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Fifty Years of Geological Cooperation between Austria, the Czech Republic and the Slovak Republic

Geochemical classification of Variscan Granitoids in the Moldanubicum (Czech Republic, Austria)

KAREL BREITER*

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Zusammenfassung

Die variszischen Granitoide des Moldanubikums werden in Gruppen (Suiten) eingeteilt, die mit den aufeinanderfolgenden Stadien der variszischen Orogenese einhergehen. Es können folgende Gesteinssuiten unterschieden werden: 1. Durbachite und mit diesen assoziierte Gesteine (~340 Ma); 2. Weinsberger Granit (Biotitgranit vom I-Typ: ~328 Ma); 3. Lásenice Granit; 4. Čímĕř Granit („Zweiglimmergranit“); 5. Eisgarner Granit sowie begleitende Sn-, Nb-, Ta-, U-Muskowit-Granite (~324 Ma); 6. Mauthausener Suite (Granite vom Biotit-Typ I, späte Intrusionen mit Mo-Mineralisation: ~315 Ma); 7. Freistätter Suite (Biotitgranite und Granodiorite vom I-Typ: ~305 Ma).
Die relative Abfolge aller dieser Gesteinssuiten ist geologisch untermauert, dennoch können die Isotopenalter der verschiedenen Intrusions-Phasen innerhalb einer Gesteinssuite stark schwanken.

Abstract

Variscan granitoids in the Moldanubicum are classified in groups and suites, which represent successive evolutionary stages of the Variscan orogenic process. Proposed suites are: 1. durbachites with associated rocks (~340 Ma); 2. Weinsberg granite (I-type biotite granite, ~328 Ma); 3. Lásenice granite (granite minimum melt); 4. Čímĕř granite (peraluminous granite); 5. Eisgarn s.s. granite with associated Sn, Nb, Ta, U enriched muscovite granites (~324 Ma); 6. Mauthausen suite (I-type biotite granites, late fractionated intrusions with Mo-mineralization) (~315 Ma); 7. Freistadt suite (I-type biotite granites and granodiorites, ~305 Ma).
The relative succession of all rock suites is documented geologically; nevertheless, the isotopic ages of individual bodies (intrusions) within the suite may vary largely.

* KAREL BREITER: Czech Geological Survey, Geologická 6, CZ 152 00 Praha 5.

Introduction

From the old classical geological maps of the Moldanubicum (HAUER, 1867–1871), granitoids are classified according to the petrographic rock name (granite, granodiorite, syenite etc.), their mineral composition (biotite, two-mica, amphibole etc.), and texture (fine- to coarse grained, porphyritic or equigranular). This "traditional" style of classification compatible with the international nomenclature (LE MAITRE, 2002) is accepted also in the most recent synthetic maps (CHÁB et al., 2007; SCHNABEL, 2002; KRENMAYER & SCHNABEL, 2006; TEIPEL et al., 2008) (Text-Figure 1).

Beside the general petrographic names, many granite bodies obtain specific local names during mapping and were classified as "type Xy". Especially among two-mica granites, tenths of local names ("types"), were defined, redefined, abandoned, and again used in a different sense. Geological names are mixed, and sometimes are in confusion, with traditional names of the quarrying districts. For example, KOUTEK (1925) and ZOUBEK (1949) introduced for granites in the "Central Moldanubian Pluton", according to their texture, the local names Mrákotín, Čímĕř, and Landštein. WALDMANN (1950) used the name Eisgarn originally for the coarse-grained porphyritic two-mica granite in the vicinity of the eponymous village N of Gmünd. This name was later incorrectly used as synonym for all varieties of medium- to coarse-grained two-mica-granites through the whole Moldanubicum. Similarly, the name "Mauthausen granite" (RICHTER, 1965) was used for all bodies of the fine-grained biotite or two-mica granites. Local rock names are also used in printed geological maps of larger scales (1:50.000, 1:25.000) in Austria and the Czech Republic. This style of classification complicated any discussion among geologists working in this area. And geologists not familiar with the history of the geological investigation of the Moldanubicum and the local literature, do not understand this terminology at all.

Massive entrance of chemical and later isotopic methods in the last forty years demonstrated a much more complicated structure of individual granite plutons and Moldanubian granitoids on the whole. The real geological units, defined geochemically and structurally, are not consistent with traditionally outlined "granite types". But the geological maps keep the old "classical" concepts.

Several attempts at a new genetic classification (FINGER et al., 1994, 1997; GERDES, 1997; GERDES et al., 1998) focused namely on the Weinsberg- and Freistadt-Mauthausen units and other granites typically developed in Austria. On the other side, the two-mica granites were preferentially studied in Bohemia (BREITER et al., 1998, 2007; BREITER & KOLLER, 1999; RENE, 2001).

Unfortunately, many isotopic ages are reported as "age of X-type granite" without accurate specification of the locality. This made usability of those data problematic, namely in case of the so-called Mauthausen and Eisgarn-type granites.

The purpose of this paper is, based on available geochemical data, to define major evolutionary units of Variscan granitoids in the Moldanubicum (South Bohemian Pluton, SBP), to outline these units in maps (Text-Figure 2), and provoke further discussion of this topic among Austrian and Czech geologists.

Data

The proposed classification is based on an extensive set of chemical, petrological and mineralogical data from all types of granitoids in the Czech part of the Moldanubicum, and from the peraluminous (two-mica) granites of the Austrian and German parts of the Moldanubicum collected by the author during the last twenty years of field investigation. Data from literature were used for classification of other types of granitoids from Austrian and German territories.

Proposed Geochemical Classification of Granitoids

All Variscan igneous rocks in the Moldanubicum should be, according to their geological relations (relative age), divided into three major rock groups:

1. granitoids older than major intrusions of peraluminous granites,
2. major intrusions of peraluminous two-mica granites (incorrectly called "Eisgarn-type granites"),
3. granitoids younger than major intrusions of peraluminous granites.

Each of the rock groups contains several intrusive suites of related granitoids. While the relative age of rock groups is well documented, the relative age of some suites, which are not in direct intrusive contact, remain in some cases unclear and may be interpreted in different ways (Weinsberg granites vs. glimmerites or Weinsberg granites vs. Lásenice granites).

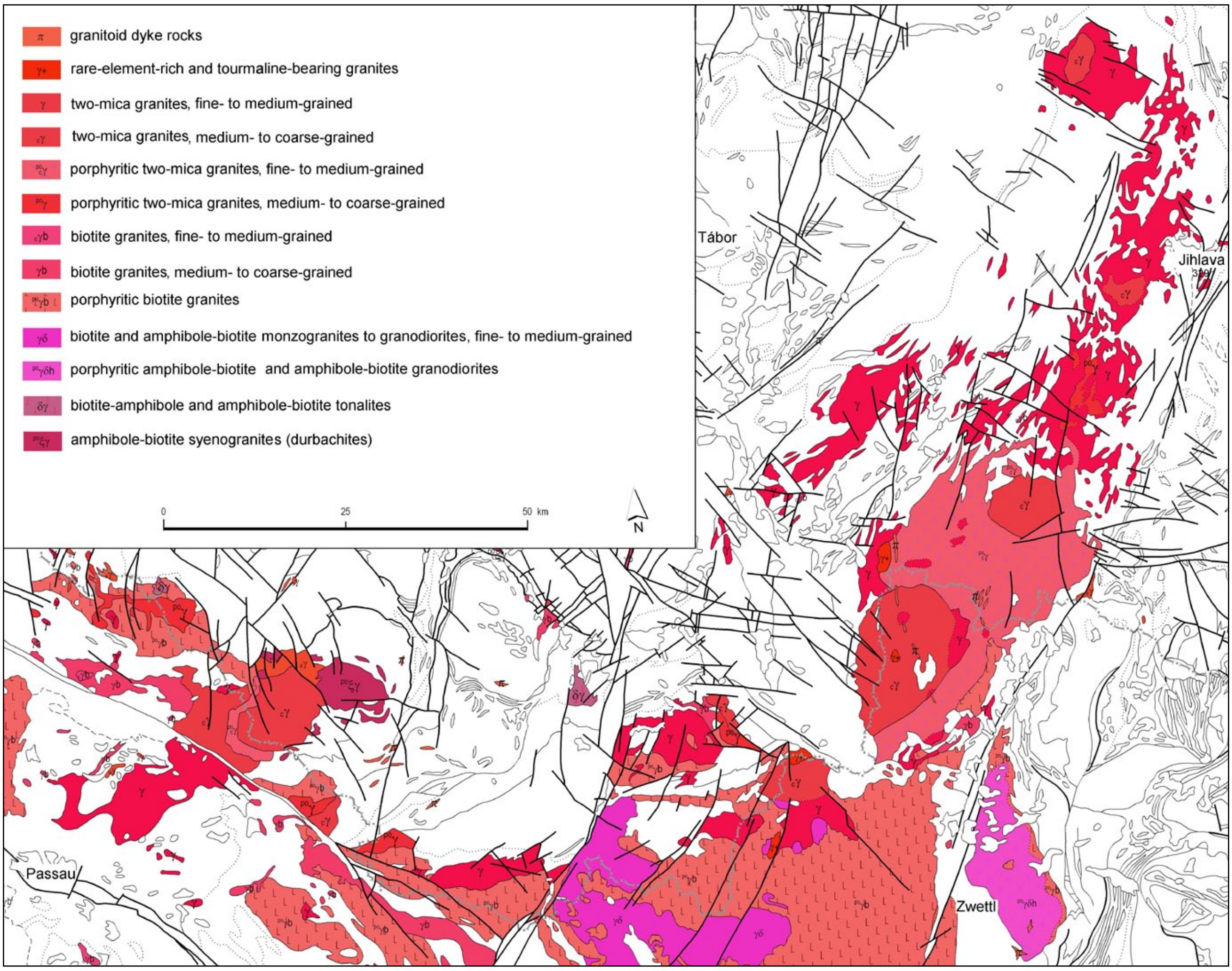
Older Group of Intrusions (pre-Eisgarn)

Suite of K- and Mg-rich Granitoids

Mafic K-Mg-rich biotite (± hornblende) melasyenite (with around 58–65 % SiO_2, 4–8 wt % MgO, 6.0–6.5 wt % K_2O, high in Ba, Sr, Th, U, Zr, xMg = 0.6–0.7), termed **durbachite,** is one of the most typical Variscan magmatic rocks of the Moldanubicum. Beside large well-known bodies through the southern Czech Republic (Třebíč, Knížecí stolec, Netolice), several small more basic (<50 wt % SiO_2) bodies were recently found in the Dreiländereck area (South Bohemia – Bavaria – Upper Austria) (BREITER & KOLLER, 2009). The very probable age of major durbachite intrusions is about 340 Ma.

The **Rastenberg granodiorite** in Austria is, in comparison with Bohemian durbachites, less potassic and less magnesian. Mingling of mafic and granodioritic melts occurs in some places within the Rastenberg pluton (FINGER et al., 1994); this phenomenon was not reported from Bohemian durbachites. The probable age of the Rastenberg granodiorite is 338±2 Ma (KLÖTZLI & PARRISH, 1996).

Several dykes of ultramafic rocks termed **glimmerites** appear in the endo- and exocontact of the Prachatice and Křišťanov granulite bodies. These rocks are mainly composed of phlogopite (xMg = 0.65–0.80) and actinolite (xMg = 0.75–0.85). Typical chemical composition (45–54 wt % SiO_2, 8–11 wt % Al_2O_3, 11–17 wt % MgO, 0.3–1.3 wt % Na_2O, 3.3–5.5 wt % K_2O, 1.2–2.4 wt % P_2O_5, 500–1000 ppm Cr, 200–600 ppm Ni) is rather unusual and differs from neighbouring durbachites (BREITER & KOLLER, 2009).



Text-Fig. 1.
Granitoid rocks in the Moldanubicum (according to Cháb et al., 2007).

Weinsberg Suite

Prevailingly coarse-grained conspicuously porphyritic biotite **Weinsberg granite** is the most widespread well-defined granite type within the whole Moldanubicum. Its equivalent in Bavaria is traditionally termed as "**Krystallgranit I**" (Propach, 1989; Teipel et al., 2008). Although distributed over the large area in the southern Moldanubicum, the Weinsberg granite is texturally as well as chemically notably homogeneous (61–65 wt % SiO_2). Nevertheless, Finger et al. (1994) mentioned some fractionation of this granite in Austria: Weinsberg I (SW part of the pluton) – Weinsberg II (NE part of the pluton) – Plochwald granite, unfortunately without any chemical data and mapping. The local fractionation centre of the Weinsberg melt was recently described also from the Bohemian Šumava Mts.: fine-grained biotite granodiorite – typical Weinsberg granite – medium-grained equigranular biotite granite (61.5–71.5 wt % SiO_2, 2.5–0.7 wt % MgO, 3.2–5.1 wt % K_2O) (Breiter, 2009). Probable age of the Weinsberg granite is about 331–327 Ma (Friedl et al., 1996; Gerdes et al., 2003).

The pyroxene-bearing domain within the Weinsberg granite near Sarleinsbach was interpreted in different ways (Klötzli et al., 2001 vs. Finger & Clemens, 2002). Poorly defined Engerwitzdorf granite is another, geologically slightly younger member of the Weinsberg suite (Finger et al., 1994).

Lásenice Suite

The **Lásenice granite** – fine- to medium-grained two-mica to biotite granite – forms the Klenov body NW of the town of Jindřichův Hradec and many small bodies near the NW margin of the SBP. Chemically, the Lásenice granite is characterised by very low contents of all compatible elements – Th, Zr, REE etc. and also U. The major element composition of this granite is near the "granite minimum melt" composition demonstrating an origin derived from crustal melting possibly during the thermal peak of the regional metamorphism in the sense of typical S-type granite (Breiter & Koller, 1999). The granite was affected by late-Variscan shearing (Klečka & Rajlich, 1984). The Lásenice granite is comparable to the **Altenberg granite** in Austria in chemical composition and shearing. According to field relations, the Altenberg granite is younger than Weinsberg granite, but older than the Mauthausen-Freistadt group of intrusions (Finger et al., 1994).

Group of Major Peraluminous Granites (Incorrectly Eisgarn s.l.)

The main intrusive event of peraluminous magmas is composed of two successive suites intruding probably in a short time interval.

Číměř Suite

The relatively slightly older fine- to medium-grained partly porphyritic peraluminous intrusions form an in detail variable, but generally chemically homogeneous suite of rocks with different textures and plenty of local names. These granites form the largest part of the "Central pluton" between the towns of Jihlava and Gmünd. Granites from the Novohradské hory Mts. and the Slepičí hory Mts. in southern Bohemia and some granites from the Šumava/Böhmerwald Mts. should be also related to this type. According to the gravity survey, granites of this group form plate-shaped bodies with a maximal thickness of about 3 km (ŠRÁMEK, pers. commun.). The medium- to coarse-grained porphyritic **Číměř granite** represents the most typical rock of this group. It forms the main part of the SBP in southern Bohemia around towns of Jindřichův Hradec, Nová Bystřice and Slavonice. Within the Austrian part of SBP, the eastern peri-contact stripe between the towns of Slavonice and Gmünd (quarries at Aalfang and Langegg) belongs also to this type. The quarrying district around the villages of Mrákotín is built up by fine- (to medium-) grained granite named by KOUTEK (1925) as Mrákotín granite, which is now interpreted as a local facies of the Číměř granite. Chemically, the Číměř granite represents a high-K peraluminous melt with higher contents of compatible elements, which implies melting conditions well above the "granite minimum melt" system within the deeper (lower?) parts of the continental crust. Inhomogeneities within the intrusion, well indicated by field gamma-ray measurements, imply insufficient homogenisation of the melt during intrusion.

Peraluminous mineralogy is expressed with abundant muscovite, microscopic sillimanite and occasionally also macroscopic pink crystals of andalusite (up to 1 mm).

Eisgarn Suite

The younger group of coarse-grained two-mica peraluminous granites (Eisgarn type in the original sense**)** forms ring-shaped bodies or stocks, often with zoned internal structure and highly fractionated late intrusions. From the NE to the SW there are bodies: Melechov, Čeřínek, Zvůle, Eisgarn s.s., and Plechý. These stocks, according to the concurrence with the gravity minima (MEURERS, 1992; BREITER et al., 1998), represent the deepest roots of the pluton (up to 10 km in the Melechov intrusion).

The most typical rock of this group is the coarse-grained porphyritic **Eisgarn granite s.s.** (WALDMANN, 1950), which forms the central part of the SBP between the towns of Nová Bystřice and Gmünd. The SW part of this body is buried below the Cretaceous and Tertiary sediments of the Třeboň basin.

The body of the Eisgarn granite s.s (N of Gmünd) shows distinct zonation: an increase of Rb, Na, P, and F and a decrease of K, Ca, Fe, Mg, Th, Zr, Sr etc. from the rim to the centre. This zonation can be explained as the product of an intensive inward oriented fractional crystallization after the intrusion. Internal zonality within the Čeřínek and Melechov bodies is less intensive. The Plechý intrusion is nearly homogeneous, only remnants of the slightly porphyritic roof-facies (Dreisessel granite) differ in the structure and the contents of Rb and Th. High peraluminity is expressed in a high content of muscovite which usually predominates biotite.

The Zvůle body represents the relatively scarce type of "reversal" zoned intrusion. The zonality is expressed here by increase of Rb and decrease of Sr from the centre towards the rims. The most fractionated part of this body is situated along its southern contact.

The Rb/Sr-age of the Eisgarn granite around 330 Ma (SCHARBERT, 1998) seams to be too high. The more probable age will be about 324 Ma (GERDES et al., 1998; BREITER & SULOVSKÝ, 2005; SIEBEL et al., 2008). The $^{87}Sr/^{86}Sr_i$ of Eisgarn and Číměř-type granites is similar ~0.712 (SCHARBERT, 1998).

Two types of younger more fractionated rocks intruded the Eisgarn granite:

A swarm of more than 30 dykes of **granite porphyries and dyke rhyolites** forms a 30 km long NNW–SSE trending zone between Lásenice in the north and Schrems in the south (KLEČKA, 1984; BREITER & SCHARBERT, 1998),

Muscovite granites (± topaz) form several stocks and irregular bodies in the axial part of the pluton (at Galthof), or on the pluton periphery (Homolka) (BREITER & SCHARBERT, 1995, 1998). These granites are the products of pronounced fractionation of the Eisgarn melt and are enriched in phosphorus, fluorine, uranium, and rare metals.

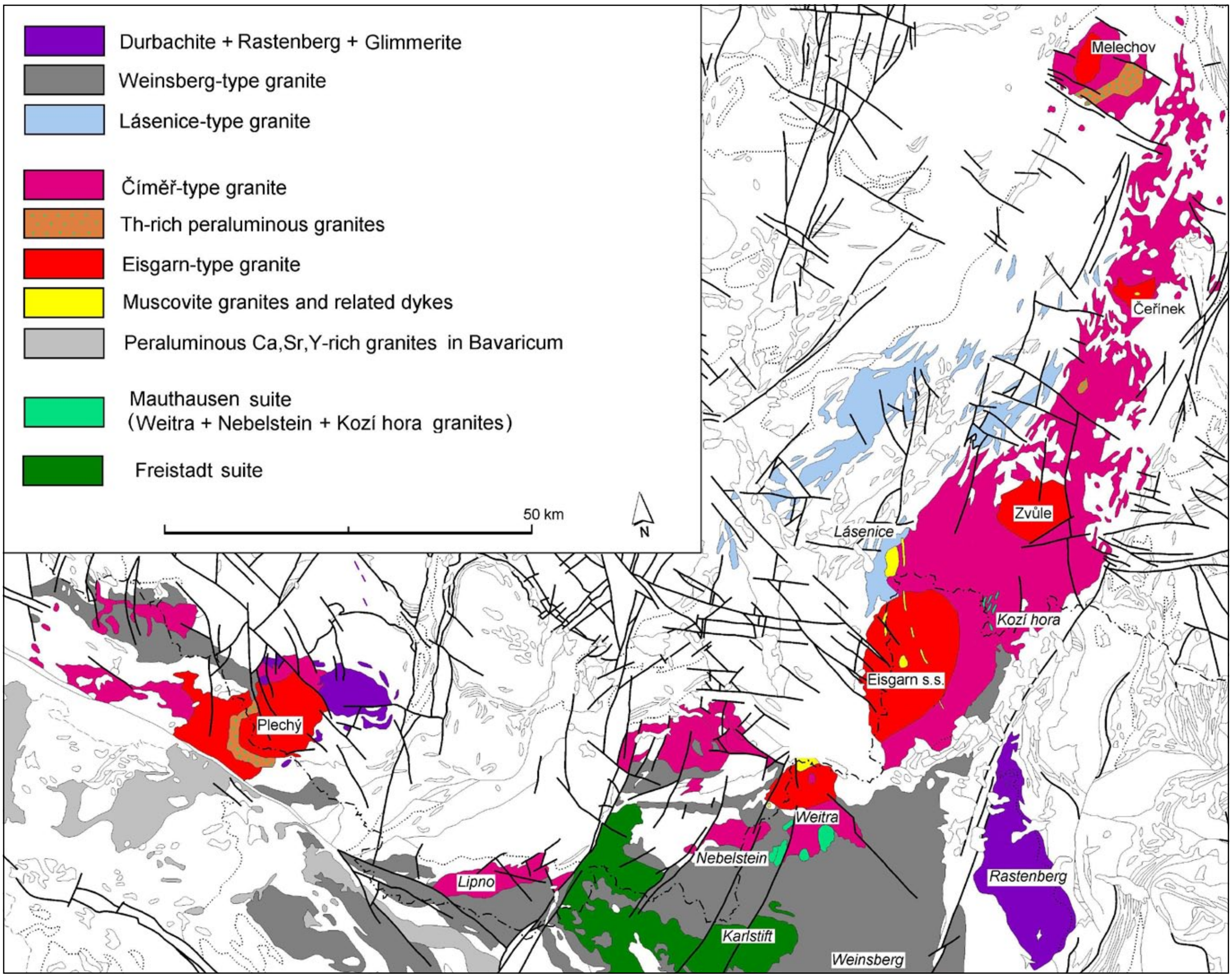
Other Peraluminous Granitoids

Between Gmünd and Weitra another body of coarse-grained porphyritic two-mica granite crops out, which chemically and mineralogically resembles the Eisgarn s.s. granite. But its substantially lower $^{87}Sr/^{86}Sr_i = 0.706$ indicate melting of another source material. Also the following muscovite granite from Nakolice-Pyhrabruck differs from those from Homolka in much lower $^{87}Sr/^{86}Sr_i$ (0.705 vs. 0.716) (BREITER & SCHARBERT, 1995; 2006).

In the Bavaricum, SIEBEL et al. (2008) defined a group of peralumine granites (mainly fine- to medium grained, biotite to two-mica granites of the Fürstenstein and Hauzenberg plutons), in age similar to the main intrusive events of peraluminous granites in Austria and Bohemia (324–319 Ma), but differing chemically being enriched in Ca, Y and Sr. This was interpreted as result of the composition of the deeper crust in the Bavaricum being different in comparison to the Moldanubicum.

Granites highly enriched in Th represent a rather special type of peraluminous granites in the Moldanubicum being sporadically found as members of different intrusive suites.

The fine-grained biotite>muscovite Lipnice granite within the Melechov massif (Číměř suite) contain up to 60 ppm Th (MLČOCH et al., 1999) and the coarse grained biotite>muscovite Steinberg granite in the Plechý pluton (Eisgarn suite) contain up to 100 ppm Th (BREITER, 2005). Th-rich monazite is the only carrier of Th in these granites. Another Th-rich granite was found at Gutau, NE of Linz, as a small (2 km^2) intrusion of fine-grained porphyritic biotite



Text-Fig. 2.
Proposed genetic classification of granitoids in Moldanubicum (contours of rock bodies according to CHÁB et al. 2007, slightly adapted).

granite (~67 wt % SiO_2) enriched in F (~0.4 wt %) and Th (up to 120 ppm) (GÖD et al., 1996). Genetic affiliation of this granite, in maps signed as Mauthausen type, is not clear.

Group of Late Intrusive Phases (post-Eisgarn)

Mauthausen Suite

High-K calc-alkaline metaaluminous to only slightly peraluminous granites and granodiorites (tonalites), rich in Ca and Sr, crop out in the southern part of the Moldanubicum, namely in Upper Austria and around Trhové Sviny in Bohemia. These rocks, traditionally termed as Mauthausen and Freistadt types bear typical features of I-type granitoids (FINGER et al., 1997) and represent the product of a new melting episode in the time interval of 315–300 Ma. Lower Rb/Sr-ratio and $^{87}Sr/^{86}Sr_i$ = 0.705–0.706 suggests melting of a tonalitic source in the deeper crust (GERDES, 1997).

The name **"Mauthausen granite"**, before synonym for all fine-grained granites in the SBP, should be used according to the original definition (RICHTER, 1965) only for relatively young granites in the southern part of the SBP around the town of Mauthausen (out of Text-Figs. 1, 2). Compared to rocks of the Freistadt suite, the more heterogeneous Mauthausen group of granites is richer in K and Rb and poorer in Ca and Sr. According to GERDES et al. (2003), the Mauthausen granite (or only some bodies among those designed as Mauthausen granite?) should be about 316 Ma old.

The biotite **Weitra granite** (name introduced by HUMER et al., 2003) comprises two macroscopically not distinguishable varieties differing only in the magnetic susceptibility. The magnetic variety crops out in the centre of the St. Martin magnetic anomaly (HEINZ & SEIBERL, 1990; GNOJEK & PŘICHYSTAL, 1997) and at "Steinerne Frau" SE of Harbach. The non-magnetic variety was found E of Nebelstein around the village of Althütten and in Weitra itself. Typical major element contents are: 71–72 wt % SiO_2, 0.7–0.8 wt % MgO, 2–3 wt % Fe_2O_{3tot}, 1.3–2.0 wt % CaO, 4.5–5.0 wt % K_2O and 2.8–3.1 wt % (in the non-magnetic variety up to 3.8 wt %) Na_2O. Characteristic features of the Weitra granite are high Sr (250–450 ppm) and low Rb (200–230 ppm). The $^{87}Sr/^{86}Sr_i$ of ~0.705 supports some relation of the Weitra granite to the Mauthausen suite.

The Weitra granite was followed by a group of dykes and stocks of muscovite granites with primitive chemical composition, which intruded the Weitra granite itself (St. Martin, Nebelstein), and also the foregoing two-mica granites

(Ober-Lembach). The evolution of the **Nebelstein magmatic centre** (two-mica to muscovite granite) finished in the formation of a small Mo-mineralization of greisen type (GÖD & KOLLER, 1989).

A small (5 x 2 km) body of fine-grained biotite granite near Schrems (Schremser granite) illustrates the problems with classification of granites according to their texture and mineral composition very well. The body was interpreted as homogeneous (WALDMANN, 1950; FUCHS & MATURA, 1976) and attributed to the Mauthausen type. Recently, KOLLER et al. (1993) discriminated here three domains with different chemical compositions and Rb-Sr characteristic. Only the central part of the body bears the composition of typical Mauthausen-type rocks. The SW part represents probably a fine-grained late portion of the Weinsberg magma and the NE part is isotopically similar to the peraluminous two-mica granites.

A ring-shaped system of small stock and dykes of biotite granite and zones of greisenization and complementary K-metasomatism at **Kozí Hora/Hirschenschlag** with occurrence of molybdenite-magnetite greisens (GÖD, 1989; BREITER et al., 1994) are only poorly known geochemically. The chemical composition of the rocks and the style of mineralization are similar to those of Nebelstein.

Freistadt Suite

The **Freistadt granodiorite** forms a composite pluton with a medium-grained rim and fine-grained core facies. Main chemical features are: 66–69 wt % SiO_2, only about 2.5 wt % K_2O, 70–80 ppm Rb and about 400 ppm Sr. The two-mica "Graben granite" is the youngest and slightly more evolved product of the fractionation of this pluton (FINGER et al., 1994).

The **Karlstift granite** (KLOB, 1970) is a fine- to medium grained biotite granite with high magnetic susceptibility cropping out between the villages of Karlstift, Sandl and Liebenau. The porphyritic variety crops out near the N and NE contact, the inner part of the body is mostly equigranular. Typical contents of SiO_2 are 67–69 wt %, K_2O 3.8–4.5 wt %, Na_2O 3.2–3.5 wt %, MgO 0.8–1.3 wt % and CaO 2.2–3.1 wt %. High concentrations of Sr (580–650 ppm) and Th (25–28 ppm) are characteristic of the porphyritic pericontact facies. The rock is markedly poor in Rb (150–170 ppm). The magnetic susceptibility and the contents of Ti, Ca, Fe, Sr and Th decrease towards the intrusion centre, while Si, K and Rb increase slightly. The $^{87}Sr/^{86}Sr_i$ = 0.706 is similar to the rocks of the Freistadt suite (BREITER & SCHARBERT, 2006).

Conclusions

Major types of granitoids in the Moldanubicum can be classified in several suites, which represent different evolutionary stages of the Variscan orogenic process. The relative succession of most rock suites is documented geologically; nevertheless, the isotopic ages of individual bodies (intrusions) within the suite may variegate in rather large intervals.

The proposed well defined suites are:

- K,Mg-rich granitoids (namely durbachites, ~340 Ma)
- Weinsberg granite (biotite I-type granite, ~328 Ma)
- Lásenice granite (granite minimum melt)
- Čímĕř granite (peraluminous granite)
- Eisgarn s.s. granite (peraluminous granites with very deep roots) with late fractionation to Sn, Nb, Ta, U-enriched muscovite granites (~324 Ma)
- Mauthausen suite (I-type biotite granites, late fractionated intrusions with Mo-mineralization) (~315 Ma)
- Freistadt suite (I-type biotite granites and granodiorites, ~305 Ma).

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