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Coupling restites and mobilizates – Geological and litho-chemical investigations of paired belts of calcsilicate fels and quartzite (SE German Basement) – *Quo vadis* David London's pegmatology?

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ABSTRACT

In some areas of the Variscan orogen felsic mobilizates (pegmatitic and aplitic rocks) are closely associated with stratiform and stockwork-like bodies enriched in Ca minerals (e.g. wollastonite, diopside-hedenbergite s.s.s., grossular-spessartine s.s.s., siderite..) and bodies aligned to them similar in structure but abundant in quartz, plagioclase and mica. Geological mapping and lithochemical studies are the tools to decipher the nature of these crystalline rocks which are common to the Hagendorf-Pleystein Pegmatite Province, SE Germany, and present in many ensialic orogens elsewhere. Geological and chemical data suggest paired belts of a restite-mobilization system. The Ca and Si metasomatites are different from calcareous metasediments and quartzites elsewhere in the SE German basement devoid of mobilizates (parent rocks: limestones and cherts). Mobilization conducive to this paired belt of metasomatites involved silica mobilized from a deep level of the crust as a result of metamorphic-metasomatic alteration of Precambrian to Early Paleozoic metagreywackes during retrograde metamorphism from HP to LP metamorphism around 680–600 °C. The arrangement of mobilizates and restites in the field has been denominated as metamorphic differentiation *sensu lato*. The zone of silica mobilization is transitional into a zone of pegmatoids and aploids that overlaps with another one characterized by rocks derived from Ca metasomatism the footwall facies of which developed in the range 750–400 °C while in the hanging wall metamorphic rocks of rare-element pegmatites 570–430 °C occurred. The intensity of Ca metasomatism diminishes from the footwall to the hanging wall rocks and reflects a subcrustal impact. These investigations call attention among exploration geologists and petrologists to an alternative origin of "metasilica" and "metacarbonate" rocks being encountered in a zoned arrangement with felsic mobilizates (pegmatitic and aplitic rocks). The current study also raises the question "*Quo vadis*" pegmatology? It is an amendment to the mainstream geoscientific handling of pegmatitic rocks as "..texturally complex igneous rocks" genetically linked to granitic plutons (see review of London (2018) in *Ore Geology Reviews*). Taking a holistic approach can give us a reality check and prevent pegmatology from converting into a one-way street (granites-only) that eventually ends up in a dead-end street. The field evidence is the litmus test for all our models created in the laboratory and on the PC. There is no ore geology without field geology.

1. Introduction

Browsing the literature of pegmatites and the practical experience gathered by the author reveals that felsic mobilizates are often associated with rather basic crystalline rocks such as meta(ultra)basic magmatic and calcsilicate rocks (Dill, 2015a). Even rather exotic desilicified rocks such as corundum fels or marble horizons are known to give host to such pegmatitic, aplitic or granitic mobilizates (Proppach, 1975; Mali, 2004; Schenk et al., 2007; Rakotondrazafy et al., 2008; Ertl et al., 2010). Metacarbonates and skarn deposits accompanied by pegmatites are relevant for the concentration of Sn, W, REE, U, Th, B, P, Mo, feldspar, feldspathoids (scapolite), alumosilicates, and graphite (Guilbert and Park, 1986; Silva and Siriwardena, 1988; Habel and Habel, 1991; Novák and Hyršl, 1992; Lentz and Suzuki, 2000; Pezzotta, and Simmons, 2001; Žáček et al., 2003; Dill et al., 2006a; Ackerman et al., 2007; Laznicka, 2010; Novák and Kadlec, 2010; Ishihara and Orihashi, 2014). Apart from crystalline rocks being strongly enriched in Ca relative to the felsic mobilizates, there is another lithological series displaying silica contents, in places, even higher than the felsic mobilizates. In the study area several lens-shaped rocks strongly enriched in

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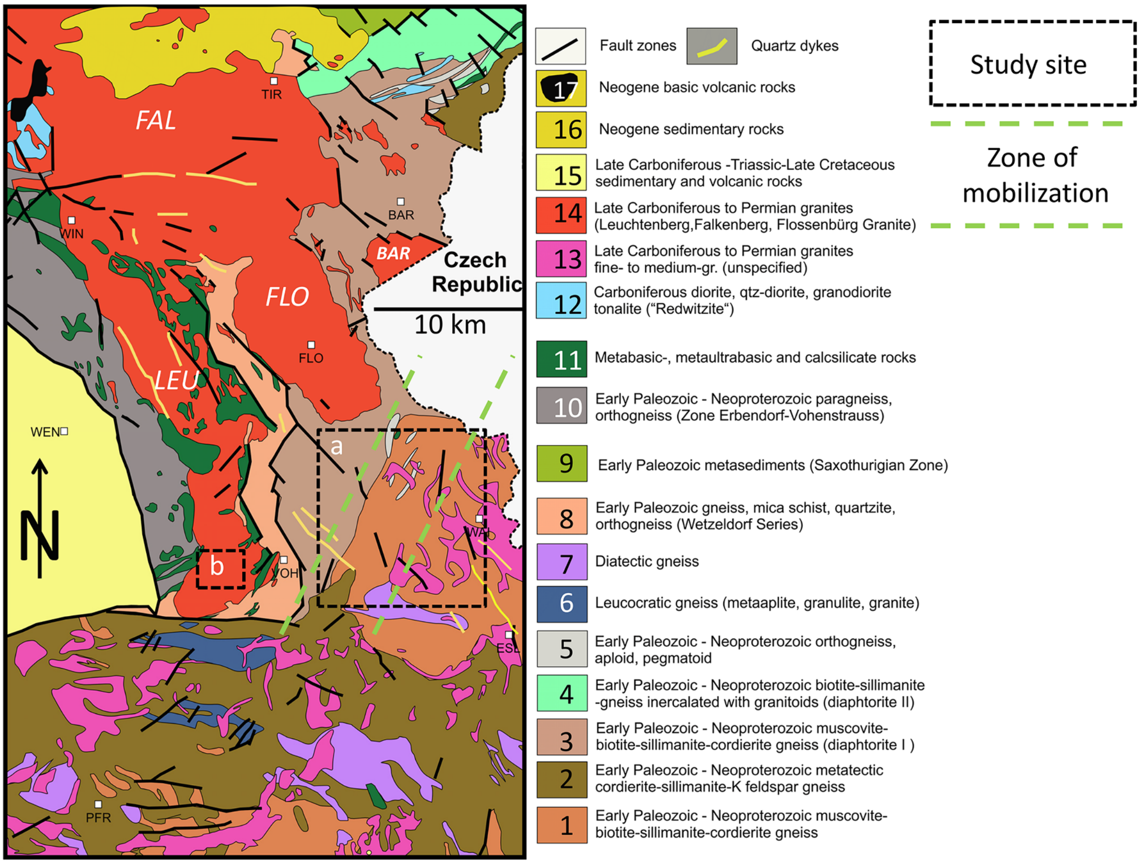


Fig. 1. The geological setting of the NE-Bavarian Pegmatite Province and the position of the study sites (a = Fig. 2, b = Fig. 3). The geological map has been modified from the map "Geological map of the Upper Palatinate Forest" 1:150,000 issued by the Bavarian Environment Agency (2009). To ease correlation with lithostratigraphic units referred to into the text and avoid repetition of age and lithology the various shades given in boxes are supplemented with Arabic numerals. Towns are given for reference: TIR = Tirschenreuth, BAR = Bärnau, WIN = Windischeschenbach, FLO = Flossenbürg, WEN = Weiden, VOH = Vohenstrauß, WAI = Waidhaus, PFR = Pfreimd, ESL = Eslarn. *FLO*: Flossenbürg Granite, *FAL:* Falkenberg Granite, *LEU*: Leuchtenberg Granite, *BAR*: Bärnau Granite.

quartz are intercalated into the metapelitic basement rocks and often intimately intercalated with felsic mobilizates (Figs. 1 and 2). These felsic mobilizates were denominated by Forster (1961, 1965) as metapegmatites and metapelites, while the metaquartzites were named by the same author as greywacke-quartzite gneiss. Steiner (1986) treated them as a felsic mobilizate and called them granitoids.

Any attempt to re-model the primary environment of deposition of the metamorphic rocks and to integrate the subsequent felsic mobilizates (granitic, aplitic, pegmatitic rocks) into this basement setting of the Variscan orogen is fraught with difficulties and provides us with a rather conflicting view of this part of the Central European crust (Dill, 2018a,b). Therefore some open questions still await an answer and, consequently are dealt with in the current study:

- Are all Ca-enriched and siliceous rocks sedimentary in origin and what was the parent environment of deposition of these metamorphic rocks like?
- Against common use during studies of crystalline rocks, strong emphasis is placed in the current study upon sedimentary petrography and the geochemistry of sedimentary rocks taken for reference.
- Are these rocks encountered in a lit-par-lit structural arrangement with the afore-mentioned felsic mobilizates are metamorphic or metasomatic in origin (Figs. 1 and 2)?
- How does this bimodal lithological suite of Ca- and Si rocks correlate in time and space to the felsic mobilizates? Taken to the extreme, are they highly differentiated products and/or restites?

Calcareous gneisses, calc-schists and – phyllites which may grade with increasing carbonate contents into different varieties of marble have found recognition in the textbooks on metamorphic petrology due to their great variety of mineral assemblages in the various P-T regimes (Table 1) (Best, 1982; Bucher and Grapes, 2011; Frost and Frost, 2013). Quartzites or metacherts are too often eclipsed because they neither stand out by a colorful mineral association nor do they pose any difficulties on the determination of the parent rocks in the eye of a petrographer of metamorphic petrology.

The current research is part of the authoŕs study of pegmatitic and aplitic rocks and mineral deposits following unconventional ways in comparison to the mainstream pegmatology.

Hence, this paper in context with the previous studies – see references- is an amendment to London's (2018) view of pegmatology that recently has been issued in "Ore Geology Reviews". The current amendment is written by a "general practitioner", a field-oriented geoscientist, who used to take a holistic approach when it comes to find a solution and who is poised to consult different "specialists" and consider their experience and knowledge" to find the right "therapy".

2. Strategy and methodology

2.1. The strategy

Whenever a mobilization takes place we have to look for a source to extract the mobile phase from and we will be confronted in the same way with a rest or residue left behind.

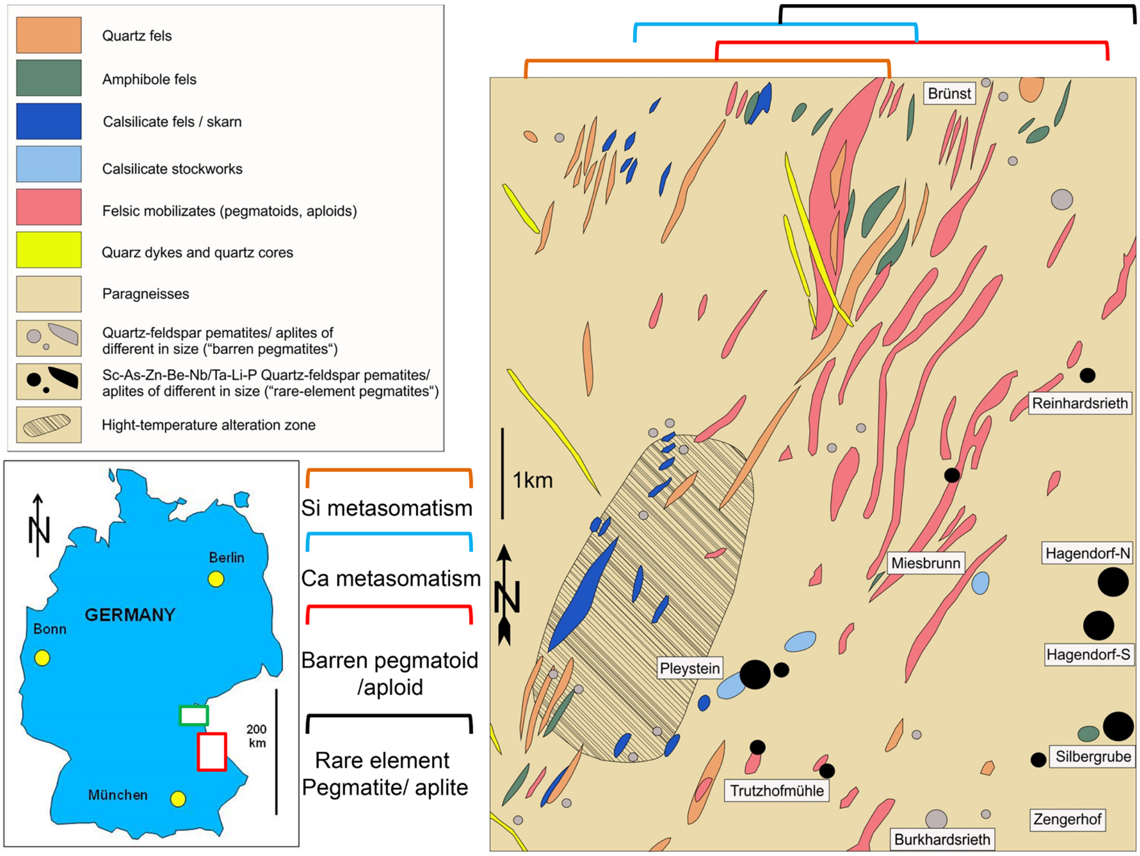


Fig. 2. Geological setting and the position of the study areas (white rectangle framed in red = Fig. 1 white rectangle framed in green = Fig. 5) in Germany. The geological map was modified from Forster (1961) supplemented by re-interpreting some of the lithological units according to the current study. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

To lay the foundation stone in classical field work (mapping) before moving forward to a more advanced level analysis, e.g., isotope studies, the current approach is taken as a bimodal investigation with emphasis placed upon geology and chemistry as far as the methods are concerned and gives priority to rather different metamorphic rocks, one showing a strong depletion in silica whereas the other one is abundant in silica. The term restite is used as a non-genetic petrological term for all immobile or less mobile parts according to Bates and Jackson (1987). It is commonly used in combination with mobilizates, a term which in accordance with the "Glossary of Geology "has been translated from the German word "Mobilisat" and coined so as to refer to the mobile phase of any consistency (Mehnert, 1968). The regional geology of felsic mobilizates pertaining to the group of pegmatitic and aplitic rocks has been deal with in several papers published only recently where the different views and philosophies are dealt with (Dill, 2015a,b, 2017, 2018a,b) (Table 2). The current paper is not to repeat these philosophies but rather calling attention among geologists from the applied and genetic disciplines to marker lithologies and the geology of these mobilizates (Roering, 1961; Kremer and Lin, 2006; Konzett et al., 2015; Silva et al., 2015; Lv et al., 2018).

2.2. The methodology

To achieve this basic goal the study draws upon the classical parts of field work, lithological and structural mapping and sampling (150 samples/whole rock approx. 1–2 kg) with follow-up mineralogical investigations using the petrographic microscope, x-ray powder diffraction (XRD) and the scanning electron microscope with an energy dispersive analytical system (SEM-EDX) for detailed mineral investigation. The third column in the tripartite geoscientific work is whole-rock lithochemistry with the major and minor elements determined by x-ray fluorescence (XRF) which has rarely been made use of by geologists dealing with these felsic mobilizates, e.g., by Neiva et al. (2011), Fuchsloch et al. (2015), Llera et al. (2015) and Dill (2018a,b). The measuring conditions concerning the XRF, SEM-EDX and XRD have been described in Dill et al. (2012, 2013a) and, hence need not described here in full detail. Great emphasis was placed upon the visualization of the chemical data in order to facilitate the comparison of data among the crystalline rock units and moreover to corroborate the attempts to trace back these metamorphic lithologies to the unmetamorphosed source rocks and their environment of deposition.

3. Geological setting

An overview of the geodynamic situation of this crustal section in Central Europe has been given by Matte (2001), von Raumer et al. (2003), Linnemann et al. (2007) and Klemd (2010). The lithology of the Central European Variscan basement is rather complex covering the interval from the Neoproterozoic through the late Paleozoic as far as the deposition, deformation, and the metamorphic magmatic history is concerned (Dallmeyer et al., 1995). As geological basis for the current investigation the official map issued by the Bavarian Environment Agency (2009) has been selected and slightly modified so as to facilitate the interrelationship between the basic rocks under study and the felsic mobilizates (Figs. 1 and 2). The NE Bavarian Basement an uplifted basement block has been encroached upon by Triassic and Cretaceous sediments and in parts covered by volcaniclastic and volcanic rocks of Late Paleozoic age (Figs. 1–15) – (Dill and Klosa, 2011 – further literature cited therein). Neogene sediments and volcanites accompanied by strong faulting (Fig. 116–17) resulted from the subsidence of the

Table 1
Lithotypes (Arabic numerals), lithology, mineral assemblage, morphology and structure of the basic/calcsilicate series (yellow) and felsic/siliceous series (brown) crystalline rocks under consideration and their relation to the felsic mobilizates. Additional information is given as to the accompanying lithologies a) Calcsilicate series b) Siliceous series.

Lithotype	Lithology	Mineral assemblage																					Morphology, structure, texture	Felsic mobilizate associated with lithotype	Lithologies associated with lithotype
		Wollastonite	Diopside	Hedenbergite	Garnet (grossularite)	Garnet (spessartine)	Vesuvianite	Clinozoisite-(epidote)	Tremolite-(actinolite)	Talc	Sphene	Prehnite	Laumontite	Pumpellyite	Calcite	Dolomite	Siderite	Ankerite	Magnesite	Strontianite	Rhodochrosite	An-rich plagioclase			
1	Calcsilicate -marble		■		▨		░	■	■	▣	■	■			■	■	■	▨	▨	░	░	░	Tabular, bedded, stratiform, laminated to massive	No	Mica schist, phyllite, (graphite schist, quartzite)
2	Calcsilicate -skarn	■	■		■		░	■	■		■	■			░	░						░	Lens-shaped, layers to massive irregular-shaped bodies	Sc-As-Zn-Be-Nb/Ta-Li-P and barren pegmatite,	Gneiss (amphibolite)
3	Ca-Mg contact fels-pegmatite		■		░	■			▨														Irregular-shaped contact zones , hinge zone of folds, massive, fels	aplite, pegmatoid, aploid	Gneiss
4	Calcsilicate-amphibolite		■						■			░	▨	░								▨	Lens-shaped, vein-type, layers, massive fels,	Pegmatoid-aploid-aplite	Amphibolite
5	Ca calcsilicate-aplite exocontact		■		▨		░	■								▨							Stockworks, nests, lenses	Sc-As-Zn-Be-Nb/Ta-Li-P and barren pegmatite	Gneiss
6	Ca-Fe calcsilicate-aplite exocontact			■					▨								▨						Stockworks, lenses	Aplite, (pegmatite) rare and barren pegmatites (?)	Gneiss

Lithotype	Lithology	Mineral assemblage										Morphology, structure, texture	Felsic mobilizate associated with lithotype	Lithologies associated with lithotype
		Quartz	Plagioclase	Biotite	Andalusite	Graphite	Muscovite	Apatite	Cordierite	Sillimanite	Zircon			
7	Quartz fels – quartzite (aploid/ pegmatoid/ granitoid)	■	░	░				░	░	░	░	Lens-shaped	Aploid, pegmatoid granitoid	Gneiss
8	Graphite fels – graphite quartzite	■		░	░	▨	▨	▨				Lens-shaped, layer	No	Gneiss, mica schist

▣ vein-type
■ abundant
▨ common
░ rare

ENE-WNW striking Eger Rift (Ulrych et al., 1999). The crystalline rocks of the NE Bavarian Basement pertain to two geodynamic units, the Saxothuringian Zone, represented by Ordovician and Cambrian rocks at the northern margin of the study area (Figs. 1–9) and the Moldanubian zone which encompasses a great variety of rocks including the rocks under consideration (Fig. 11–8, 10–15). The Moldanubian Zone is made up of an autochthonous unit (Fig. 11–8) called the Moldanubicum *sensu stricto* and an allochthonous one (Fig. 1, 10–11) named the Teplá-Barrandian zone or in Bavaria as Zone of Erbendorf-Vohenstrauß “ZEV” (Malkovsky, 1979; Weber and Behr, 1983, Stettner, 1992; Franke et al., 1995). The Late Variscan granitic rocks resembling the pegmatitic with regard to their basic chemical and mineralogical compositions are exposed in large complexes of S-type granites in a NNW-SSE trending zone and are arranged in order of their age of intrusion (Fig. 1 – in parts 4, 5–7, 12–14): Leuchtenberg (LEU), Falkenberg (FAL) Flossenbürg Granites (FLO) with its eastern outlier at Bärnau (BAR) (Voll, 1960; Forster 1965; Forster and Kummer, 1974; Steiner, 1986). The origin of some more basic enclaves of intrusive rocks of granodioritic through gabbroic composition called “Redwitzites” is still enigmatic (no. 12) (Stettner, 1992). The study areas are framed in the Moldanubicum *sensu stricto* (Fig. 1a) and in the allochthonous one (Figs. 1b and 3) called the Zone of Erbendorf-Vohenstrauß “ZEV” with a dashed line.

4. Geological and lithological results

Based upon the lithology, mineral assemblage and field evidence, such as structure and morphology, eight lithotypes have been defined, six of them belonging to the calcareous or calcsilicate rock series and

Table 2
Classification scheme of pegmatitic and aplitic rocks for applied and genetic economic geology (**CMS** classification scheme = **C**hemical composition-**M**ineralogical composition-**S**tructural geology) (Dill, 2015a,b).

ORE BODY

Host rock lithology	**Metamorphic rocks**			**Metamorphic and magmatic rocks**	**Magmatic rocks**	**Remarks**
1st order term **Type of pegmatitic/ aplitic rock**	**Pseudopegmatite/ pseudoaplite**	**Metapegmatite/ metaaplite**	**Pegmatoid/ aploid**	**Pegmatite/ aplite**	**Plutonic pegmatite/ aplite**	**Mandatory**
	Aplitic: grain size << host rock and homogeneous Pegmatitic : grain size >> host rock and heterogeneous **Fixed terminology**				Aplitic: grain size << host rock Pegmatitic : grain size >> host rock host rock and heterogeneous	
Specific type of host rock	*Gneiss, amphibolite , eclogite* *e.g., cordierite-sillimanite-gneiss-hosted pegmatoid*				*Granite, syenite, granodiorite* *e.g. syenite pegmatite*	*Optional*
Determination	Mapping in the field the ore-host rock relation and measuring the grain size by visual examination					
2nd order term **Shape and structure**	**Tabular, schlieren, stock-like, pockets, vein-type, pipes, chimneys, floors** e.g. tabular Sc-Nb aplite, schlieren quartz-albite pegmatoid **Open terminology**				**Miarolitic, pod-like, pockets, vein-type, schlieren** e.g. miarolitic granite pegmatite	**Mandatory**
Internal structure	Unzoned - rimmed-complex/ ungraded-complex/ graded (e.g. UST) **Open terminology**					
Size (thickness)	*cm-sized, dm-sized , meter-sized*					*Optional*
Determination	Mapping in the field the shape by visual examination and measuring the morphological increments and size with a yardstick					
3rd order term **Chemical qualifier**	**Sn, W, Ta, Nb, Sc, Be, Li, Cs, Rb, REE ,Y, U, Th, B, F, P, Zr** **e.g. Nb-Li pegmatite, (Sc-U)-Nb-P aploid** **Open terminology**					**Mandatory** Can be linked to the "Chessboard classification scheme of mineral deposits", using alpha-numerical codes
Determination	By visual inspection of rock-forming minerals, including hand lens for accessory minerals (put in brackets) Rock-forming and accessory minerals ⇒ chemical symbols (e.g. beryl, euclase ⇒ Be, Li mica ⇒ Li, allanite ⇒ REE, if necessary LREE)					
4th order term **Mineralogical qualifier**	**quartz, feldspar, foid, garnet, zeolite, mica, corundum, graphite** **e.g. (andalusite)-quartz-feldspar metapegmatite, graphite- feldspar-quartz pegmatite** **Open terminology**					**Mandatory** Can be linked to the "Chessboard classification scheme of mineral deposits", using alpha-numerical codes
Specific type of minerals for gemstone-bearing pegmatites , fine-tuning and genetic interpretation	*e.g. Al pegmatite (ruby), F-Sn-W granite pegmatite (topaz>fluorite), Li-Nb-P pegmatite (triphylite), Li-Nb-P pegmatite (amblygonite)* **Open terminology**					*Optional - Composite of level 3 and 4*
Determination	See 3nd order term for determination an					

ORE COMPOSITION

another two to the siliceous suite (Table 1, Figs. 3 and 4). The term lithotype was coined and used frequently in coal petrography in connection with the macerals and in the current litho-chemical study transferred from this organic domain into an inorganic part of geosciences applying the key message of this technical term (Scott, 2002).

4.1. The lithotypes of the calcsilicate series

Lithotype 1: Lithotype 1 is composed of calcsilicate rocks alternating with marble horizons with thicknesses varying from 150 to 200 m and lined up along the southern exocontact of the Fichtelgebirge Pluton, where they are named collectively as "Wunsiedel Marble" after a town nearby (Table 1, Fig. 5a) (Richter and Stettner, 1979). The current lithotype is well-bedded and intercalated into mica schists, phyllites, and quartzites and can be traced over a distance of several tens of kilometers and mapped at various positions within Neoproterozoic through Cambrian units (Wurm, 1961; Hecht et al., 1999) (Fig. 5b and c). At outcrop the different lithologies abundant in graphite and muscovite can easily be distinguished by its different shades of gray and beige (Fig. 5b and c). In hand specimens it takes on a more massive texture and can be denominated in the field either as a schist or as tremolite, grossular or diopside fels depending upon the prevailing rock-forming minerals detected with the unarmed eye and their degree of orientation (Fig. 5d). Dark brown colors are indicative of stratiform siderite mineralization which was mined in some places for iron (Horstig von and Teuscher, 1979; Dill, 1989). Earthy to "fatty" specimens result from abundant talc or steatite, the last mining operation of which was only recently terminated at Göpfersgrün (Dill et al., 2008a). Mobilizates as depicted in Fig. 2 do not exist all across the area covered by lithotype 1.

Lithotype 2 + 3: Lithotype 2 and 3 are genetically related with each other (Fig. 6). Both lithotype occur side by side in areas abundant in felsic mobilizates and form discontinuous layers and lenses that often show up in swarms (Figs. 2 and 4). They never occur in "seam-like" beds ore strata like lithotype 1 and are not traceable over a distance of more than a few hundreds of meter (Fig. 5a). The most striking field observations is the antithetic trend of felsic mobilizates and calcsilicate rocks of lithotype 2 and 3 (Fig. 2). Both rock types exclude each other but grade into each other (Figs. 2 and 6a). Biotit-plagioclase gneiss

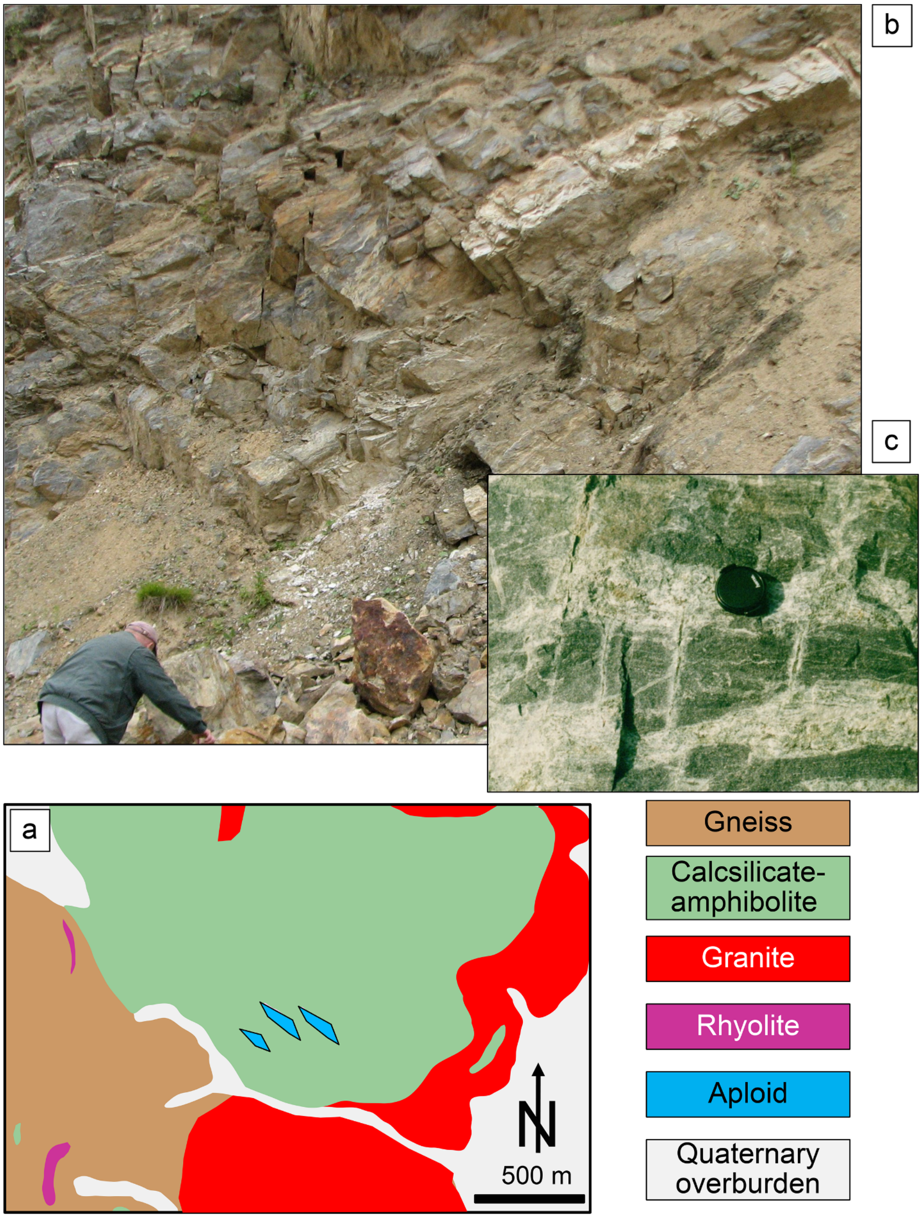


Fig. 3. Geological setting of lithotype 4, at outcrop and in specimen a) Simplified geological map of the study site west of Vohenstrauss in calc-silicate amphibolites. Geology modified from Weger et al. (2003). b) Calcsilicate amphibolite with aploid intercalated parallel to the S planes. c) Feldspar-quartz mobilizates in the calcsilicate amphibolite.

converts into pegmatoids via a reaction zone of calcsilicates (lithotype 3) in the hinge zone of open folds which pinches out towards the limps (Fig. 6a). Tightly folded calcsilicate bands gradually change into massive types of calcsilicates which, in places, give host to skarn ore minerals, e.g., scheelite found at Gsteinach, Sinatengrün and Göpfersgrün, SE Germany (Fuessl and Weber 2009; 2011). They do, however, not show up in the barren or rare-element pegmatites/pegmatoids, proper (Fig. 6b–d, Table 1) (Dill, 2015b). The texture of these calcsilicate rocks is massive and most of the rocks mapped during field work are categorized as fels (Fig. 6b and d).

Lithotype 4: Metabasic rocks are very common along the western margin of the Bohemian Massif and have frequently been targeted upon during the pre-well site studies of the Continental Deep Drilling Program (Schüssler, 1990; Bosbach et al., 1991; Weger and Masch, 1994). Some of these metabasic rocks grade into calcsilicate-amphibolites and are closely associated in space with zones abundant in pegmatoids and aploids, e.g., West of Vohenstrauß, at Muglhof and Windischeschenbach (Fuessl and Weber, 2009, 2011). (Figs. 1 and 3a). The transitional character of some of these calcsilicate amphibolites can also be deduced from the map of Fig. 2 where these metabasic rocks are situated towards the NW of the zone of mobilizates in the immediate surroundings of the cluster of calcsilicate rocks (lithotype 2). In the area "b" of Fig. 1, calcsilicates give host to Na-K aploids and pegmatoids (Fig. 3b and c). They form layers with felsic mobilizates concentrated parallel to the S planes or infill veins. In the area "a" it is amphibole fels grading into the afore-mentioned Na-K aploids and pegmatoids (Figs. 1 and 2).

Lithotype 5–6: Lithotype 5 and 6 calcsilicate rocks only differ from each other with regard to their mineral assemblage (Table 1). They are bound to stockwork mineralization with thin veinlets, rotational breccias, nests and small lenses in the exocontact of pegmatites (Figs. 4 and 7a, b). They are representative of the most distal part of the pegmatite system (Fig. 4). Towards the pegmatite stock, lithotypes 5 and 6 are substituted for by aplite veins devoid of calcsilicate rocks, whereas on the opposite side they pass into sterile paragneisses as the quantity of calcsilicate minerals diminishes (Fig. 4). Both types of calcsilicate

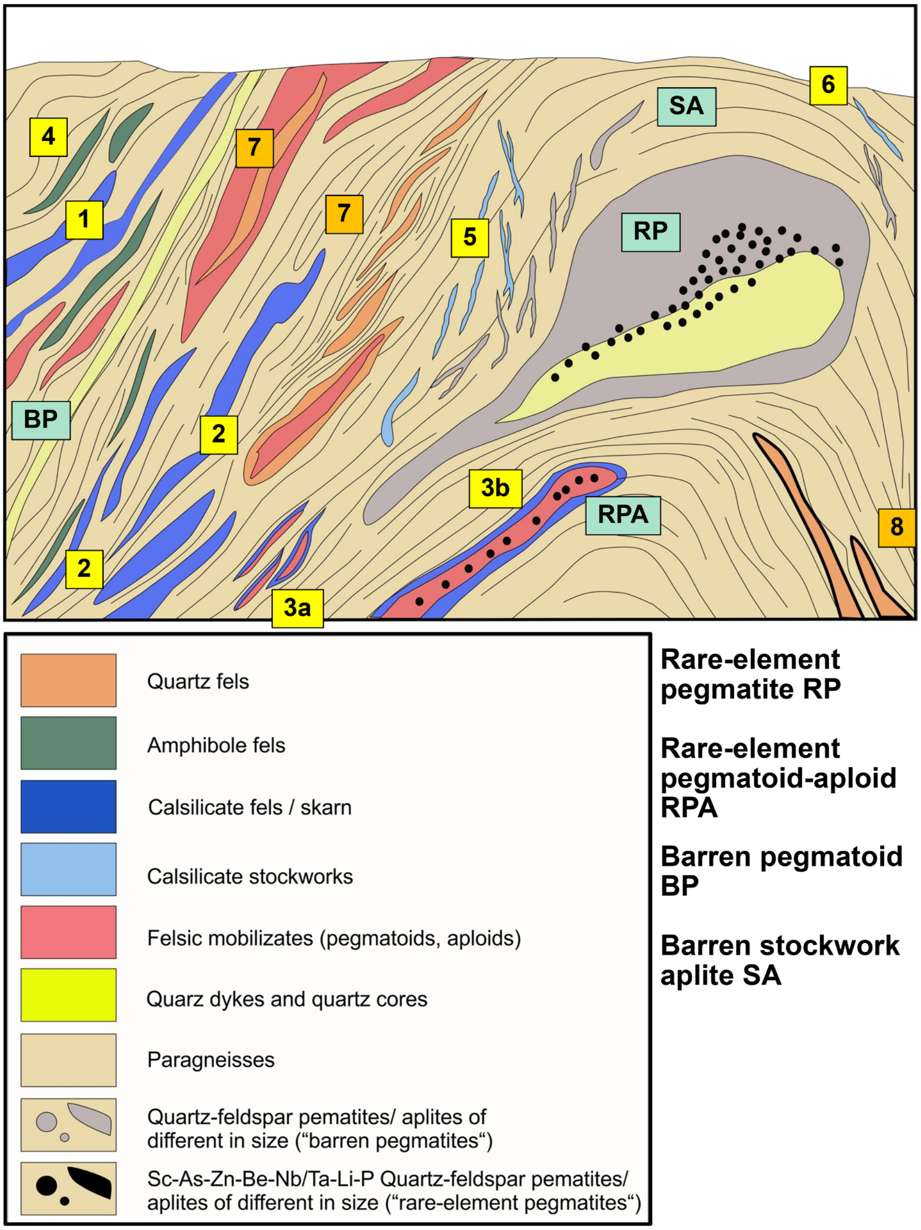


Fig. 4. Idealized cross section through the crystalline basement illustrating the felsic and basic crystalline basement rocks under study and the pegmatitic and aplitic rocks associated with them in space and time. For location in the map see Fig. 2 and for more information on the lithology, mineralogy and chemical composition see Table 1. The classification of the felsic mobilizates corresponds to the CMS classification scheme (Chemical composition-Mineral assemblage-Structural geology) of Dill (2015a,b).

stockworks are only found around Pleystein in the hanging wall of the pegmatite stock (Fig. 2).

4.2. The lithotypes of the siliceous series

Lithotype 7: Lithotype 7 rocks which were for the first time mapped along the western edge of the zone of mobilization by Forster (1961, 1965) and denominated as greywacke-quartzite gneiss appear in a twofold way intergrown with pegmatoids in the transition zone (Fig. 2). They either surround these felsic mobilizates or less frequently form the core zone of pegmatoids which show the same NNE-SSW trend (Figs. 2 and 4). Moreover they are the only lithotypes undergoing strong boudinage along their host shear planes, a structural setting also known from pegmatite deposits elsewhere in the world (Fig. 7c and d).

Lithotype 8: Lithotype has been encountered only West of the zone of mobilization. It contains small veinlets with quartz but is far off the area intersected by pegmatoids and aploids (Fig. 7e).

5. Mineralogical results

The crystalline rocks of the calcsilicate and the siliceous series have granoblastic non-directional textural or porphyroblastic features. There are no hints pointing to the parent rock be it magmatic or sedimentary in origin. In view of this, both lithological series are shown in two different tables (Table 1a and b) and the rock-forming minerals are listed in an x-y plot as a function of the eight lithotypes treated in the previous section for the outward appearance at outcrop.

In the calcsilicate series the most common minerals belong to the diopside-hedenbergite solid solution series (=s.s.s.). They developed in all calcsilicate rocks under study. Second in abundance are minerals of the amphibole s.s.s and of the clinozoisite-epidote s.s.s. (Table 1a). Sphene and prehnite are less widespread and wollastonite has been

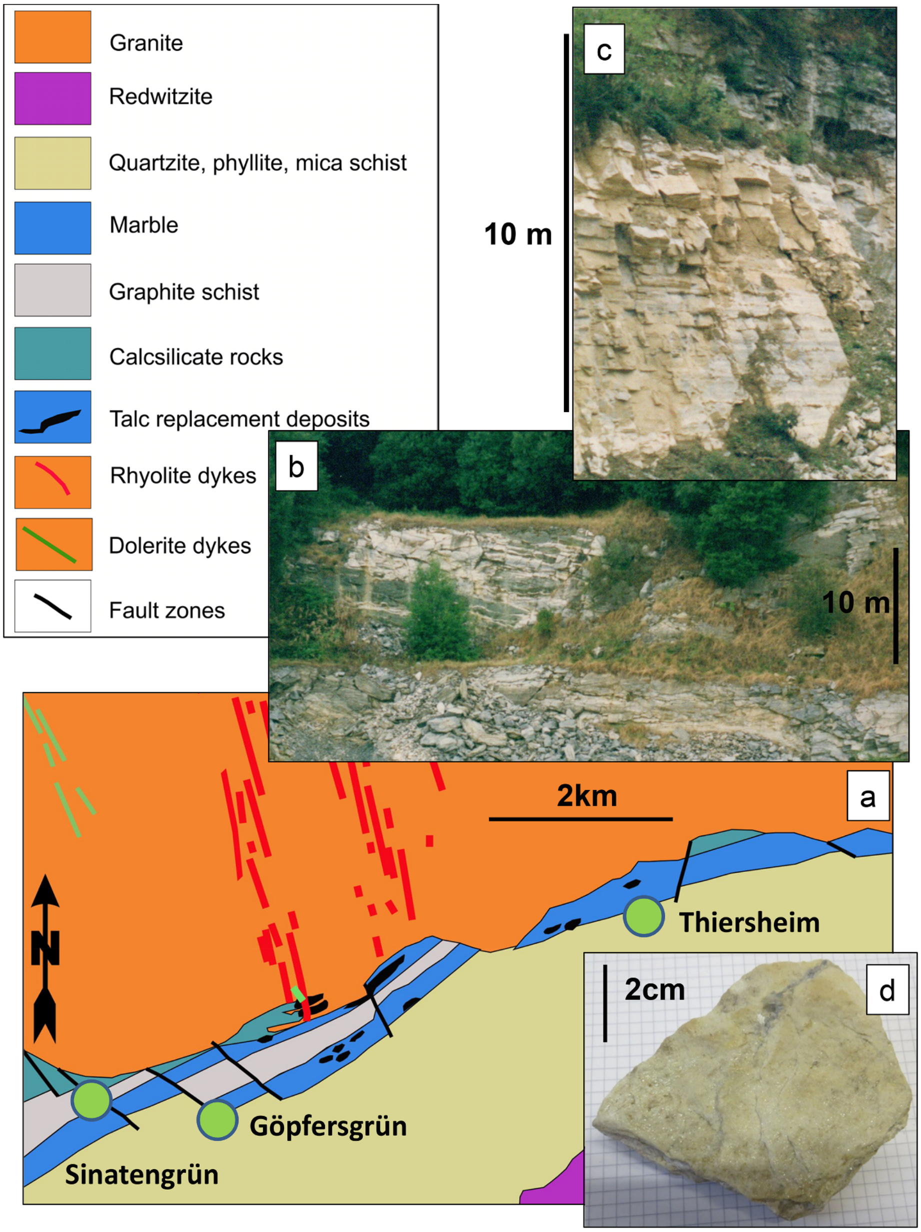


Fig. 5. Metasedimentary Neoproterozoic-Cambrian calcsilicate-marble series "Wunsiedel Marble" (Lithotype I). The lithotype I is pervasively talcized where intersected by rhyolite and diabasic dykes. a) Layers of calcsilicate rocks and marble horizons alternating with graphite schists are intercalated into metapsammopelitic rocks at the southern edge of the Fichtelgebirge Pluton (geology modified from Hecht et al., 1999). b) Calcsilicate-marble unit at outcrop near Pullenreuth c) Well-bedded calcsilicate-marble unit (close-up view of Fig. 5b). Gray layers are enriched in graphite and muscovite, beige ones in calcsilicate minerals (see Table 1). Locality: Pullenreuth. d) Hand specimen typical of lithotype 1 named as tremolite-bearing calcsilicate fels at Sinatengrün. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

found only in lithotype 2, where it forms bundles of pale white aggregates in calcsilicate fels (Fig. 8a). The most variegated spectrum of carbonate minerals has been observed in lithotype 1. As a sporadic Ca-bearing mineral, porphyroblasts of scheelite have also been detected at Göpfersgrün and W of Pleystein, near Gsteinach, in a local vesuvianite skarn of lithotype 1 and a garnet-diopside-vesuvianite skarn of lithotype 2 (Fig. 8b and c)(Keck, 1963; Vierling, 1975; Schmid and Weinelt 1978, Tennyson, 1983; Dill, 1985). It does not form ore grade similar to the stratiform Fe carbonate mineralization referred to in lithotype 1 (Section 4.1). The same holds true for cassiterite which is dispersed in lithotype 1 and 2 and also found in placer deposits next to the skarn W of Pleystein (Figs. 2 and 8d) (Dill et al., 2006b). Scheelite and cassiterite are cast in the role of marker minerals at the best but do not play a role as an ore mineral in the present geological setting. The mineral assemblage of the siliceous series is rather monotonous when compared with the calcsilicate series but nevertheless rather distinct (Table 1a and b). This is especially as to the predominance of phyllosilicates, apatite and graphite in lithotype 8 relative to lithotype 7.

6. Chemical results

Chemical facies analysis has rarely been conducted in metamorphic rocks and has almost exclusively been restricted to sedimentary environments of deposition (Shankar et al, 1987; Hatch and Eventual, 1992; Nesbitt and Young, 1996; Garver et al., 1996; McManus et al., 1999; Astakhov and Polyakov, 2000; Hsu et al., 2003; Astakhov et al., 2009; Rychkova et al., 2015). In view of the calcsilicate and siliceous rocks under consideration examples of chemical facies analysis are difficult to find. In addition to the lithology, the litho-chemical composition is the second pillar based upon which the genetic discussion is performed in the current study. Two different approaches are taken one treating and illustrating the true chemical composition (Section 6.1) and the second one normalizing the chemical composition to standard metamorphic country rocks hosting both the mobilizates and the siliceous and calcsilicate rocks under study and to reference sedimentary rocks.

Fig. 6. Lithotypes 2 and 3 and their outward appearance in the field a) Specimen illustrating the contact zone between the biotite-plagioclase gneiss and the pegmatoid layer (Pg) in the hinge zone of an open anticlinal structure at Kupferholz. For mineralogy of the calcsilicate rocks in the contact zone see Table 1 (Lithotype 3). The section denotes the zonation as a result of metamorphic differentiation into felsic mobilizates and restite. b) Massive calcsilicate-skarns of lithotype 2 at Gsteinach. c) Tightly folded calcsilicates of lithotype 2 at Gsteinach. d) Massive vesuvianite-grossular calcsilicate-skarn at Gsteinach.

6.1. Chemical raw data and the lithotypes

The datasets describing the major and minor elements of the eight lithotypes strongly differ from each other (Fig. 9). The major elements are visualized by descriptive statistic means of whisker diagrams (box plots) because of their well defined maximum of 100 wt%, whereas the minor element are not well reproducible in diagrams like those not even in a logarithmic scale and thus are listed in Table 3.

The major element variation of lithotypes 1a and 1b are a mirror image of the abundance of silicates and carbonate minerals (Fig. 9a and b). Anomalously high values of W and Sn are not causatively linked to the environment of deposition. This is also true for the Sn and W contents in lithotype 2 which have only mineralogical significance and their anomalously high values have not been obtained from channel samples as used to be done during exploration campaigns (Table 3). In the Bohemian Massif of Austria, a W mineralization bound to calcsilicate rocks similar to lithotype 2 was discovered in amphibolite to higher amphibolite facies (Beran et al., 1985). The average W content of 1500 ppm W determined during an exploration campaign may be taken also as a realistic grade suitable to approximate the mean of the scheelite mineralization in lithotype 2. In the quarry “Oberbaumühle” near Windischeschenbach, macroscopic crystals of pucherite ($BiVO_4$), which furnish evidence for the above arguments, were found (pers. com. by the reviewer, M. Fuessl). Between lithotype 1 and 2 there is striking change in the variation of Si, the Na/K ratio, Ti, Cr, V and Zr , all of which increase whereas Si goes down. The variation of the elements indicated by the “red box” (1st and 3thd quartiles) shows a narrower spread than in the previous plots of lithotype 1 (Fig. 9a–c, Table 4). Lithotype 3 sees a further increase in Si, but shows a reversal of the Na/K ratio and a downturn in Ti, V, and Zr. Vanadium, however, increases relative to lithotype 2. Lithotype 4 calcsilicate amphibolites deviate from the rocks of the previous lithotype 3. Their Na/K ratio is significantly greater than 1 and similar to lithotype 2 (Fig. 9c and e) (Table 4). This is also true for Zr and Ti contents, which are greater than

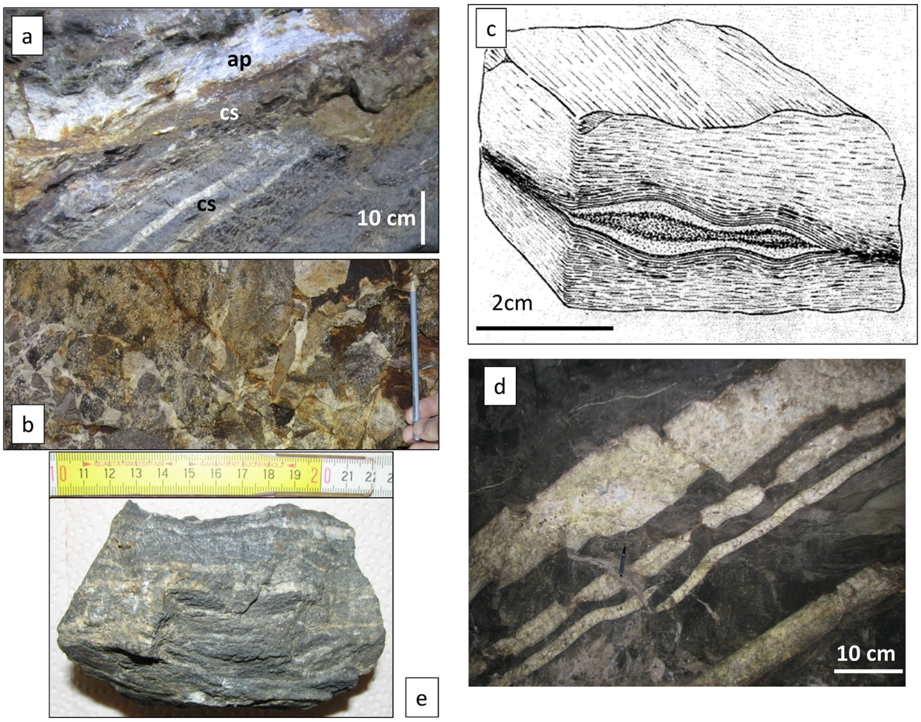


Fig. 7. Lithotype 5, 7 and 8 in hand specimen and underground. a) Aplite and calcsilicates intimately intergrown with each other in an underground storage system at Pleystein-Finkenhammer (lithotype 5). b) Aplite breccia with rotated fragments of gneiss in the town center of Pleystein (lithotype 5). c) Sketch of a hand specimen showing elongated segments of quartz fels converted into a pinch-and-swell textured aggregates along the S planes in the para gneisses (boudinage) (modified from Forster (1965)) (lithotype 7). d) Underground photograph take at the Cachoera Li Mine, Brazil, showing a similar structure as in Fig. 7c with spodumene pegmatite layers subjected to strong shearing and boudinage. e) Graphite quartzite with quartz mobilizates parallel to the S planes. Walthurn near Vohenstrauß (lithotype 8).

those of lithotype 3 and as far as Ti is concerned also greater than lithotype 2. Lithotypes 5 and 6 show again a reversal of the Na/K ratio and only distinguish themselves with regard to the Fe content which increases in lithotype 6 relative to lithotype 5. As to their Ti and Zr values they resemble lithotype 2. The siliceous lithotypes 7 and 8 only show elevated silica contents but with significantly different spreads (Fig. 9h and i). They are different in their Na/K ratios which is higher in lithotype 7 than in 8 (Table 3). Table 3 lists the most diagnostic elements and element ratios for the chemical subdivision of the various lithotypes in context with the various steps of mobilization and the physical-chemical regime pertinent to each lithotype.

6.2. *Chemical facies variation in relation to metamorphic and sedimentary reference types*

In Section 6.1 the absolute element contents of the major elements were illustrated in x-y plots (Fig. 9). To facilitate a rapid visual comparison of the chemical data of the various lithotypes 1 through 8, spider diagrams were designed, one showing the major element patterns (SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O, P_2O_5) and another one illustrating the trace elements relevant for the discussion of the emplacement of the mobilizates, their potential restites and for the discrimination during the environment analysis (As, Ba, Bi, Cu, Mo, Nb,

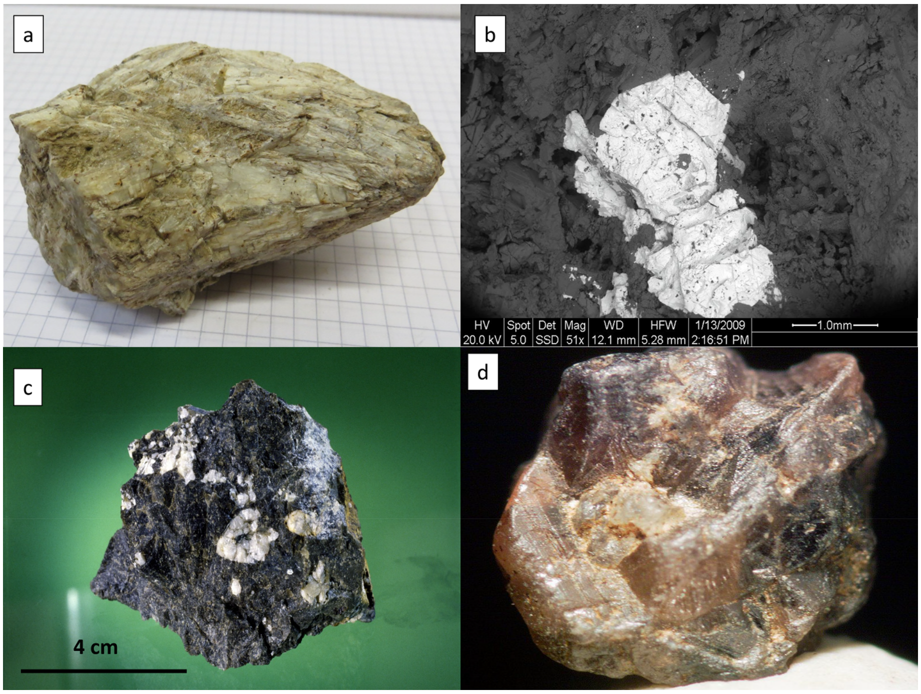


Fig. 8. Mineralization in calcsilicate rocks and skarn. a) Bundles of pale white wollastonite make up the calcsilicate fels at the Galgenberg area to the W of Pleystein (lithotype 2). b) Anhedral aggregates of scheelite in the garnet-diopside-vesuvianite skarn west of Pleystein at Gsteinach. SEM (lithotype 2). c) Porphyroblasts of scheelite in a vesuvianite skarn fels at Göpfersgrün (lithotype 1). d) Cassiterite aggregate made up of twinned cassiterite crystals from the alluvial-fluvial placer deposits of the drainage-system in the environs of the Pleystein pegmatite, downstream of the garnet-diopside-vesuvianite skarn west of Pleystein at Gsteinach (lithotype 2).

Ni, Pb, Rb, U, Zn, Zr and REE $_{tot}$) (Fig. 10a–c). The spider diagrams of the calcsilicate and siliceous series are categorized into three chemical patterns: (1) circular patterns, (2) lens-shaped patterns, (3) stellate patterns according to Dill (2018a,b). Major elements and diagnostic minor or accessory elements are represented in spider diagrams in a suitable way so as to allow for a genetic comparison among the lithotypes (Dill et al., 2014; Paxton et al., 2016).

Both element sets in Fig. 10 were normalized using the biotite-cordierite-sillimanite gneiss of the Moldanubian Region that is most widespread for reference and also typical of the study area allowing their maximum and mean values to be plotted on a logarithmic scale in the various diagrams. In addition to that, the samples of the siliceous rocks under study were also normalized to quartzites, using the Taunus Quartzite as reference, and to a standard greywacke from the literature to test whether the lithological classification as greywacke-quartzite is justified (Forster, 1965; Schroll, 1975). The Taunus Quartzite is a quartz arenite which was largely deposited during the Devonian in the Variscan Orogen in Central Europe Since its metamorphic regime it went through was rather low compared to the amphibolite facies metamorphic rocks under consideration its shallow marine shelf environment can still be easily deduced from sedimentological features and textures observed at outcrop (Hahn, 1990; Dallmeyer et al., 1995; Wehrmann et al., 2005).

6.2.1. The litho-chemical facies of the calcsilicate series

The lithotypes 1a and 1b distinguish themselves only by their abundance in calcsilicate and carbonate minerals, respectively, and, hence, are both members of the stellate diagram type. A marked depletion in Ti, a low in Na and K are accountable for this pattern (Fig. 10a). The same holds true for the minor elements which have only one striking peak of As (Table 4, Fig. 10a). The situation is not very much different for the subtype 1b. Only the minor elements have peaks of As, Pb, Cu, and Zn. Lithotype 2 is a transitional type between stellate and circular considering the major elements with an enrichment of Ca, Mn, Ti and P. It has to be categorized as stellate to lens-shaped with regard to the minor elements As, Bi, Zr, Zn, Mo, Nb and Ni which show elevated values relative to the gneiss standard (Table 4). Its element enrichments are significantly different from those of lithotype 1 expressed by the increased Ti, Fe, Si, Zr, Nb, and Bi contents while similarities exist with regard to the Mn, Rb and Ba contents. Considering the variation of the normalized major element contents, lithotype 3 is a consequent continuation of what might be called an approximation of shape to the standard circle expressed by the red-ring pattern (Fig. 10a). Only Ca, Mn, P and K display values greater than 1. The minor element association displays a lens-shaped to circular pattern with As, Ba, Pb and Rb marking the elongation of this lens. The lithotypes 5 and 6 are most closely to the ideal circular shape to be attained during this sequence of chemical patterns. Lithotype 5 still has some “humps” of Ca, Mn and P. The minor elements show only a small “hump” of U. Lithotype 6 is almost a perfect match of the circle with only Ca deviating from the circular red-pattern. The ideal circular pattern is reached among the minor elements with As being depleted relative to the gneiss standard (Fig. 10b). Lithotype 4 is representative of a circular pattern characterized by the elements such as P, Ti, K, Mg, and Ca, they are cast in the role of “positive marker elements” (enrichment) whereas Nb, Rb, and Pb featuring as “negative marker elements” (depletion) (Fig. 10b, Table 4).

6.2.2. The litho-chemical facies of the siliceous series

The siliceous pattern of lithotype 7 is similar in shape to the circular pattern of lithotype 6, but with small “off-shoots” of P and Mn. This is

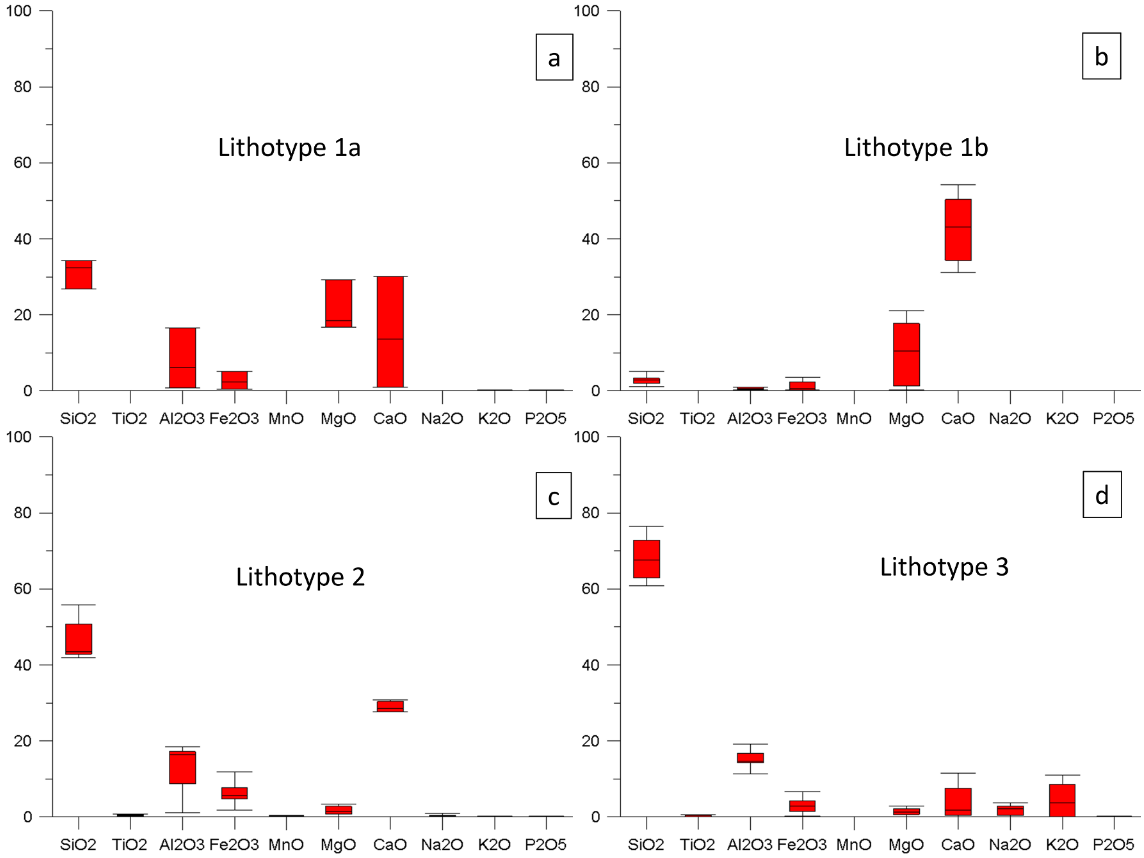


Fig. 9. Major elements of lithotypes displayed by means of whisker diagrams a) Major elements of lithotype 1a. b) Major elements of lithotype 1b. c) Major elements of lithotype 2. d) Major elements of lithotype 3. e) Major elements of lithotype 4 f) Major elements of lithotype 5. g) Major elements of lithotype 6. h) Major elements of lithotype 7. i) Major elements of lithotype 8.

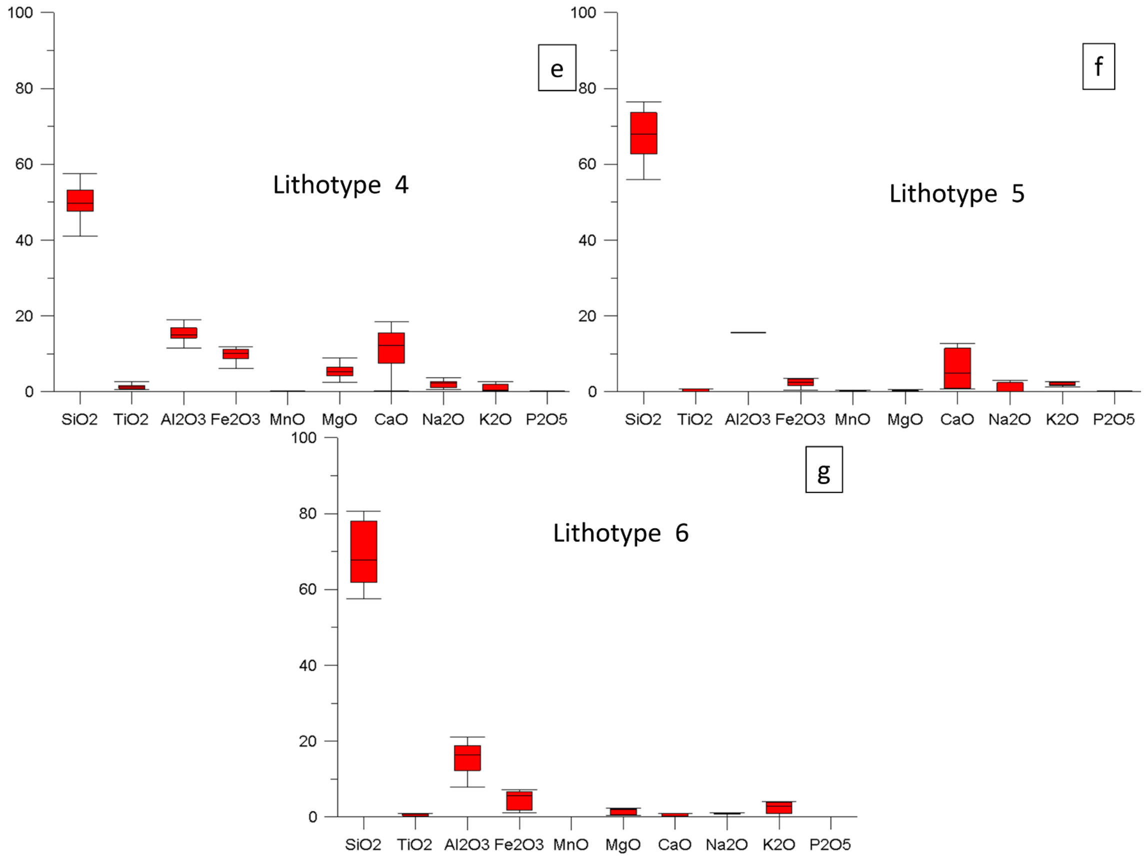


Fig. 9. (*continued*)

also valid for the minor elements where the circular pattern is only distorted by the peak of Zr which is of the same magnitude as at lithotype 2. Lithotype 8 is difficult to describe as to its shape but the shape shows the best approximation to the circular pattern as being compared with the surrounding paragneisses. The typical major elements are P, Ca, Mg, Ti and K and among the minor elements Mo, As, U and Rb stand out.

6.2.3. *Calcsilicate and siliceous series vs. Sedimentary parent rocks*

Calcsilicate rocks of lithotype 1a and 2 are normalized to unmetamorphosed impure marine limestones derived from different sites in the Persian Gulf region, from Thailand and Germany (Fig. 10d). Classification schemes of limestones which pay attention to the mineralogical composition are based on dolomite, calcite and non-carbonate minerals and designed as triplot: They are crucial for the industrial use of calcareous rocks and also proved most appropriate for the comparison of the parametamorphic rocks and potential parent rocks (Leighton and Pendexter, 1962). The impure limestone and dolomite fields are displayed in Fig. 11. Compared to the reference “impure limestone” lithotype 1a shows the best fit, whereas lithofacies 2 has values significantly increased, in places, by some orders of magnitude. The same procedure has been applied to the lithotype 7 in the siliceous series to show the best fit using the double-triplot designed by Friedman et al. (1992) to determine the compositional maturity of arenaceous deposits devoid of a matrix or with a matrix (matrix: grains < 30 µm) (Fig. 12). There exists a conspicuous chemical difference in the spider diagram between lithotype 7 and pure quartzites but a great similarity in shape with greywackes (Fig. 10d). To interpret the original chemical facies of the paragneisses forming the country and host rocks in the pegmatite province, they are normalized to the

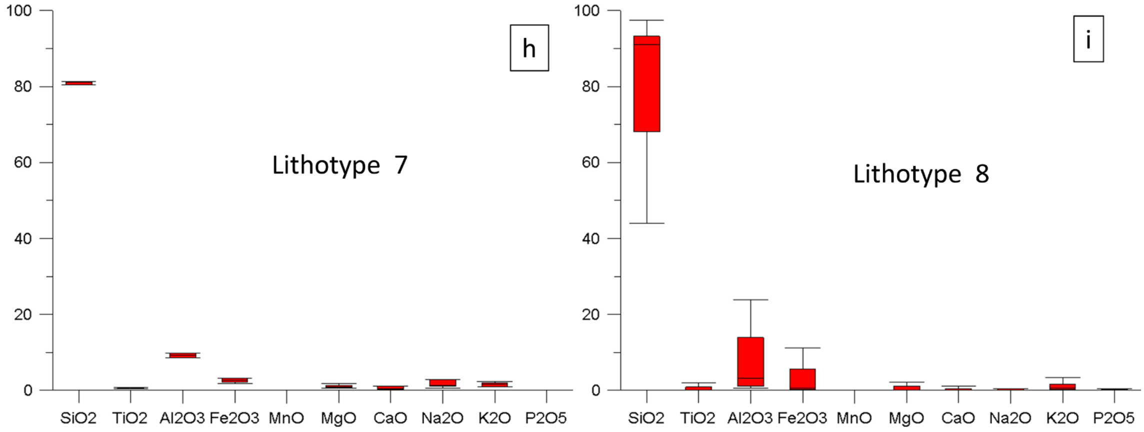


Fig. 9. (*continued*)

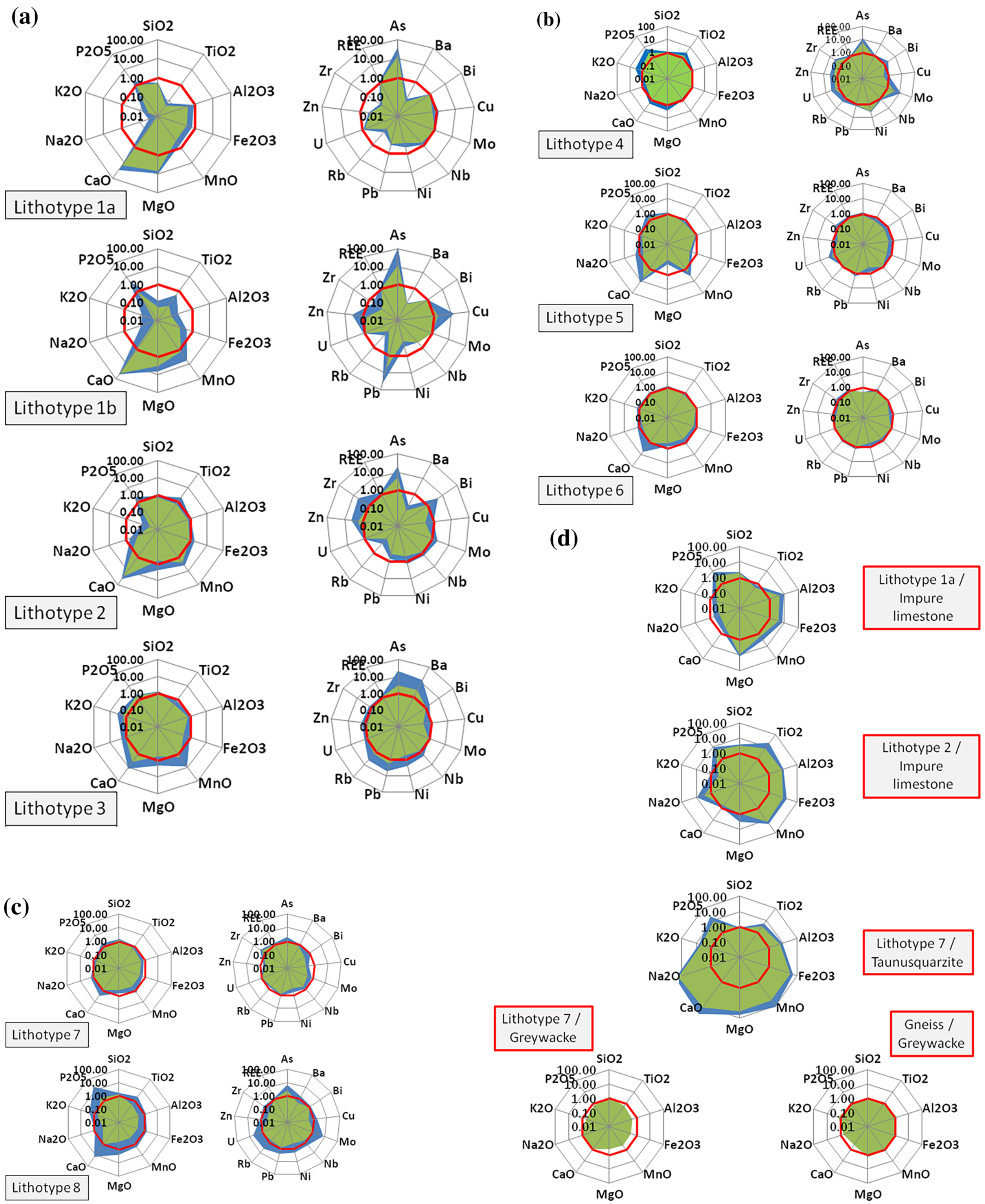


Fig. 10. Spider diagrams to reveal the increase of major and minor elements of lithotypes of the calcsilicate and siliceous series relative to a paragneiss standard of the study area in the NE Bavarian Basement. The data are plotted on a logarithmic scale with the “red ring” denoting the reference line 1. Below 1 denotes depletion and above enrichment of elements. For more information on the lithotypes see Section 4.1 of the text. a) Major and minor element spider diagrams of lithotypes 1a (enriched in calcsilicate minerals), 1b (enriched in carbonate minerals), 2, and 3. b) Major and minor element spider diagrams of lithotypes 4 (normalized to amphibolite), 5, and 6. c) Major and minor element spider diagrams of lithotypes 7 and 8. d) Lithotype 1 normalized to impure limestones (authors personal database of marine limestones from Thailand, Persian Gulf, Germany, unpublished) and lithotype 7 normalized to reference samples of a quartzite (sampling done by the author) and greywacke (Schroll, 1975). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

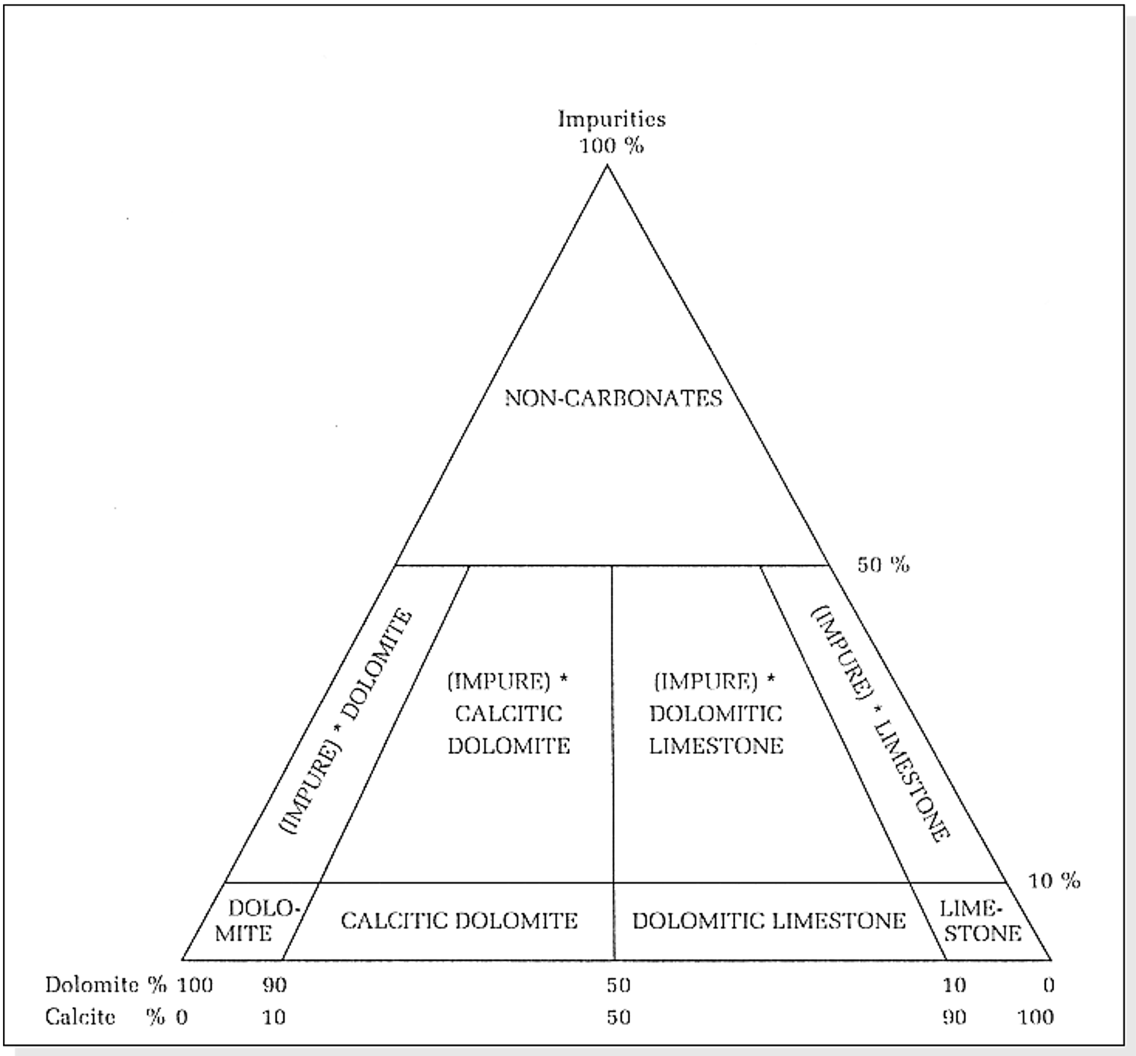


Fig. 11. Chemical classification of calcareous rocks according to Leighton and Pendexter (1962).

standard greywacke (Fig. 10d). Both patterns resemble each other yet with some minor but decisive deviations from the red-pattern ring. The gneissic country rocks are depleted in Si, Ca, and Na, whereas lithotype 7 is only enriched in silica and depleted in all other major elements (Fig. 10d).

7. Discussion

7.1. Meta-sedimentary facies versus metasomatic facies (restite-mobilizate)

In the succeeding discussion isochemical processes operative under elevated temperatures (regional metamorphism) are compared to allochemical ones (metasomatism). In order to distinguish true metasedimentary calcsilicates and metachert/metabiolites from similar calcsilicates and siliceous rocks belonging to the restite-mobilizate couple marker elements are listed in Table 4 and discussed in the succeeding section as to the depositional environments of which they are typical.

7.1.1. Lithotypes 1a, 1b, and 8 – sediments undergoing regional metamorphism (isochemical processes)

Lithotype 1 is interpreted as a series deposited in a marine shelf environment composed of limestones alternating with arenaceous to argillaceous sediments and interbedded into units made up of black shales, clean sandstones and claystones (Table 4). The stratigraphic section is endowed with well-bedded to massive reefal calcareous rocks and its metasediments may be traced over a wide distance reflecting its primary occurrence: As to depositional environment this lithology is akin to many Mesozoic stratigraphic series such as the Jurassic where the tripartite subdivision of gray- to black shales, sandstones and limestones can be taken as an unmetamorphosed instance (Arzani, 2004). The detrital input (Ti, Zr) in form of zircon and rutile was very low so that large marble horizons could predominate over impure limestones or calcareous sandstones. The impoverishment in terms of Na and K relative to the reference type is held to be an indication of sabkha-like evaporites with Na- and K chlorides and sulfates which cannot survive regional metamorphism (Fig. 10a). True sabkha environments may also spark the formation of scapolite s.s.s which takes up the fluid component provided by the decomposition of the evaporite minerals and can be recognized in metacarbonates (Feldmann, 1996; Křìbek et al., 1997; Dasgupta and Tim Pal, 2005). Elevated Mn contents signal the low Eh and the proximity to the black shales (Dubois et al., 2015). The smaller the boxes of the various lithotypes the more likely we are confronted with metasomatic rather than metasedimentary rocks which used to show a wider compositional range (Fig. 9).

Lithotype 1 when normalized to a reference impure limestone shows elevated Mg, Mn, Al and Fe contents due to dolomitization and higher detrital input than in the reference type. The minor elements do not reflect the primary environment of sedimentation but resulted from a base metal mineralization found in this unit. Elevated W and Sn contents are neither sedimentary facies markers nor do they result from the

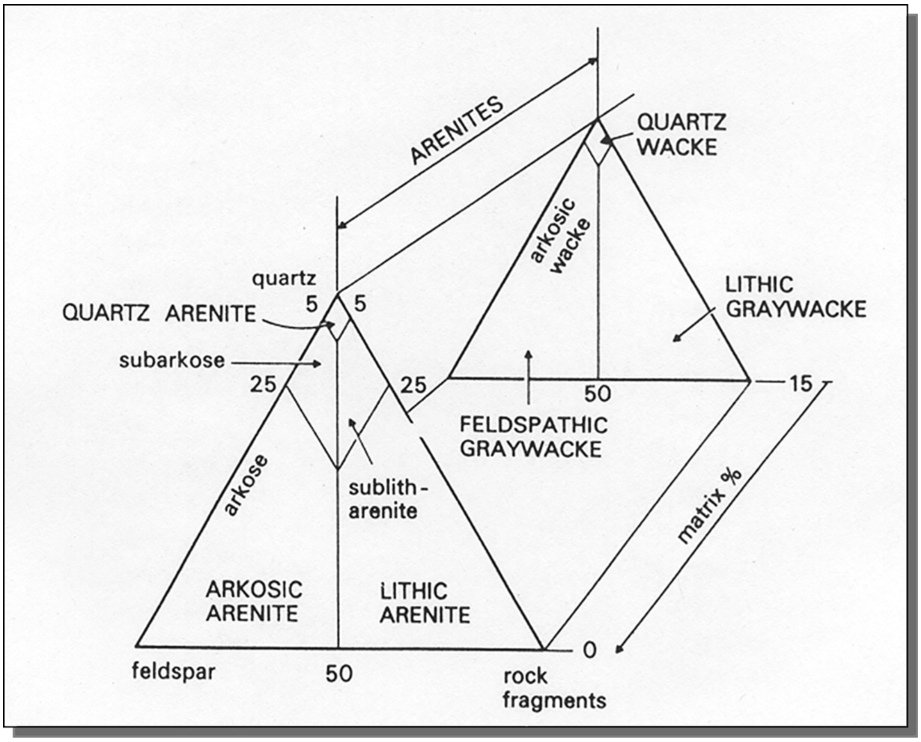


Fig. 12. Classification of arenaceous sedimentary rocks based upon the compositional maturity after Friedman et al. (1992).

adjacent granite. They are confined to a local scheelite mineralization at Göpfersgrün which is controlled by Permian rhyolite dykes vented along a deep-seated lineamentary structure zone (Fig. 5, Table 3). This holds true also for the scheelite mineralization encountered W of Pleystein, near Gsteinach, in the calcsilicates of lithotype 2 (Vierling, 1975). Examples showing a lithological shelf platform transition from calcareous sediments into black shales have been described from the Lower Cambrian of the Upper-Yangtze Region in South China (Mei Mingxiang et al., 2007). Mobilizates do not play any part in the resultant host rock lithotypes of the basement.

While lithotype 1 is representative of the true metasedimentary calcsilicates associated with marble, lithotype 8 represents the true metasedimentary type of the siliceous series. Depending upon the content of silica this rock type can be interpreted as transitional from black shales into carbonaceous metacherts. The metacherts low in organic carbon are similar to lithotype 7. That is why this metacherts are discussed as to their marker and facies elements for distinction (Table 4, Fig. 10c). Elevated Ca contents attest to small calcareous intercalations, Mn denotes the poor aeration of the basin and P opens the pathway to metaphosphorites associated with them (Dubois et al., 2015). Elevated K and Rb contents are representative of the argillaceous component of the sediments. Molybdenum and the vanadium/chromium ratio furnish evidence for the reducing conditions of the depositional environment and the elevated U contents, recognized in some places justify their denomination as “hot shales” (Lüning et al., 2003, 2005). The V/Cr ratio has been applied to distinguish between dysaerobic and anaerobic redox regimes (Dill, 1985a,b,c). About 60% of the samples under study have V/Cr ratios exceeding the level 2 and thus qualify as true euxinic environments of deposition. This metasedimentary environment of the crystalline basement is also devoid of felsic mobilizates as it is the case with the true metacarbonates.

7.1.2. Lithotypes 2, 3, and 7 – metasomatic rocks in the footwall rocks of the pegmatites (allochemical processes)

Evidence for metasomatic (allochemical) processes can be observed in the footwall as well as hanging wall or roof rocks of the pegmatite stocks (Figs. 2, 13–15). As they are strikingly different with regard to their structure and temperature regime, the lithotypes of metasomatic rocks are discussed as separate entities each in a section of its own 7.1.2 and 7.1.3 (Fig. 15).

Lithotype 2 resulted from metasomatism (see Ti, Zr) with very small amounts of felsic mobilizate left *in situ* (Na) (Figs. 9c, 10a). The circular to stellate pattern of lithotype 2 being normalized to impure limestones shows the highest increase ever in Ti, Al, Fe, Mn, Na, and P (Fig. 10d). It is a clear manifesto that this calcsilicate (skarn) lithology has not been derived from a simple regional metamorphism of, e.g., calcareous sandstones or arenaceous limestones interbedded with siliciclastics as observed in lithotype 1a. It resulted from a complex metasomatic/allochemical processes affecting the metapsammopelites which are represented in the region by the ubiquitous cordierite-sillimanite-biotite gneisses (Fig. 10a). The stellate-circular pattern of lithotype 2 being normalized to the paragneisses shows a good fit with regard to Al, Fe, Mg, and Ti, an abundance in Ca, Mn and P, and a depletion with regard to K and Na compared with the surrounding paragneisses. In other words, it is a paragneiss that underwent an introduction of Ca and to a small extent also of Mn and P along with a significant depletion in Na and K. In the course of this Ca metasomatism felsic Na-K mobilizates were spawned. Among the trace elements Zr corroborates the idea of a restites or residue. Other elements such as Zn, Mo, Nb and Ni follow suit in this residue building. Lithotype 2 is depleted in Rb, Ba and Pb which are accommodated in the lattice of K feldspar and minerals characteristic of the pegmatitic and aplitic mobilizates. The idea of a Ca metasomatism is not new and has already been put forward by Voll (1960) in the region to the West of the Hagendorf-Pleystein Pegmatite Province, in his petrographic study which no modern-day study can compete with in the area. Scheelite and cassiterite present in these calcsilicate rocks are often interpreted as a result of metasomatic processes affecting marble horizons, as demonstrated for the Mogok district in Myanmar (Shun et al., 2016). As mentioned in the previous section, the W-Sn association is genetically related to a younger mineralizing process and parental marbles horizons from which this minerals in lithotype 2 could have been originated from, do not exist in the region (Fig. 2) (Dill et al., 2006b).

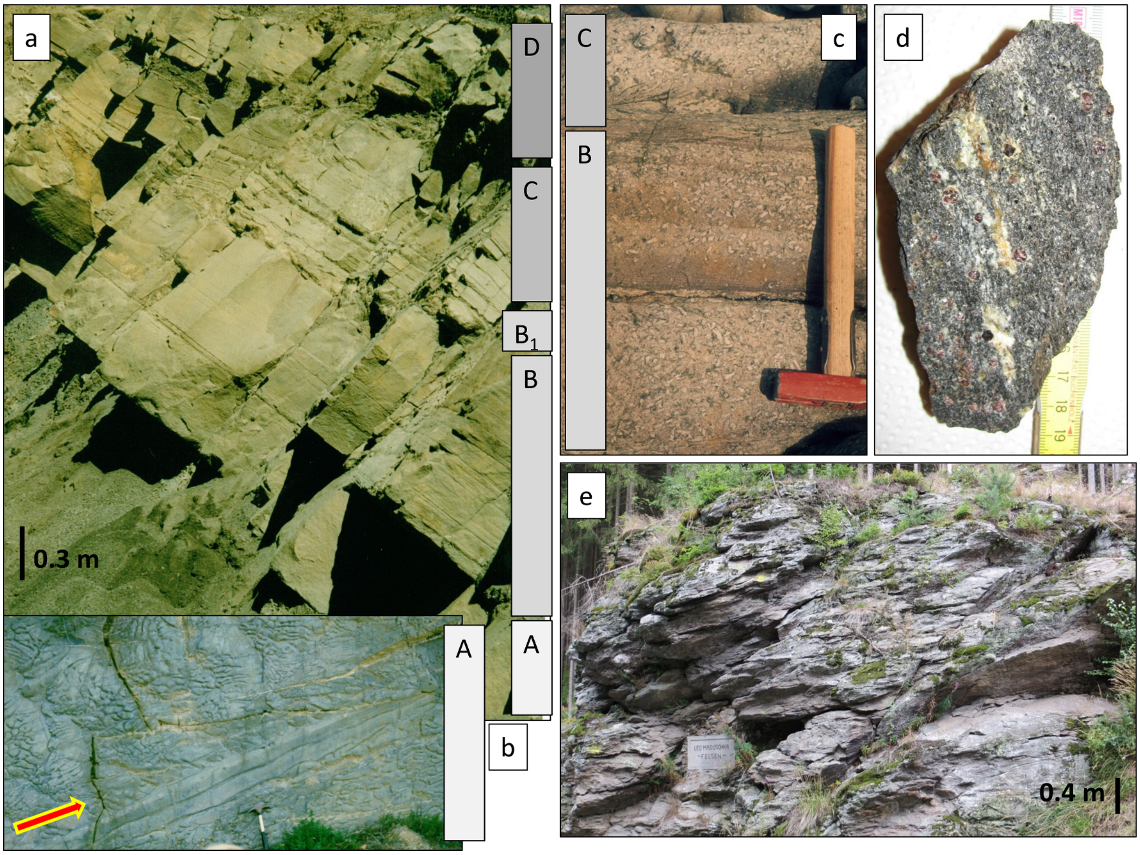


Fig. 13. From the unaltered turbidite to the paragneiss that form the host rocks of the felsic mobilizates and the restites in Hagendorf-Pleystein Pegmatite Province. a) Distal megaturbidite in deep water marine argillaceous basin plain sediments of Late Cretaceous age, near Wilbur Springs, USA. BOUMA sequence described below: Facies A: Conglomerates and pebbly medium- to coarse-grained sandstones. Different forms of grading Facies B: Coarse to fine-grained sandstone, in parts with lamination, dewatering dish structures and ripples. B1 is rife with hematized pyrite and plant remains Facies C: Sandstones with only minor channeling Facies D: Very fine to medium- grained sandstones b) Graywacke of Ordovician age with well preserved sole marks (flute casts). The arrow head marks the paleocurrent of the turbidity current. near Troy, USA. Scale: hammer head. Lower part of facies A. c) Metagreywackes in the Scottish Highlands of Early Paleozoic to Proterozoic (?) age display graded bedding (below) and convolute and ripple bedding (above) typical of turbidity currents (transition of facies B–C). Metamorphic differentiation provoked crystallization of andalusite near the end of the hammer handle and cordierite near the hammer head. d) Almandine-bearing biotite-sillimanite-cordierite gneiss in the Hagendorf-Pleystein Pegmatite Province. e) Strongly sheared biotite gneiss north of Pleystein. These rocks and the specimen of Fig. 13d are pervasively regionally metamorphosed greywackes or metapsammopelites. The reference paragneiss for normalization has been derived from the gneisses shown in Fig. 13d and e.

Lithotype 3 is a transitional type as mentioned above. Subtype 3a is genetically equivalent to lithotype 2 and typical of the reaction zone between paragneiss and mobilize (Figs. 4 and 6a, c). It developed at the same level as lithotype 2 and has only been met in the western part of the Hagendorf-Pleystein Pegmatite Province. It is a para-utochthonous process where the felsic mobilizates have not fully been separated from the residue yet (Fig. 4). By contrast there are barren and rare-element pegmatoids at a distal position relative to lithotype 2 which are rimmed by calcsilicate minerals too. This subtype is called lithotype 3b and differs from 3a by increased amounts of Fe and Mn in the equivalent solid solution series (lithotype 2/3a: grossular –dominated garnet ⇒ lithotype 3b: spessartine-dominated garnet). The circular chemical pattern of the major elements and the lens-shaped one of the minor elements attest to an intimate association of feldspar-quartz mobilizates and residual mineral aggregates. The major elements Ca and Mn represent the residual part and K, P, Ba, Pb and Rb the mobile component. The cited trace elements are accommodated in the lattice of feldspar.

Although chemically completely different from the Ca-enriched lithotypes, lithotype 7 is a member of the footwall association and warrants a more detailed discussion. It has been categorized by Forster (1961, 1965) as a metasedimentary rock and named by this author as greywacke-quartzite gneiss. A comparison with a Paleozoic marine reference quartzite ("Taunus-Quarzit") failed in a striking way, ruling out clean sandstones as a potential parent sedimentary rock (Fig. 10d). The normalization with the reference greywacke offers a more positive effect of a circular pattern, but the best fit is achieved when normalizing the paragneisses to the greywacke standard (Fig. 10d). Excluding Ca and Na the paragneiss coincides with the reference red circle of greywacke. As a consequence of this, the ubiquitous cordierite-sillimanite-biotite gneisses shown in Fig. 13 and which act as host rocks of the restites and the numerous felsic mobilizates have originated from metamorphosed Proterozoic greywackes, quite contrary to what has been claimed by Forster (1961, 1965).

From the sedimentological point of view greywackes, are flysch sediments consisting of argillaceous and arenaceous sediments up to the size of conglomerates, developing synorogenically and covering vast parts of the central zone of an orogens (Cummins, 1962; Dott, 1964; Sestini, 1970) (Fig. 13). In the Central European Variscides (Ardennes, Rheinisches Schiefergebirge, Harz, Fränkisch-Thüringisches Schiefergebirge) these siliciclastics cover vast areas together with slates (McCann, 2008)). The sedimentary structures and textures of these deep-marine turbidities are well preserved in the Mesozoic, Paleozoic and even some Precambrian rocks (Kneller and Buckee, 2000; Mulder et al., 2006; Salles et al., 2008; Meiburg and Kneller, 2010) (Fig. 13a–c). In the area under study all sedimentological features have completely

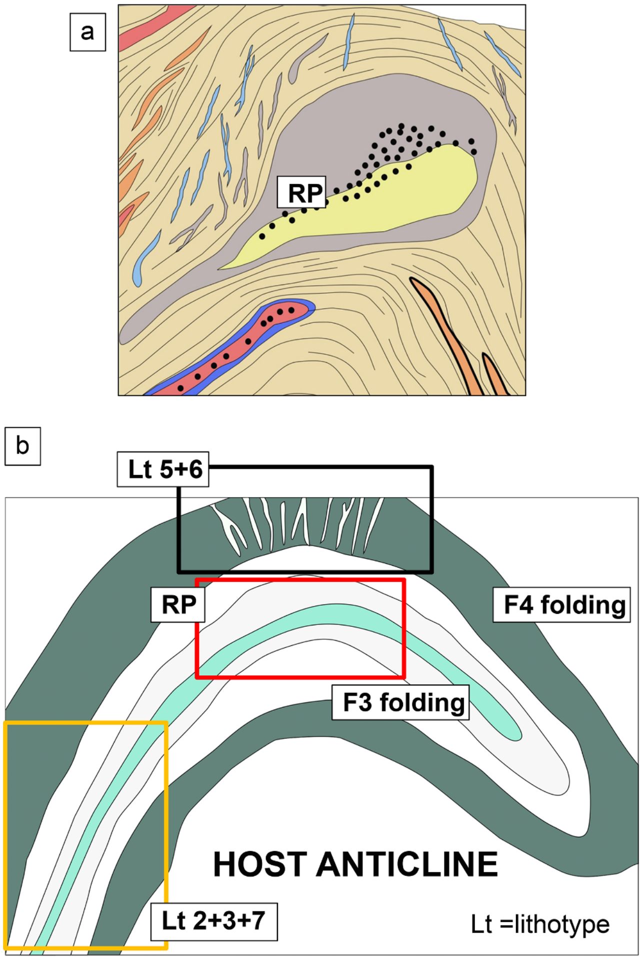


Fig. 14. Refolding, metamorphic mobilization and differentiation entail the formation of zoned anticlinal pegmatite bodies, e.g., Kreuzberg-Pleystein. a) Zooming in Fig. 4 and focusing on the anticlinal hinge-zone hosted pegmatites and aplites which evolved from metamorphic rocks through metamorphic differentiation in zones of high heat flow, mobilizing K, Na and Si and leaving behind a chemical residue enriched in Ca, Mg and Fe in the exocontact of the zoned pegmatite. b) A previous folding in the host anticline has been produced by folding F 3 and was re-folded so as to create the present-day anticlinal structure (idealized model based on large-scale examples at outcrop reported by Forster (1965) and Stein (1988). The fractures in the hinge zone of F4 corresponds to lithotypes 5 and 6.

been obliterated by the medium-pressure – high-temperature regional metamorphism around 370 Ma and the strong low-pressure- high-temperature regional metamorphic event about 320 Ma ago, so that only one loophole is left open to take refuge to lithochemical measures for constraining the environment of deposition of the various rock types (Hansen et al., 1989; Glodny et al., 1995) (Fig. 13d and e, Table 5).

The trace elements Zr and Ti within the lithotype 7 are remnants of the greywackes where they are accommodated in the lattice of rutile and zircon, two common heavy minerals accumulated together with tourmaline (schorl-dravite s.s.s) due to their very strong resistance to weathering and postdepositional alteration, including metamorphism. The classical ZTR index used as a measure of the maturity of sediments and to assess the degree of weathering and diagenetic alteration, which was introduced by Hubert (1962), can also be applied to this lithotype. It is categorized as "supermature" with a Zr-Ti residue and highest degree of silica accumulation ever. Lithotype 7 is the "missing link between the metapsammopelites (greywackes) as the host and source rock of mobilizates on one side and the ensuing pegmatoids and aploids on the other side. Lithotype 7 a highly fractionated mobilizate with a residue either forms the center of the afore-mentioned mobilizates or the margin (Figs. 2 and 4).

7.1.3. Lithotypes 5 and 6 – Ca metasomatites in the hanging wall rocks of the pegmatites (allochemical processes)

In the hanging wall metamorphic rocks of the pegmatite stock (< 500 m away from the pegmatite stock), lithotype 5 and 6 form a pendant to the assemblage of lithotypes 2, 3 and 7 in their footwall rocks (< 1000 m away from the pegmatite stock) (Figs. 9f, g and 14a, b). The chemical patterns of both lithologies most closely resemble the metamorphic basement rocks around (Fig. 10b). This calcsilicate mineralization originated from the hanging wall paragneisses as a result of a Ca metasomatism. Both lithotypes 5 and 6 only chemically differ from each other by a strong depletion of Fe in lithotype 5 relative to lithotype 6. The way this mineralization resulted from metamorphic differentiation can be deduced from Fig. 14 which has been designed according to the field work of Forster (1965), Stein (1988), Mücke (2018) and the author's regional study of the felsic mobilizates. According to the field observations by Stein (1988), F3 generation of folding is accompanied by a retrograde metamorphism. High heat flow with temperatures close to 800 °C and refold of older fold structures (F3 ⇒ F4) are accountable for the asymmetric emplacement, the morphology and the zonation of the hinge-zone-related pegmatites RP (Fig. 14a and b). The structural setting depicted well agrees with the map of Uebel (1975), who for the first time recognized an internal subdivision of the Hagendorf-South Pegmatite into an Older Pegmatite and Younger Pegmatite which are connected by a brecciated chimney that allowed the overprinting of the barren older one by a younger rare-element pegmatite (Dill, 2015b)

Emplacement of the older pegmatite, *sensu* Uebel (1975) started off in a process that might be called metamorphic differentiation *sensu lato*. The classical papers on metamorphic differentiation trying to explain K- and Na-enriched layers of granitic gneiss interbedded with Fe- and Mg-enriched gneissic and schistose layers were published by O'Harra (1961) and Bowes et al. (1964). The term is used in the current paper to describe the similarities in the outward appearance between the reference types and outcrops under study(Figs. 2 and 13c). The processes lead to the split up into a barren Na-K feldspar pegmatite in the hinge zone and a restite-mobilizate lithotype 7 along the limbs of the anticline (Fig. 15a). Subsequently another process involved the emplacement of another siliceous melt abundant in rare elements provoking stockwork-like hydrofracture veinlets filled with lithotype 5 and 6 in the roof of the existing pegmatite and giving rise to the lithotypes 2 and 3 in the footwall of the pegmatite (Dill, 2018a,b) (Table 5) (Fig. 15b).

7.1.4. The Ca metasomatites in the metabasic rocks (lithotype 4)

The lithotype 4 is exposed in large metabasic complexes forming feldspar-quartz-bearing mobilizates of its own and its raw data normalized to a standard amphibolite lacking calcsilicate minerals typical of the area (Figs. 1 and 10b). Unlike the metasedimentary rock, the latter metabasic rocks were targeted upon in a petrographical, petrological and geochemical investigation by Schüssler (1990). According to the cited author, the amphibolites hosting lithotype 4 have as protolith modern tholeiites of ocean islands or anomalous mid-ocean ridge segments. Metabasic rocks may play a significant role in the run-up to the emplacement of rare-element pegmatites as exemplified by pegmatite deposits at Bancroft and Tanco/Bernic Lake, Canada, Greenbushes, Australia, Varuträsk, Sweden or Iveland, Norway (Goad, 1990; Partington et al., 1995; Selway et al., 2000; Van Lichtervelde et al., 2006; Jacobson et al., 2007). The most proximal rare-element pegmatite deposits under operation are situated at Koralpe, Austria, where Li pegmatitic lenses and layers are interbedded with amphibolites (Göd, 1989). Typical calcsilicate minerals reported from there are clinozoisite-epidote, scapolite, prehnite, and sphene, all of which, excluding scapolite are also known from the calcsilicate-amphibolites in the NE Bavarian Crystalline Basement (Niedermayer and Göd, 1992). In

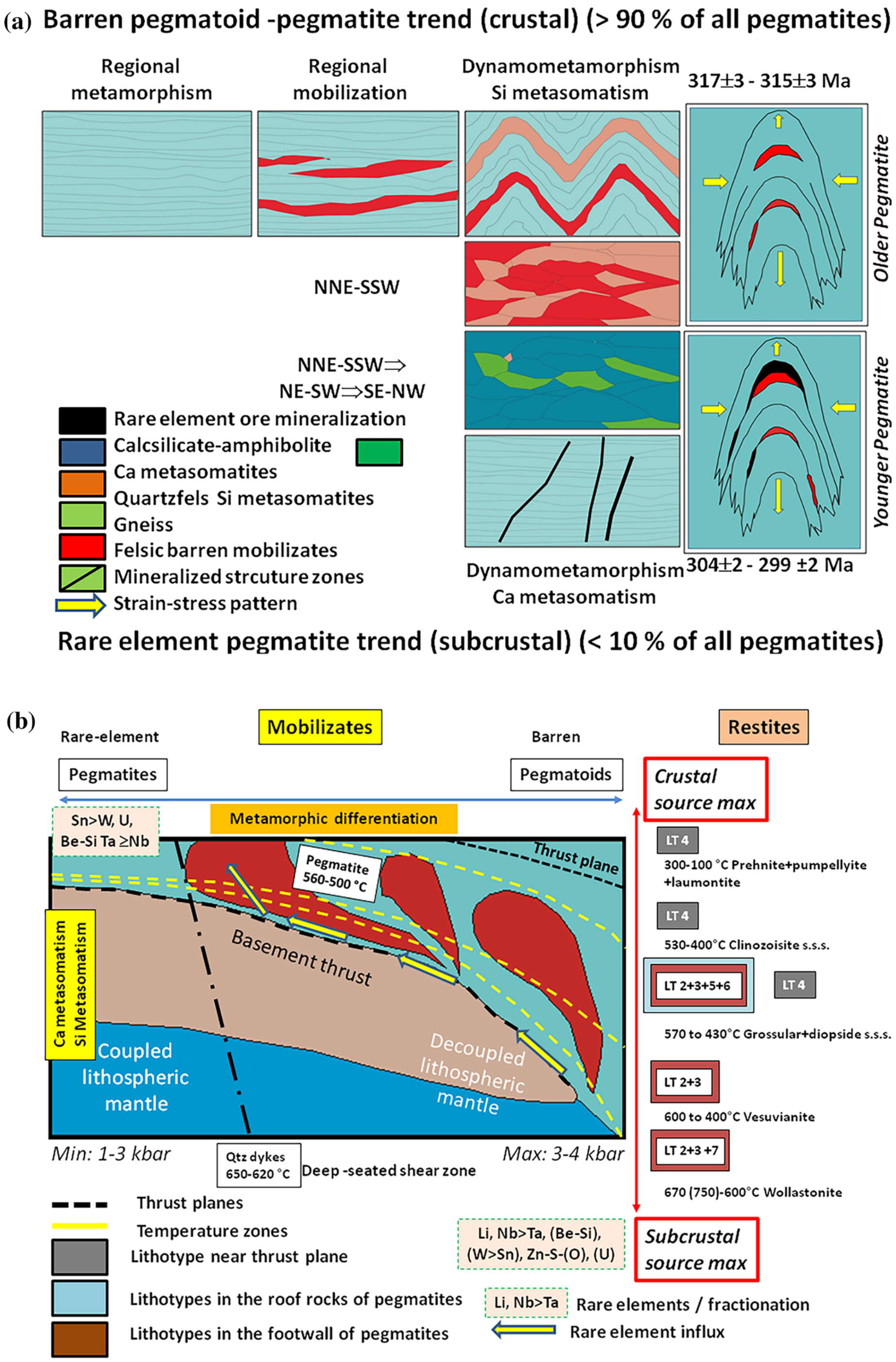


Fig. 15. The synoptical overview of the restite-mobilizate relationship in a Variscan-type system. a) The structural and chronological evolution in a metamorphic – metasomatic setting and the existence of two trends of mobilization (see also Fig. 15b) Barren pegmatoid-pegmatite trend (Intracrustal): 1. Regional metamorphism ⇒ 2. Regional mobilization ⇒ 3. Dynamometamorphism (e.g. folding) ⇒ 4. Older Pegmatites in structural traps (hinge zones of anticlines) 317 ± 3–315 ± 3 Ma , structural elements NNE-SSW Rare element pegmatite trend (subcrustal to lower crustal) superimposed on the “barren trend: 1. Dynamometamorphism with deep-seated structural elements tapping the lower and subcrustal parts structural elements 304 ± 2–299 ± 2 Ma, NNE-SSW ⇒ NE-SW⇒SE-NW b) The physical-chemical regime influenced by crustal and subcrustal processes (see also Fig. 15a) x-axis: Change in pressure (1–3 kbar), variation and fractionation of rare elements, variation from barren pegmatoids to rare-element pegmatites y-axis: Change in the temperature of formation (100–750 °C), change in the crustal and subcrustal impact on the composition of pegmatitic rocks, position of lithofacies types (LT) generated by the Ca- and Si metasomatism.

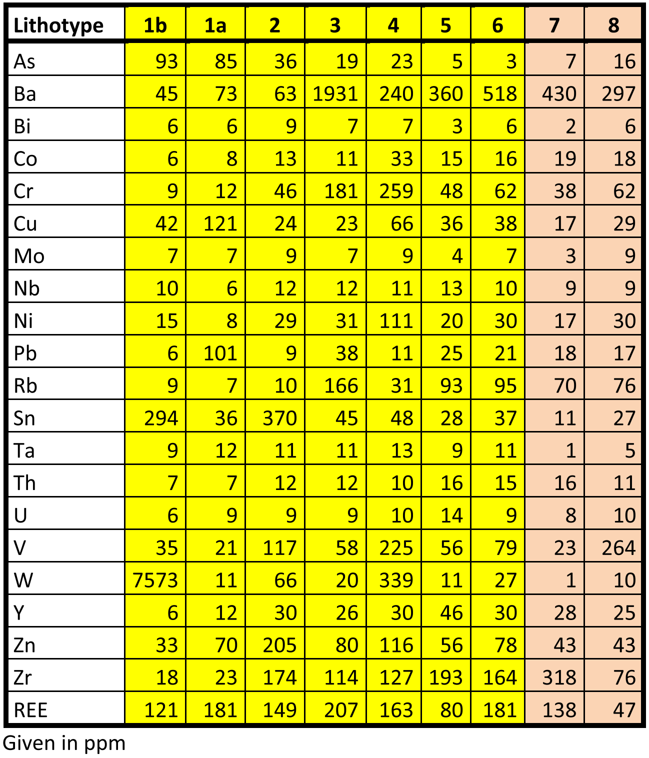
the area under consideration metabasites are only linked to barren pegmatoids and aploids. Liebscher et al. (2007) investigated in this metamorphic complex zoisite-bearing high-pressure pegmatites originating from eclogites and eclogite–amphibolites. The majority of aploids and pegmatoids are barren alkaline feldspar-, quartz- and muscovite-bearing mobilizates derived from layered hornblende gneisses as in the study area “b” of Fig. 1 (Okrusch et al., 1991). Considering the geodynamic setting, all members of lithotype 4 belong to klippen of a former coherent nappe complex (Dill, 2015b). Lithotype 4 calcsilicate-amphibolite does not distinguish itself very much from a typical amphibolite apart from its strong enrichment in K, P and Ti. It should not come a surprise to anybody to encounter such circular pattern denoting restite and mobilizate component all in one as the intimate interbedding of calcsilicate-amphibolite and felsic mobilizates is seen (Figs. 3b, c and 10b). This mobilization has no impact on elements like Rb, Pb and Nb as all pegmatoids are barren ones. From the physical and rheological point of view syn-tectonic pegmatitization along with shearing along nappe boundaries has been described by Piasecki and Cliff (1988), Ertl et al. (2012) and Culshaw et al. (2014).

7.2. *The physical-chemical regime of the lithotype associations*

7.2.1. *The meta-sedimentary lithotype associations 1 and 8*

The physical-chemical regimes of lithotype association 1 refer to the primary environment of deposition and the subsequent regional metamorphism which these sedimentary lithologies went through. The first one evolved under near ambient conditions with two subenvironments characterized by euxinic conditions (Eh < 0) and another one devoid

Table 3
Mean values of trace elements of the lithotypes under consideration.



Lithotype	1b	1a	2	3	4	5	6	7	8
As	93	85	36	19	23	5	3	7	16
Ba	45	73	63	1931	240	360	518	430	297
Bi	6	6	9	7	7	3	6	2	6
Co	6	8	13	11	33	15	16	19	18
Cr	9	12	46	181	259	48	62	38	62
Cu	42	121	24	23	66	36	38	17	29
Mo	7	7	9	7	9	4	7	3	9
Nb	10	6	12	12	11	13	10	9	9
Ni	15	8	29	31	111	20	30	17	30
Pb	6	101	9	38	11	25	21	18	17
Rb	9	7	10	166	31	93	95	70	76
Sn	294	36	370	45	48	28	37	11	27
Ta	9	12	11	11	13	9	11	1	5
Th	7	7	12	12	10	16	15	16	11
U	6	9	9	9	10	14	9	8	10
V	35	21	117	58	225	56	79	23	264
W	7573	11	66	20	339	11	27	1	10
Y	6	12	30	26	30	46	30	28	25
Zn	33	70	205	80	116	56	78	43	43
Zr	18	23	174	114	127	193	164	318	76
REE	121	181	149	207	163	80	181	138	47

Given in ppm

Given in ppm.

of graphite which came into existence under Eh > 0. The ubiquity of calcareous rocks attests to intrastratal solutions of pH > 7 (alkaline fluids). Lithotype 8 is an all-round poorly aerated environment with approximately 2/3 of the original paleogeography representing truly anaerobic and 1/3 of it dysaerobic conditions (Dill, 1985a,b,c).

During the second stage of regional metamorphism affecting lithotype 1 diopside and grossular evolved as index minerals to constrain the upper T limit of the physical-chemical regime. In places, vesuvianite also appears on the scene. Following the studies in Bucher and Grapes (2011) the temperature covered the interval 430 °C to 570 °C when grossular and diopside s.s.s. were the only stable Ca silicates. A moderately higher temperature of up to 600 °C is likely to have been when vesuvianite formed. The granites nearby rarely show an aureol of hornfels along their edges and if present at all, only hornfels bearing minerals indicative of the lowermost one, called albite-epidote facies according to Winkler (1976) It attests to a temperature interval of approximately 400–500 °C. The temperature provided by the granitic intrusion is insufficient to achieve the mineral transformation observed in the calcilicate rocks of lithotype 1. The siliceous lithotype 8 rarely offers suitable marker minerals to determine the metamorphic conditions with the exception of andalusite present in the more pelitic subfacies. This alumonsilicate shows a rather wide temperature of formation, particularly under low pressure (Bohlen et al., 1991). In the area under consideration a temperature of around 550 °C attesting to low grade-stage conditions is the most realistic interpretation.

7.2.2. The metasomatic association in the footwall rocks of the pegmatites (lithotypes 2, 3, 7)

In lithotype associations 2, 3 and 7 that is encountered in the footwall of the pegmatite stocks, the most decisive calcsilicate mineral to determine the temperature of formation is wollastonite observed in lithotype 2. The process of CaO and SiO_2 reacting with each other and leading to wollastonite has already been discussed by V.M Goldschmidt and cited in many petrological textbooks, among others in the textbook of Bucher and Grapes (2011). Observations in the field suggest that the X_{CO2} was rather high and a temperatures of 600 °C existed at a depth of 2 km below ground, corresponding to 500 bar. Doubling the depth needs temperatures of between 650 and 670 °C to produce wollastonite. At a confining pressure of 3000 bar, a maximum temperature of around 750 °C can be claimed to produce wollastonite in this lithotype association. Other sections containing diopside, grossular, vesuvianite, and clinozoisite s.s.s. evolved under temperature of as low as 400. Those parts enriched in Ca amphibole, a marginal facies, came into being under more elevated P_{H2O} than the central facies which is abundant, e.g., in diopside. In the contact aureole of the Leuchtenberg Granite measuring as much as 500 m in width which was mapped 15 km to the West of the study area, diopside is a rare constituent (Bauberger, 1993). The Flossenbürg Granite at outcrop immediately N of the study area did not evolved a pronounced contact halo at all. Its thermal impact on the metamorphic wall rock is expressed only by disseminated tourmaline and topaz minerals (Fischer 1964, 1965) (Fig. 1). These findings in the field are a clear indication that the thermal event accountable for the lithotype 2 mineral assemblage could not have resulted from the adjacent late Paleozoic granites. And the heat source has to be looked for at a deeper subcrustal level (Fig. 15b).

Lithotype 3b frequently contains spessartine-enriched garnet s.s.s. instead of grossular-enriched garnet found in lithotype 3a adjacent to lithotype 2 (Fig. 4). Manganiferous garnet may point to higher temperatures, but it has to be treated as a marker only together with apatite. Spessartite-bearing almandine s.s.s. coupled with the above phosphates and silicates are marker for the depth of formation or the present-day level of erosion. At greater depth Mn is accommodated into the lattice of the garnet s.s.s. (Schaaf et al., 2008). At shallower depth where most of the stock-like pegmatites were emplaced Mn is bound to the crystal structure of apatite leading to manganiferous apatite (Falster et al., 1988; Pieczka, 2007). The lens-shaped pegmatoids with Mn-garnet-bearing contact zones are typical of the footwall zone of the stock-like pegmatites (Fig. 4). Chemical zonation from Mn to Mg is in line with a prograde temperature regime during metamorphism (Parkinson, 2000; Zeh and Millar ,2001). For the pure spessartite composition the lower reaction limit at pressures between about 200 and 1500 atm is at 410 °C. For spessartite-almandine s.s.s. the limit rose with increasing almandine content from 410 °C ($spess_{90}alm_{10}$) to 500 °C ($spess_{50}alm_{10}$) according to the author mentioned above (Matthes, 1961). Lithotype 7 bears cordierite and sillimanite as accessory minerals, minerals indicative of HT and LP metamorphic processes in the region which cannot be considered as an evidence for the T and P of formation because they were absorbed into the siliceous mobilizates from the surrounding metamorphic rocks. The main component silica itself is used as a tool to constrain the temperature of formation (Wark and Watson, 2006; Dill et al., 2012). The temperature interval during which lithotype 7 developed covers the range 600 to 680 °C. For comparison, the stock-like pegmatite nearest to these silica mobilizates at Pleystein yielded for the same method applied a temperature range of 500 to 560 °C (Figs. 2 and 4). A swarm of quartz dykes at the western margin of the study area gave a temperature between 620 and 650 °C (Figs. 2, 4 and 15b).

7.2.3. The metasomatite association in the hanging wall rocks of the pegmatites (lithotypes 5, 6)

The lithotype associations of type 5 and 6 display some distinct characteristics with regard to the redox conditions and the pH of the fluids. Based upon calculations involving siderite, the pH of the fluids ranges from pH 3–7.5 and the Eh values lie in the interval −0.75 to +0.5 V in lithotype 6 (Tables 1 and 4). For lithotype 5, where dolomite formed instead of siderite the fluid composition lies in the narrow range around neutral (pH 6–8) and the Eh spreads from −0.5 to +0.75 V. The temperature of formation with diopside s.s.s. used as the marker mineral stands between 430 and 570 °C (Fig. 15b).

Table 4
Lithotypes: Their physical–chemical regime and the environment of formation.

Litho-Type (Lt)	Lithology	Lithologies associated with lithotype	Marker element contents (wt. %) / ratios	Chemical pattern	Physical-chemical regime	Environment of formation
1	Calcsilicate -marble	Mica schist, phyllite, (graphite schist, quartzite)	Si (0-35), Mg+Ca (15-75), Na/K (0.2-0.5) wide spread among elements Zr, Ti (min)	Stellate: max: Mg, Ca min: Ti, K, Na max: As min: Zr, Zn, Cu, Rb, Pb, Ni	Sedimentary: Eh>0 and Eh < 0 Metamorphic-metasomatic :430-570°C (< 600°C)	Marine shelf sediments composed of limestones alternating with arenaceous to argillaceous sediments and interbedded in sedimentary units made up of black shales, clean sandstones and claystones
2	Calcsilicate -skarn	Gneiss (amphibolite)	Si (25-55), Mg+Ca (10-50), Na/K (3.4) narrow spread, Zr, Ti (max)	Stellate to circular: max: Ca, Mn, P, Ti min: K, Na Stellate to lens-shaped: max: As, Bi, Zr, Zn, Mo, Nb, Ni min: Rb, Ba, Pb	Metamorphic-metasomatic 400 - 750°C	Calcsilicate restite with incipient mobilization in paragneisses in the footwall rocks of pegmatite stocks as a consequence of Ca metasomatism (restite of differentiation of the pegmatite stocks left behind after removal of the mobilizate)
3	Ca-Mg contact fels-pegmatite	Gneiss	Si (60-75), Mg+Ca (<10), Na/K (0.4) narrow spread, Zr, Ti (min)	Circular : max: Ca, Mn, P, K Lens-shaped to circular: max: As, Ba, Pb, Rb	(3a) for temperature of 3a see lithotype 2 (3b) formed at higher pressure (Mn garnet) than the stock-like pegmatites (Mn-apatite). The distal mobilizates developed between 410 – 500°C	(3a) Ca-enriched calcsilicate reaction zones in paragneisses with proximal mobilizates in the footwall host rocks of pegmatite stocks (3b) Distal mobilizates with Fe-Mn calcsilicate reaction zones in the footwall host rocks of pegmatite stocks
4	Calcsilicate-amphibolite	Amphibolite	Si (40-65), Mg+Ca (5-30) Na/K (0.3) narrow spread, Zr, Ti (max)	Circular: max: P, Ti, K, Mg, Ca Lens-shaped to stellate: max: Mo, As, Zr, Ni, Zn, U min: Nb, Rb, Pb	570°C (diopside) 100 to 300°C (prehnite-pumpellyite) 230 to 260°C (laumontite)	Calcsilicate reaction zone in metabasic igneous rocks with proximal mobilizates (barren pegmatoids) in the nappe complexes of the basement. Related to the shear processes along the thrust plane
5	Ca calcsilicate-aplite exocontact	Gneiss	Si (55-75), Mg+Ca (<15), Na/K (0.5), narrow spread, Zr, Ti (max)	Circular: max: Ca, Mn, P min: U	Eh -0.5 to 0.75, pH 6 to 8 430 to 570°C	Distal mobilizates with calcsilicate reaction zone in paragneisses under oxidizing conditions in the hanging wall zone of pegmatite stocks (2nd restite of differentiation of the pegmatite stocks)
6	Ca-Fe calcsilicate-aplite exocontact	Gneiss	Si (55-80), Mg+Ca (<10), Na/K (0.4) narrow spread, Zr, Ti (max)	Circular: max: Ca	Eh -0.75 to 0.5, pH 2 to 7 430 to 570°C	Distal mobilizates with calcsilicate reaction zone in paragneisses under reducing conditions in the hanging wall zone of pegmatite stocks (2nd restite of differentiation of the pegmatite stocks)
7	Quartz fels – quartzite (aploid/ pegmatoid/ granitoid)	Gneiss	Si (70-90) narrow spread, Na/K (1.0) Zr, Ti (max)	Circular: max: Ca, Mn, P max: Zr	Mobilizate 600 to 680°C	Distal siliceous mobilizate squeezed into paragneisses in places undergoing fractionation (see intimate association with pegmatoids and aploids). Part of the first squeezing off of a melt by metamorphic differentiation.
8	Graphite fels – graphite quartzite – meta-phosphorite	Mica schist	Si (70-90) wide spread, Na/K (0.3) Zr (min), Ti (max)	Circular: max: P, Ca, Mg, Ti, K Mo, As, U, Rb	Eh ≤ 0 (anaerobic >> dysaerobic), ≈ 550°C	Metapelites grading into metabiolites, argillaceous sediments and cherts in environments of deposition different as to their redox regime

7.2.4. *The metasomatic calcsilicate amphibolites of lithotypes 4*

Klemd et al. (1994) investigated calcsilicates interlayered with metabasic rocks in the Münchberg Gneiss Complex, another klippe besides the Zone of Erbendorf-Vohenstrauß in the Oberpfalz both of which are relicts of a former coherent allochthonous nappe complex (Fig. 1). The authors estimated a temperature of 630 °C. The calcsilicate-amphibolites of lithotype 4 formed at a lower temperature of as much as 570 °C similar to the other diopside-bearing calcsilicates in the neighborhood (Fig. 15b). The lower temperature limit during which calcsilicate rocks underwent alteration is set by laumontite which develops between 230 and 260 °C at 3 kbar. The T interval of prehnite and pumpellyite is likely to be between 100 °C and 300 °C (Bucher and Grapes, 2011) (Fig. 15b).

7.3. *The evolution of lithotypes*

To put these calcsilicate and siliceous rocks into chronological order cooling ages of biotite, muscovite and U/Pb data of columbite as well as whole rock Rb/Sr data are applied (Table 1 and 5). The term metasomatism has been used following the definition put forward by Zharikov et al. (2006): Metasomatism is a metamorphic process by which the chemical composition of a rock or rock portion is altered in a pervasive manner and which involves the introduction and/or removal of chemical components as a result of the interaction of the rock with aqueous fluids (solutions). Metasomatic rocks, in general, have a granofelsic or granoblastic structure as observed in the samples under study. Lithotype 2 and 3 in the footwall rocks of pegmatite stocks well fulfill the requirements drawn up in this definition (Fig. 10a and b).

7.3.1. *Lithotypes of the pre-mobilization stage*

The metasedimentary lithotypes 1 and 8 used for comparison with the lithotypes of the restite-mobilizate couple and as reference types for meta-carbonates and meta-silicas in the study area are of Neoproterozoic to early Paleozoic age based on lithostratigraphic correlation (Voll, 1960, Forster, 1961, 1965, Bauberger, 1993). It is the period of sedimentation of the calcareous rocks (lithotype 1), the carbonaceous cherts, black shales and phosphorites (lithotype 8) and the greywackes and sandstones converted into paragneisses, some of which are host to the restites and mobilizates discussed previously.

Table 5
The “minero-stratigraphy” of lithotypes in the framework of metamorphism and pegmatitization.

Geological events	Age	Litho-type	Lithology	Source age data	Metasomatic processes	Temperature of Lithotype	Marker mineral
Environment of deposition	Neoproterozoic to early Paleozoic	1+8	Calcareous sediments (LT 1), greywackes, chert (Lt 8), black (LT 8)shales, phosphorites (LT 8)	Voll (1960), Forster (1961, 1965), Bauberger (1993)			
Nappe emplacement + thrusting	377 - 372.5 Ma	4	Amphibolites, calcsilicate amphibolites, pegmatoids, aploids	Kreuzer et al. (1993)	Ca metasomatism	570 to 100 °C	Diopside to laumontite
HP to LP regional metamorphism	372 to 319 Ma		Gneisses, amphibolites	Wemmer and Ahrendt (1993)			
Intrusion of Older Granites	326±2 - 321±8 Ma		Granite to granodiorite	Köhler et al. 1974, 2008			Diopside
Older Pegmatites	317±3 - 315±3 Ma		Barren Fsp-Qtz pegmatites, pegmatoids, aploids	Glodny et al. (1995)	Si metasomatism	680 to 600°C	no
Intrusion of Younger Granites	311.9±2.7 - 304±11 Ma		Granite	Köhler et al. 1974, 2008			no
Younger Pegmatites	303.8±1.9 - 299.6±1.9 Ma	2, 3, 5, 6	Rare element pegmatites Fsp-Qtz + P-Li-Nb/Ta-Be-Zn-As-Sc + Sn-W + overprinting of older pegmatitic and aplitic rocks	Dill et al. (2008b, 2009)	Ca metasomatism	750 to 400°C	wollastonite
Subcrustal magmatic dykes	306±4 – 295.1±3 Ma		Lamprophyres, dolerites	Kreuzer et al. (1993)			no

7.3.2. Lithotypes of the mobilization in the allochthonous units

Lithotype 4 is widespread near the thrust plane of the nappe complexes of the Münchberg Gneiss Complex and the Zone of Erbendorf-Vohenstrauß, a dynamometamorphic event operative between 377 and 372.5 Ma and a maximum temperature of 570 °C (Figs. 1 and 3) Tables 4 and 5) (Kreuzer et al. 1993).

Basalts ⇒ Amphibolites (regional metamorphism)

Amphibolites ⇒ barren Na-K pegmatoids/aploids + Calcsilicates (Ca metasomatism – retrograde metamorphism)

These Ca metasomatic processes are confined to allochthonous units only. They are intracrustal with no introduction of rare metals from an outside source. Shortly afterwards, between 363 and 372 Ma the region was subject to a MP/HP regional metamorphism succeeded by a much younger LP metamorphism down to 319 Ma (Wemmer and Ahrendt, 1993) (Table 4, Fig. 1). The waning phases of this LP event overlaps with the intrusion of the “Older Granites”, the most proximal representative of which is the Leuchtenberg Granite which as being radiometrically dated yielded an age in the range 326 ± 2–321 ± 8 Ma and whose temporal impact on the adjacent crystalline basement provoked diopside as marker mineral to evolve but was not able bring wollastonite into being as shown in Fig. 15b (Fig. 1). In the granite quarry, called “Hegner-Bruch”, near Leuchtenberg, pumpellyite was found on a macroscopic scale intergrown with topaz, beryl, fluorite, cassiterite, scheelite, zinnwaldite, and phlogopite (Strunz and Mücke, 1975). Its intrusion crossed from the allochthonous unit into the autochthonous units and shows a NNW-SSW trend (Köhler et al., 1974, 2008). The “Younger Granites”, represented by the Flossenbürg Granite gave whole rock ages in the range 311.9 ± 2.7–304 ± 11 Ma. Muscovite cooling ages of the barren pegmatite at Brünst yielded an age of 316 ± 3 and for Hagendorf-South 317 ± 3. These pegmatites being slightly older than the Flossenbürg Granite and even closer to its contact did not show any T marker minerals similar to the Leuchtenberg Granite.

7.3.3. Lithotypes of the mobilization in the autochthonous units - metamorphic differentiation sensu lato

In accordance with the mapping of Uebel (1975) and the authoŕs own observation who several times paid a visit to the Hagendorf-South pegmatite in the late 1970s and in the early 1980s during an exploration campaign on U, the Older Pegmatite can be correlated with the metamorphic differentiation *sensu lato* and silica mobilization giving rise to lithotype 7 (Dill, 2015a,b) (Fig. 15a). The metamorphic differentiation may be described schematically as follows:

Greywackes ⇒ Paragneiss (regional metamorphism HP-LP)

The biotite-sillimanite-cordierite gneisses show litho-chemically the best fit with greywackes they are only slightly depleted in Ca relative to the reference greywacke (Fig. 10d).

Paragneiss (= metagreywacke) ⇒ mobilizate/barren Si enriched Na > K pegmatoids-pegmatites + restites/Ca, Mn, P, Zr (metamorphic differentiation *sensu lato* and silica mobilization).

It is a tripartite evolution with all steps structurally related to metamorphism. The mobilization started off from regionally meta-sedimentary rocks. The felsic mobilizates are traced back to diaphtoritic processes (Fig. 1 – No 3 diaphtorite I). More than 90% of pegmatitic and aplitic rocks end up like this, as a barren feldspar-quartz-muscovite pegmatoid attractive only as deposit of industrial minerals (Dill, 2015a). But not so in the study area, where a structural boundary exists between diaphtorite I and muscovite-biotite-sillimanite-cordierite gneiss (Fig. 1 – No 3 and No 1). Dynamometamorphism along this lithological boundary is coupled with a local Si metamorphism which paved the way for the pegmatite stocks of Brünst, Pleystein, Hagendorf-North and Hagendorf-South to form around 317 ± 3–315 ± 3 Ma which coincides structurally with the Older Granite (Figs. 2 and 15a).

Considering the literature on metamorphic petrology and structural geology, metamorphic differentiation as it is on display in Fig. 13c or put forward by O’Harra (1961) and Bowes et al. (1964), or used by Bramwell (1985) is not in the forefront of current investigations (Fletcher, 2000). These papers try to explain element migration conducive to layers and bands in gneissic metamorphic rocks. This strict use of metamorphic differentiation does not appear in the study area either (Fig. 1). The term is used for an intimate intergrowth and a lit-par-lit arrangement of mica-feldspar-quartz pegmatoids and -aploids with quartz fels which according to the CMS classification scheme proposed by Dill (2015a,b) have to be denominated as (mica-feldspar) quartz pegmatoids (Figs. 1, 4 and 10c, d). Metamorphic differentiation *sensu lato* is operative at a dimension of hundreds of meter to kilometers at temperatures between 600 and 680 °C rather than metamorphic differentiation *sensu stricto* which is only operative on the centimeter or decimeter scale (Figs. 2 and 13c).

7.3.4. Lithotypes of the mobilization in the autochthonous units – Ca metasomatism

The metasomatic process discussed in Section 7.3.3 is followed directly by Ca metasomatism at a temperature between 750 and 400 °C with the most striking marker mineral wollastonite that cannot be produced by any of the granites around or the regional metamorphism. The strongest Ca metasomatism is recorded from lithotype 2 and the least one from lithotype 6 (Fig. 4). All of them have derived from paragneisses (Fig. 10). They are correlated with the formation of Nb-Ta minerals (Coltan) between 303.8 ± 1.9 and 299.6 ± 1.9 Ma and the presence of lamprophyric dykes found all across among the pegmatitic rocks which formed in the time span 306 ± 4–295.1 ± 3 Ma (Kreuzer et al., 1993; Dill et al., 2008b, 2009). The link to the afore-mentioned Si metasomatites has been recorded by Takagi et al. (2007). Small bodies composed mostly of intermediate plagioclase and quartz in a Late Cretaceous granitic batholith indicate that the rocks were formed by calcium metasomatism along fractures and shear zones.

Kent et al. (2000) who investigated metasomatic alteration associated with regional metamorphism in the Willyama Supergroup recorded a loss of Na, Mg, Rb, and Fe along with an increase in Ca and Mn. Stowell et al. (1996) recorded an episodic flow of metamorphic fluids and Ca metasomatism in calcic pelites of the contact aureole of a dioritic complex in Alaska, USA. With some exceptions, the mole fraction of spessartine decreases and almandine fraction increases toward the rim of garnet s.s.s., a situation also observed in the Trutzhofmühle Aploid whose rim has to be attributed to the lithotype 3 (Dill et al., 2008b). The process is frequently associated with the enrichment of tungsten, which is conducive to scheelite mineralization (Shabeer et al., 2003) as encountered in lithotype 2. The question where the calcium came from can only be answered by providing geological circumstantial evidence. There is a predecessor existing in the metabasic rocks of lithotype 4 and in metaultrabasic rocks of the nappe complex (Table 5) (Klemd et al., 1994). These investigations were extended to subduction complex of the Tianshan mountains, western China, where massive blue schist is cross-cut by an eclogite-facies major fluid conduit (Bierlein et al., 2009). The blue schist-eclogite facies differs from the geodynamic setting observed in the immediate surroundings of the Ca metasomatites but it directs our thoughts to subcrustal basic to ultrabasic sources activated along shear or thrust planes (Figs. 1 and 2). These chemical and structural elements are present in the area and a mantle bulge is indicated by deep seismic measurements (Dill, 2018). A transformation of high Nb/Ta rutile into low Nb/Ta titanite which is associated with preferred mobilization of Nb over Ta is recorded by Bierlein et al. (2009). These finds lead from the "barren pegmatite" into the Nb-bearing-rare element pegmatites (Younger Pegmatite *sensu* Uebel) where Nb-enriched columbite is a common ore mineral and an appropriate geological clock (Table 5, Fig. 15a). The mineralized structure zones no longer are arranged in NNE-SSW direction but experience a clock-wise rotation towards NW-SE (Figs. 1, 2 and 15a).

7.4. Synopsis and a critical outlook to "quo vadis" pegmatology

7.4.1. Restite and mobilization – An old genetic model in a new jacket

The evolution of pegmatitic rocks is a complex process in time and space, as exemplified by the evolution of many pegmatitic rocks worldwide in general and the Hagendorf-Pleystein Pegmatite Province at the western edge of the Bohemian Massif in particular. Its origin is linked with the geodynamic development during the waning stages of the Variscan (Hercynian) Orogeny which affected parts of Europe and northern America where it gave rise to pegmatitic rocks from the Devonian(419 Ma) through the Permian (252 Ma) (Dill, 2015a,b). Pegmatization is the consequence of the interplay of crustal and subcrustal physical and chemical processes which as far as the Variscides are concerned took place in an ensialic geodynamic setting. One facet of this evolution marking the initial stages of mobilization is treated in the current paper.

Coupling restites and mobilizates or looking for the source and host rocks of a deposit is not a new concept for the region under study but has already been demonstrated for another fuel commodity uranium whose deposits are lined up along the western and northern edge of the Bohemian Massif (Dill, 1986a; Dill et al., 2008a). Early Paleozoic carbonaceous sediments named the "Graptolite Shale Facies" extend from Northern Europe to the Arabian peninsula and on account of their stratabound U enrichment, in places also accompanied by P, are called "hot shales" (Dill, 1985b, 1986b; Lüning et al., 2005). They are the source rock and restite, where the U was mobilized from and found in the so-called "hot granites" of Late Paleozoic age. They were nicknamed "hot" due to the presence of accessory minerals abundant in U and featuring an intermediate repository for the detritus and ore-forming fluids of numerous platform sediments in its aftermaths (Dill, 1994). Uranium enrichment to ore grade and the emplacement of U deposits is not the result of a simple fractionation of the granites but the interplay of plutonic mobilization, sodium metasomatism, and propylitic wall rock alteration associated with a strong desilicification of the granites resultant in the formation of "episyenites" in this region (Dill, 1983). The abnormally high U values of around 14 ppm U determined in the Late Variscan Younger Granites played a paramount role as the source for supergene U mineralizations (Richter and Stettner, 1979). It was not until the Neogene (Mio-Pliocene) that the granites played a full part during the formation of "*per descensum*" U deposits and cast into the role of a restite, at least in their topmost zone undergoing pervasive chemical weathering under tropical to subtropical climates (Dill et al., 2010). During project "Concentration of Uranium and the Genesis of Uranium deposits" in 1979–1985 which the author was involved in, one could demonstrate that the granite is not the "Father of all things" but it is a "Failed arm" of fractionation particularly for "*per ascensum*" uranium accumulation. Uranium concentration achieving ore grade is a dual-source process highlighted by a "polymetallic" crustal-related mineralization and a "monotonous", subcrustal-related uranium mineral association both of which were distinguished from each other by simple mapping in the field, at outcrop and in underground galleries subsequently mineralogically tested in the laboratory by marker elements such as Se (crustal) and Ti (subcrustal) (Dill, 1985c). This multiple-phase process of hypogene uranium concentration and remobilization reached its climax stage during the Late Carboniferous-Permian, a period of time which marks a turning of the tides in geodynamic terms from a mobile crustal section in what is called today Central Europe into the stable Mesoeurope which is a technical term in geology coined by the late German Professor H. Stille to describe the physical-chemical results of the Late Paleozoic Variscan (Hercynian) orogeny within the European crust. The stepwise presentation of the U story for central Europe has also recently been addressed in the review by Romer and Cuney (2018). The cited processes of U accumulation in this Mid-European crustal section chronologically coincides with the emplacement of pegmatitic and aplitic rocks. Both restite-mobilizate couples albeit different with regard to their mineralogical and petrological outward appearance share the same geodynamic setting, and thus they are two sides of the same coin, a physical-chemical process during the waning stages of the Variscan Orogeny characterized by high heat flow and pervasive structural disturbances.

7.4.2. The granite-only approach in pegmatology a "failed arm"

The above excursion into the history of research of uranium in Central Europe is to show the gradual change of the mindset in economic geology and may also be an answer to a potential question being posed when perusing the current text on pegmatites: "Why didńt you base your studies on the results and ideas of the "Černý & London School" (Černý, 1991; London, 2008, 2018). The credo has been summarized by London (2018) as follows: "………*Pegmatites occur as segregations near the roofward contact of their source pluton, as dike swarms emanating from their plutons into the surrounding igneous and metamorphic rocks, and as planar to lenticular intrusive bodies whose sources are not* *exposed"…. The ore-forming processes within granitic pegmatites are entirely igneous as a result of extended fractional crystallization of large granitic plutons, and in response to crystallization at a highly supersaturated state of the melt in pegmatite-forming bodies………*

The outcome of their work is that there are no alternatives and fractionation of granites is a prerequisite for pegmatites leading to two principal categories of pegmatites LCT- and NYF-type and to a plethora of classification schemes of pegmatitic rocks almost as numerous as pegmatites formed on the globe (Dill, 2015a,b, 2016). *Panta Rei* the saying of Heraclitus means "everything flows"; it is not only a concept in the philosophy of a Greek philosopher but should also be the platform of natural sciences and help us to dive away from dogmas and doctrines. There is only one alternative to study the origin of pegmatites in accordance with the geology through time, by looking at them from different angles, or in other words, taking a holistic approach and covering as many disciplines in earth sciences as possible. As an example for this holistic approach which is becoming more and more popular with other sciences such as medicine the following sequence of papers of mine on pegmatitic and aplitic rocks is presented in context with their focal disciplines targeted upon:

(1) Applied and genetic economic geology and mineral processing of pegmatitic and aplitic rocks on a global scale (Dill, 2007, 2010, 2015a, 2018a; Dill and Weber, 2013; Dill et al., 2006a, 2008a)
(2) Regional geology, geochemical surveys, geodynamics, field geology, mineralogy, geochronology and deep-geophysics (gravimetric, geoelectrical, magnetic and seismic measurements) (Dill, 2006c, 2007b, 2015b, Dill et al., 2010b, 2011a, 2013b)
(3) A descriptive classification scheme of mobilizates and their associated rocks in terms of structural geology, whole-rock geochemistry and mineralogy on a global scale (Dill, 2015a,b, 2016). The CMS classification scheme of pegmatitic rocks is an acronym of **C**hemical composition-**M**ineral assemblage-**S**tructural geology
(4) Sedimentary petrography and climatical-related geomorphology on a global scale to understand the pegmatites as they were brought into a shallow zone under near-ambient conditions, at outcrop for exploration targeting (Dill, 2017; Dill et al., 2007a, 2008c, 2011b)
(5) Structural geology and whole-rock chemistry of felsic mobilizates in a field-based study coupled with an extensive litho-chemical sampling campaign (Dill, 2018a,b)

Although being a field-oriented geoscientist I welcome experimental and laboratory results if they are helpful to reveal the physical-chemical regime of pegmatitization.

The present study is not a repetition of the processes involved in pegmatitization and the reader is thus referred to the cited literature above but the logical expansion of this "catena" of investigations into the "kitchen of mobilization", dealing with mobilizates and their mirror images, the restites left behind after mobilization. The outcome of these studies referred to above and in the current one is:

- The pegmatitic rocks are separate entities and in the majority of cases the "brother" "or" "sister" of the granites and only in some cases the "son" or "daughter". Pegmatites have to be viewed and set vis-à-vis other ore types such as greisens, episyenites, skarns etc. and discussed as a function of depth and deformation in a crustal zone of varying heat flow together with other commodities adjacent to them
- Their origin is controlled by a series of physical and chemical hypogene and supergene processes extending over a longer period of time. They are operative from the source rock via the original deposit up to the zone of hypogene and supergene alteration
- The principal binary classification scheme into LCT and NYF pegmatites is mostly used as a placeholder in papers on pegmatites and only masks the crustal and subcrustal/mantle impact on the pegmatite deposits. They are not characteristic of one deposit but may be present side-by-side or overlap each other in the same pegmatite fields and/or provinces
- The deadlock in this mineralogy-only approach of pegmatology and the conspicuous confusion during the classification observed in this group of lithology is self-explanatory in view of the lack of large-scale field work and the reluctance to integrate all geoscientific disciplines as possible (*Omnes viae Romam ducunt*).
- You cannot simulate the growth of mega-crystals in the field by experimental work using a test-tube in the laboratory only. Experimental work is a "blood-test" of geology but it is not the "therapy". Physical-chemical data provided by experimental work in the laboratory are essential for field work, but you should not try and postulate a new orogeny with only one hand specimen.
- There are more than 90% of barren felsic mobilizates in crystalline rocks worldwide the majority of which with no granites close by and thus missing particular attention of geoscientists. Among the remaining 10% of rare-element pegmatites the genetic relation to granites in time and space is still untested in many cases. The conduits of the mineralizing fluids are not found in practice. In contrast to their presence in the crust, the number of papers dealing with rare-element pegmatites is enormous as they are a real treasure box for all those in search of new minerals.

It is not only the Paleozoic Variscan orogen where the granite-only model is difficult to apply to pegmatites but also two examples of paramount importance from the Precambrian are at odds with this granitic model in pegmatitization.

The giant Li pegmatite at Greenbushes, Australia, is hosted by crystalline rocks pertaining to the metabasic and metaultrabasic clan in a medium- to high temperature and medium pressure regime similar to what we are faced with in the current area under study. Partington (1990) and Partington et al. (1995) listed three major events to have controlled the concentration of the Li–Sn–Ta ore. At 2527 Ma the initial crystallization of the pegmatitic rocks and the metasomatism of the country rocks took place-see this paper for resemblance. Around 2430 Ma synkinematic and synmetamorphic hydrothermal alteration produced a second event succeeded by subsequent deformation and metamorphism at ca. 1100 Ma-it resembles the dynamometamorphic processes in Fig. 15a. The Li pegmatite at Greenbushes is bound to a shear zone not very much different from the shear processes recorded in this paper. Any attempts to find a parental granitoids failed, because the most proximal one dated to be 90 m.y older than the pegmatite. Even if this pegmatite setting is much older than the one under consideration, there are many similarities between the two.

Müller et al. (2017) published a paper for the Scandinavian pegmatite province in Northern Europe entitled "*The Sveconorwegian Pegmatite Province – Thousands of pegmatites without parental granites*". The pegmatites formed in the interval between 1094 Ma and 901 Ma in a compressional or extensional orogenic settings unrelated to pluton-scale magmatism similar to the younger Variscan counterpart in central Europe. The authors concluded: "in light of this, the genetic criteria of the pegmatite family classification scheme [NYF versus Lithium-Cesium-Tantalum (LCT)] will have to be re-evaluated".

It needs no further comments on my part. No wonder, in the list of references of London (2018) you will not find these two important papers and many more addressing similar issues. Such studies coming to a different conclusion obviously do not fit into the mainstream philosophy of pegmatology. Although it is not anything out of the ordinary in geosciences to ignore other ideas, studies with a limited view may provide a totally unrealistic picture of geosciences and strike at the roots of sciences in general. Handling pegmatology in a way like that will lead to a "failed arm" of this part of geosciences.

8. Conclusions – Formation of restite and mobilizate lithotypes

During the waning stages of the Variscan Orogeny (Late Paleozoic) a series of felsic mobilizates (pegmatitic and aplitic rocks) evolved along the western edge of the Bohemian Massif associated in space and time with five lithotypes enriched in calcsilicate minerals and one siliceous lithotype. They are different with regard to the degree of mobilization leading to barren and rare element Variscan-type pegmatites, the most relevant of which are concentrated in the Hagendorf-Pleystein-Pegmatite Province and to the formation of residues (Figs. 2, 4 and 15) (Dill, 2018a,b).

(1) The mobilizates and the remaining restites evolved from paragneisses (meta-greywackes) undergoing high-grade regional metamorphism
(2) Mobilization during the waning stages of the Variscan Orogeny provoked the first barren K-Na feldspar –quartz pegmatoids/aploids to form which became self-intrusive and trapped in hinge zones of anticlines ("Older Pegmatite")
(3) Dynamometamorphic processes which create structures tapping deeper parts of the crust and even subcrustal parts sparked processes of metasomatism leading in case of Ca to the basic and ultrabasic metasomatites and on the other hand to meta-silica rocks reflecting high Si mobility
(4) The kinematic processes are framed by thrust planes subparallel to the metamorphic architectural planar elements and lithological boundaries as well as lineamentary shear zones
(5) The temperature regime of the thrustal movements is characterized by the LT 4 regime. It lies between 570° and 100 °C (the latter figure is confined to shallow shear zones which may be traced down to deeper zones of mobilization bringing about K-Na pegmatoids/aploids). The temperature of formation of the quartz lodes lies in the range 650°-620 °C
(6) The temperature regime of the mobilizing events in the footwall of the pegmatite stocks between 670 (7 5 0) °C and 430 °C is represented by the lithotypes 7, 3, and 2. The stockwork-like LT 5 and 6 in the hanging wall rocks formed between 570 °C and 430 °C
(7) The pressure regime lies between 3 and 4 kbar at the deepest part of the thrust plane and 1 kbar at the shallower parts
(8) The rare elements were delivered from a lower crustal to subcrustal source and gave rise to the "Younger pegmatite"
(9) Rare element differentiation is a function of the depth of emplacement and the proximity of their ore body to the source. True rare-element pegmatites formed at great depth while minor granitic pegmatites and granite-hosted rare-metal granites hosting the so-called Sn-W greisen were emplaced at shallow depth. The system becomes full circle at shallow depth overlapping with processes discussed for uranium in Section 7.4.1.

A model trying to explain the origin of pegmatites cannot be all-embracing because each model has specific timebound parameters, exclusive to a period of time typical of the evolution of the Earth similar to a bio-stratigraphic unit, and general features which are attributable to other deposits significantly different in age. The two examples above from Scandinavia and Australia hallmark these different specific and general elements. That is why I call the current pegmatite model as "Variscan-Type" which covers a certain period of time, called the Phanerozoic period and reaches its climax during the Late Paleozoic. It keeps the door open for different genetic models elaborated for different stages of the Earth́s evolution which on one hand passes through some kind of an ontogenesis (1st order level) and on the other hand a process of cellular regeneration or recycling (2nd order level).

What should be universal in pegmatology and should cater for an all-purpose application is the classification scheme of pegmatitic rocks (Dill, 2015a,b, 2016). This is a common place truth applicable to other kinds of lithogenesis controlled by physical-chemical processes in geosciences. The CMS classification is descriptive so as to cover all genetic types, it is open for additional remarks and can also be run in a short version apt to genetic and applied pegmatology. The predecessor of the special "CMS classification scheme of pegmatites" is the general "Chessboard classification scheme of mineral deposits" (Dill, 2010).

In contrast to the handling in the current study done only for the sake of illustration, the application in practice ought to follow the reverse order:

(1) description and classification based on the outward appearance and measured data,
(2) genetic interpretation.

In pegmatology we are often faced with a mixture of genetic and descriptive elements accountable for the confusion in the description and classification of pegmatites and we are confronted eventually with an attempt to take refuge to a one-way (granitic) model or to seek the "deus ex machina" at depth or claim it to have fallen victim to erosion.

The amendment to the mainstream geoscientific handling of pegmatitic rocks demonstrates that there are several ways in the evolution of pegmatitic rocks. From whatever angle you look at them you come to the same conclusion, that only a holistic approach can give us a reality check and direct our thoughts to the right way we have to go in a certain stage of evolution. It prevents pegmatology from getting a one-way street (granites-only) that eventually ends up in a dead-end street. Experimental work is important as far as the provision of physical-chemical datasets is concerned but there is no geology without field geology. The platform to discuss all this is the map showing the essentials of the pegmatites involved, because pegmatite deposits are first and foremost three-dimensional geological bodies abundant in certain commodities and not fictitious systems. We cannot cast aside nature. There are more than 1000 mobilizates, granitic in composition but lacking all the hallmarks of pegmatites claimed by London (2018), with no pluton nearby and only a minority of them hosting rare elements (Dill, 2010, 2015a). My geoscientific credo: "There is no (economic) geology without field geology".

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References

Ackerman, L., Zachariáš, J., Pudilová, M., 2007. P-T and fluid evolution of barren and lithium pegmatites from Vlastějovice, Bohemian Massif, Czech Republic. Int. J. Earth Sci. 96, 623–638.
Arzani, N., 2004. Diagenetic evolution of mudstones: black shales to laminated limestones, an example from the lower jurassic of SW Britain. J. Sci. 15, 257–267.
Astakhov, A.S., Polyakov, D.M., 2000. Distribution of heavy metals and multielement geochemical associations in grain-size fractions of the bottom sediments of the Sea of Japan". Geochem. Int. 38, 895–905.
Astakhov, A.S., Rujian, Wang, Ivanov, M.V., 2009. Geochemistry of Sedimentation in the Chukchi Sea and the Adjacent Sector of the Arctic Basin: Chemical Typification, Role of Biosedimentation, and the Influence of Endogenous Activity,". Geology of the Earth's Polar Areas. Proceedings of 42th Tectonic Conference, Moscow, Russia, pp. 28–32 (in Russian).
Bates, R.L., Jackson, J.A., 1987. Glossary of Geology, 3rd edition. American Geological Institute, Alexandria, pp. 788.
Bauberger, W., 1993. Erläuterung zur Geologischen Karte von Bayern 1:25000 Blatt Tännesberg. Geological Survey of Bavaria, München, pp. 104.
Bavarian Environment Agency, 2009. Geological map of the Upper Palatinate Forest 1:150,000. Munich.
Beran, A., Göd, R., Götzinger, M., Zemann, J., 1985. A scheelite mineralization in calcsilicate rocks of the Moldanubicum (Bohemian Massif) in Austria. Miner. Deposita 20, 16–22.
Bierlein, F.P., Groves, D.I., Cawood, P.A., 2009. Metallogeny of accretionary orogens—the connection between lithospheric processes and metal endowment. Ore Geol. Rev. 36, 282–292.

Best, M.G., 1982. Igneous and Metamorphic Petrology. W. H. Freeman & Co Ltd., pp. 630.

Bohlen, S.R., Montana, A., Kerrick, D.M., 1991. Precise determinations of the equilibria kyanite ¼ sillimanite and kyanite ¼ andalusite and a revised triple point for Al_2SiO_5 polymorphs. Am. Mineral. 76, 677–680.

Bosbach, D., Stosch, H.-G., Seidel, E., 1991. Magmatic and metamorphic evolution of metagabbros in the Münchberg Massif, N.E Bavaria. Contr. Mineral. Petrol. 107, 112–123.

Bowes, D.R., Wright, A.E., Park, R.G., 1964. Layered intrusive rocks in the Lewisian of the North-West Highlands of Scotland. Quarter. J. Geol. Soc. London 120, 153–184.

Bramwell, M.G., 1985. Metamorphic differentiation; a mechanism indicated by zoned kyanite crystals in some rocks from the Lukmanier region, Switzerland. Mineral. Mag. 49, 59–64.

Bucher, K., Grapes, R., 2011. Petrogenesis of Metamorphic Rocks. Springer, Heidelberg, pp. 428.

Černý, P., 1991. Rare-element granitic pegmatites: Part I: Anatomy and internal evolution of pegmatite deposits. Part II: Regional and global environments and petrogenesis. Geosci. Canada 18, 49–81.

Culshaw N., Gerbi C, Marsh J, Regan P. 2014 Nappe-bounding shear zones initiated on syn-tectonic, pegmatite-filled extensional shear fractures during deep-crustal nappe flow in a large hot orogen. Geophysical Research Abstracts Vol. 16, EGU2014-2311, 2014 EGU General Assembly 2014.

Cummins, W.A., 1962. The Greywacke problem. Geol. J. 3, 51–72.

Dallmeyer, R.D., Franke, W., Weber, K., 1995. Pre-Permian Geology of Central and Eastern Europe. Heidelberg, Springer, Berlin, pp. 604.

Dasgupta, S., Tim Pal, S., 2005. Origin of grandite garnet in calc-silicate granulites: mineral-fluid equilibria and petrogenetic grids. J. Petrol. 46, 1045–1075.

Dill, H.G., 1983. Plutonic mobilization, sodium metasomatism, propylitic, wall rock alteration and element partitioning from Höhensteinweg uranium occurrence (Northeast Bavaria). Uranium 1, 139–166.

Dill, H.G., 1985c. The polymetallic and monotonous uranium parageneses – a contribution to the position of endogenous uranium mineralization at the western edge of the Bohemian Massif. Neues Jahrbuch für Mineralogie, Mh. 1985, 184–192.

Dill, H.G., 1985a. Die Vererzung am Westrand der Böhmischen Masse: Metallogenese in einer ensialischen Orogenzone. Geologisches Jahrbuch D 73, 3–461.

Dill, H.G., 1985b. Granite-related and granite-induced ore mineralization of the western edge of the Bohemian Massif. In: High heat production (HHP) granites, Hydrothermal, circulation and ore genesis. The Inst. of Mining and Metallurgy, pp. 55–70.

Dill, H.G., 1986a. Fault-controlled uranium black ore mineralization from the western edge of the Bohemian Massif (NE Bavaria/F.R. Germany). International Atomic Energy Agency, pp. 275–291.

Dill, H.G., 1986b. Metallogenesis of the Early Paleozoic Graptolite Shales from the Graefenthal Horst (Germany). Econ. Geol. 81, 889–903.

Dill, H.G., 1989. Metallogenetic and geodynamic evolution in the Central European Variscides – a pre- well site study for the German Continental Deep Drilling Programme. Ore Geol. Rev. 4, 279–304.

Dill, H.G., 1994. Facies variation and mineralization in Central Europe from the late Paleozoic through the Cenozoic. Econ. Geol. 89, 268–287.

Dill, H.G., 2007. A review of mineral resources in Malawi: with special reference to aluminium variation in mineral deposits. J. Afr. Earth Sci. 47, 153–173.

Dill, H.G., 2010. The “chessboard” classification scheme of mineral deposits: mineralogy and geology from aluminum to zirconium. Earth-Sci. Rev. 100, 1–420.

Dill, H.G., 2015b. The Hagendorf-Pleystein Province: The center of pegmatites in an ensialic orogen.- Modern Approaches in Solid Earth Sciences. ISBN-978-3-319-18805-8. Springer, Dortrecht, Heidelberg, London, New York, pp. 475.

Dill, H.G., 2015a. Pegmatites and aplites: their genetic and applied ore geology. Ore Geol. Rev. 69, 417–561.

Dill, H.G., 2016. The CMS classification scheme (**C**hemical composition-Mineral assemblage-**S**tructural geology) – linking geology to mineralogy of pegmatitic and aplitic rocks. Neues Jahrbuch für Mineralogie Abhandlungen 193, 231–263.

Dill, H.G., 2017. An overview of the pegmatitic landscape from the pole to the equator – applied geomorphology and ore guides. Ore Geol. Rev. 91, 795–823.

Dill, H.G., 2018a. Geology and chemistry of Variscan-type pegmatite systems (SE Germany) – with special reference to structural and chemical pattern recognition of felsic mobile components in the crust. Ore Geol. Rev. 92, 205–239.

Dill, H.G., 2018b. Gems and placers – a genetic relationship *par excellence*. Minerals 8 (470), 1–43.

Dill, H.G., Weber, B. , 2013. Gemstones and geosciences in space and time. Digital maps to the, Chessboard classification scheme of mineral deposits“. Earth Science Reviews 127, 262-299 plus supplementary material (99 maps showing gemstone deposits by country, geology and geomorphology) related to this article to be found on-line at http://dx.doi.org/10.1016/j.earscirev.2013.07.006.

Dill, H.G., Khishigsuren, S., Majigsuren, Y., Myagmarsuren, S., Bulgamaa, J., Hongor, O., 2006a. A review of the non-metallic industrial minerals of Mongolia: the impact of geological and geographical factors on their formation and use. Int. Geol. Rev. 48, 129–173.

Dill, H.G., Melcher, F., Fuessl, M., Weber, B., 2006b. Accessory minerals in cassiterite: a tool for provenance and environmental analyses of colluvial-fl uvial placer deposits (NE Bavaria, Germany). Sed. Geol. 191, 171–189.

Dill, H.G., Weber, B., Fuessl, M., Melcher, F., 2006c. The origin of the hydrous scandium phosphate kolbeckite from the Hagendorf – Pleystein pegmatite province, Germany. Mineral. Mag. 70, 281–290.

Dill, H.G., Melcher, F., Fuessl, M., Weber, B., 2007a. The origin of rutile-ilmenite aggregates (“nigrine”) in alluvial-fluvial placers of the Hagendorf pegmatite province, NE Bavaria, Germany. Mineral. Petrol. 89, 133–158.

Dill, H.G., Gerdes, A., Weber, B., 2007b. Cu-Fe-U phosphate mineralization of the Hagendorf-Pleystein pegmatite province, Germany: with special reference to Laser-Ablation-Inductive-Coupled-Plasma Mass Spectrometry (LA-ICP-MS) of iron-cored torbernite. Mineral. Mag. 71, 371–387.

Dill, H.G., Klosa, D., 2011. Heavy-mineral-based provenance analysis of Mesozoic continental-marine sediments at the western edge of the Bohemian Massif, SE Germany: with special reference to Fe-Ti minerals and the crystal morphology of heavy minerals. Int. J. Earth Sci. 100, 1497–1513.

Dill, H.G., Techmer, A., Weber, B., Fuessl, M., 2008c. Mineralogical and chemical distribution patterns of placers and ferricretes in Quaternary sediments in SE Germany: the impact of nature and man on the unroofing of pegmatites. J. Geochem. Explor. 96, 1–24.

Dill, H.G., Melcher, F., Gerdes, A., Weber, B., 2008b. The origin and zoning of hypogene and supergene Fe-Mn-Mg-Sc-U-REE-Zn phosphate mineralization from the newly discovered Trutzhofmühle aplite (Hagendorf pegmatite province, Germany). Can. Mineral. 46, 1131–1157.

Dill, H.G., Sachsenhofer, R.F., Grecula, P., Sasvári, T., Palinkaš, L.A., Borojević-Šoštarić, S., Strmić-Palinkaš, S., Prochaska, W., Garuti, G., Zaccarini, F., Arbouille, D., Schulz, H.-M., 2008a. Fossil fuels, ore – and industrial minerals. In: McCann, T. (Ed.), Geology of Central Europe. Geological Society of London, Special Publication, London, pp. 1341–1449.

Dill, H.G., Weber, B., Gerdes, A., Melcher, F., 2009. The Fe-Mn phosphate aplite “Silbergrube” near Waidhaus, Germany: epithermal phosphate mineralization in the Hagendorf-Pleystein pegmatite province. Mineral. Mag. 72, 1143–1168.

Dill, H.G., Gerdes, A., Weber, B., 2010a. Age and mineralogy of supergene uranium minerals – tools to unravel geomorphological and palaeohydrological processes in granitic terrains (Bohemian Massif, SE Germany). Geomorphology 117, 44–65.

Dill, H.G., Hansen, B., Keck, E., Weber, B., 2010b. Cryptomelane a tool to determine the age and the physical-chemical regime of a Plio-Pleistocene weathering zone in a granitic terrain (Hagendorf, SE Germany). Geomorphology 121, 370–377.

Dill, H.G., Weber, B., Botz, R., 2011a. The baryte-bearing beryl-phosphate pegmatite Plössberg – a missing link between pegmatitic and vein-type barium mineralization in NE Bavaria, Germany. Geochemistry 71, 377–387.

Dill, H.G., Kaufhold, S., Dohrmann, R., 2011b. A late-stage hydrothermal phosphate-bearing montmorillonite argillitisation from the tourmaline-bearing pegmatite of Alto dos Quintos Mine, Northeast Brazil. Clay Miner. 46, 473–485.

Dill, H.G., Skoda, R., Weber, B., Berner, Z., Müller, A., Bakker, R.J., 2012. A newly-discovered swarm of shearzone-hosted Bi-As-Fe-Mg-P aplites and pegmatites in the Hagendorf-Pleystein Pegmatite Province, SE Germany: a step closer to the metamorphic root of pegmatites. Can. Mineral. 50, 943–947.

Dill, H.G., Skoda, R., Weber, B., Müller, A., Berner, Z.A., Wemmer, K., Balaban, S.-I., 2013a. Mineralogical and chemical composition of the Hagendorf-North Pegmatite, SE Germany – a monographic study. Neues Jahrbuch für Mineralogie Abhandlungen 190, 281–318.

Dill, H.G., Hansen, B.T., Weber, B., 2013b. U/Pb age and origin of supergene uranophane-beta from the Borborema Pegmatite Mineral Province, Brazil. J. South Am. Earth Sci. 45, 160–165.

Dill, H.G., Balaban, S.-I., Witt, B., Wershofen, H., 2014. Capturing digital data of rock magnetic, gamma-ray and IR spectrometry for in-situ quality control and for the study of the physical-chemical regime of residual kaolin deposits, SE Germany. Ore Geol. Rev. 57, 172–190.

Dott Jr., R.H., 1964. Wacke, graywacke and matrix–what approach to immature sandstone classification? J. Sediment. Petrol. 34, 625–632.

Dubois, M., Lopez, M., Orberger, B., Rodriguez, C., Boussafir, M., Dreux, G., Rodrigues, S., Pambo, F., 2015. The Mn-carbonate rich black shales of the Bangombe Plateau, Francevillian basin, Gabon. Mineral Resources in a Sustainable World, pp. 1–4.

Ertl, A., Mali, H., Schuster, R., Körner, W., Hughes, J.M., Brandstätter, F., Tillmanns, E., 2010. Li-bearing, disordered Mg-rich tourmaline from a pegmatite-marble contact in the Austroalpine basement units (Styria, Austria). Mineral. Petrol. 99, 89–104.

Ertl, A., Schuster, R., Hughes, J.M., Ludwig, T., Meyer, H.-P., Finger, F., Darby, Dyar M., Ruschel, K., Rossman, G.R., Klötzli, U., Brandstätter, F., Lengauer, C.L., Tillmanns, E., 2012. Li-bearing tourmalines in Variscan granitic pegmatites from the Moldanubian nappes, Lower Austria. Eur. J. Mineral. 24, 695–715.

Falster, A., Simmons, W.B., Moore, P.B., 1988. Fillowite, Lithiophilite, Heterosite/Purpurite and Allvaudite-Varulite group minerals from a Pegmatite in Florence County, WI. In: Abstract 15th Rochester Mineralogical Symposium, Rocks and Minerals 63, p. 455.

Feldmann, F., 1996. The structural and metamorphic evolution of the marble and calc-silicate rocks of the Baklykraal quarry near Alldays, Central Zone. Thesis Rand Afrikaans University, Johannesburg, Limpopo Belt South Africa. M. Sc, pp. 132.

Fischer, G., 1964. Ein Beitrag zur stofflichen Verteilungsanalyse. Neues Jahrbuch Mineralogie Monatshefte 9–11, 269–283.

Fischer, G., 1965. Über die modale Zusammensetzung der Eruptiva im ostbayerischen Kristallin. Geologica Bavaria 55, 7–33.

Fletcher, R., 2000. Three examples of metamorphic differentiation. J. Virtual Explorer. 02. https://doi.org/10.3809/jvirtex.2000.00010.

Forster, A., 1961. Erläuterungen zur Geologischen Karte von Bayern 1: 25000 Blatt Eslarn. GLA München 90, pp.

Forster, A., 1965. Erläuterungen zur Geologischen Karte von Bayern 1: 25000 Blatt Vohenstrauss/Frankenreuth. GLA München 174, pp.

Forster, A., Kummer, R., 1974. The pegmatites in the area of Pleystein-Hagendorf/North Eastern Bavaria. Fortschritte Mineralogie 52, 89–99.

Franke, W., Kreuzer, H., Okrusch, M., Schüssler, U., Seidel, E., 1995. Saxothuringian Basin: Exotic metamorphic nappes, stratigraphy, structure and igneous activity. In: Dallmeyer, D., Franke, W., Weber, K. (Eds.), Pre-Permian Geology of Central and Western Europe. Springer, Berlin, pp. 277–294.

Friedman, G.M., Sanders, J.E., Kopaska-Merkel, D.C., 1992. Principles of Sedimentary

Deposits: Stratigraphy and Sedimentology. Macmillan, USA, pp. 717.

Frost, B.R., Frost, C.D., 2013. Essentials of Igneous and Metamorphic Petrology 1st. Edition Cambridge University Press, Cambridge, pp. 314.

Fuchsloch, W.C., Nex, P.A.M., Kinnaird, J.A., 2015. Classification, mineralogical and geochemical variations in pegmatites of the Cape Cross – Uis Pegmatite Belt, Namibia. 7th International Symposium on Granitic Pegmatites, PEG 2015 Książ, Poland, pp. 22–24.

Fuessl, M., Weber, B., 2009. Nördliche Oberpfalz-Weißes Gold und schwarzer Basalt. Goldschneck Verlag, Wiebelsheim, pp. 133.

Fuessl, M., Weber, B., 2011. Fichtelgebirge-Sprudelnde Quellen und Meere aus Stein. Goldschneck Verlag, Wiebelsheim, pp. 123.

Garver, J.I., Royce, P.R., Smick, T.A., 1996. Chromium and nickel in shale of the Taconic foreland: a case study for the provenance of fine-grained sediments with an ultramafic source. J. Sediment Res. 66, 100–106.

Glodny, J., Grauert, B., Krohe, A., 1995. Ordovizische Pegmatite in variszischen HT-Metamorphiten des KTB-Umfeldes: Hinweis auf hohe Stabilität des Rb–Sr-Systems in Muskoviten. Terra Nostra 95, 98.

Goad, B.E., 1990. Granitic pegmatites of the Bancroft area, southeastern Ontario/Ontario Geological Survey. Open File Report 5717, 1–459.

Göd, R., 1989. The spodumene deposit at “Weinebene” Koralpe, Austria. Miner. Deposita 24, 270–278.

Guilbert, J.M., Park Jr., C.F., 1986. The geology of ore deposits. W.H. Freeman and Co., New York, pp. 985.

Habel, A., Habel, M., 1991. Der ehemalige Kalksteinbruch Wimhof, Vilshofen a.d.Donau. Mineralien-Welt 2, 60–63.

Hahn, H.D., 1990. Fazies grobklastischer Gesteine des Unterdevons (Graue Phyllite bis Taunusquarzit) im Taunus (Rheinisches Schiefergebirge). Unpublished Ph.D. Dissertation. University Marburg, Marburg, pp. 173.

Hansen, B.T., Teufel, S., Ahrendt, H., 1989. Geochronology of the Moldanubian-Saxothuringian Transition Zone, Northeast Bavaria-. In: Emmermann, R., Wohlenberg, J. (Eds.), The German Continental Deep Drilling. Program (KTB), pp. 55–66.

Hatch, J.R., Leventhal, J.S., 1992. Relationship between inferred redox potential of the depositional environment and geochemistry of the Upper Pennsylvanian (Missourian) Stark Shale Member of the Dennis Limestone, Wabaunsee County, Kansas, USA. Chem. Geol. 99, 65–85.

Hecht, L., Freiberger, R., Gilg, H.A., Grundmann, G., Kostitsyn, Y.A., 1999. Rare earth element and isotope (C, O, Sr) characteristics of hydrothermal carbonates: genetic implications for dolomite-hosted talc mineralization at Göpfersgrün (Fichtelgebirge, Germany). Chem. Geol. 155, 115–130.

Horstig von, G., Teuscher, E.O., 1979. Die Eisenerze im Alten Gebirge NE-Bayerns. Geologisches Jahrbuch D 31, 7–47.

Hsu, S.C., Lin, F.J., Jeng, W.L., Chung, Y.C., Shaw, L.M., 2003. Hydrothermal signature in the southern okinawa trough detected by the sequential extraction of settling particles”. Mar. Chem. 84, 49–66.

Hubert, J.F., 1962. A zircon-tourmaline-rutile maturity index and the interdependence of the composition of heavy mineral assemblages with the gross composition and texture of sandstones. J. Sediment. Res. 32, 440–450.

Ishihara, S., Orihashi, Y., 2014. Zircon U-Pb age of the Triassic granitoids at Nui Phao, northern Vietnam. Bullet. Geol. Survey Jpn. 65, 17–22.

Jacobson, M., Calderwood, M., Grguric, B., 2007. Pegmatites. of Western Australia.

Keck, E., 1963. Oberpfälzer Granate – Vorkommen und chemische Zusammensetzung. Aufschluss 12, 316–319.

Kent, A.J.R., Ashley, P.M., Fanning, C.M., 2000. Metasomatic alteration associated with regional metamorphism: an example from the Willyama Supergroup, South Australia. Lithos 54, 33–62.

Klemd, R., 2010. The Early Variscan allochthonous domains: the Münchberg Complex, Frankenberg, Wildenfels, and Góry Sowie. In: Linnemann, U., Romer, R.L. (Eds.), Pre-Mesozoic Geology of Saxo-Thuringia– From the Cadomian Active Margin to the Variscan Orogen. Schweizerbart, Stuttgart, pp. 221–232.

Klemd, R., Matthes, S., Schüssler, U., 1994. Reaction textures and fluid behavior in very-high pressure calc-silicate rocks of the Münchberg gneiss complex, Bavaria, Germany. J. Metamorph. Geol. 12, 735–745.

Kneller, B., Buckee, C., 2000. The structure and fluid mechanics of turbidity currents: a review of some recent studies and their geological implications. Sedimentology 47 (Supplement 1), 62–94.

Köhler, H., Müller-Sohnius, D., Cammann, K.C., 1974. Rb/Sr-Altersbestimmungen an Mineral- und Gesamtgesteinsproben des Leuchtenberger und Flossenbürger Granits. NE-Bayern. Neues Jb Mineral Abh. 123, 63–85.

Köhler, H., Propach, G., Troll, G., 2008. Isotopische (Sr, Nd) Charakterisierung und Datierung Varistischer Granitoide der Moldanubischen Kruste Nordbayerns. Geologica Bavarica 110, 170–203.

Konzett, J., Schneider, T., Hauzenberger, C., Krenn, K., Melcher, F., Gerdes, A., 2015. Staurolite-rare metal-bearing pegmatites from the Eastern Alps, Northern Italy: variable rare-metal enrichment during regional metamorphic anatexis? 7th International Symposium on Granitic Pegmatites, PEG 2015 Książ. Poland 38–39.

Kremer, P.D., Lin, S., 2006. Structural geology of the Bernic Lake area, Bird River greenstone belt, southeastern Manitoba (NTS 52L6): implications for rare element pegmatite emplacement. Report of Activities Manitoba Science. Technology Energy and Mines, Manitoba Geological Survey, pp. 206–213.

H. Kreuzer F. Henjes-Kunst E. Seidel U. Schüßler B. Bühn Ar-Ar spectra on minerals from KTB and related medium pressure units. KTB-Report 1993 Hannover 93–2, 133–136.

Kříbek, B., Hladíková, J., Frýda, J., 1997. Scapolite- and anhydrite-bearing rocks from the Moldanubian zone of the Bohemian Massif: metamorphosed exhalites and evaporites. MAEGS–10. Session 4, 62.

Laznicka, P., 2010. Giant Metallic Deposits, 2nd ed. Springer, Berlin, Heidelberg.

Leighton, M.W., Pendexter, C., 1962. Carbonate rock types. In: Ham, W.E. (Ed.), Classification of Carbonate Rocks. Amer. Assoc. Petrol. Geol. Mem., pp. 162–185.

Lentz, D.R., Suzuki, K.A., 2000. Low F Pegmatite-Related Mo Skarn from the Southwestern Grenville Province Ontario, Canada: phase equilibria and petrogenetic implications. Econ. Geol. 95, 1319–1337.

Liebscher, A., Franz, G., Frei, D., Dulski, P., 2007. High-Pressure Melting of Eclogite and the P-T–X History of Tonalitic to Trondhjemitic Zoisite-Pegmatites, Münchberg Massif, Germany. J. Petrol. 48, 1001–1019.

Linnemann, U., Nance, R.D., Kraft, P., Zulauf, G., 2007. The Evolution of the Rheic Ocean: From Avalonian-Cadomian Active Margin to Alleghanian-Variscan collision. The Geological Society of America Special Paper, Boulder, Colorado, pp. 1–630.

Llera, A.R., Fuertes-Fuente, M., Hernández, A.C., 2015. Barren and Sn-Ta (Nb)-Li bearing pegmatites from NW Spain: a mineralogical, petrological and geochemical study. 7th International Symposium on Granitic Pegmatites, PEG 2015, Książ, Poland, pp. 42–43.

London, D., 2018. Ore-forming processes within granitic pegmatites. Ore Geol. Rev. 101, 343–389.

London, D. Pegmatites. Canadian mineralogist, special publication, 10. Mineralogical Association of 2008 Canada, Ottawa 1 347.

Lüning, S., Kolonic, S., Loydell, D.K., Craig, J., 2003. Reconstruction of the original organic richness in weathered Silurian shale outcrops (Murzuq and Kufra basins, southern Libya). GeoArabia 8, 299–307.

Lüning, S., Shahin, Y.M., Loydell, D., Al-Rabi, H.T., Masri, A., Tarawneh, B., Kolonic, S., 2005. Anatomy of a world-class source rock: distribution and depositional model of Silurian organic-rich shales in Jordan and implications for hydrocarbon potential. Am. Assoc. Pet. Geol. Bull. 89, 1397–1427.

Lv, Zheng-Hang, Zhang, Hui, YongTang, Yun-Long Liu, Zhang, Xin, 2018. Petrogenesis of syn-orogenic rare metal pegmatites in the Chinese Altai: evidences from geology, mineralogy, zircon U-Pb age and Hf isotope. Ore Geol. Rev. (on line).

Mali, H., 2004. Die Spodumenpegmatite von Bretstein und Pusterwald (Wölzer Tauern Steiermark, Österreich). Joannea – Mineralogie 2, 5–53.

Malkovský, M., 1979. Tektogenese der Plattformbedeckung des Böhmischen Massivs. Knihovna Ústř Úst Geol Praha 53, 1–176.

Matte, P., 2001. The Variscan collage and orogeny (480 ± 290 Ma) and the tectonic definition of the Armorica microplate: a review. Terra Nova 13, 122–128.

Matthes, S., 1961. Ergebnisse zur Granatsynthese und ihre Beziehungen zur natürlichen Granatbildung innerhalb der Pyralspit-Gruppe. Geochim. Cosmochim. Acta 23, 233–246.

McCann, T., 2008. The Geology of Central Europe - Volume 1 Precambrian and Palaeozoic Volume 2 Mesozoic and Cenozoic. The Geological Society of London, pp. 1500.

McManus, J., Berelson, W.M., Hammond, D.E., Klinkhammer, G.P., 1999. Barium Cycling in the North Pacific: Implication for the Utility of Ba as a Paleoproductivity and Paleoalkalinity Proxy”. Paleoceanography 14, 53–61.

Mehnert, K.R., 1968. Migmatites and the Origin of Granitic Rocks. Elsevier, Amsterdam, pp. 391.

Meiburg, E., Kneller, B., 2010. Turbidity currents and their deposits. Annu. Rev. Fluid Mech. 42, 135–156.

Mingxiang, Mei, Yongsheng, Ma., Hai, Zhang, Xiaoqing, Meng, Yonghong, Chen, 2007. From basin black shales to platform carbonate rocks: a study on sequence stratigraphy for the lower cambrian of the upper-yangtze region in South China. Acta Geol. Sin. 81, 739–755.

Mücke, A., 2018. Der Pegmatit von Hagendorf-Süd: Überblick und Bilanz – Unter besonderer Berücksichtigung der Primärphosphate. Aufschluss 6, 348–369.

Mulder, T., Lecroart, P., Hanquiez, V., Marches, E., Gonthier, E., Guedes, J., Thiébot, E., Jaaidi, B., Kenyon, N., Voisset, M., Perez, C., Sayago, M., Fuchey, Y., Bujan, S., 2006. The western part of the Gulf of Cadiz: contour currents and turbidity currents interactions. Geo-Mar. Lett. 26, 31–41.

Müller, A., Romer, R.L., Pedersen, R.-B., 2017. The Sveconorwegian Pegmatite Province – thousands of pegmatites without parental granites. Can. Mineral. 55, 283–315.

Neiva, A.M.R., Silva, P.B., Ramos, J.M.F., 2011. Geochemistry of granitic aplite-pegmatite veins and sills and their minerals from Cabeço Dos Poupos, Sabugal, Central Portugal. Asociación Geológica Argentina, Serie D, Publicación Especial 14, 141–143.

Nesbitt, H.W., Young, G.M., 1996. Petrogenesis of sediments in the absence of chemical weathering: effects of abrasion and sorting on bulk composition and mineralogy”. Sedimentology 43, 341–358.

Niedermayer, G., Göd, R., 1992. Das Spodumenvorkommen auf der Weinebene und seine Mineralien. Carinthia II 182 (102), 21–35.

Novák, M., Kadlec, T., 2010. Vlast jovice near Zruc nad Sázavou. Contaminated anatectic pegmatites and tourmaline-bearing granite–pegmatite system cutting Fe skarn. In: Novák, M., Cempírek, J. (Eds.), Acta Mineral. Petrogr., Field Guide Series 6, pp. 36–41.

Novák, M., Hyršl, J., 1992. Locality No.3: Vlastějovice near Zruč nad Sázavou, pegmatites with fluorite penetrating skarn. In: Novák, M., Černý, P. (Eds.), International symposium on mineralogy, petrology and geochemistry of granitic pegmatites Lepidolite 200. Czech Republic. Field trip guidebook, Nové Město na Moravě, pp. 33–37.

O’Hara, M.J., 1961. Zoned ultrabasic and basic gneiss masses in the Early Lewisian Complex at Scourie, Sutherland. J. Petrol. 2, 248–276.

Okrusch, M., Matthes, S., Klemd, R., O'Brien, P.J., Schmidt, K., 1991. Eclogites at the northwestern margin of the Bohemian Massif: a review. Eur. J. Min. 3, 707–730.

Parkinson, C.D., 2000. Coesite inclusions and prograde compositional zonation of garnet in whiteschist of the HP-UHPM Kokchetav massif, Kazakhstan: a record of progressive UHP metamorphism. Lithos 52, 215–233.

Partington, G.A., 1990. Environment and structural controls on the intrusion of the giant rare metal Greenbushes Pegmatite, Western Australia. Econ. Geol. 85, 437–456.

Partington, G.A., McNaughton, N.J., Williams, I.S., 1995. A review of the geology, mineralization, and geochronology of the greenbushes pegmatite, Western Australia. Econ. Geol. 90, 616–635.

Paxton, S.T., Aufill, M., Kamann, P., Krstyniak, A., 2016. Spectral gamma-ray response of Oklahoma Shales in outcrop. http://www.ogs.ou.edu/pdf/GSPaxton FinalS.pdf.

Pezzotta, F., Simmons W.B., 2001. Field Course on the Rare Element Pegmatites of Madagascar. Technical Program and Field Trip Guidebook, June 11 - 22, 2001 Antananarivo, Madagascar, 20 pp.

Piasecki, M.A.J., Cliff, R.A., 1988. Rb-Sr dating of strain-induced mineral growth in two ductile shear zones in the Western Gneiss Region of Nord-Trendelaq, central Norway. Nor. geol. unders. Bull. 413, 33–50.

Pieczka, A., 2007. Beusite and an unusual Mn-rich apatite from the Szklary granitic pegmatite, Lower Silesia, southwestern Poland. Can. Mineral. 45, 901–914.

Proppach, G.W., 1975. Der Korund-Hercynit-Fels von Plößberg. Aufschluss – Special 26, 65–80.

Rakotondrazafy, A.F.M., Giuliani, G., Ohnenstetter, D., Fallick, A.E., Rakotosamizanany, S., Andriamamonjy, A., Ralantoarison, T., Razanatseheno, M., Offant, Y., Garnier, V., Maluski, H., Dunaigre, C., Schwarz, D., Ratrimo, V., 2008. Gem corundum deposits of Madagascar: a review. Ore Geol. Rev. 34, 134–154.

Richter, P., Stettner, G., 1979. Geochemische und petrographische Untersuchungen der Fichtelgebirgsgranite. Geologica Bavarica 78, 1–144.

Roering, C., 1961. The mode of emplacement of certain Li and Be-bearing pegmatites in Kharib-District South-West Africa, University of Witwatersrand. Inf. Circ. 4, 1–40.

Romer, R.L., Cuney, M., 2018. Phanerozoic uranium mineralization in Variscan Europe – More than 400 Ma of tectonic, supergene, and climate-controlled uranium redistribution. Ore Geol. Rev. 102, 474–504.

Rychkova, I., Shaminova, M., Sterzhanova, V., Baranova, A., 2015. Lithologic-facies and paleogeographic features of Mid-Upper Jurassic oil-gas bearing sediments in Nurolsk depression (Western Siberia) IOP Conference Series Earth. Environ. Sci. 27, 1–6.

Salles, T., Lopez, S., Eschard, R., Lerat, O., Mulder, T., Cacas, M.C., 2008. Turbidity current modeling on geological time scales. Mar. Geol. 248, 127–150.

Schaaf, P., Sperling, T., Müller-Sohnius, D., 2008. Pegmatites from the Bavarian Forest, SE Germany: geochronology, geochemistry and mineralogy. Geologica Bavarica 108, 204–303.

Schenk, O., Urai, J.L., Van der Zee, W., 2007. Evolution of boudins under progressively decreasing pore pressure – a case study of pegmatites enclosed in marble deforming at high grade metamorphic conditions, Naxos, Greece. Am. J. Sci. 307, 1009–1033.

Schmid, H., Weinelt, W., 1978. Lagerstätten in Bayern. Geologica Bavarica 77, 1–160.

Schroll, E., 1975. Analytische Geochemie-Methodik. Ferdinand Enke Verlag, Stuttgart, pp. 292.

Schüssler, U., 1990. Petrographie, Geochemie und Metamorphosealter von Metabasiten im KTB-Zielgebiet Oberpfalz. Geologica Bavarica 95, 5–99.

Scott, A.C., 2002. Coal petrology and the origin of coal macerals: a way ahead ? Int. J. Coal Geol. 50, 119–134.

Selway, J.B., Černy, P., Hawthorne, F.C., Novák, M., 2000. The Tanco pegmatite at Bernic Lake, Manitoba. 15 Internal tourmaline. Can. Mineral. 38, 877–891.

Sestini, G., 1970. Flysch facies and turbidite sedimentology. Sed. Geol. 4, 559–597.

Shabeer, K.P., Okudaira, T., Satish-Kumar, M., Binu-Lal, S.S., Hayasaka, Y., 2003. Ca-W metasomatism in high-grade metapelites: an example from scheelite mineralization in Kerala Khondalite Belt, southern India. Mineral. Mag. 67, 465–483.

Shankar, R., Subbarao, K.V., Kolla, V., 1987. Geochemistry of Surface Sediments from the Arabian Sea. Mar. Geol. 1987, 253–279.

Shun, Guo, Yi, Chen, Chuan-Zhou, Liu, Wang Jian-Gang, Su., Bin, Gao Yi-Jie, Fu-Yuan, Wu., Kyaing, Sein, Yue-Heng, Yang, Qian, Mao, 2016. Scheelite and coexisting F-rich zoned garnet, vesuvianite, fluorite, and apatite in calc-silicate rocks from the Mogok metamorphic belt, Myanmar: implications for metasomatism in marble and the role of halogens in W mobilization and mineralization. J. Asian Earth Sci. 117, 82–106.

Silva, D., Lima, A., Gloaguen, E., Noronha, F., Gumiaux, C., Guillou-Frottier, L., 2015. What's new on the pegmatite field Barroso Alvão? 7th International Symposium on Granitic Pegmatites, PEG 2015 Książ. Poland 93–94.

Silva, K., Siriwardena, C., 1988. Geology and the origin of the corundum bearing skarn at Bakamuna, Sri Lanka. Miner. Deposita 23, 186–190.

Stein, E., 1988. Die strukturgeologische Entwicklung im Übergangsbereich Saxothuringikum/ Moldanubikum in NE-Bayern. Geologica Bavarica 92, 5–131.

Steiner, L., 1986. Die Granitoide des Oberpfälzer Waldes-Voruntersuchungen zum Kontinentalen Tiefbohr-Programm (KTB). German Science Foundation, Hannover, pp. 109.

Stettner, G., 1992. Geologie im Umfeld der Kontinentalen Tiefbohrung Oberpfalz-Einführung und Exkursionen. Bayerisches Geologisches Landesamt, München, pp. 240.

Stowell, H.H., Menard, T., Ridgway, C.K., 1996. Ca-metasomatism and chemical zonation of garnet in contact-metamorphic aureoles, Juneau Gold Belt, southeastern Alaska. Can. Mineral. 34, 1195–1209.

Strunz, H., Mücke, A., 1975. Die variskischen Granite der nördlichen Oberpfalz. Der Aufschluss – Special 26, 105–116.

Takagi, T., Naito, K., Collins, L., Iizumi, S., 2007. Plagioclase-quartz rocks of metasomatic origin at the expense of granitic rocks of the Komaki District, southwestern Japan. Can. Mineral. 45, 559–580.

Tennyson, Ch., 1983. Granat von Bayerischen Fundstätten. Aufschluss 7, 275–285.

Uebel, P.-J., 1975. Platznahme und Genese des Pegmatit von Hagendorf-Süd. Neues Jahrbuch Mineralogie Monatshefte 1975, 318–322.

Ulrych, J., Pivec, E., Lang, M., Balogh, K., Kropácek, V., 1999. Cenozoic intraplate volcanic rock series of the Bohemian Massif: a review. Geolines 9, 123–129.

Van Lichtervelde, M., Linnen, R.L., Salvi, S., Beziat, D., 2006. The role of metagabbro rafts on tantalum mineralization in the Tanco granitic pegmatite, Manitoba. Can. Mineral. 44, 625–644.

Vierling, W., 1975. Zur Mineralogie der Oberpfalz. Aufschluss – Special 26, 3.

Voll, G., 1960. Stoff, Bau und Alter in der Grenzzone Moldanubikum/ Saxothuringikum in Bayern unter besondere Berücksichtigung gabbroider, amphibolitischer und kalksilikatführender Gesteine. Beiheft Geologisches Jahrbuch 42, 1–382.

Von Raumer, J.F., Stampfli, G.M., Bussy, F., 2003. Gondwana-derived microcontinents – the constituents of the Variscan and Alpine collision orogens. Tectonophysics 365, 7–22.

Wark, D.A., Watson, E.B., 2006. TitaniQ: a titanium-in-quartz geothermometer. Contrib. Miner. Petrol. 152, 743–754.

Weber, K., Behr, J.H., 1983. Geodynamic interpretation of the Mid-European Variscides. In: Martin, H., Eder, F.W. (Eds.), Intercontinental fold belts. Springer, Berlin/ Heidelberg/New York, pp. 427–469.

Weger, M., Masch, L., 1994. Deformation of gabbro-amphibolites in the SW Barrandian Zone (W Bohemian Massif, NE Bavaria)-Acadian Terrane collision. J. Czech Geol. Soc. 39, 122–123.

Weger, M., Masch, L., Höll, R., Krömer, E., 2003. Geologische Karte Waldthurn 1:25000. Bavarian Environment Agency, Munich.

Wehrmann, A., Hertweck, G., Brocke, R., Jansen, U., Königshof, P., Plodowski, G., Schindler, E., Wilde, V., Blieck, A., Schultka, S., 2005. Paleoenvironment of an Early Devonian Land-Sea Transition: a Case Study from the Southern Margin of the Old Red Continent (Mosel Valley, Germany). Palaios 20, 101–120.

Wemmer, K., Ahrendt, H., 1993. Age determination on retrograde processes in rocks of the KTB and the surrounding area. KTB-Report 93–2, 129–131.

Winkler, H.G.F., 1976. Petrogenesis of Metamorphic Rocks. Springer 348.

Wurm, A., 1961. Geologie von Bayern. Gebrüder Bornträger, Berlin, pp. 555.

Žáček, V., Novák, M., Raimboult, L., Zachariáš, J., Ackerman, L., 2003. Locality No. 8: Vlastějovice near Ledeč nad Sázavou. Fe-skarn, barren fluorite pegmatite. In: Novák, M. (Ed.), International symposium on light elements in rock forming minerals LERM 2003. Czech Republic. Field trip guidebook, Nové Město na Moravě, pp. 61–70.

Zeh, A., Millar, I.L., 2001. Metamorphic Evolution of Garnet–Epidote–Biotite Gneiss from the Moine Supergroup, Scotland, and Geotectonic Implications. J. Petrol. 42, 529–554.

Zharikov, V.A, Pertsev, F, N.N., Rusinov, V.L., Callegari, E., Fettes, D.J. 2006. Metasomatism and metasomatic rocks. IUGS Subcommission on the Systematics of Metamorphic Rocks, Web version 01.02.07, www.bgs.ac.uk/scmr/home.html.