malásek et al. (1987)
1 – lithium albite granite, 2 – porphyritic fine-grained biotite granite (a) porphyritic fine-grained granite (marginal (b)), 3 – Teplice rhyolitic complex, 4 – granite porphyry, 5 – muscovite-biotite metagranite, 6 – muscovite-biotite orthogneiss, 7 – muscovite-biotite paragneiss, 8 – Quaternary sand and gravel overlying Tertiary sediments, 9 – felsic to microgranitic granite and syenite porphyries in gneiss, 10 – metapegmatite and meta-aplite, 11 – tin and tungsten and fluorite veins, 12 – underground course of flat veins at Cínovec, 13 – faults, 14 – surface extension of the greisen fields, 15 – old shafts, 16 – old drifts, 17 – border between Czech Republic and Germany.

coal intercalations of Westphalian B/C age. Volcanic rocks of this complex are cut by syenogranite porphyry dykes and by felsic porphyries. The whole area is underlain by the partly hidden, continuous body of the Krušné hory batholith of young Variscan age (330–295 m.y., Tischendorf & Förster 1990). The main geological features of the area are shown in Figs. 1 and 2.

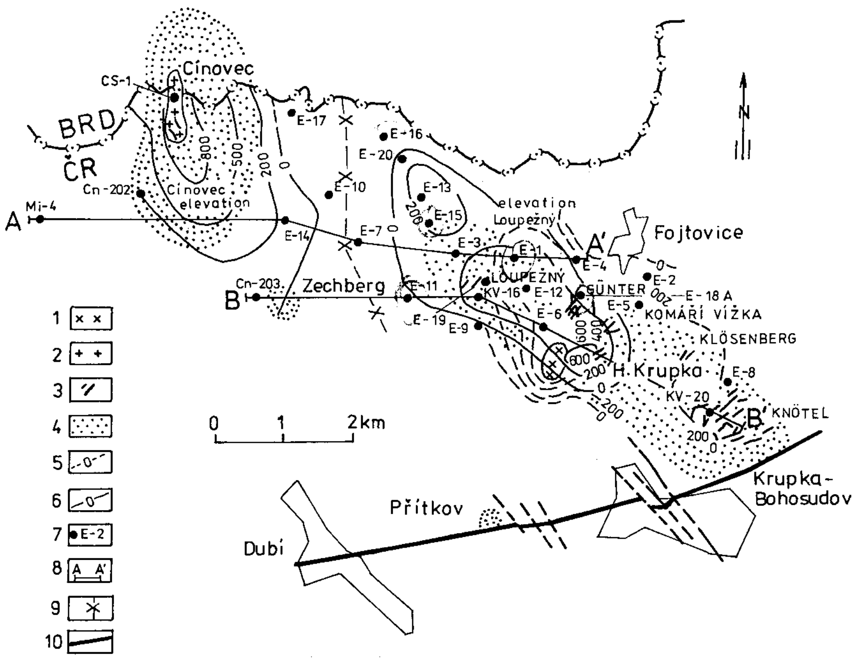

Fig. 2. The morphology of the hidden granite surface in the area between Cínovec and Krupka, partly modified from Chrt & Malásek (1984)
1 – outcrop of biotite granite of the YIC first sequence at Preisselberg, 2 – outcrop of lithium-albite granite of the YIC second sequence at Cínovec, 3 – the main veins and zones with Sn, W and Mo mineralization, 4 – area of intense greisenization at the surface, 5 – isolines of the granites of the first sequence in meters above sea level, 6 – isolines of the lithium albite granites, 7 – deep drillings, 8 – profile lines shown on Figs. 3 and 4, 9 – the approximate underground boundary between the Cínovec and Krupka plutons, 10 – the Krušné hory fault zone.

The crystalline complex west of the Teplice rhyolite body is composed of muscovite-biotite paragneisses, in places intensively migmatitized. The crystalline basement east of the Teplice rhyolite consists of orthogneisses and of cataclastic meta-granites and of migmatitized paragneisses. The Teplice rhyolite body in the area studied is formed by rhyolite and ignimbrite varieties rich in phenocrysts and by felsic rhyolites (Štemprok & Lomozová 1983, Jiránek et al. 1988). Along the north-eastern margin of the Teplice rhyolite, a body of syenogranite and granite porphyry about 1 km wide intruded, splitting to the south into several thinner dykes. Numerous other dykes intersected the Teplice rhyolite some distance from the contact. To the south, the crystalline complex is cut off by the major Krušné hory-Erzgebirge fault zone of NE strike which borders the lignite-bearing basin with Tertiary sediments and a thick Quaternary cover.

On Czech territory there are three major mineral deposits. The Cínovec tin and tungsten deposit occurs in the centre of the Teplice rhyolite at the border between Czechia and Germany. The Krupka deposit extends as major and minor occurrences of tin and tungsten ore over about 6 km^2 near the eastern margin of the Teplice rhyolite. The Vrchoslav fluorite deposit is located near the Krušné hory fault zone near the village Přítkov. At the present time all mines are closed. Whereas the Cínovec deposit closed in 1991 and the Vrchoslav mine in 1967, the Krupka deposit has never been mined in recent time despite intense exploration in the postwar period.

Earlier geological and metallogenetic studies

The older literature on the Krupka and Cínovec districts was reviewed by Beck (1914), Oelsner (1952), and Schröcke (1952). Data on the *Cínovec* deposit were presented by Štemprok (1960 and 1961), who studied the main system of the deposit. The petrology of the granite cupola, based on a 1596 m deep borehole, was examined by Štemprok (1965), Štemprok & Šulcek (1969) and Cocherie et al. (1991). The results of an intense exploration programme in the Cínovec area were described by Tichý (1965), Čabla & Tichý (1965) and Janečka (1973). Studies on the alterations of the Cínovec granite were given by Štemprok (1965) and Čada & Novák (1974). Data on the German part of the deposit are in Bolduan et al. (1967). The geochemistry of the granite and of the greisens was studied by Hoffman & Trdlička (1966), and lithium in the greisens by David (1990). The rare-earth elements in the granites and greisens were studied by Štemprok (1989) and at the contact between rhyolite and granite by Tischendorf et al. (1988).

The *Krupka* deposit was described in detail by Beck (1903, 1914) but new information became available in the fifties and sixties when Fiala & Pácal (1965) described the Preisselberg (Preiselberk) granite body and the tin deposit, and Janečka & Štemprok (1967) reported on the results of new exploration for Sn-W deposits. Žák (1959, 1966a, b) described the mineralogy of the Knötel deposit and the genesis of various ore and gangue assemblages. A brief description of the deposit is also given in Baumann et al. (1974).

In 1973–1987, the drilling programme of Geoindustria was launched (Malásek et al. 1973 and 1987), in the course of which 20 drillholes to a depth of 600 to 800 m were made. The results were briefly presented by Chrt & Malásek (1984) and some new interpretations maintaining their classification of YIC granites are given in this paper. Fluid inclusion studies from the vein deposits in Cínovec & Krupka are in Ďurišová (1971) and Ďurišová (1978), and an interpretation of the bismuth textures for geothermometry are given in Štemprok (1971b). The metallogenic productivity of the Teplice rhyolite body and of the adjacent areas based on hard rock geochemistry has been discussed by Štemprok & Lomozová (1983).

Mining history

The first recorded mining was in the Krupka area (Bílek et al. 1964) where cassiterite placers were mined. The beginning of mining of primary deposits is dated from the 13th century and lasted in the Krupka area to about second half of the 19th century. The most active periods of mining are documented at the end of the 15th century. Molybdenum ores were mined for a short time in the Krupka (Knötel) deposit during World War II.

In the Cínovec district the historical record of tin mining is dated from 1378. The most active tin mining at the deposit was at the beginning of the 19th century. In 1897 wolframite was mined for the first time along with cassiterite. A new period of mining lasted from the beginning of World War II until 1991, and the greisen bodies were mined since 1978.

The Krušné hory batholith

The surface of the batholith

The results of drilling have determined the underground surface of the granites of the Younger Intrusive Complex between the Cínovec granite and the granite outcrop at Preisselberg and the known granite in the Knötel orefield about 600 to 800 m below the present surface. Gravity measurements could not be interpreted due to the only minute differences in the densities of the country rocks.

Two major, partially hidden granite bodies (plutons or "stocks") were distinguished in the Czech part of the batholith area:

a) the Cínovec granite pluton between the Cínovec granite outcrop and the depression on the underground granite surface in the drill holes E-10, E-7 and E-16 (Fig. 2).
b) the Krupka granite occurring between the village of Přední Cínovec, Komáří Vížka hill and the town of Bohosudov, east of the depression (Chrt & Malásek 1984).

The Cínovec pluton

The contact of the Cínovec body with the Teplice rhyolite is steep on the western side (40° to 60°) and in the narrowest part of the outcrop (Fig. 1) it is almost vertical. To the west it passes into a depression of the granite which was also verified by drillhole Mi-4 near Vápenice (Fig. 3). To the south, southeast and east the contact dips at a moderate angle (under 10° to 30°) towards the Zechberg hill; its depth was determined in drillhole Cn-203. The whole granite pluton is composed of lithium-albite granites which are underlain at Cínovec at a depth of 730 m by protolithionite medium-grained granites (Rub et al. 1983). Minor dykes of aplitic lithium-albite granite (Fig. 2), marginal pegmatite (Stockscheider) and intra-ore granite dykes are present.

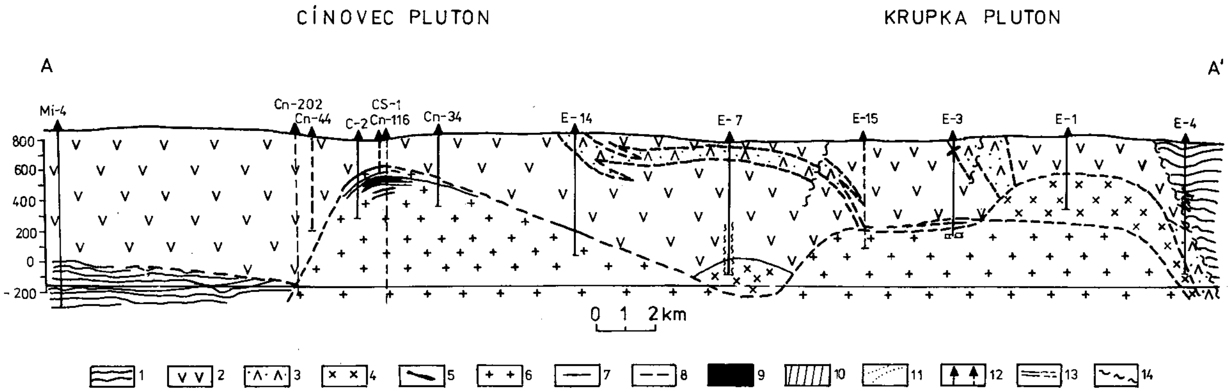

Fig. 3. Geological section along the line marked A–A′ in Fig. 2, showing the form of the partly hidden Cínovec and Krupka plutons with their Sn-W deposits (from Chrt & Malásek 1984, supplemented)

1 – gneiss complex undifferentiated, 2 – Teplice rhyolitic complex, 3 – granite porphyry, 4 – biotite granite of the YIC first sequence, 5 – lamprophyre dykes, 6 – lithium albite granite of the YIC second sequence, 7 – geological boundary (verified), 8 – geological boundaries (interpreted), 9 – greisenization with high Sn-W values, 10 – greisenization with low Sn-W values (see Fig. 4), 11 – interpreted continuation of the greisen bodies, 12 – drilling in or close to the line of section, 13 – underground workings close to the line of section, 14 – faults.

The Krupka pluton

The Krupka pluton extends over an area of about 20 km^2 and is mostly hidden under the Teplice rhyolite and the orthogneiss complex. Isolated outcrops are the stock at Preisselberg and the greisenized aplite stockwork of Zwickenpinge (near drillhole KV-2) in the Knötel orefield. The pluton was revealed by the galleries of the 5th of May mine at Vrchoslav and Martin and Večerní Hvězda galleries in the Knötel orefield. The central flat cupola occupies about 6 km^2. Near the village of Přední Cínovec, its NW slope inclines about 50–60° whereas the southern dip near the Loupežný hill is under 40–50°. The small stock of Preisselberg I and the isolted stock with overlying pegmatite in the Knötel orefield (Fig. 4) have a neck-like shape with relatively steep contacts marked by zones of eruptive and intrusive breccias at Preisselberg (Fiala & Pácal 1965) and at the Knötel deposit (Oelsner 1952). The Krupka pluton is composed of fine-to medium-grained biotite granites near its upper contact and is underlain by lithium-albite granites, all of which are multiphase and consist of two to three facies.

Tectonics

The distribution of granitic outcrops and of mineralizations appears to be controlled by a major NW trending Cínovec lineament in the northern part of the Bohemian massif (Štovíčková (1973). In the eastern Krušné hory/Erzgebirge this zone can be separated into two parallel running lines controlling the location of cupolas and deposits, the first one connecting the Sadisdorf deposit in Germany with the Preisselberg stock in the south-east (Malásek et al. 1987). The second one extends parallel from Schenkenhöhe to Sachsenhöhe in Germany (Fig. 5). However, the importance of N-S trending tectonic directions was stressed by Škvor (1978) who drew attention to the N-S elongation of the outcrop of the Cínovec granite (Fig. 1) and its continuation towards the major deposit of Altenberg with its additional cupola of biotite granite.

The NW tectonics and their intersections with fault systems of lower order have a decisive significance for the detailed shape of the granite surface and also for the distribution of the mineralization. This is in detail controlled by the NE strike of veins which are parallel to earlier microgranites and lamprophyres in the area between Krupka and Telnice. The NW strike of tin- and tungsten-bearing veins is exceptional, e.g. of the Lukáš veins (Luxer Gang) in the area between Preisselberg and Knötel.

Flat dipping vein systems are strictly limited to the immediate granite contacts, as in Cínovec or in the Krupka district (Knötel), and are apparently related to contraction of the cooling granite.

The tectonic analysis of the Teplice rhyolite (Jiránek et al. 1988) indicated that after its solidification, the S-N acting stress produced NW and NE jointing. Continuing stress led to the displacement of granite porphyry dykes.

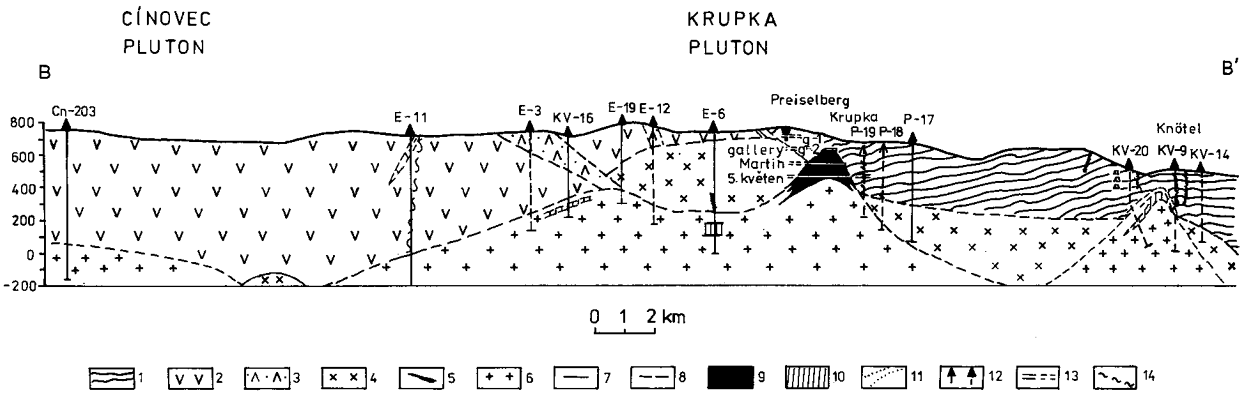

Fig. 4. Geological section along the line marked B–B′ in Fig. 2, showing the hidden granite surface of the Cínovec and Krupka plutons between the Zechberg, Loupežný and Knötel districts, with their Sn and W deposits (from Chrt & Malásek 1984, supplemented). For explanations see Fig. 3.

The latest stage has developed N-S and E-W tectonics which caused the subsidence of the extrusive and intrusive bodies relative to the neighbouring crystalline complex. Rejuvenation of movement on the faults and joint systems occurred after the intrusion of Variscan igneous rocks. The fluorite-barite vein deposits at Vrchoslav formed in a NW-striking fault systems.

Post-Variscan movements have not affected the granitic surface in a significant way. For its detailed form the pre-granitic tectonics were apparently decisive.

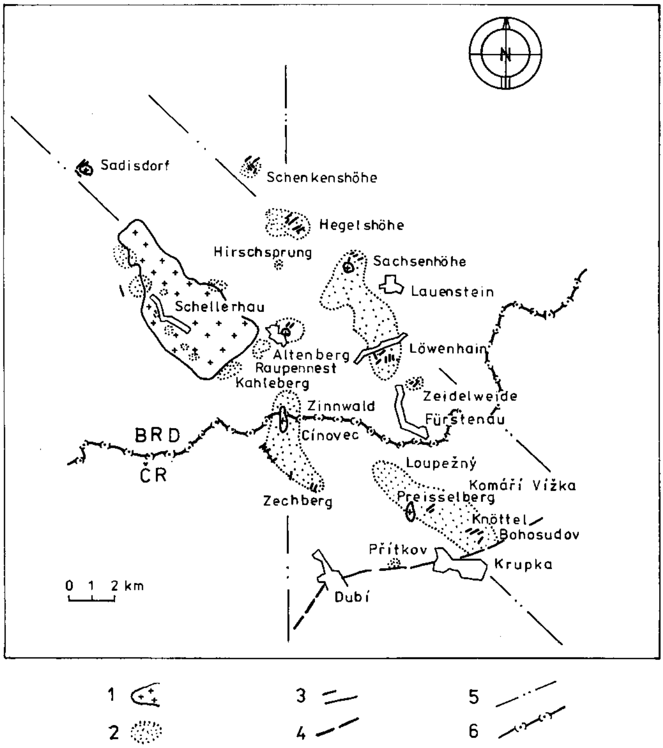

Fig. 5. The distribution of YIC granite outcrops associated with NW lineaments in the eastern Krušné hory/Erzgebirge, according to Malásek et al. (1987).
1 – outcrops of the granites of the Younger Intrusive Complex, 2 – greisen fields, 3 – ore veins and greisen bodies, 4 – the Krušné hory fault zone, 5 – lines connecting the granitic outcrops and ore showings, 6 – the border between Czech Republic and Germany

Variscan magmatism

Age determinations of granitoids in the eastern Krušné hory by the K/Ar method indicated a wide interval from 355 to 256 m.y. (summary by Škvor 1975) which is not consistent with Rb/Sr data for the Krušné hory/Erzgebirge pluton by Gerstenberger (1985; Tischendorf & Förster 1990) yielding 330–295 m.y. for both complexes.

Reliable geological data are the palaeontological Westphalian C/D ages of the Teplice rhyolite in Mikulov (Šimůnek in Jiránek et al. 1988) and near Schmiedeberg (Lobin in Pälchen et al. 1984).

The earliest Variscan intrusions (Table 1) in the area west of the Teplice rhyolite are the Fláje monzogranite and the granite of Moldava (Sattran 1960, 1982, Novák et al. 1981). The Fláje granites were classified with the Older Intrusive Complex of the Krušné hory batholith for sequential and petrochemical reasons (Štemprok 1986). The magmatism of the new cycle following the emplacement of the Older Intrusive Complex started with the extrusion of rhyolites in two stages: early extrusive and younger extrusive-intrusive. The formation of rhyolites, ignimbrites and tuffs was followed by the intrusion of granite porphyry dykes. The extrusion of rhyolites was preceded by dykes of microgranitic quartz porphyry which are intersected by the N-S fault systems along which the Teplice rhyolite extruded. According to Wetzel (in Pälchen et al. 1984) these dykes occur in two age sequences.

The granites of the Younger Intrusive Complex (Fig. 5) in the eastern Krušné hory are of two distinct petrological types:

a) biotite syenogranites interpreted as intrusive granites (called granites of the first sequence by Malásek et al. (1973), JG_1 to JG_3 granites by Lange et al. (1972), Baumann et al. (1974) and Wetzel (in Pälchen et al. 1984) and
b) lithium-albite granites, called granites of the second sequence by Malásek et al. (1973) and metasomatic granites by Lange et al. (1972) and Štemprok (1986).

The granites of these two sequences are multiphase. Earlier phases are commonly fine-grained and porphyritic and later phases are medium-grained and occassionally porphyritic.

The intrusion of these two sequences was separated by the intrusion of lamprophyres (kersantites) according to Chrt et al. (1974) or by the intrusion of the rhyolite dykes of the second generation according to Wetzel (in Pälchen et al. 1984).

The intrusion of the so-called micrograrites continued into the stage of tin and tungsten mineralization. Štemprok (1971) observed the intersection of a quartz-molybdenite vein by an aplitic dyke which was in turn greisenized. A lamprophyric dyke associated with a flat quartz-cassiterite-wolframite vein at the Martin gallery in Krupka was described by Chrt (1957). The beginning of the YIC granite intrusion was preceded according to Wetzel (in Pälchen et al. 1984) by the intrusion of lamprophyres (kersantite and minette) after the formation of granite porphyries. In the Krupka pluton, kersantites are younger than the porphyritic microgranite of the first sequence. Lamprophyres are apparently enclosed as xenoliths in a lithium-albite granite (E-18). The youngest lamprophyres observed by Wetzel (in Pälchen et al. 1984) can possibly be correlated with the lamprophyre associated with the Lukáš vein in the Krupka district.

Thus the complicated picture of late Variscan magmatism shows an alternation of the intrusion of acid and mafic igneous rocks during the whole course of late Variscan magmatism (Kramer 1988), suggesting mantle influence for the crustally derived magmatism.

Table 1. Variscan magmatism in the eastern Krušné hory pluton according to Chrt et al. (1974), Novák et al. (1981) and Wetzel (in Pälchen et al. 1984).

Sequences derived from the Bohemian part							Sequence from the Saxony part [3]	
Age		Granite complexes		Intrusive and extrusive phases	Dykes	Occurrences		younger porphyric microgranites
Permian					Younger lamprophyre	Krupka (Lukáš)		chloritized lamprophyres
					Intra-ore microgranite	Cínovec, Loupežný		rhyolite dykes of the 3rd generation
			2nd sequence	Medium-grained lithium albite granites, lithium-albite microgranite		Cínovec Loupežný Preisselberg II	[2] JGm	
Carboniferous	Stephanian	Younger Intrusive Complex (YIC)			Lamprophyres, porphyrites	Preisselberg Klösenberg Günther		rhyolite dykes of the 2nd generation
			1st sequence	aplitic granite, medium-grained biotite syenogranite	Aplite	Preisselberg I	[1] JG_I–JG_3	
				porphyritic microgranite		Preisselberg I Moldava		
								lamprophyres
	Westfalian	Effusion and subvulcanic complex ("Teplice rhyolitic complex")			Granite porphyry	Krupka, Cínovec		porphyric microgranite
				Ignimbrites, rhyolite (rhyodacite) tuffs	Felsic porphyry	Teplice, Cínovec, Krupka-Preisselberg		Teplice rhyolite
					Microgranitic (felsic) porphyry	Komáři Vížka, Telnice Moldava-Vápenice		rhyolite dyke system
								rhyolite dykes of the 1st generation
		Transional complex		Fine-grained granite		Moldava		rhyolitoids Schönfeld
		Older Intrusive Complex (OIC)		Biotite monzogranite, two-mica granites	Metasomatic albite syenite	Fláje Moldava, Telnice		

[1] Intrusive phases of the YIC granites as classified in Saxony (Lange etal. 1972)
[2] Metasomatic granites of the YIC granites
[3] Andesitoid dykes not included

The origin of the lithium-albite granites represents a problem which was not unequivocally solved by field and laboratory evidence. The sharp contacts of the lithium granites with the rhyolites, granite porphyries and biotite microgranites of the first sequence suggest the magmatic intrusion of lithium-albite granitic magma (the explanation preferred by one of the authors – J. K. Novák). A gradual downward transition of lithium-albite granites into medium-grained protolithionite granites (which texturally resemble the main granites of the Krušné hory YIC complex, Lange et al. 1972, Štemprok 1986) leads to the preference of a metasomatic explanation by the other author (Štemprok), involving the replacement of the main granite by albitic granite (apogranite in the sense of Beus et al., 1962) along its upper contact (Fig. 6).

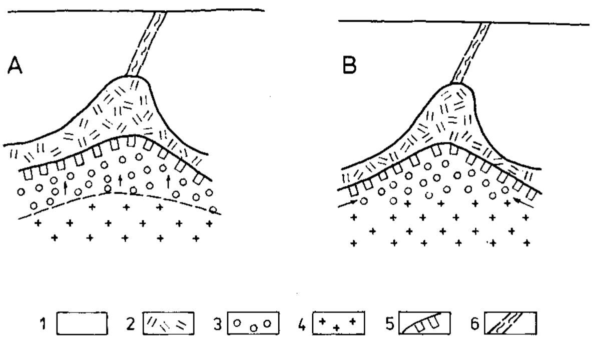

Fig. 6. Two alternative explanations for the position of the lithium-albite granites under the biotite microgranites of the YIC first sequence. A – lithium-albite granites intruded between the porphyritic microgranite and the medium-grained protolithionite granites, B – lithium-albite granite formed by replacement of the medium-grained essentially biotite granite of the YIC second sequence along the contact with the granites of the YIC first sequence.
1 – crystalline envelope, 2 – biotite granites of the first sequence, 3 – lithium-albite granites, 4 – biotite (protolithionite) granites, 5 – stockscheider, 6 – fault zone in the envelope.

Petrology of the late Variscan igneous rocks

Teplice rhyolite

This is a medium- to coarse-grained, porhyritic brown to violet rock with phenocrysts (1 to 5 mm) of quartz, potash feldspar, and less frequent plagioclase, biotite, amphibole and pyroxene in a groundmass of 0.005 to 0.4 mm grain-size consisting of potash feldspar, quartz, subordinate plagioclase, biotite, muscovite, accessoric hematite, magnetite, ilmenite, rutile and secondary topaz, cassiterite, sericite, chlorite, fluorite and pyrite (Fiala 1959, Štemprok & Lomozová 1983, Jiránek et al. 1988).

Ignimbrites are of the same mineralogical composition with common fragments of phenocrysts of quartz and potash feldspar in the fine-grained groundmass containing remnants of the altered glass.

Granite porphyry

It occurs as intrusion up to 1 km wide or as dykes of several dozens of meters thickness. It is porphyritic dark brown or red with phenocrysts of pink potash feldspar, quartz and plagioclase up to 20 mm in fine-grained groundmass of quartz, potash feldspar, plagioclase, biotite, muscovite, accessoric hematite and magnetite. Among its varieties there are more quartz-rich and dark mafic types (Jiránek et al. 1988).

Granites

The modal compositions of the granites of the Older Intrusive Complex (OIC, Fláje and Moldava) and of the Younger Intrusive Complex (YIC, Preisselberg and Cínovec) are shown in Fig. 7. The Fláje granite of the OIC is a monzogranite whereas the Moldava granite is a monzo- to syenogranite. The Preisselberg granite of the YIC is a syenogranite and the lithium-albite granite of the second sequence of the YIC a alkali feldspar granite. Greisenized granites fall into the field of quartzoic granitoids.

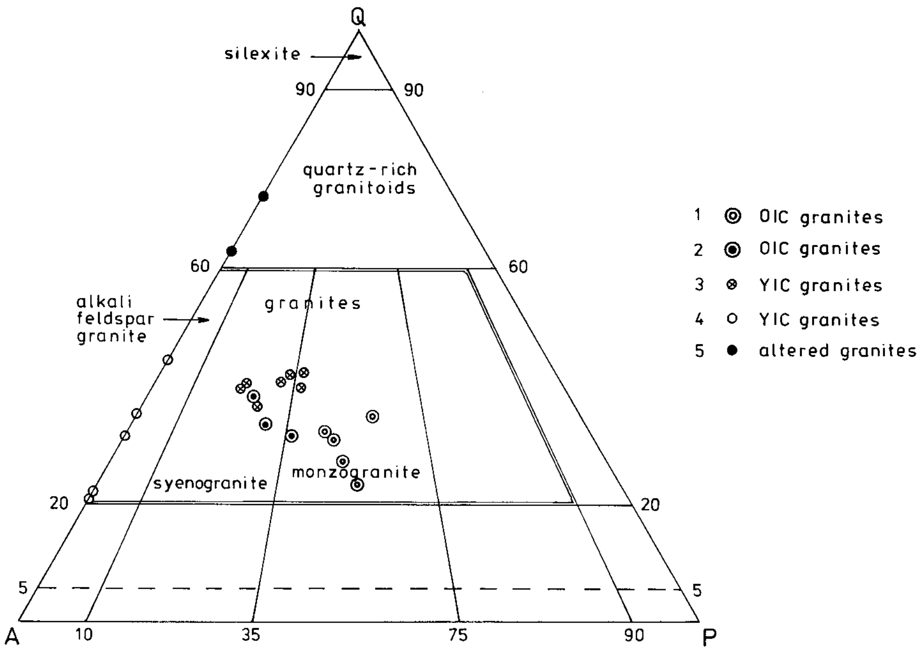

Fig. 7. Average modal compositions of the granites and altered granites from the Fláje, Moldava, Cínovec and Krupka granite bodies (see Table 1).
1 – Fláje, 2 – Moldava, 3 – Preisselberg biotite granite, 4 – Cínovec lithium-albite granite, 5 – greisenized Cínovec albite granite.

Granites of the first sequence

The porphyritic microgranite contains phenocrysts of perthitic potash feldspar up to about 20 mm, quartz in typical drop-like grains and brown biotite in aggregates and scales not exceeding 3 mm. The groundmass consists of quartz, potash feldspar, plagioclase (oligoclase) and subordinate biotite in grains of 0.1 to 0.2 mm. Accessories are mainly topaz (Stark 1932), apatite, zircon and pyrite.

A similar mineralogical composition is that of medium-grained (0.6 to 1 mm) syenogranite which occurs as facies transition within the porphyritic microgranite.

The aplitic granite is a white to pink, fine-grained, scarcely porphyritic rock. It contains rare phenocrysts of quartz, perthitic K-feldspar, biotite and plagioclase. The groundmass (0.2 to 0.5 mm) consists of quartz, potash feldspar, albite, biotite and hematite. This granite occurs as younger intrusion in the Preisselberg area (Fiala & Pácal 1965) and as dykes in gneiss in the Knötel ore-field (e.g. Mahler dyke) (Beck 1914, Žák 1966a, b).

Granites of the second sequence

Lithium-albite porphyritic microgranite occurs in the Cínovec intrusion as xenoliths in the medium-grained lithium-albite granite. It contains potash feldspar phenocrysts and drop-like quartz crystals to about 3–7 mm size in a 0.1 to 0.3 mm groundmass containing potash feldspar, albite, quartz and zinnwaldite. Topaz, fluorite, hematite, sericite, kaolinite and dickite occur as accessory and deuteric minerals. In the Preisselberg II cupola it is a scarcely porphyritic variety. Lithium-albite medium-grained granite forms the predominant type of lithium-albite granites in the Cínovec pluton. It occurs also in the Krupka region in the apical parts of the hidden pluton in the Knötel district (drillholes KV-9, KV-20). It is a greenish or greyish-white rock consisting of quartz, slightly perthitic potash feldspar, albite and zinnwaldite (in two generations) as the main constituents. Accessories are topaz, fluorite, cassiterite, columbite, rutile, monazite, bastnaesite, zircon, scheelite, wolframite and others (Cocherie et al. 1991). This rock is often strongly altered. Light greenish colours are caused by common pervasive sericitization which is accompanied by kaolinization. The modal composition of lithium albite granites from Cínovec is given in Table 2.

Protolithionite medium-grained porphyritic granites constitute the lower part of the Cínovec granite cupola as red to pink, occasionally coarse porphyritic granites with phenocrysts of quartz and strongly perthitic potash feldspar and a groundmass 2–3 mm in size consisting of albite, potash feldspar, protolithionite as the only mica, zircon, apatite and monazite (Rub et al. 1983). Protolithionite-bearing granites of the YIC second sequence were found also in the Krupka pluton (e.g. borehole E-9) in association with the lithium-albite granites.

Lamprophyres

Amphibole kersantite occurs as a dark grey porphyritic dyke rock consisting of biotite and light-green amphibole from 0.4 to 1.5 mm and tablets of andesine up to about

Table 2. Average modal composition of lithium-albite granites from the Cínovec South deposit

	1	2	3	4	5
quartz I	20.09	31.19	28.84	34.12	38.07
quartz II	5.96	0.59	0.48	5.75	2.19
potash feldspar (perthite)	38.30	23.88	32.93	19.18	8.15
adularia	8.95	11.30	5.45	0.54	0.20
albite	16.38	18.88	12.01	0.80	0.41
zinnwaldite I	5.15	5.87	6.23	9.06	15.20
zinnwaldite II	0.93	0.66	0.37	1.19	1.76
muscovite	0.02	0.05	0.06	0.11	2.11
topaz	0.24	0.27	0.31	0.41	0.16
clay minerals (sericite + kaolinite)	2.97	6.85	12.32	27.07	31.44
fluorite	0.83	0.33	0.86	1.13	0.05
cassiterite	0.07	0.05	0.05	0.31	0.03
wolframite	0.05	0.04	0.04	0.10	0.03
scheelite	0.05	0.04	0.04	0.08	0.02
sulfides	0.01	–	0.01	0.14	0.12
number of specimens	26	31	26	62	7

1 – fine-grained porphyritic albite granite (partly feldspathized and recrystallized)
2 – medium-grained albite granite, feldspathized
3 – medium-grained albite granite, sericitized
4 – medium-grained albite granite, greisenized and sericitized
5 – medium-grained albite granite, greisenized and sericitized

0.8 mm. Fibrous amphibole formed by the replacement of augite in pseudomorphs whose margins are intergrown with biotite and magnetite. The phenocrysts of andesine enclose small columns of actinolitic amphibole and biotite up to about 0.1 mm. The groundmass consists of andesine, biotite, less frequent amphibole, opaque minerals and apatite in the grain size range of 0.2 to 0.4 mm. In addition to kersantites, dykes of minettes and spessartites were identified showing variable degrees of alteration.

Granite correlation

The correlation of granites found in isolated outcrops and drillholes offers many difficulties especially among the granites of the YIC first intrusion sequence, but it is less difficult in the lithium-albite granites of the YIC second sequence.

Biotite-bearing granites are exposed in the Schellerhau granite massif (Seim et al. 1982). This intrusion consists of an earlier fine-grained porphyritic granite (Gp) and a non-porphyritic medium-grained granite (Gn) which are considered as separate intrusive phases. Because of their sequence and textures the porphyritic biotite granite is possibly the closest to the Preisselberg biotite granite and also to the Altenberg outer granite (Aussengranit) as described by Seim & Leipe (1987).

The younger medium-grained granite in the Schellerhau massif can be correlated with the protolithionite medium-grained porphyritic granite occupying the lower part of the

Table 3. Average modal composition of greisens from the Cínovec and Preisselberg II deposits

	1	2	3	4	5	6	7	8
quartz I	65.83	51.66	52.42	28.40	59.66	58.52	55.69	49.90
quartz II	3.06	10.29	14.16	24.53	2.57	16.27	14.00	9.97
potash feldspar	1.32	0.33	0.61	6.61	–	–	–	0.07
adularia	0.29	0.14	0.19	0.15	0.08	0.01	0.54	0.03
albite	0.17	0.13	0.14	1.26	0.02	0.02	0.03	0.06
zinnwaldite I	18.38	18.18	16.60	6.64	–	–	–	–
zinnwaldite II	0.39	3.95	4.25	6.78	–	–	–	–
Fe-zinnwaldite	–	–	–	–	23.64	0.75	5.10	23.15
muscovite	0.27	0.04	0.82	11.86	0.68	2.85	16.75	4.26
topaz	1.16	8.43	1.39	0.27	6.77	13.95	1.89	6.70
clay minerals (sericite + kaolinite)	7.65	5.10	7.60	12.08	3.17	5.22	4.21	3.78
fluorite	1.01	0.91	0.76	0.26	1.35	1.17	0.67	0.60
hematite	–	–	–	–	0.80	0.35	0.40	0.73
cassiterite	0.31	0.48	0.60	0.38	0.07	0.09	0.13	0.40
wolframite	0.08	0.17	0.23	0.12	0.39	0.26	0.25	0.11
scheelite	0.05	0.07	0.06	0.18	0.35	0.46	0.21	0.18
sulfides	0.03	0.11	0.16	0.47	0.01	0.05	0.09	0.02
number of specimens	28	239	153	7	11	83	9	58

1 – zinnwaldite-quartz greisen (Cínovec)
2 – topaz-zinnwaldite-quartz greisen, recrystallized (Cínovec)
3 – zinnwaldite-quartz greisen, recrystallized (Cínovec)
4 – mica-quartz greisen with relics of feldspars, recrystallized (Cínovec)
5 – topaz-zinnwaldite-quartz greisen (Preisselberg II)
6 – topaz-quartz greisen (Preisselberg II)
7 – muscovite-quartz greisen with zinnwaldite, recrystallized (Preisselberg II)
8 – topaz-zinnwaldite quartz greisen, recrystallized (Preisselberg II)

Cínovec intrusion. Both granites correspond well texturally to the main Krušné hory granite from the Western pluton (Štemprok 1986). The lithium enrichment of the Cínovec granite cupola might have contributed to the higher lithium content of micas in the lower granites in Cínovec compared with the Schellerhau massif.

The position of the lithium-albite granite as the latest in the sequence is consistent in the Altenberg granite, at Cínovec and in the Preisselberg II granite body. There is, however, a large difference in the volumes of these granites, from large bodies occupying the apical parts of the pluton in Cínovec to small cupolas in the Preisselberg II body, to very small (several meters only) bodies in the Altenberg granite (Seim & Leipe 1987).

Chemical composition

Representative granite compositions in Fig. 8 plot near the ternary minimum in the normative Ab-Q-Or diagram with a slight shift of the points for lithium-albite granites towards the Ab apex of the diagram. The granites are corundum normative with no clear separation of the biotite and lithium-mica granites from each other. Most granites are Al-oversaturated which also holds for lithium-albite varieties.

The diagram Li_2O-SiO_2 (Fig. 9) clearly separates the lithium-rich albite granites from the lithium-poor biotite granites and shows that the greisenized rhyolites and granite porphyries range with the lithium albite granites in their Li_2O values. New chemical

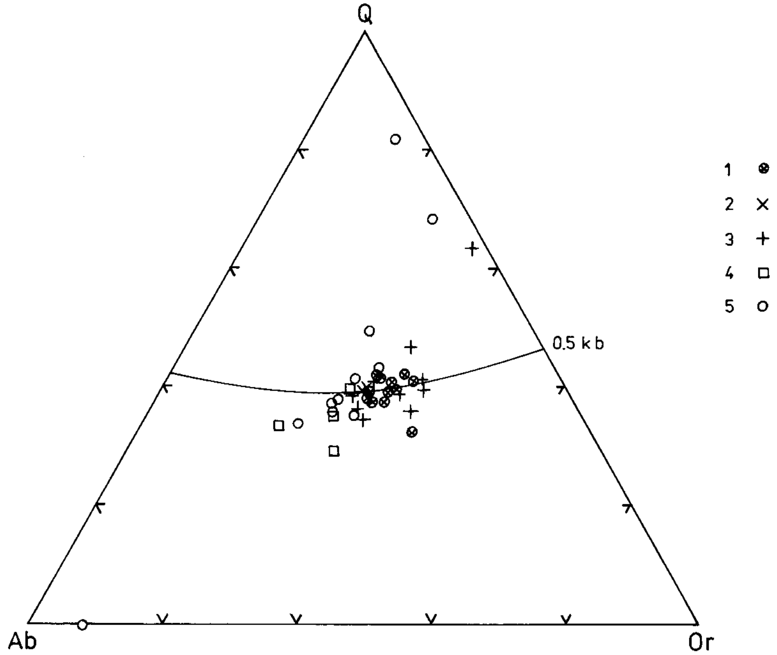

Fig. 8. Plot of normative Q-Ab-Or for the main types of granite of the Younger Intrusive Complex from the eastern Krušné hory (based on the present and literature data).
1 – biotite porphyritic microgranites (Krupka pluton), 2 – protolithionite microgranites (Cínovec pluton), 3 – porphyritic medium-grained protolithionite granites (Cínovec pluton), 4 – lithium-albite porphyritic microgranites Cínovec and Preisselberg II (Cínovec and Krupka plutons), 5 – lithium-albite medium-grained granites (Cínovec and Krupka plutons).

analyses of some greisenized rocks of the Krupka pluton are shown in Table 5. The composition of some lithium-iron micas is given in Table 6 (analyses of separated mineral fractions).

The evaluation of 474 samples of the granites from 12 drillholes showed significant differences in the U and Th average contents in the granites of the YIC first and second sequences (Chlupáčová in Malásek et al. 1987). While the average contents in the granites of the first sequence are 10 ppm U and 42 ppm Th, the granites of the second sequence have more than 30 ppm U in altered varieties and about 23 ppm Th. In non-altered lithium-albite granites the average contents are about 20 ppm U and about 50 ppm Th.

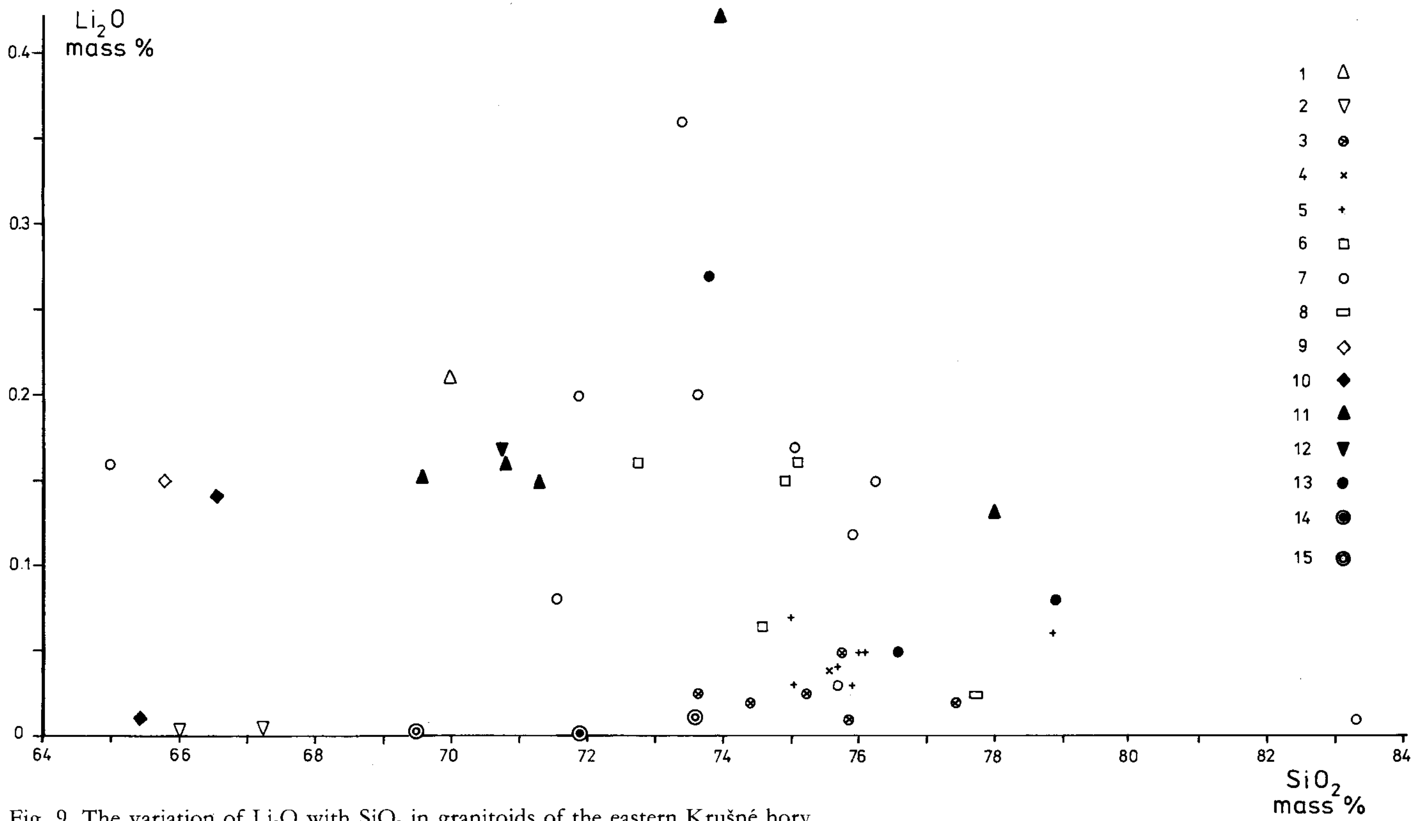

Fig. 9. The variation of Li_2O with SiO_2 in granitoids of the eastern Krušné hory.
1 – Teplice rhyolitic complex, 2 – granite porphyry, 3 – porphyritic microgranites of the Krupka pluton, 4 – porphyritic microgranites of the Cínovec pluton, 5 – porphyritic medium-grained protolithionite granites of the Cínovec pluton, 6 – lithium-albite microgranites of the Cínovec and Krupka plutons, 7 – medium-grained albite granites of the Cínovec and Krupka plutons, 8 – aplitic granites from the Krupka pluton, 9 – albitites, 10 – episyenites, 11 – greisenized rhyolites, 12 – greisenized granite porphyry, 13 – greisenized lithium-albite granites from the Cínovec and Krupka plutons, 14 – Moldava granites, 15 – Fláje monzogranites

Table 4. New chemical analyses of the granites of the Younger Intrusive Complex and of a lamprophyre.

	1	2	3	4	5	6	7
SiO_2	75.73	75.70	74.59	72.72	71.54	75.87	53.74
TiO_2	0.07	0.09	0.06	0.03	0.02	0.03	1.24
Al_2O_3	12.11	12.36	13.41	14.08	16.15	13.19	12.84
Fe_2O_3	0.75	0.61	0.24	0.11	0.30	1.11	1.99
FeO	0.74	0.55	0.35	1.13	0.57	–	4.65
MnO	0.03	0.03	0.026	0.068	0.03	0.04	0.12
MgO	0.13	0.25	0.21	0.19	0.22	0.06	10.26
CaO	0.59	0.64	0.74	1.00	0.73	0.34	6.27
Li_2O	0.05	0.05	0.065	0.16	0.08	0.12	–
Na_2O	2.96	2.14	5.11	3.39	4.43	4.09	1.10
K_2O	5.06	5.19	3.27	4.36	3.45	4.33	4.34
P_2O_5	0.05	0.10	0.05	0.06	0.04	0.04	0.61
H_2O+	1.17	1.87	1.14	1.84	2.05	0.59	1.84
CO_2	0.06	0.12	–	–	0.08	0.03	0.79
SO_3	0.01	0.01	0.05	0.03	0.04	–	–
S	–	–	–	–	–	0.05	–
F	0.56	0.49	0.36	0.74	n.d.	0.43	0.11
H_2O-	0.01	0.28	0.63	0.54	0.61	0.09	0.33
total	100.07	99.98	100.30	100.45	100.34	100.56	100.03
$-O=2F$	−0.23	−0.18	−0.15	−0.31		−0.25	−0.05
total	99.84	99.80	100.15	100.14		100.31	99.98

1 – porphyritic syenogranite of the 1st sequence, borehole E-5, 642.5 m
2 – siderophyllite-bearing albite granite of the 2nd sequence, borehole E-9, 709.3 m
3 – porphyritic albite microgranite of the 2nd sequence from the 5. květen gallery (Preisselberg II stock)
4 – porphyritic microgranite of the 2nd sequence from the 5. květen gallery (Preisselberg II stock)
5 – albitized granite with protolithionite of the 2nd sequence, borehole E-3, 603.2 m
6 – intra-mineralization granitic dyke, borehole E-13, 691.4 m
7 – amphibole kersantite, borehole E-4, 341.3 m

Postmagmatic alterations

One of the essential features of the granites in the Cínovec-Krupka region is the presence of massive deuteric alterations, which affected all granites and the rocks in their envelope. There are areas of intense alteration among which the so-called greisen fields (Zwitterfelder) are the most important (Figs. 1 and 2).

The types of alteration can be divided into pervasive alterations, where the dependence on jointing and fissuring is indistinct, and joint-controlled ones, which closely follow small fissures and joints in the rock. The granites of the YIC first sequence are most often affected by joint-controlled greisenization, whereas the granites of the YIC second sequence are commonly altered by pervasive alteration.

Table 5. New chemical analyses of greisenized rocks from the Krupka pluton.

	1	2	3	4	5	6
SiO_2	70.73	73.82	78.86	76.58	54.68	47.29
TiO_2	0.21	0.04	0.03	0.02	1.11	0.91
Al_2O_3	13.78	13.78	11.01	12.78	14.23	14.30
Fe_2O_3	0.44	0.42	0.60	0.06	1.30	1.66
FeO	1.23	0.61	0.56	0.85	4.72	6.82
MnO	0.03	0.06	0.02	0.02	0.14	0.27
MgO	0.26	0.20	0.01	0.05	6.34	7.99
CaO	1.23	0.65	0.32	0.73	7.32	4.60
Li_2O	0.17	0.27	0.08	0.05	0.02	0.08
Na_2O	2.34	2.90	3.98	3.61	1.76	0.21
K_2O	6.16	4.75	3.08	4.69	4.55	5.72
P_2O_5	0.12	0.17	0.01	0.02	0.84	0.36
H_2O+	1.30	1.83	0.33	0.47	2.62	8.40
CO_2	–	0.04	0.06	0.27	–	–
SO_3	–	0.01	–	–	–	0.03
S	0.04	–	0.02	0.02	–	–
F	1.24	0.79	0.33	0.30	0.67	1.29
H_2O-	0.36	0.45	0.06	0.09	0.35	0.09
total	99.64	100.79	99.36	100.61	100.65	100.02
-O=2F	−0.52	−0.33	−0.14	−0.12	−0.28	−0.54
total	99.12	100.46	99.22	100.49	100.37	99.48

1 – greisenized granite porphyry from the 5. květen gallery
2 – greisenized lithium-albite granite of the 2nd sequence, borehole E-9, 443.5m
3 – greisenized lithium-albite granite of the 2nd sequence, borehole E-15, 684.0 m
4 – greisenized lithium-albite granite, borehole E-20, 779.8 m
5 – greisenized lamprophyre from the 5. květen gallery
6 – greisenized and chloritized minette, from the 5. květen gallery

Pervasive alteration

K-metasomatism in the lithium-albite granites is a common pervasive-type alteration. The metasomatism of the lithium-albite granites took place at the expense of quartz and resulted in the formation of episyenite underlying some greisen zones at Cínovec (drillhole CS-1). The rock is composed of perthitic potash feldspar, adularia, albite, variable amounts of zinnwaldite and accessory fluorite and topaz.

Greisenization occurs as pervasive alteration in the lithium-albite granites of Cínovec and Krupka (Preisselberg II and Knötel) (Baumann et al. 1974). Greisens form irregular, commonly lens-shaped bodies at the direct contact with the country rock or at a distance from the contact, separated by fine-grained granite and by the marginal pegmatite (Stockscheider) from the actual contact surface. Greisens typically imitate the grain size of the original rock and are characteristically zonal. They consist essentially of quartz, micas (zinnwaldite and protolithionite) and muscovite, topaz, sericite, fluorite, cassiterite

Table 6. Chemical analyses of lithium-iron micas from the Preisselberg II stock (Krupka pluton).

	1	2	3	4
SiO_2	39.43	41.55	35.46	36.56
TiO_2	0.08	0.05	1.80	2.02
Al_2O_3	22.05	23.10	17.16	16.87
Fe_2O_3	9.04	7.09	3.56	7.45
FeO	8.48	8.04	20.12	17.28
MnO	0.70	0.59	0.86	0.53
MgO	0.03	0.06	3.68	3.23
CaO	0.23	0.06	0.08	0.22
Li_2O	2.60	2.52	0.84	0.72
Na_2O	0.30	0.25	0.36	0.30
K_2O	9.41	9.05	8.55	8.14
Rb_2O	0.98	0.96	0.56	0.49
Cs_2O	0.015	0.02	0.01	0.01
P_2O_5	0.16	0.19	0.47	0.35
H_2O+	3.55	3.85	4.36	4.34
SO_3	0.02	0.06	0.01	0.01
F	4.35	3.69	3.11	2.98
H_2O-	0.59	0.60	0.38	–
total	102.01	101.74	101.38	101.51
$-O=2F$	−1.83	−1.55	−1.31	−1.25
total	100.18	100.19	100.07	100.26

1 – zinnwaldite, veinlet in lithium-albite granite, from the 5. květen gallery, 1332 m
2 – zinnwaldite, mica-quartz greisen in lithium-albite granite, from the 5. květen gallery, 1415 m
3 – Li-siderophyllite, veinlet in biotite microgranite (exocontact), from the 5. květen gallery, 1164 m
4 – Li-siderophyllite, mica-quartz greisen in biotite microgranite, from the 5. květen gallery, 1173 m

or wolframite (scheelite), and the relics of the original granite feldspars. Typical modal compositions of the greisens from various localities are shown in Table 3. Quartz occurs in two generations at Cínovec and Preisselberg II, and zinnwaldite is also in two generations at Cínovec.

Sericitization

This is the second most wide-spread type of postmagmatic alteration, affecting practically all granites in the region. The presence of fine-grained muscovite and hydromuscovite is responsible for the greenish colour of most lithium-albite granites and is manifested essentially in the feldspar and mica component of the granites. Hydromuscovite was also identified as an essential constituent of the ore veins in the Krupka district (Konta 1960). In the granites of the YIC first sequence, sericitization involves the replacement of albite-oligoclase by sericite in the cores of plagioclase crystals.

Joint-controlled alteration

K-feldspar metasomatism was observed in the Preisselberg granite as zones of perthitic potash feldspar in grains of several cm in drillhole Z-1, and also in the Teplice rhyolite. Joint-controlled albitization was noted in the syenogranites of the first YIC sequence, e.g. in drillhole E-5 at Komáří Vížka where albite replaced the earlier potash feldspar along a fissure and the resulting albite texture approached that in lithium-albite granites. Albitization is wide-spread in the granites of the YIC second sequence and leads to the formation of metasomatic albitites. Thus, flat-lying purely albitic schlieren occur in most of the lithium-albite medium-grained granites, suggesting the replacement by albite along the flatly dipping fissure system which has been also used by later greisenization (albitization I). Albitization II followed greisenization (Čada & Novák 1974).

Greisenization

Joint-controlled greisenization is significant mainly in strongly fissured microgranites, granite porphyries and rhyolites. In the granites of the YIC first sequence, rhyolites and granite porphyries, greisenization leads to dark green or black rock colours. The black colour is due to dark green protolithionite which may amount to 24 modal % (Table 3). Also in the lithium-albite granites, greisenization follows the fissure system of the granite and the walls of the quartz veins, but the colour of greisens is grey to brown.

At Cínovec, Čada & Novák (1974) distinguished two stages of greisenization similar to Kühne et al. (1972). The earlier one is characterized by the formation of quartz-zinnwaldite-topaz greisens (1st stage) and the later one by the formation of zinnwaldite II-quartz-muscovite greisens (2^{nd} stage), where the minerals are essentially formed by recrystallization of the greisen minerals of the first stage. The younger greisens are probably separated from the earlier ones by the intrusion of intra-mineralization microgranitic dykes. These two stages of greisenization are distinguished in Table 3 by quartz I and II, zinnwaldite I and II and muscovite of the second greisenization stage. According to Čada & Novák (1974), the second stage of greisenization is responsible for the bulk of tin mineralization and the scheelitization of wolframite.

Ore deposits

There are two major districts of tin and tungsten mineralization in the area. The Cínovec district zones (Fig. 10), and the Krupka district is separated into the Loupežný, Preisselberg, Günther, Komáří Vížka, Klösenberg, and Knötel ore fields (Fig. 1).

The Cínovec (Zinnwald) Sn-W deposit

Tin and tungsten mineralization is spatially associated with a cupola of lithium-albite granites at the village of Cínovec. The deposit is divided by the state border into a

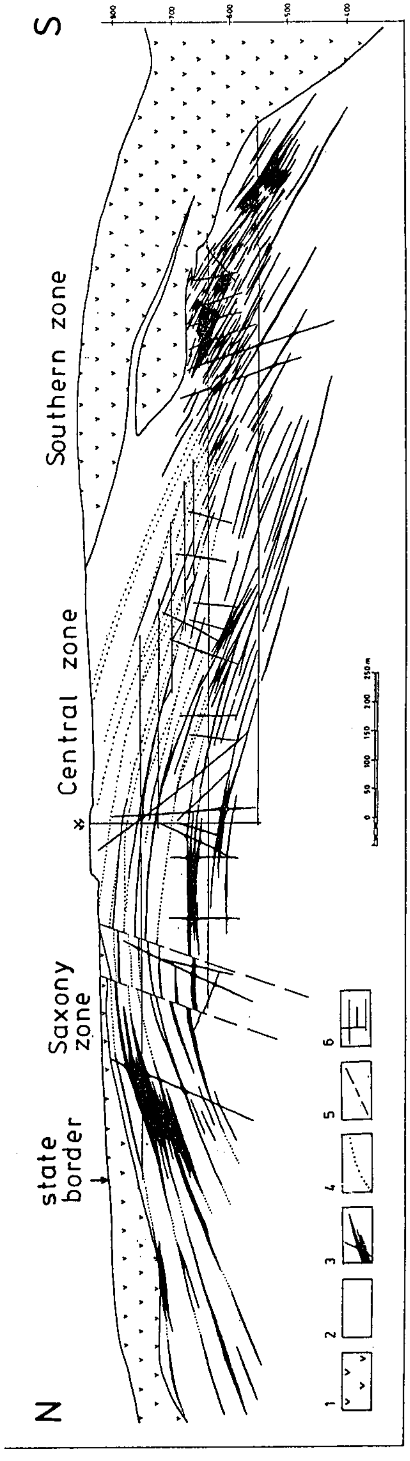

Fig. 10. North-south geological section from Germany into the Czech part through the Cínovec granite cupola.
1 – Teplice rhyolitic complex, 2 – lithium-albite granites, 3 – greisens, 4 – quartz veins, 5 – faults, 6 – schematic representation of the mine levels

northern and a southern part. There has been mining in the post-war period only on the Czech side of the border.

The deposit consist of two morphological types of ores (Fig. 10):

a) irregular metasomatic greisens several tens of m in size, following the morphology of the granite contact. They consist of several types of greisens and greisenized granites (Table 2), and
b) flat thin greisen zones and quartz veins with wall-rock greisens which formed along joints and fissures.

Flat greisen veins are developed to a depth of about 250 m from the present surface and dip from subhorizontal in the centre to 5° to 45° at the flanks of the intrusion. From 250 m to about 450 m below the surface, NE striking veins and greisen zones of the second greisen stage prevail (David 1990). The greisens consist of quartz, zinnwaldite and topaz, with variable amount of fluorite and hydromuscovite. Cassiterite commonly contains inclusions of tapiolite, columbite, tantalite and Nb-Ta rutile (Hoffman et al. 1965).

Cassiterite predominates over wolframite and scheelite in greisens and greisenized granites (Cínovec South deposit with 0.2% Sn and 0.04% W). In the vein system wolframite is in equal proportion or predominates over cassiterite. Cassiterite forms impregnations in greisens and greisenized granites. The form of the ore bodies is highly irregular, depending on the intersection of steep and flat fissures and the development of late-stage greisens in three principal zones of NE strike (Čada & Götz 1978) (Fig. 10). These are

a) the Saxony zone (in the north) with greisens and a vein system mainly in the German part,
b) the Central zone with flat-dipping essentially quartz veins and wall-rock greisens, and
c) the Southern zone consisting only of large irregular bodies of greisens.

A strong intravenous metasomatism was postulated by Štemprok (1960) with preferential migration of fluids into the fissured vein system.

In the veins the mineralization can be differentiated into four mineralization stages:

1) quartz (barren quartz veins),
2) greisens (formation of greisens and ore mineralization),
3) K-feldspar which leads to pegmatite-like ore textures,
4) sulphides, with the formation of subordinate arsenopyrite, galena, sphalerite, tennantite, chalcopyrite, bismuth, bismuthinite, wittichenite, pyrite and opal, accompanied by common sericitization.

The rare mineral roquesite ($CuInS_2$) occurs as fine inclusions in galena and chalcocite (Novák et al. 1991). Supergene alteration has strongly influenced the sulphide component of the ore bodies, e.g. led to the formation of malachite, philipsbornite, mimetite, olivinite etc. (David et al. 1990).

Krupka Sn-W-Mo deposit

The deposits and showings of tin, tungsten and molybdenum mineralization in the Krupka region can be separated into:

a) contact dependent, associated with greisens in the endocontact of apical parts of the granites, and
b) exocontact, with a looser dependence on the granite surface and essentially of vein and veinlet form.

Loupežný ore-field

Greisenized rhyolites occur on the SW slope of Loupežný Hill and in its vicinity. At the contact of rhyolites with the granites, and partly underlying the granites of the first sequence, there are greisen zones in the endocontact of lithium-albite granites (Fig. 3, 4). The Loupežný cupola has a size of 6 km^2 and is flat at 200 m above sea level with dips of 40–50° at the margin. The mineralization is very low grade ($<0.1\%$ Sn) with a wide scatter of cassiterite.

Preisselberg (Preiselberk) ore-field

The district includes the deposits and showings west of the village of Horní Krupka with the Preisselberg greisen (I) ore deposit and the Preisselberg II greisenized albite granite. The ore-field comprises also the occurrence of the Lukáš (Luxer) vein (Štemprok 1964).

Preisselberg I stockwerk tin deposit

This is located about 1 km west of Komáří Vížka Hill. The greisen body has the thickness of about 25 m and a length of up to 80 m and dips 85° NE. The body consists of a stockwerk of greisenized microgranite, granite porphyry and rhyolite, each of which forms very fine-grained, dark green or black greisens (Fiala & Pácal 1965). Exploration showed about 1.2 million tonnes of low-grade tin ores in the form of very fine-grained cassiterite.

Preisselberg II tungsten-tin deposit

The deposit is associated with a very small cupola of albite granite which underlies the Preisselberg porphyritic syenogranite and forms an assymetric cupola within the Preisselberg stock (Fig. 4). The deposit consists of greisen lenses in the apical parts of the medium to fine-grained albite granite. The greisens are dark green consisting essentially of Fe-zinnwaldite, quartz and topaz, or light grey rich in quartz and topaz (Table 2). In apical parts, cassiterite predominates over wolframite. Mo-bearing scheelite and native bismuth, arsenopyrite, chalcopyrite and pyrite are rare. The medium part consists of topaz-quartz greisens with subeconomic W contents (Tichý 1981).

Lukáš vein (Luxer Gang)

This is a 130° striking vein dipping 35° SW, extending for about 2 km with a thickness ranging from 20 to 50 cm (Beck 1914, Žák 1966a, b). It is composed of quartz, Li-siderophyllite (Rieder et al. 1970). K-feldspar, albite, fluorite, clay minerals, cassiterite, wolframite, bismuth and topaz. It resembles a pegmatite but is actually a feldspathized quartz vein (Štemprok 1964). Of rare minerals, bismutite ($Bi_2O_2CO_2$), kettnerite ($CaFBiOCO_3$), and zavarickiite (BiOF) have been described by Prachař (1988) in association with bismuth.

Komáří Vížka (Mückentürmchen and Günther) ore-fields

The ore-field includes the hill of Komáří Vížka and the Günther field located about 0.75 km west of it. The ore-fields are in the orthogneiss complex of the eastern Krušné hory which is intersected by NE dykes of microgranite quartz porphyry (Fiala 1959). The main ore mineralization is concentrated at the ancient mine working of Komáří Hill, where there is an open pit which originated by the mining of greisenized biotite gneiss and microgranite quartz porphyry for coarse-grained cassiterite (0.66 and 1.25% Sn, Beck 1914). The ore consists of quartz veinlets and wall-rock greisens containing cassiterite, chalcopyrite, pyrite and arsenopyrite which have been followed to a depth of about 200 m in the area of the ancient Göppel shaft.

The Günther ore-field consists of steep quartz veins with wall-rock greisens containing cassiterite, wolframite, molybdenite and bismuth, whose thickness usually does not exceed 50 cm (drillhole S-2). The upper portions of these veins have been removed by ancient mining. Among numerous dykes, aplites and lamprophyres occur, some of which were greisenized.

Knötl (Bohosudov) ore-field

The district is located north of the town Bohosudov close to the Krušné hory/Erzgebirge fault zone and is within the gneiss complex consisting of orthogneiss and migmatitized paragneiss. The district shows a manifold variety of ore assemblages, associated spatially with a pegmatite body and the lithium-albite granite which was greisenized in its apical parts (Žák 1959, 1966a, b). The main ore body is similar to a large stock in a zone of brecciation (Oelsner 1952) which passes into granite dykes and a pegmatite. The ore types can be divided into:

a) quartz greisen by the greisenization of aplites in the apical parts of the cupola,
b) quartz veins with molybdenite and bismuth, striking essentially E-W, with wall-rock greisenization,
c) mineralized pegmatites with molybdenite,
d) the greisenized body of the Večerní hvězda gallery, which consists of greisenized fine to medium-grained albite granite with molybdenite and wolframite, and
e) greisenized granites in the endocontact zone, consisting of quartz-Li mica-topaz greisens with poor tin mineralization (drillholes KV-20 and KV-9 – Baumann et al. 1974).

In addition to the ore types closely related to the hidden surface of the YIC granites, there are numerous quartz veins with wall-rock greisenization which have been the object of mining in mediaeval times. The ancient shafts in Fig. 1 in the Krupka region partly mark their distribution. These veins have a thickness of several cm and in addition to quartz contain lithium micas (zinnwaldite and protolithionite), clay minerals (hydromuscovite, dickite, Konta 1960), fluorite, coarse-grained cassiterite, wolframite, molybdenite, chalcopyrite and bismuth. The veins have strike NE dipping 75 to 80° NW, or are flat striking 60 to 70° and dipping 15 do 20° S.

Greisen occurs as a replacement body of an earlier aplite stockwerk at Zwickenpinge in the Knötel district. The mostly quartz-topaz greisen is rich in copper minerals, essentially in chalcopyrite and chalcocite. The predominantly E-W Mahler complex dyke of aplite was greisenized in the Knötel ore-field. Occasionaly lamprophyre dykes (Fiala 1959) with NE strike dipping 75° SE were encountered in the envelope of the granite intrusions and are intersected by quartz veins with cassiterite in the orthogneisses of the Knötel and Klösenberg field.

Lamprophyres belong to minettes, kersantites, spessartitic kersantites and odinitic lamprophyres. In drillhole E-8 at Klösenberg a composite dyke of syenite porphyry and altered porphyrite was found.

Dependence of mineralization on the upper surface of the granite

The shape of the granitic elevations depends closely on the lithology of the country rocks into which the granites intruded. In the Teplice rhyolite and granite porphyries, the granite morphology is flat and the elevations have a smooth dome-like structure (Fig. 3). The more abrupt western granite contact at Cínovec is caused by later tectonics along the western contact (Čabla & Tichý 1965). In the orthogneisses, and also in the granite porphyry, the elevations have steeper contacts and a stock-like form (Preisselberg I and Preisselberg II) (Fig. 4).

The topographically highest granite elevations appear to be best mineralized (see Fig. 3 and 4), whereas those which are related to the undulation of the upper granite surface of lower levels are weakly mineralized. Low-grade (essentially lower than 0.1 % Sn) mineralization occurs in greisens associated with the bending of the subhorizontal course of the granitic surface towards the flanks at Loupežný, where the greisens contain either protolithionite or Li-siderophyllite. Greisenization developed not immediately at the contact but below the stockscheider and a fine-grained carapace granite.

The original interpretation of Chrt et al. (1974) presumed the each of the granitic sequences within the YIC granites produced its own mineralization. Thus mineralization of cassiterite and wolframite was repeated at least twice, with the intrusion of biotite syenogranite and with the lithium-albite granites. Our interpretation prefers a single cycle of tin and tungsten mineralization which followed the formation of the lithium-albite granites and lamprophyres and was interspersed with the intrusion of intra-ore granitic dykes. Thus the granites of the first sequence appear to have served as the envelope for the granites of the second sequence, and were mineralized as exocontact greisen or as vein bodies in them.

Discussion

The geological setting of the eastern Krušné hory Mts. offers a case study for the relationship between ore-bearing granites and associated ore deposits. The area is composed of a late Variscan volcano-plutonic complex characterized by the extrusion and intrusion of rhyolites complexes and granite porphyries and the shallow intrusion of granites. Even if Spengler's (1949) original guess at a 1 km depth of intrusion of the Cínovec granite appears speculative and was questioned by Schust (1980), a high-level emplacement not deeper than about 2 km below the surface appears justified by recent paleogeographic considerations and the sequential relationship between the rhyolites and the granites of the first sequence.

Our observations support the view of Plimer (1987) on the origin of carapace granites at the margins of ore-bearing plutons. The fine-grained porphyritic granites of the YIC first sequence were influenced by rapid cooling under near-surface conditions and acted as carapace granites in the Krupka pluton. They might have been poor in volatiles and thus capable of rising to the highest position in the crust. The lithium-albite granites are related to the YIC second sequence which were intruded into the preheated carapace granites as a sequence of volatile-rich (mainly fluorine-rich) granites and fluids.

The formation of the lithium-albite granites offers a problem which has been explained by postmagmatic reworking in the solid state (Beus et al. 1962), or by primary crystallization as demonstrated by Kovalenko & Kovalenko (1976) for ongonites.

An origin of the lithium-albite granites by metasomatism has been assumed by Štemprok & Šulcek (1969) for the Cínovec granites, and the same granites were classified as metasomatic granites in the whole area of the Krušné hory batholith by Lange et al. (1972). The idea was doubted by Breiter et al. (1991) on the basis of experiments by Manning (1981, 1982) who showed that the effect of fluorine on the crystallization of granites is to lower the liquidus below the temperature of the feldspar solvus.

However, the experimental data do not sufficiently explain the coexistence of potash and sodium feldspars under low pressure conditions, and Bowden (1982) solved this problem for Nigerian albite granites by the concept of rock-fluid retention which caused metasomatism and significant mineralization.

The present authors prefer to explain the second intrusion of the granites which formed lithium-albite granites, either by the accumulation of the volatile constituents in the granite cupolas of the intrusion of the second sequence, or by a metasomatic reworking of the second sequence granites under the cover of porphyries, rhyolites and of the carapace granites of the first sequence.

Recent interpretation of REE patterns of the lithium-albite granites at Cínovec (Cocherie et al. 1991) suggests a prolonged contact of these granites with hydrothermal fluids, favouring the participation of aqueous solutions in the origin of the lithium-albite granites. As shown by one of us (Štemprok 1963), the contact plane of the granite represented the major surface of discontinuity after emplacement and primary solidification. On this most of the late and postmagmatic phenomena have been focused, for example the intrusion of aplitic dykes, pervasive alteration in the carapace granites, and the development of joint-controlled greisenization after solidification of the upper level granites. There has been a strong contraction in many of the granites at the time of joint formation. Thus there has been a strong interaction of the contact plane of the granites with the still-liquid magmas at depth, and with the sources responsible for the hydrothermal fluids.

The $\delta^{34}S$ values of greisen molybdenites from Krupka and Cínovec (Drábek et al. 1989) give a very narrow range from -2.8 to -1.0‰ CDT which correspond to sulphides from igneous plutonic rocks. Fluid inclusions studied (Ďurišová 1971, 1978, 1988) give evidence for high salinity inclusions (35–40% NaCl) in addition to low salinity ones (10 to 0.5% NaCl equiv.) and small amounts of CO_2. These data agree well with those of R. Thomas (in Tischendorf, ed., 1989) obtained on similar assemblages in the German part of the province.

These data support an orthomagmatic model for the origin of the tin and tungsten mineralization, with the metal component derived from magmatic differentiation of granitoid rocks and hydrothermal solutions affecting the upper contact of granite (Štemprok 1963).

Conclusions

The Czech part of the eastern Krušné hory encloses two districts with tin and tungsten mineralization. The western one of the Cínovec greisen type lies at the border between the Czech Republic and Germany at Cínovec, and is associated with a partly hidden body of zinnwaldite-albite granite which continues south-east into a depression of the granite surface. It encloses a flat vein and greisen mineralization of cassiterite and wolframite with lithium micas.

The eastern Krupka body (Preisselberg II) consists of upper biotite syenogranites which are underlain by lithium-albite granites. These granites of both sequences form small granitic stocks with steep slopes which were greisenized in their endocontact parts. In the Krupka district abundant vein mineralization occurs as quartz-cassiterite and quartz-wolframite veins in the western part, but as quartz-molybdenite veins in the eastern (Knötel) part accompanied by a pegmatite at Knötel.

The plutons formed at a high level as multiphase intrusions in which the granites of the second sequence were accompanied by intense albitization and greisenization. The mineralization is strongly contact-dependent in greisen-type deposits and shows a looser relationship in the vein-type deposits.

The mineralization occurred as a single process following the origin of lithium-albite granites, and was concentrated close to the contact plane between the earlier granites, extrusives or dykes. Although belonging to a single period, the mineralization shows a distinct zoning characterized by a distribution of quartz-cassiterite-wolframite mainly in the Cínovec area and quartz-molybdenite-bismuth assemblages mainly in the Knötel district.

The formation of lithium-albite granites offers evidence for both magmatic and metasomatic explanations. The magmatic hypothesis accepts the possibility of a high intrusion level of fluorine-rich magmas and their crystallization with the retention of volatile constituents, whereas the metasomatic hypothesis postulates a solid-state metasomatism of the upper contact of the granite by volatiles from the lower crustal levels.

The ores are mostly of lower grade (about 0.1 to 0.3 % Sn + W) in the greisen bodies, whereas they are higher grade in the veins which have been important in past mining. At the present time, mining in the area has been abandoned because hard-rock underground mining for tin and tungsten ores is uneconomic under present conditions.

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