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Durbachites–Vaugnerites – a geodynamic marker in the central European Variscan orogen

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ABSTRACT

Durbachites–Vaugnerites are K–Mg-rich magmatic rocks derived from an enriched mantle source. Observed throughout the European Variscan basement, their present-day geographical distribution does not reveal any obvious plate-tectonic context. Published geochronological data show that most durbachites–vaugnerites formed around 335–340 Ma. Plotted in a Visean plate-tectonic reconstruction, the occurrences of durbachites–vaugnerites are concentrated in a hotspot like cluster in the Galatian superterrane, featuring a distinctive regional magmatic province. Reviewing the existing local studies on Variscan durbachite–vaugnerite rocks, we interpret their extensive appearance in the Visean in terms of two factors: (i) long-term mantle enrichment above early Variscan subduction systems; and (ii) melting of this enriched subcontinental mantle source during the Variscan collision stage due to thermal anomalies below the Galatian superterrane, possibly created by slab windows and and/or the sinking of the subducted Rheic slab into the mantle. The tectonic reorganization of Europe in the Late Palaeozoic and during the Alpine orogeny has torn apart and blurred this marked domain of durbachites–vaugnerites.

Introduction

The term 'Durbachit' (Sauer, 1893) was first used for a biotite- and amphibole-rich border facies of lamprophyric character recognized around a granite body near Durbach, in the Central Black Forest. Petrographically similar rocks became known in early work as vaugnerites (Mts. de Lyonnais, Fournet 1833, Lacroix, 1917), or as redwitzites (Marktredwitz, Fichtelgebirge, NE Bavaria, Willmann, 1920).

The mineral assemblage of these rocks is, in general, K-feldspar, quartz, plagioclase, Mg-rich biotite, actinolitic hornblende, ± clinopyroxene, ± rare orthopyroxene, titanite, apatite, allanite, zircon and pyrite. Not always, but very often, durbachites–vaugnerites exhibit a granitoid texture with phyric K-feldspars and the term melagranite is commonly used for such varieties in the literature. Geochemically, the rocks are characterized by a metaluminous composition at mostly intermediate SiO_2 contents (55–70 wt.%), and the unusual combination of very high K_2O contents (4–9 wt.%) with relatively high Mg numbers – formerly corresponding to De La Roche *et al.*'s (1980) sub-alkaline trend. The trace element signature of the rocks typically involves very high Ba (1000–3000 ppm) and Sr contents (500–1000 ppm) and elevated contents of Th (Holub, 1977; Gerdes *et al.*, 2000; Ferré and Leake, 2001; Finger *et al.*, 2007; Janoušek and Holub, 2007). There is wide agreement from geochemical studies and experimental work that igneous rocks of the durbachite–vaugnerite type represent magmas from an enriched mantle source, variably modified by fractionation, magma mixing and crustal contamination (Holub, 1997; Gerdes *et al.*, 2000; Solgadi *et al.*, 2007; Parat *et al.*, 2010).

Durbachites/Vaugnerites seem to represent a rock type that is particularly characteristic for the Variscan belt. They are reported from many of the European Variscan basement areas (Fig. 1), but their mere geographical distribution cannot satisfy any large-scale model for their formation (c.f. Von Raumer *et al.*, 2012). Linear arrangements of such magmatic bodies have been noted in a regional context (Rossi *et al.*, 1990; Rossi and Cocherie, 1995; Ferré and Leake, 2001; Finger *et al.*, 2007). Schaltegger (1997) discussed for the first time a possible genetic relation with a palaeosuture; a model involving partial melting of an enriched mantle at the transition from thickening to collapse of the Variscan orogenic belt was presented by Solgadi *et al.* (2007). Von Raumer (1998) discussed a possible belt-like arrangement of these plutons along the whole Variscan orogen, relating the durbachite-bearing basement areas of the Tauern Window and the Alpine External Massifs with those of Corsica, the French Central Massif, Black Forest, Vosges and the Bohemian Massif. New palinspastic reconstructions of the Variscan domain (Stampfli *et al.*, 2011, 2013) may help to better understand the palaeogeographic distribution of these distinctive magmatic rocks and the geodynamic background of magma formation.

Occurrences of durbachites–vaugnerites in central Europe – a review

Figure 1 shows localities from where rocks of the durbachite–vaugnerite type have been as yet reported. At first sight, the rocks seem to be irregularly distributed all over Variscan Europe. They have been found in the Bohemian Massif, Black Forest, Vosges (Moldanubian Zone), in the

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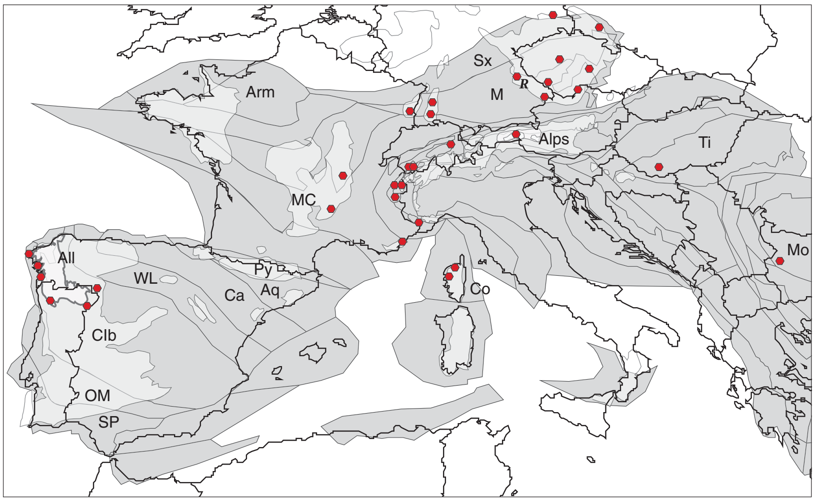

Fig. 1 Geographical distribution of durbachite–vaugnerite localities (red dots, consult references in Tab. 1 for precise localities) and their pre-Mesozoic hosts in Central Europe (map modified after Stampfli *et al.,* 2006), ***R*** – Redwitzite locality; Grey – Subdivision of the European pre-Mesozoic basement areas (light grey) into Geodynamic Units (GDU's, first time Stampfli *et al.,* 2006, Hochard 2008) inspired by Franke (1989). For a better understanding and identification, the contours of the specific geodynamic units are used: AM: Armorica; Aq: Aquitaine; BM: Bohemian Massif; CIb: Central Iberian basement; Ca: Cantabrian terrane; M: Moldanubian basement (Bohemian Massif, Black Forest, Vosges); MC: French Central Massif; Mo: Moesian platform; OM: Ossa Morena; Py: Pyrenees; SP: South Portuguese zone; Sx: Saxothuringian zone; Ti: Tisia unit; WL: West Asturian–Leonese zone. Dark contours: geographical limits.

Massif Central and Corsica, but also within the Alpine domain (External Massifs, Hohe Tauern). Furthermore, we find these rocks some 2000 km to the west in north-western Spain and far to the east in Bulgaria.

Bohemian massif

This massif hosts several large durbachite-type plutons, mostly located in the Moldanubian Zone. They have been extensively studied during the past years and a wealth of high-quality petrographic, geochemical, isotopic and geochronological data are available (Central Bohemian Pluton, Holub, 1977, 1997; Třebíč Massif, Holub *et al*., 1997; Knížecí Stolec pluton, Verner *et al*., 2008; Rastenberg Pluton, Klötzli and Parrish, 1996; Gerdes *et al*., 2000). All workers agree that the Moldanubian durbachite magmas contain components from an enriched mantle source perhaps contaminated by subducted crust, and experienced variable later modification by crustal contamination, admixing of lower crustal melts or fractional crystallization. Another important finding is that all these plutons intruded almost contemporaneously around 338 Ma (c.f. Table 1). New papers (Finger *et al*., 2007; Janoušek and Holub, 2007; Janoušek *et al*., 2012) hold unanimously the view that the petrogenesis of the Moldanubian durbachite magmas must be seen in the context of collision of the various Bohemian terrane fragments. The idea is that processes subsequent to subduction led to a significant temperature increase below the orogen, triggering the melting of metasomatized and contaminated mantle domains. A special feature of the Moldanubian durbachite intrusions is that they are temporally and spatially related to the exhumation of HP-HT rocks (Finger *et al*., 2007; Janoušek and Holub, 2007).

A few Durbachite plutons occur also in the Saxothuringian and Lugian part of the Bohemian massif (Niemcza area, Polish Sudetes: Leichmann and Gaweda, 2001; Mazur *et al*., 2007; Meissen Massif: Wenzel *et al*., 1997, 2000; Nasdala *et al*., 1999). These plutons show basically the same compositions and ages as the Moldanubian ones.

The redwitzites (Troll, 1968; Siebel *et al*., 2003) of the western Bohemian Massif (*R* in Fig. 1) have a slightly different petrogenesis. Although representing also relatively mafic magmas with melt components from an enriched mantle source, they cannot be directly correlated with the Bohemian durbachite plutons due to their significantly younger age of ~322 Ma (Kovaříková *et al*., 2007). These redwitzite magmas intruded at a time, when the whole southwestern Bohemian massif was invaded by numerous, mainly crustally derived granitic magmas (formation of the Saxo-Danubian Batholith – Finger *et al*., 2009). Mingling phenomena between the felsic granites and the mafic redwitzite magmas are ubiqitous. The redwitzites often appear as comagmatic enclaves in the granites.

Black Forest

The durbachites of the Black Forest (Schwarzwald) form only relatively small bodies that appear to be connected to late Variscan granitoid intrusions dated at around 333 Ma (Schaltegger, 2000). The durbachite rocks themselves have as yet not been precisely dated by geochronological methods. Although the durbachites of the Black Forest are name given for this rock type, they resemble the Bohemian redwitzites at least in the point that they intrude contemporaneously with large volumes of Variscan crustal granites, in which they appear as magmatic enclaves (Oberkirch granite, Otto, 1974). Durbachite plutons of a larger size, like those from the Bohemian Massif are not known from the Black Forest area.

Vosges

In the southern Vosges, durbachitic magmas occur in the form of Visean Mg-K volcanics or as monzonitic–granodioritic intrusions (e.g. Granite des Crêtes, Granite des Ballons), dated at 342 ± 1 to 339.5 ± 2.5 Ma (Schaltegger *et al*., 1996). In the central Vosges, durbachite-type magmatism occurred coeval with the formation of migmatites and late Variscan granitoid intrusions at around 332 Ma (Schaltegger *et al*.,

Table 1 Durbachite–Vaugnerite age data.

Terrane	Locality	Ages (Ma)	References
Bohemian Massif	Central Bohemian Pluton	343 ± 6 Zrn ev	Holub *et al.*, 1997
			Janoušek & Gerdes 2003
	Rastenberg Pluton	337 ± 1 Zrn, Rt	Klötzli and Parrish, 1996
	Knížecí Stolec Pluton	338 ± 2	Verner *et al.*, 2008
		341 ± 8 CHIME	
		340 ± 8 Zrn ev	Holub *et al.*, 1997
		338–335	Kotková *et al.*, 2003
	Třebíč Massif	342 ± 3 SHRIMP	Kusiak *et al.*, 2010
	Jihlava Massif	348 ± 18 CHIME	Kusiak *et al.*, 2010
		335 ± 1 Ma	Kotková *et al.*, 2010
			Janoušek *et al.*, 2010
	Marktredwitz	324–321 Zrn ev	Siebel *et al.*, 2003
	Slavkovský les	323–326 Zrn ev	Kovaříková *et al.*, 2007;
			Kovaříková *et al.*, 2010
Saxothuringian	Meissen	340 ± 16 U/Pb	Nasdala *et al.*, 1999
			Wenzel *et al.*, 1997
French Central Massif	Guéret massif	350–340 Rb/Sr	Galán *et al.*, 1997
	Livradois	<360 ± 4 mnz	Gardien *et al.*, 2011
	Velay, related to coarse granitoids	>335–315 Ma?	Ledru *et al.*, 2001
Vosges		340 ± 2 U/Pb	Schaltegger *et al.*, 1996
		332 + 3/-2 U/Pb	Schulmann *et al.*, 2002
Black Forest		~330	Hegner *et al.*, 1996
Massif de Maures	Reverdit Tonalite	334 ± 3 U/Pb	Moussavou, 1998
External Massifs	Aar-Massiv	334 ± 2 U/Pb	Schaltegger and Corfu, 1992
	Aiguilles Rouges	332 ± 2 U/Pb	Bussy *et al.*, 1998
	Belledonne	335 ± 13 U/Pb	Debon *et al.*, 1998
	Pelvoux, Rochail	343 ± 11 U/Pb	Guerrot and Debon, 2000
	Argentera Massif	337 ± 8 U/Pb	Debon & Lemmet 1999
Tauern Window		~ 340 SHRIMP	Eichhorn *et al.*, 2000
	Ahorn Gneiss	334 ± 5 U/Pb	Veselá *et al.*, 2011
Corsica		~337	Ménot *et al.*, 1996
			Rossi and Cocherie, 1995
		342 ± 1 U/Pb	Rossi *et al.*, 2009
Central Iberia	Bayo – Vigo region	~349 U/Pb	Gallastegui, 2005
Tisia Massif	Mecsek Mountains	339 ± 10 Zrn ev	Klötzli *et al.*, 2004
Moesian Platform	Svoge region	337–338 U/Pb	Buzzi *et al.*, 2010

1997; Schulmann *et al.*, 2002), closely resembling the situation in the Black Forest.

French Massif Central

In the *French Massif Central,* the appropriate rocks are traditionally termed vaugnerites and are mainly observed in the eastern part of the massif, in the neighbourhood of the Late Variscan anatectic–granitic Velay dome. As shown in the classical papers by Sabatier (1980, 1991), these vaugnerites appear in most cases as rounded enclaves in late Variscan granitoid bodies. Larger intrusive bodies as well as dikes of vaugnerites are rare. Ledru *et al.* (2001, their fig. 5a,b) mention irregular shaped monzodiorite xenoliths – 'durbachites' – narrowly related to porphyric granitoids (335–315 Ma) emplaced before the cordierite–granites of the Velay dome (Ledru, oral comm.).

Central Iberian domain

In the *Central Iberian domain*, Gil Ibarguchi (1980, 1981, 1982) described occurrences of vaugnerite-type magmatic rocks from the western coastal areas. Comparable rocks have been discovered in the anatectic Tormes Dome of the autochthonous basement (López-Moro and López-Plaza, 2004). Many localities are situated along the border zone of the allochthonous domain in north-western Spain (Gallastegui, 1993, 2005; her fig. 2.6). In particular, the Bayo-Vigo zone contains many outcrops of 'early granodiorites' with a presumed Lower Carboniferous age, which host rounded enclaves of vaugnerites (Gallastegui, 2005).

Corsica

In *Corsica*, vaugnerites form either independent bodies of up to 500 m diameter, enclaves of >10 m within the high-K granites, or they appear as synplutonic dikes. Dated around 337 Ma, the rocks were interpreted as early orogenic, mixed high-K crustal and mantle melts (Orsini, 1976; Rossi and Cocherie, 1995; Ménot *et al.*, 1996; Ferré and Leake, 2001; Rossi *et al.*, 2012). Rossi *et al.* (2009) proposed that the vaugnerites of Corsica follow a sinistral transpressional fault zone, sealing the contact of former Armorica-derived (Corsica) and Gondwana-derived (Sardinia) basement terranes (cf. Laporte *et al.*, 1991).

Alpine domain

In particular in the external massifs, several gneisses and metagranitoids with durbachitic affinities and Viséan formation ages have been found (Aar: Schaltegger, 1994; Schaltegger and Corfu, 1992, 1995; Aiguilles Rouges: Bussy *et al*., 1998, 2000; Von Raumer and Bussy, 2004; Belledonne: Debon *et al*., 1998; Guillot *et al*., 2009; Argentera: Lombardo *et al*., 1997, 2011). 'K-feldspar amphibolites' (meta-durbachites) with actinolitic lumps and layers (former ultramafic layers) in the Mont-Blanc/Val Ferret area have comparable ages (Von Raumer and Bussy, 2004), and vaugnerite–durbachite magmatic enclaves and intrusive bodies of Visean age were observed in the Pelvoux area (Le Fort, 1973; Banzet, 1987; Vittoz *et al*., 1987; Guerrot and Debon, 2000). Le Fort's (1973) Gneiss d'Olan is likely to be a volcanic–subvolcanic durbachitic complex of Visean age (cf. Von Raumer, 1998). Finally, the basement of the Tauern Window (Eastern Alps) comprises a series of variably gneissified high-K granitoids of Visean age that can be included into the durbachite group (Finger *et al*., 1993; Eichhorn *et al*., 2000; Ahorn-Gneiss, Veselá *et al*., 2011).

Tisia domain

In the Hungarian *Tisia* domain (Mórágy unit of the Mecsek Moutains), K–Mg-rich granitoids of Tournaisian to early Visean age show features of durbachitic magmas (Klötzli *et al*., 2004).

Variscan axial zone of Bulgaria

Syenitic–monzodioritic rocks from the Svoge region (Cortesogno *et al*., 2004) with an age of 337–338 Ma were recently described by Buzzi *et al.* (2010). These rocks have strong similarities to the durbachite–vaugnerite rocks of central Europe.

Plate-tectonic background

The ideas about the Variscan orogeny in Central Europe and their plate-tectonic reconstructions have considerably evolved. If considering recent reconstructions (Stampfli *et al*., 2011, 2013), the Variscan orogen is seen as a collage of three terranes, Armorica, Ligeria and Galatia (Fig. 2B). These terranes split off from the Gondwana margin in the Devonian, when the Palaeotethys opened, and drifted in the shape of an elongate magmatic arc system in the direction of Laurussia. This new concept involves a longlasting and orogen-wide Andean type evolution in the Devonian. Numerous occurrences of Devonian HP pressure rocks give clear evidence for this early Variscan subduction stage and are aligned in the model along the northern margin of the Armorican–Ligerian–Galatian arc system. In the Carboniferous, the three individual terranes Armorica, Ligeria and Galatia collided and were dragged along each other to form a new thick superterrane, which, in turn, collided with the Laurussian continent margin and terranes derived therefrom (e.g. Hanseatic Terrane, former part of Avalonia). Note that, during the collision of Galatia and Ligeria, the intra-Alpine Variscan units moved into the south of the Moldanubian domain. At about the same time, the Armorican basement units moved in a position north of the former Ligerian Cordillera.

In Late Visean times (Fig. 2C), we observe a cluster of durbachite–vaugnerite rocks in the centre of the Galatian superterrane. This plutonic province seems to straddle the suture between the Armorican terrane and the Ligerian–Galatian terrane amalgame. Thereby, most of the durbachites–vaugnerites are positioned in Ligerian–Galatian basement units, i.e. in the upper plate of the collison zone. Only a few (the Saxothuringian and Moesian occurrences of durbachites) are situated within Armorica-derived basement massifs.

Discussion

Many durbachites/vaugnerites are, in a broad sense, granitoid rocks. However, in most of the large granite areas on earth, they appear to be insignificant. For instance, durbachites–vaugnerites play, to our knowledge, no role in the granite-rich Lachlan fold belt (Bruce Chappell, pers. comm.). Neither they appear to play a role in the voluminous Cordilleran I-type granite belts along the North and South American west coast. This implies that large-scale processes of granite formation normally do not produce such rocks. In fact, descriptions of igneous rocks similar to durbachite–vaugnerite rocks exist only sporadically in the literature, with the exception of the Variscan fold belt, where they definitely reach their highest concentrations. Monzonitic rocks associated with syenites and high Sr–Ba granites reported by Anderson *et al.* (2006) from a distinct zone in the Fennoscandian Shield could be equivalent to the Variscan durbachites–vaugnerites. These 1.8 Ga old rocks are post-collisional with respect to the Svecofennian orogeny and are thought to be derived from an enriched mantle source heated up through slab break-off or a plume. From the viewpoint of geochemistry, but less with regard to rock textures and modal compositions, the durbachite–vaugnerite rocks show affinities to post-collisional ultrapotassic, mafic to intermediate mantle magmatism in Tibet (Miller *et al*., 1999; Guo *et al*., 2013), North Korea (Peng *et al*., 2008) or eastern China (Yang *et al*., 2005; Wang *et al*., 2007). However, potassium enrichment is on the whole much stronger in these Asian rocks.

Accepting the common view that magmas of the durbachite–vaugnerite family are extracted from enriched mantle sources (Holub, 1997; Gerdes *et al*., 2000; Janoušek and Holub, 2007), we conclude that at least two prerequisites must have existed in the Variscan regions where the rocks formed. First, these regions must have been underlain by fertile enriched mantle material. Second, a proper tectonothermal trigger must have appeared in the Visean to get this source melted.

The common scenario for building up an enriched mantle reservoir is subduction (Fitton *et al*., 1991; Hawkesworth *et al*., 1995; Wilson *et al*., 1997). Aqueous fluids derived from the downgoing slab infiltrate the mantle wedge and bring along water-soluble chemical elements. Where the thermal conditions are appropriate, this fluid input will cause peridotite melting and arc magmatism. Where the melting curve of the peridotite is not overstepped, the mantle will be successively hydrated. The formation

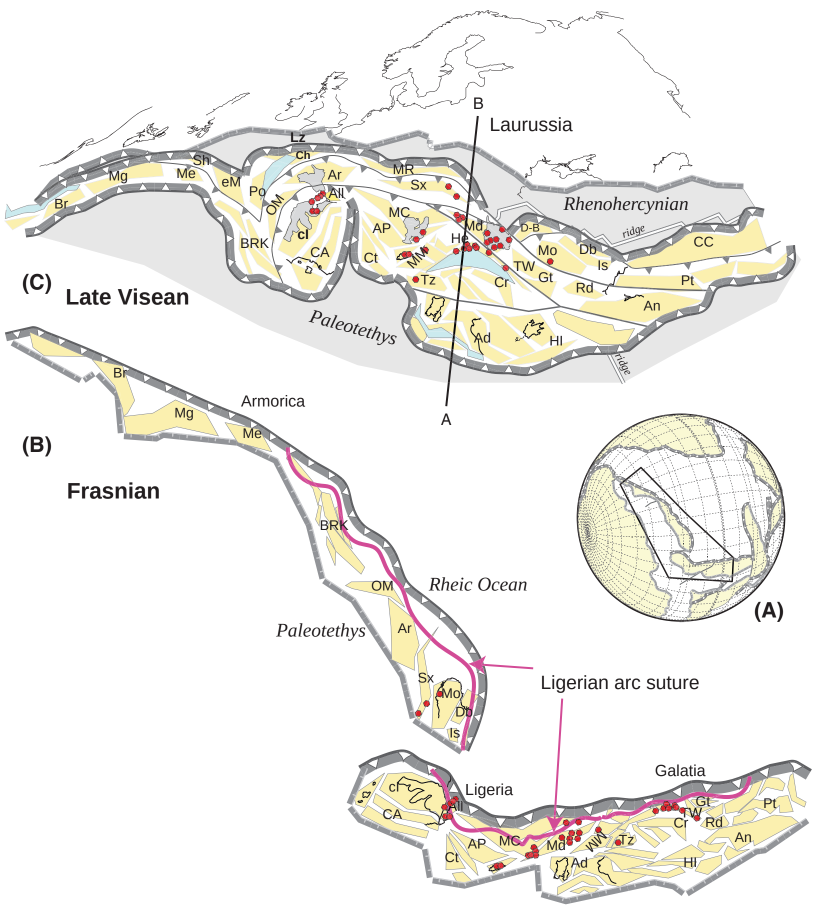

Fig. 2 Durbachites/Vaugnerites in the context of their Late Devonian to Carboniferous plate-tectonic environment. **A** – Frasnian reconstruction after Stampfli *et al.* (2011) for location of B. **B** – Distribution of durbachites/vaugnerites in their Frasnian context, modified after Stampfli (2012). Red dots: Location of durbachites in their future geodynamic unit (Fig 2C), indicating a certain proximity to the Ligerian suture (Stampfli *et al.*, 2013) and to basement areas (yellow polygons) with Late Devonian HP evolution (compare Stampfli *et al.*, 2011; Von Raumer *et al.*, 2013; their Fig. 6B). **C** – Late Visean distribution of durbachites/vaugnerites (red dots) with contours of the main Variscan basement areas (grey) and Visean rift-basins (light blue). Heavy contours correspond to geographical limits. Modified from Stampfli *et al.* (2013). A–B: location of cross-section models in Fig. 3. Identification of basement areas: AA – Austroalpine; Ad – Adria and Sardinia; An – Anatolic; AP– Aquitaine Pyrenees and Corsica; Ar – Armorica; Br – Brunswick; BRK – Betics-Rif-Kabbilies; Ca – Cantabrian and West Asturian-Leonese zones; CC – Caucasus; Ch – Channel; Cr – Carpathian; Ct – Catalunia; cI and All – Central Iberian basement with allochthonous units; Db – Dobrogea; D–B – Dacides–Bucovinian; eM – Eastern Moroccan Meseta; He – External Alpine massifs; HI – Hellenidic; Is – Istambul; Md – Moldanubian (Bohemian Massif, Black Forest, Vosges); MC – Massif Central; Me – Moroccan Meseta; Mg – Meguma; MM – Montagne Noire-Maures and Tanneron; Mo – Moesia; MR – Mid-German Rise; OM – Ossa Morena; Po – south Portuguese; Pt – Pontides (Karakaya); Sh – Sehoul block; Sx – Saxothuringia; TW – Tauern Window; Tz – Tizia.

of phlogopite in such mantle domains causes an increased fertility with reference to a possible later melting event. Elements compatible for phlogopite, mainly K, Ba, Rb, will then be strongly enriched in partial melts derived from such a source. Good examples for such a scenario are the late-Pliocene high K–Mg volcanic rocks from the Taiwan region, which are supposed to be derived from a metasomatized phlogopite-bearing harzburgitic source in the lithospheric mantle (Chung *et al.*, 2001; Wang *et al.*, 2006).

Turning back to the Variscan situation, we propose that long-lasting Devonian subduction of the Rheic Ocean has created a strongly enriched mantle underneath the northern half of the Armorican–Ligerian–Galatian terrane chain. A genetic context between durbachite–vaugnerite formation and these earlier subduction processes is supported by the fact that almost all durbachite–vaugnerite-bearing basement areas show a record of Devonian/early Carboniferous HP-metamorphism or arc magmatism (see Fig. 2 and our earlier review section).

A crucial point is the geological situation in the Visean. It has long been recognized that this was the time of fast post-collisional basement exhumation in many parts of the Variscides, which is reflected not only in the geochronological data of the exhumed rocks but also in a high sedimentation rate in coeval basins (Zwart and Dornsiepen, 1978; Matte, 1986). In particular along the suture between the Ligerian and the Armorican terrane, high-pressure, high-temperature granulites, initially about 1000 °C hot (O'Brien and Carswell, 1993; Krenn and Finger, 2010), were exhumed from mantle depth (ca. 60 km) to the surface within a few million years (O′Brien, 2000; Friedl *et al.*, 2011). These HP–HT granulites witness anomalously high temperatures underneath the collision zone, which are commonly explained in terms of rising astenosphere following a process of slab break-off (Finger *et al.*, 2007; Janoušek and Holub, 2007).

Considering the new tectonic models of Stampfli *et al.* (2011, 2013), the high heat flow during the Visean could be explained in terms of a detachment of a relatively cold mafic underplate, representing the completely subducted oceanic crust of the Rheic Ocean. Figure 3 shows that most durbachite–vaugnerite occurrences are situated at that time right above this presumed zone of slab sinking. Note that the model of Stampfli *et al.* (2011, 2013) involves a subduction of the Rheic Ocean on either side, i.e. subduction to the south below the Galatian superterrane and to the north below the Hanseatic terrane. The latter represents a ribbon-like continental fragment detached from Laurussia and consisting mainly of pieces of Avalonia. The slab roll-back of the Rheic was responsible for the early-to-middle Devonian opening of the Rhenohercynian Ocean along Laurussia, and of the Palaeotethys along the Gondwana margin (Fig. 3). In the Late Devonian, the collision of the Hanseatic and Galatian terranes corresponds to the disappearance of the Rheic Ocean that triggered subduction reversal on both sides of the amalgamating terranes, i.e. the Rhenohercynian started to subduct southward, whereas the Palaeotethys subducted northward. The passive margins of both terranes were then changed into active margins and this is well expressed by the apparition of flysch-like deposits followed by volcanism at the turn of the Devonian. After subduction reversal in the Early Carboniferous, slab windows may have developed beneath the Galatian/Hanseatic terrane collage due to the subduction of mid-ocean ridges on both sides (Fig. 3). We consider it possible that these slab windows have given a particular important impetus for the formation of the durbachites–vaugnerites. Other models for the Variscides involve only a southward subduction of a single Rheic Ocean (e.g. Schulmann *et al.*, 2009; Nance *et al.*, 2010). However, also in that case, a high heat flow scenario can be constructed similar to that in Fig. 3, if a process of slab break-off, slab retreat, or a slab window is invoked (e.g. the model of Vanderhaeghe and Duchêne, 2010, which involves crust/mantle decoupling combined with slab retreat).

Conclusion – the general picture of an evolving orogen

Visean magmatic rocks of the durbachite–vaugnerite type characterize the Variscan basement areas of the Helvetic domain, the Tauern Window, as well as the entire Moldanubian Zone between the Bohemian Massif and the French Central Massif and Corsica. Notably, other Variscan basement areas of central Europe as for instance, in the Carpathians, are completely devoid of these rocks (e.g. Broska *et al.*, 2013). Because the respective magmas are most likely derived from an enriched mantle source, we propose a supra subduction position for the durbachite–vaugnerite-bearing basement units. The significance of these K–Mg-rich rocks as markers of a suture zone was discussed already by Schaltegger (1997). Edel (2001) related their formation to an environment of wrenching and orogen parallel extension. The hotspot-like distribution of the durbachites–vaugnerites above the suture between the Armorican terrane (lower plate) and the Ligerian–Galatian terrane amalgame (Fig. 3) probably reflects large-scale thermal anomalies in the mantle underneath, for which various late-collisional tectonic processes could have been responsible (slab sinking or slab break-off, slab windows, slab retreat). Following that logic, magmatic rocks of the durbachite–vaugnerite type should also be discovered in the allochthonous units of the Central Iberian basements (Fernández-Suárez *et al.*, 2007) and in the Limousin area, which resembles in its tectonic situation the allochthonous units of the Central Iberian basements (c.f. Berger *et al.*, 2012). Indeed, we may infer from rock descriptions given in Gallastegui (2005) that the 'older granodiorites' from Central Iberia correspond widely to the melagranitic, K-feldspar-phyric durbachite types known from the Bohemian Massif (e.g. the Rastenberg granodiorite, Gerdes *et al.*, 2000), and a comparable relationship may have existed between angular durbachite xenoliths and their K-feldspar-phyric granitoid hosts of the Velay area (see above). The gradual post-Visean juxtaposition of terrane assemblages (e.g. Giorgis *et al.*, 1999; Guillot *et al.*, 2009; Schulmann *et al.*, 2009) led to a general narrowing of the orogen, the disappearance of the Rheic Ocean and the subduction of the Palaeotethys ridge (Fig. 3). Parts of the Variscides were affected by intensive crustal melting at that time and large batholiths formed. We find, for instance, widespread migmatization (since about 330 Ma) in the Bavarian zone of the Bohemian Massif (Finger *et al.*, 2007) or the Velay dome in the Massif Central, with the intrusion of late Variscan (about 310 Ma) cordierite-bearing peraluminous granitoids (Montel *et al.*, 1992; Ledru *et al.*, 2001). Equivalents of these late Variscan migmatites and cordierite-bearing peraluminous granitoids also occur in the External domain (Bussy *et al.*, 2000; Olsen *et al.*, 2000; Lombardo *et al.*, 2011), and are followed there by slightly younger intrusions (around 300 Ma) of Fe–K-type granitoids emplaced in a pull-apart system (e.g. Mont-Blanc granite, Von Raumer and Bussy, 2004). This late magmatic evolution has to be seen in the frame of the collapsing Carboniferous cordillera (roll-back of the Palaeothethys slab after the closure of the Rhenohercynian Ocean). Observations in the intra-Alpine and Carpathian basement show that magmatism changed during the Permian to a bimodal type, with gabbros on one hand, and felsic A-, I- and S-type granites and rhyolites on the other hand (e.g.

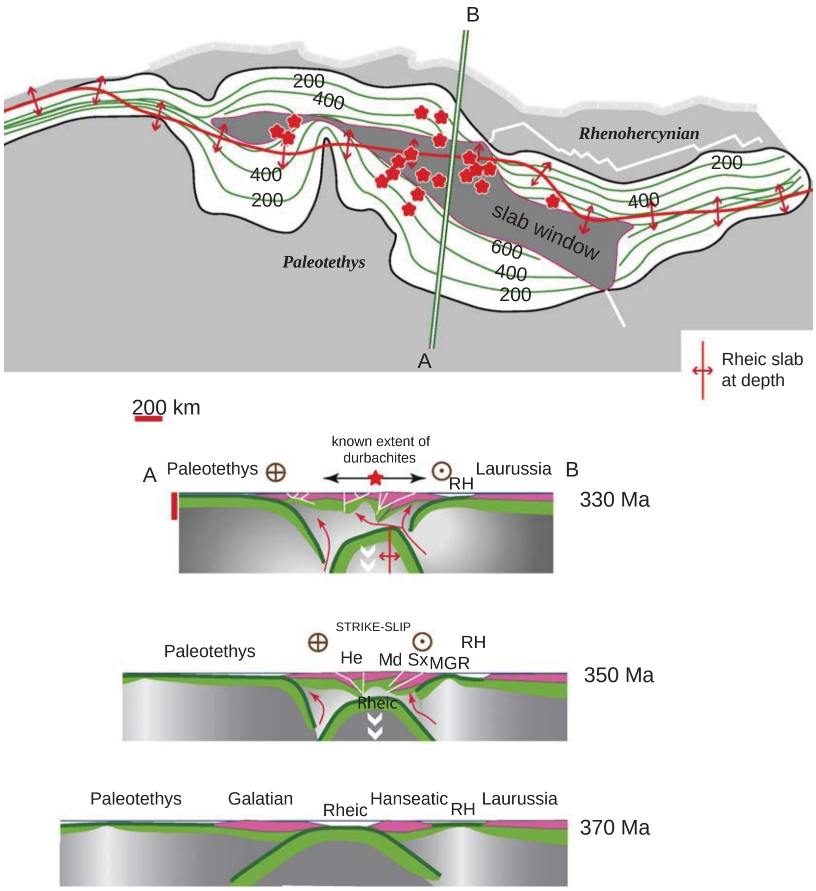

Fig. 3 Model of Stampfli *et al.* (2013) showing the Variscan evolution (370–330 Ma) from Devonian subduction to Visean continental collision. Map: Distribution of durbachites/vaugnerites (compare Fig. 2B) above a supposed double slab window (dark grey) formed by the subducted ridges of the Palaeotethys and the Rhenohercynian oceans with relics of a former slab of Rheic Ocean at depth and its Variscan orogenic framework evolving from the Devonian to the Late Visean (cf. cross-sections). Numbers: supposed depth (km) of slab. Cross-section models: Section A–B across the Variscan domains of the Devonian Galatian–Hanseatic Rheic Ocean section (370 Ma) with subduction of the Rheic slab and the subsequent collisional evolution during 350 Ma and 330 Ma and subduction reversal. The former Galatian blocks: Helvetic (He), Moldanubian (Md), Saxothuringian (Sx) and the former Hanseatic block: Mid-German Cristalline Rise (MGR) basement, separated from the Laurussian domain in the North by the Rhenohercynian Ocean (RH).

Finger *et al.*, 2003; Veselá *et al.*, 2011), and evolves, during the Permian, into bimodal magmatism, gabbros included, as observed in the Alpine domain (Von Raumer *et al.*, 2013).

In conclusion, the durbachite–vaugnerite magmatic assemblage is interpreted as a geodynamic marker for a prominent late-collisional melting event within the enriched subcontinental mantle underneath the Variscan orogen and we consider slab windows as a possible trigger. This orogenic configuration of the Visean was then strongly overprinted during the Upper Carboniferous and Permian extension (Stampfli *et al.*, 2013), leading to a wide post-Variscan basin and range system and the opening of Meliata-type back-arc basins. The final lithospheric re-equilibration to sea level conditions was attained during Triassic times and affected nearly the entire orogene, before Alpine tectonics led to the formation of the present-day puzzle.

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References

Anderson, U.B., Eklund, O., Fröjdö, S. and Konopelko, D., 2006. 1.8 Ga magmatism in the Fennoscandian Shield; lateral variations in subcontinental mantle enrichment. *Lithos*, **86**, 110–136.

Banzet, G., 1987. Interaction croûte-manteaux et genese du plutonisme subalcalin du Haut Dauphiné occidental (Massifs cristallins externs): vaugnérites, durbachites et granitoides magnésio-potassiques. *Géologie Alpine*, **63**, 95–117.

Berger, J., Féménas, O., Mercier, J.Cl, Ohnenstetter, D. and Bruguier, D.,

2012. Ophiolite and eclogites from Limousin (French Massif Central): keys to Variscan subduction processes. *Géol. Fr.*, **2012**, 65–66.

Broska, I., Petrik, I., Be'eri-Shlevin, Y., Majka, J. and Bezak, V., 2013. Devonian/Mississippian I-type granitoids in the Western Carpathians: A subduction-related hybrid magmatism. *Lithos*, **162**, 27–36.

Bussy, F., Delitroz, D., Fellay, R. and Hernandez, J., 1998. The Pormenaz Monzonite (Aiguilles Rouges, Western Alps): an additional evidence for a 330 Ma-old magnesio-potassic magmatic suite in the Variscan. *Schweiz. Min. Petr. Mitt.*, **78**, 193–194.

Bussy, F., Hernandez, J. and von Raumer, J., 2000. Bimodal magmatism as a consequence of the post-collisional readjustment of the thickened variscan continental lithosphere (Aiguilles Rouges/Mont-Blanc massifs, western Alps). *Trans. Royal Soc. Edinburgh, Earth Sciences*, **91**, 1–2, 221–233.

Buzzi, L., Gaggero, L., Grozdanov, L., Yanev, S. and S. Slejko, F., 2010. High-Mg potassic rocks in the Balkan segment of the Variscan belt (Bulgaria): implications for the genesis of orogenic lamproite magmas. *Geol. Mag.*, **147**, 434–450.

Chung, S.-L., Wang, K.-L., Crawford, A.J., Kamenetsky, V.S., Chen, C.-H., Lan, C.-Y. and Chen, C.-H., 2001. High-Mg potassic rocks from Taiwan: implications for the genesis of orogenic potassic lavas. *Lithos*, **59**, 153–170.

Cortesogno, L., Gaggero, L., Ronchi, A. and Yanev, S., 2004. Late orogenic magmatism and sedimentation within Late Carboniferous to Early Permian basins in the Balkan terrane (Bulgaria): geodynamic implications. *Int. J. Earth. Sci. (Geol. Rundsch.)*, **93**, 500–520.

De La Roche, H., Leterrier, J., Grandclaude, P. and Marchal, M., 1980. A classification of volcanic and plutonic rocks using R1–R2 diagram and major element analyses - its relationship with current nomenclature. *Chem. Geol.*, **29**, 183–210.

Debon, F. and Lemmet, M., 1999. Evolution of Mg/Fe ratios in late Variscan plutonic rocks from the External Crystalline Massifs of the Alps (France, Italy, Switzerland). *J. Petrol.*, **40**, 1151–1185.

Debon, F., Guerrot, C., Ménot, R.P., Vivier, G. and Cocherie, A., 1998. Late Variscan granites of the Belledonne massif (French Western Alps): an Early Visean magnesian plutonism. *Schweiz. Min. petr. Mitt.*, **78**, 69–87.

Edel, J.B., 2001. The rotations of the Variscides during the Carboniferous collision: paleomagnetic constraints from the Vosges and the Massif Central/France). *Tectonophysics*, **332**, 69–92.

Eichhorn, R., Loth, G., Höll, R., Finger, F., Schermaier, A. and Kennedy, A., 2000. Multistage Variscan magmatism in the central Tauern window (Austria) unveiled by U/Pb SHRIMP zircon data. *Contr. Min. Petr.*, **139**, 418–435.

Fernández-Suárez, J., Arenas, R., Abati, J., Martínez Catalán, J.R., Whitehouse, M.J. and Jeffries, T.E., 2007. U-Pb chronometry of polymetamorphic high-pressure granulites: An example from the allochthonous terranes of the NW Iberian Variscan belt. In: *4-D Framework of Continental Crust* (R.D. Hatcher Jr., M.P. Carlson, J.H. McBride and J.R. Martínez Catalán, eds), *Geol Soc Am Mem*, **200**, 469–488.

Ferré, E.C. and Leake, B.E., 2001. Geodynamic significance of early orogenic high-K crustal and mantle melts: example of the Corsica Batholith. *Lithos*, **59**, 47–67.

Finger, F., Frasl, G., Haunschmid, B., Lettner, H., von Quadt, A., Schermaier, A., Schindlmayr, A. O. and Steyrer, H. P., 1993. The Zentralgneise of the Tauern Window (Eastern Alps): Insight into an Intra-Alpine Variscan batholith. In: *The Pre-Mesozoic geology in the Alps* (J. von Raumer and F. Neubauer, eds). Springer, Heidelberg, pp. 375–391.

Finger, F., Broska, I., Haunschmid, B., Hrasko, L., Kohút, M., Krenn, E., Petrík, I., Riegler, G. and Uher, P., 2003. Electron-microprobe dating of accessory monazites from Western Carpathian basement granitoids: Plutonic evidence for an important Permian rifting event subsequent to Variscan crustal anatexis. *Int. J. of Earth Sci.*, **92**, 86–98.

Finger, F., Gerdes, A., Janušek, V., René, M. and Riegler, G., 2007. Resolving the Variscan evolution of the Moldanubian sector of the Bohemian Massif: the significance of the Bavarian and the Moravo–Moldanubian tectonometamorphic phases. *J. Geosciences*, **52**, 9–28.

Finger, F., Gerdes, A., René, M. and Riegler, G., 2009. The Saxo-Danubian Granite Belt: magmatic response to postcollisional delamination of mantle lithosphere below the southwestern sector of the Bohemian Massif (Variscan orogen). *Geol. Carp.*, **60**, 205–212.

Fitton, J.G., James, D. and Leeman, W.P., 1991. Basic magmatism associated with late Cenozoic extension in the western United States: compositional variations in space and time. *J. Geoph. Res.*, **96**, 13693–13711.

Fournet, J., 1833. *Géologie lyonnaise*. De Barret, Lyon.. 744 p.

Franke, W., 1989. Tectonostratigraphic units in the Variscan belt of central Europe. *Geol. Soc. Amer. Spec. Paper*, **290**, 67–89.

Friedl, G., Cooke, R. and A., Finger, F., McNaughton, N. J., and Fletcher, I. R., 2011. Timing of Variscan HP-HT metamorphism in the Moldanubian Zone of the Bohemian Massif: U-Pb SHRIMP dating on multiply zoned zircons from a granulite from the Dunkelsteiner Wald Massif, Lower Austria. *Min. Petrol.*, **102**, 63–75.

Galán, G., Corretgé, L.G. and Laurent, O., 1997. Low-potassium vaugnerites from Guéret (Massif Central, France). Mafic magma evolution influenced by contemporaneous granitoids. *Mineral. Petrol.*, **59**, 165–187.

Gallastegui, G., 1993. Petrología del macizo granodiorítico de Bayo-Vigo (Provincia de Pontevedra, España). Tesis Doctoral, Dpto. de Geología, Univ. Oviedo, 363pp.

Gallastegui, G., 2005. Petrología del macizo granodiorítico de Bayo-Vigo (Provincia de Pontevedra, España). *Serie Nova Terra*, **26**. Laboratorio Xeolóxico de Laxe. Área de Xeoloxía e Minería do Seminario de Estudos Galegos. Ediciós O Castro, La Coruña, 414pp.

Gardien, V., Vanderhaeghe, O., Arnaud, N., Cocherie, A., Grange, M. and Lécuyer, C., 2011. Thermal maturation and exhumation of a middle orogenic crust in the Livradois area (French Massif Central). *BSGF*, **182**, 5–24.

Gerdes, A., Wörner, G. and Finger, F., 2000. Hybrids, magma mixing, and enriched mantle melts in post-collisional Variscan granitoids: the Rastenberg Pluton, Austria. In: *Orogenic prozesses: Quantification and modelling in the Variscan belt* (W. Franke, V. Haak and D. Tanner, eds). *Geol. Soc. London, Spec. Publ.*, **179**, 415–431.

Gil Ibarguchi, J.I., 1980. Las vaugneritas de la Región de Finisterre (Galicia, NW de España). Probables productos de magmas anatécticos residuales. *Cuad. Lab. Xeol. Laxe*, **1**, 21–30.

Gil Ibarguchi, J.I., 1981. A comparative study of vaugnerites and metabasic rocks from the Finisterre region (NW Spain). *N. Jb. Mineral. Abh.*, **143**, 91–101.

Gil Ibarguchi, J. I., 1982. Metamorfismo y plutonismo de la región de Muxía-Finisterre (NW, España). Corpus Geologicum Gallaeciae, 2ª Serie I, 1–253.

Giorgis, D., Thélin, P., Stampfli, G.M. and Bussy, F., 1999. The Mont-Mort metapelites: Variscan metamorphism and geodynamic context (Briançonnais basement, western Alps, Switzerland).

Schweiz. Min. Petr. Mitt., **79**, 381–398.
Guerrot, C. and Debon, F., 2000. U-Pb zircon dating of two contrasting Late Variscan plutonic suites from the Pelvoux massif (French Western Alps). *Schweiz. Min. Petr. Mitt.*, **80**, 249–256.
Guillot, S., Di Paola, S., Ménot, R.P., Ledru, P., Spalla, M.I., Gosso, G. and Schwartz, S., 2009. Evidence for a main Paleozoic suture zone in the Belledonne, Grandes Rousses and Oisans massifs (External Crystalline Massifs, Western Alps*). Bull. Soc. Géol. France*, **180**, 483–500.
Guo, Z.F., Wilson, M., Zhang, M.L., Cheng, Z.H. and Zhang, L.H., 2013. Post-collisional, K-rich mafic magmatism in south Tibet: constraints on Indian slab-to-wedge transport processes and plateau uplift. *Contrib. Mineral. Petrol.*, **165**, 1311–1340.
Hawkesworth, C., Turner, S., Gallagher, K., Hunter, A., Bradshaw, T. and Rogers, N., 1995. Calc-alkaline magmatism, lithospheric thinning and extension in the Basin and range. *J. Geoph. Res.*, **100**, 10271–10286.
Hegner, E., Köhl-Ebert, M. and Altherr, R., 1996. The composition of the carboniferous upper mantle below southern Germany and implications for Variscan crust formation. *Schriften der Alfred-Wegener -Stiftung, Terra Nostra*, **96**, 99–100.
Hochard, C., 2008. *GIS and Geodatabases Application to Global Scale Plate Tectonics Modelling*. PhD Thesis, University of Lausanne, Switzerland, 164 pp.
Holub, F.V., 1977. Petrology of inclusions as a key to petrogenesis of the durbachitic rocks from Czechoslovakia. *Tscherm. Min. Petr. Mitt.*, **24**, 133–150.
Holub, F.V., 1997. Ultrapotassic plutonic rocks of the Durbachite Series in the Bohemian Massif; petrology, geochemistry and petrogenetic interpretation. *J. Geol. Sci., Economic Geol. Mineralogy*, **31**, 5–26.
Holub, F.V., Cocherie, A. and Rossi, Ph, 1997. Radiometric dating of granitic rocks from the Central Bohemien plutonic complex/Czech Republic): constraints on the chronology of thermal and tectonic events along the Moldanubian-Barrandian boundary. *C. R. Acad. Sci.*, **325**, 19–26.
Janoušek, V. and Holub, F.V., 2007. The causal link between HP–HT metamorphism and ultrapotassic magmatism in collisional orogens: case study from the Moldanubian Zone of the Bohemian Massif. *Proc. Geologists' Ass.*, **118**, 75–86.
Janoušek, V. and Gerdes, A., 2003. Timing the magmatic activity within the Central Bohemian Pluton, Czech Pepublik: Convential U-Pb ages for the Sazava and Taborintrusions and their tectonic significance. *J. Czech. Geol. Soc.*, **48**, 70–71.
Janoušek, V., Gerdes, A., Holub, F. V. and Verner, K., 2010. Dating Variscan ultrapotassic intrusions in the Bohemian Massif - separating myth from reality. In: *DATING 2010* (M. Kohút, ed.), State Geological lnstitute of Dionyz Stur, Bratislava, Conference Proceedings, Bratislava 30. 4. 2010, pp. 15–16
Janoušek, V., Lexa, O., Schulmann, K. and Maierová, P., 2012. What drives remelting of thickened continental crust in the Bohemian Massif?. *Géol. France*, **2012–1**, 128–129.
Klötzli, U.S. and Parrish, R.R., 1996. Zircon U/Pb and Pb/Pb geochronology of the Rastenberg granodiorite, South Bohemian Massif, Austria. *Mineral. Petrol.*, **58**, 19–21.
Klötzli, U.S., Buda, G. and Skiöld, T., 2004. Zircon typology, geochronology and whole rock Sr-Nd isotope systematic of the Mecsek Mountain granitoids in the Tisia Terrane (Hungary). *Mineral. Petrol.*, **81**, 113–134.
Kotková, J., Schaltegger, U. and Leichmann, J., 2003. 338–335 Ma old intrusions in the E Bohemian massif—a relic of the orogen-wide durbachitic magmatism in European Variscides. *J. Czech Geol. Soc.*, **48**, 80–81.
Kotková, J., Schaltegger, U. and Leichmann, J., 2010. Two types of ultrapotassic plutonic rocks in the Bohemian Massif — Coeval intrusions at different crustal levels. *Lithos*, **115**, 163–176.
Kovaříková, P., Siebel, W., Jelínek, E., Štemprok, M., Kachlík, V., Holub, F. V. and Blecha, V., 2007. Petrology, geochemistry and zircon age for redwitzite at Abertamy, NW Bohemian Massif (Czech Republic): tracing the mantle component in Late Variscan intrusions. *Chemie der Erde – Geochemistry*, **67**, 151–174.
Kovaříková, P., Siebel, W., Jelínek, E., Štemprok, M., Kachlík, V., Holub, F.V. and Blecha, V., 2010. Dioritic intrusions of the Slavkovský les (Kaiserwald), Western Bohemia: their origin and significance in late Variscan granitoid magmatism. *Int. J. Earth Sci.*, **99**, 545–565.
Krenn, E. and Finger, F., 2010. Unusually Y-rich monazite-(Ce) with 6-14 wt.% Y2O3 in a granulite from the Bohemian Massif: implications for high-temperature monazite growth from the monazite-xenotime miscibility gap thermometry. *Min. Mag.*, **74**(2), 217–225.
Kusiak, M.A., Dunkley, D.J., Suzuki, K., Kachlík, V., Kędzior, A., Lekki, J. and Opluštil, S., 2010. Chemical (non-isotopic) and isotopic dating of Phanerozoic zircon—A case study of durbachite from the Třebíč Pluton, Bohemian Massif. *Gondw. Res.*, **17**, 153–161.
Lacroix, A., 1917. La composition chimique de la vaugnerite et la position de cette roche dans la systématique. *Bull. Soc. Fr. Min.*, **40**, 158–162.
Laporte, D., Fernandez, A. and Orsini, J.B., 1991. Le complexe d'Ile Rousse, Balagne, Corse du Nord-Ouest: pétrologie et cadre de mise en place des granitoïdes magnésiopotassiques. *Géol. France*, **1991–4**, 15–30.
Le Fort, P., 1973. Géologie du Haut-Dauphiné cristallin (Alpes françaises). *Sciences de la Terre Mém.*, **25**, 1–373.
Ledru, P., Courrioux, G., Dallain, C., Lardeaux, J.-M., Montel, J.-M., Vanderhaeghe, O. and Vitel, G., 2001. – The Velay dome (French Massif Central): melt generation and granite emplacement during orogenic evolution. –. *Tectonophysics*, **342**, 207–237.
Leichmann, J. and Gaweda, A., 2001. Klodsko-Zloty Stok and Niemcza Zone Granitoids - a shallow level intrusion of Durbachites in the Rhenohercynian Zone. *Mitt. Österr. Mineral. Ges. Wien*, **146**, 169–170.
Lombardo, B., Rubatto, D., Colombo, F. and Compagnoni, R., 1997. Variscan eclogites and HP Granulites in the Malinvern-Argentera complex (Argentera massif, Western Alps): PT estimations and U/Pb zircon ages. *Terra Nova* **9**. *Abstract Suppl.*, **1**, 18–19.
Lombardo, B., Compagnoni, R., Ferrando, S., Radulesco, N. and Rolland, Y., 2011. *Variscan geology of the Argentera Massif, Western Alps and comparison with the Maures-Tanneron Massifs (France)*, pp. 139–163. Ann. Mus. Hist. nat. Nice, XXVI.
López-Moro, F.-J. and López-Plaza, M., 2004. Monzonitic series from the Variscan Tormes Dome (Central Iberian Zone): petrogenetic evolution from monzogabbro to granite magmas. *Lithos*, **72**, 19–44.
Matte, P., 1986. Tectonics and plate tectonics model for the Variscan belt of Europe. *Tectonophysics*, **126**, 329–374.
Mazur, S., Aleksandrowski, P., Turniak, K. and Awdankiewicz, M., 2007. Geology, tectonic evolution and Late Palaeozoic magmatism of the Sudetes – an overview. In: *Granitoids in Poland* (A. Kozłowski and J. Wiszniewska, eds), AM Monograph, **1**, 59–87, KNM PAN-WG UW, Warszawa
Ménot, R.P., Paquette, J.L. and Orsini, J.B., 1996. *Le plutonisme carbonifère de*

Balagne (Corse); geochronology haute precision U-Pb sur zircons. 16ème Réunion Annuelle des Sciences de la Terre, p. 56. Soc. Géol. France, Orléans.

Miller, C., Schuster, R., Klötzli, U., Frank, W. and Purtscheller, F., 1999. Post-collisional potassic and ultrapotassic magmatism in SW Tibet: Geochemical and Sr-Nd-Pb-O isotopic constraints for mantle source characteristics and petrogenesis. *J. Petrol.*, **40**, 1399–1424.

Montel, J.M., Marignac, C., Barbey, P. and Pichavant, M., 1992. Thermobarometry and granite genesis: the Hercynian low-P, high-T Velay anatectic dome (French Massif Central). *J. Met. Geol.*, **10**, 1–15.

Moussavou, M., 1998. Contribution à l'histoire thermotectonique varisque du massif des Maures par la typologie du zircon et la géochronologie U/Pb sur minéraux accessoires. Ph.D. thesis, Univ. Montpellier 2, France, 187pp.

Nance, R.D., Gutiérrez-Alonso, G., Keppie, J.D., Linnemann, U., Murphy, J.B., Quesada, C., Strachan, R.A. and Woodcock, N.H., 2010. Evolution of the Rheic Ocean. *Gondwana Res.*, **17**, 194–222.

Nasdala, L., Wenzel, T., Pidgeon, R.T. and Kronz, A., 1999. Internal structures and dating of complex zircons from Meissen Massif monzonites, Saxony. *Chem Geology*, **156**, 331–341.

O'Brien, P.J., 2000. The fundamental Variscan Problem: high-temperature metamorphism at different depths and high-pressure metamorphism at different temperatures. In: *Orogenic Pocesses: quantification and modelling in the Variscan Belt* (W. Franke, V. Haak, O. Onken and D. Tanner, eds), *Geol Soc London Spec Publ*, **179**, 369–386.

O'Brien, P.J. and Carswell, D.A., 1993. Tectonostratigraphic evolution of the Bohemian massif: evidence from high pressure metamorphic rocks. *Geol. Rundsch.*, **82**, 531–555.

Olsen, S.N., Johnson, C.M., Beard, B.L. and Baumgartner, L.P., 2000. New U-Pb zircon data and constraints on the age and mode of migmatization in the Aar massif, Central Alps. *Eur. J. Mineral.*, **12**, 1245–1260.

Orsini, J.B., 1976. Les granitoïdes hercyniens Corso-Sardes: mise en évidence de deux associations magmatiques. *Bull. Soc. Geol. France*, **18**, 1203–1206.

Otto, J., 1974. Die Einschlüsse im Granit von Oberkirch (Nord Schwarzwald). *Ber. Naturf. Ges. Freiburg*, **64**, 83–174.

Parat, Fl, Holtz, F., René, M. and Almeev, R., 2010. Experimental constraints on ultrapotassic magmatism from the Bohemian Massif (durbachite series, Czech Republic). *Contr. Min. Petrol.*, **159**, 331–347.

Peng, P., Zhai, M., Guo, J., Zhang, H. and Zhang, Y., 2008. Petrogenesis of Triassic post-collisional syenite plutons in the Sino-Korean craton: an example from North Korea. *Geol. Mag.*, **145**, 637–647.

Rossi, Ph. and Cocherie, A., 1995. A belt of high-K plutonic rocks related to crustal extension: evidence from the European Variscan. In: *The origin of granites and related rocks* (M. Brown and P. M. Piccoli, eds) Third Hutton Symposium College Park, Maryland. Abstract-Volume pp. 128–129.

Rossi, Ph., Cocherie, A. and Johan, V., 1990. The geodynamic significance of Mg-K plutonism as constrained by mineralogical and geochemical data from Corsica (France) and the Bohemian Massif (Czechoslovakia). In: *IGCP Int Conference on Paleozoic orogens in Central Europe, Göttingen-Giessen 1990*, IGCP 233, Göttingen, 253–256.

Rossi, P., Oggiano, G. and Cocherie, A., 2009. A restored section of the "southern Variscan realm" across the Corsica–Sardinia microcontinent. *C. R. Acad. Sci. Geoscience*, **341**, 224–238.

Rossi, Ph, Cocherie, A. and Fanning, C.M., 2012. U-Pb-zircon precise dating of volcanic-plutonic formationsin the Corsica Batholith: evidence of a thermal Upper-Stephanian to Lower Permian peak. *Géol France*, **2012–1**, 181–182.

Sabatier, H., 1980. Vaugnérites et granites, une association particulière de roches grenues acides et basiques. *Bull Minéral*, **103**, 507–522.

Sabatier, H., 1991. Vaugnérites: Special Lamprophyre-derived mafic enclaves in some hercynian granites from Western and Central Europe. In: *Enclaves and granite petrology* (J. Didier and B. Barbarin, eds). *Developments in Petrology*, **13**, 63–81.

Sauer, A., 1893. Der Granitit von Durbach im nördlichen Schwarzwald und seine Grenz-Facies von Glimmersyenit (Durbachit). *Mitt. Bad. Geol. Landesanst.*, **2**, 231–276.

Schaltegger, U., 1994. Unravelling the pre-Mesozoic history of Aar and Gotthard massifs (Central Alps) by isotopic dating - a review. *Schweiz. Min. Petr. Mitt.*, **74**, 41–51.

Schaltegger, U., 1997. Magma pulses in the Central Variscan Belt: episodic melt generation and emplacement during lithospheric thinning. *Terra Nova*, **9**(5/6), 242–245.

Schaltegger, U., 2000. U-Pb geochronology of the Southern Black Forest batholith (Central Variscan belt): timing of exhumation and granite emplacement. *Int. J. Earth Sci.*, **88**, 814–828.

Schaltegger, U. and Corfu, F., 1992. The age and source of Late Hercynian magmatism in the Central Alps: evidence from precise U-Pb ages and initial Hf isotopes. *Contr. Mineral. Petrol.*, **111**, 329–344.

Schaltegger, U. and Corfu, F., 1995. Late Variscan "basin and range magmatism and tectonics in the Central Alps: evidence from U-Pb geochronology. *Geodin. Acta*, **8**, 82–98.

Schaltegger, U., Schneider, J.L., Maurin, J.C. and Corfu, F., 1996. Precise U-Pb Chronometry of 345-340 Ma old magmatism related to syn-convergence extension in the southern Vosges (Central Variscan Belt). *Earth. Pl. Sci. L.*, **144**, 403–419.

Schaltegger, U., Maurin, J.C., Schulmann, K. and Fanning, M., 1997. U-Pb single grain and SHRIMP zircon dating of granulites and migmatites of the Vosges mountains: multiple melting during rapid exhumation. *Terra Nova*, **9** Abstract suppl. 1, 112

Schulmann, K., Schaltegger, U., Ježek, J., Thompson, A.B. and Edel, J.B., 2002. Rapid burial and exhumation during orogeny: thickening and synconvergent exhumation of thermally weakened and thinned crust (Variscan orogen in western Europe). *Am. J. Sci.*, **302**, 856–879.

Schulmann, K., Konopásek, J., Janoušek, V., Lexa, O., Lardeaux, J.M., Edel, J.-B., Štípská, P. and Ulrich, S., 2009. An Andean type Palaeozoic convergence in the Bohemian massif. *C. R. Geosci. Paris*, **341**, 266–286.

Siebel, W., Chen, F. and Satir, M., 2003. Late-Variscan magmatism revisited: New implications from Pb-evaporation zircon ages on the emplacement of redwitzites and granites in NE Bavaria. *Int. J. Earth Sci.*, **92**, 36–53.

Solgadi, F., Moyen, J.F., Vanderhaeghe, O., Sawyer, E. and Reisberg, L., 2007. The role of crustal anatexis and mantle-derived magmas in the genesis of synorogenic Hercynian granites of the Livradois area, French Massif Central. *The Canadian Mineralogist*, **45**, 581–606.

Stampfli, G.M., 2012. The Geodynamics of PANGEA formation. *Géol. France*, **2012–1**, 206–209.

Stampfli, G.M., Hochard, C. and von Raumer, J.F., 2006. Reconstructing the Palaeozoic Gondwana margin and its redistribution: new aspects. *Geophysical Research* Abstracts 8, EGU06-A-02708.

Stampfli, G.M., von Raumer, J. and Wilhem, C., 2011. The distribution of Gondwana derived terranes in the early

Paleozoic. In: *The Ordovician of the World* (J.C. Gutiérrez-Marco, I. Rábano, and D. García-Bellido, eds) Instituto Geológico y Minero de España. *Madrid, Cuadernos del Museo Geominero*, **14**, 567–574.

Stampfli, G.M., Hochard, C., Vérard, C., Wilhem, C. and von Raumer, J., 2013. The geodynamics of Pangea formation. *Tectonophysics*, **593**, 1–19.

Troll, G., 1968. Gliederung der redwitzitischen Gesteine Bayerns nach Stoff- und Gefügemerkmalen. *Bayerische Akademie der Wissenschaften, mathem.-naturw. Kl. Abh. N. F.*, **133**, 1–86.

Vanderhaeghe, O. and Duchêne, St, 2010. Crustal-scale mass transfer, geotherm and topography at convergent plate boundaries. *Terra Nova*, **22**(5), 315–323.

Verner, K., Žák, J., Nahodilová, R. and Holub, F. V., 2008. Magmatic fabrics and emplacement of the cone-sheet-bearing Knížecí Stolec durbachitic pluton (Moldanubian Unit, Bohemian Massif): implications for mid-crustal reworking of granulitic lower crust in the Central European Variscides. *Int. J. Earth Sci. (Geol. Rundsch.)*, **97**, 19–33.

Veselá, P., Söllner, F., Finger, F. and Gerdes, A., 2011. Magmato-sedimentary Carboniferous to Jurassic evolution of the western Tauern window, Eastern Alps (constraints from U-Pb zircon dating and geochemistry). *Int. J. Earth. Sci. (Geol. Rundsch.)*, **100**, 993–1027.

Vittoz, P., Costarella, R., Vivier, G. and Oliver, R.A., 1987. Typologie des granitoïdes hercyniens du Haut Dauphiné par l'étude des terres rares et de la morphologie des cristaux de zircon: mise en évidence d'une zonation magmatique dans ce massif. *Géologie Alpine*, **63**, 119–136.

Von Raumer, J.F., 1998. The Palaeozoic evolution in the Alps: from Gondwana to Pangea. *Geol. Rundsch.*, **87**, 407–435.

Von Raumer, J.F. and Bussy, F., 2004. Mont-Blanc and Aiguilles-Rouges: Geology of their polymetamorphic basement (External massifs, France-Switzerland). *Mémoires de Géologie (Lausanne)*, **42**, 1–203.

Von Raumer, J.F., Janoušek, V. and Stampfli, G.M., 2012. Durbachites-Vaugnerites – a time-marker across the European Variscan basement. *Géol. France*, **2012–1**, 178–180.

Von Raumer, J., Bussy, F., Schaltegger, U., Schulz, B. and Stampfli, G.M., 2013. Pre Mesozoic Alpine basements – their place in the European Paleozoic framework. *GSA Bulletin*, **125**(1/2), 89–108.

Wang, Kuo-Lung, Chung, Sun-Lin, O'Reilly, S.Y., Sun, Shen-Su, Shinjo, Ryuichi and Chen, Chang-Hwa, 2006. Geochemical Constraints for the Genesis of Post-collisional Magmatism and the Geodynamic Evolution of the Northern Taiwan Region. *J. Petrol.*, **45**, 975–1011.

Wang, F., Lu, X.X., Lo, C.H., Wu, F.Y., He, H.Y., Yang, L.K. and Zhu, R.X., 2007. Post-collisional, potassic monzonite-minette complex (Shahewan) in the Qinling Mountains (central China): Ar-40/Ar-39 thermochronology, petrogenesis, and implications for the dynamic setting of the Qinling orogen. *J. Asian Earth Sci.*, **31**, 153–166.

Wenzel, T., Mertz, D.F., Oberhänsli, R., Becker, T. and Renne, P.R., 1997. Age, geodynamic setting, and mantle enrichment processes of a K-rich intrusion from the Meissen massif (northern Bohemian massif) and implications for related occurrences from the mid-European Hercynian. *Geol. Rundsch.*, **86**, 556–557.

Wenzel, T., Oberhänsli, R. and Mezger, K., 2000. K-rich plutonic rocks and lamprophyres from the Meissen Massif (northern Bohemian Massif): geochemical evidence for variably enriched lithospheric mantle sources. *N. Jahrb. Mineral. Abhandl.*, **175**, 249–293.

Willmann, K., 1920. Die Redwitzite, eine neue Gruppe von granitischen Lamprophyren. *Z. D. Geol. Ges.*, **72**, 1–33.

Wilson, M., Tankut, A. and Gulec, N., 1997. Tertiary volcanism of the Galatia province, north-west central Anatolia, Turkey. *Lithos*, **42**, 105–121.

Yang, J.H., Chung, S.L., Wilde, S.A., Wu, F.Y., Chu, M.F., Lo, C.H. and Fan, H.R., 2005. Petrogenesis of post-orogenic syenites in the Sulu Orogenic Belt, East China: geochronological, geochemical and Nd-Sr isotopic evidence Source. *Chem. Geol.*, **214**, 99–125.

Zwart, H.J. and Dornsiepen, U.F., 1978. The tectonic framework of Central and Western Europe. *Geol. Mijnbouw*, **57**, 627–654.