Rare-elements (Li-Be-Ta-Sn-Nb) magmatism in the European Variscan belt, a review

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Abstract. The European Variscan belt, which is characterized by a huge amount of granitic intrusions, displays several significant rare-elements pegmatites and/or granites fields which could represent an important source of raw materials. An overview of these occurrences gave the possibility to discuss the processes at their origin and their common classification. Indeed, the spatial and temporal distributions of rare-element pegmatites in the European Variscan belt suggest that rare-elements magmatism would rather be related to local specific conditions (in particular sources, tectonic and thermal regime) than lower crustal processes like rare-elements enrichment subsequent to their release during granulite metamorphism. Actual classification of rare-elements pegmatites, based on their geochemistry and mineral composition, does notallow to discern pegmatites formed in different tectonic regimes and which exhibit various internal structures (e.g. the pegmatites of the *lepidolite*-subclass from Western Iberia and from the Moldanubian domain of the Bohemian Massif for example).

Keywords.LCT pegmatites – rare-elements magmatism – rare metals - colombite-tantalite dating – Variscan belt

1 Introduction

Lithium and tantalum belong to the so-called rare elements or rare metals which are critical for the development of some technologies related to energy saving and telecommunications. The most important sources of raw materials for these metals are rare-element granites and pegmatites, in particular for tantalum (Linnen et al., 2012). Also, they represent important economic storehouses for industrial minerals like feldspar, quartz, mica or kaolin (Glover et al., 2012). Rare-elements magmatic bodies representing an economic potential are pegmatites of the LCT (Lithium, Caesium, Tantalum) class (Černý&Ercit, 2005 and references therein) and high-phosphorus peraluminous rare-elements granites (Linnen et al., 2005), which principally emplace in orogenic settings (Martin & De Vito, 2005).

The European Variscan belt results of the Upper Paleozoic convergence and collision between two megacontinents, Gondwana in the south and Laurasia in the north, with several intervening microcontinents and closures of several oceanic domains (Matte, 1986; 1991). It is characterized by huge amounts of granitic intrusions, and also displays several districts of rare-elements granites and pegmatites related deposits (Fig. 1).

In this synthesis, we give a quick overview of three mainEuropean Variscan districts, i.e. the Moldanubian domain of the Bohemian massif, the French Massif Central (FMC), with new geochronological data, and the NW Iberia. This provides a basis for questioning the origin of rare-elements magmatism and the actual classification of rare-elements pegmatites, in particular the LCT pegmatites.

2 Main rare-elements districts in the European Variscan belt

2.1 The Bohemian massif

The Bohemian Massif represents the easternmost part of the European Variscan belt. From west to east, four major units have been described in the Bohemian Massif (Matte et al., 1990; Cháb et al., 2010 and references therein):(i) the Saxothuringian domain, consisting of a Neoproterozoic basement covered by Paleozoic sequences, lately intruded by numerous plutons of S- and A-type granites; (ii) the Teplá-Barrandian domain, interpreted as an independent crustal block and composed by a Neoproterozoic basement and a Lower Paleozoic cover poor in Variscan magmatic activity; (iii) the Moldanubian domain, corresponding to the inner part of the orogen and consisting of a medium- to high-grade metamorphic complexes intruded by numerous Carboniferous granitoids of calc-alkaline (I-type) and peraluminous (S-type) characteristics;(iv) the Brunovistulicum domain, representing a Neoproterozoic basement with Early to Late Paleozoic cover. Granitic pegmatites are widespread in most of the domain (Breiter et al., 2010). However, the LCT pegmatites (Černý&Ercit, 2005) are most common in the Moldanubian domain, with currently about 70 individual dykes known in the region. Their emplacement seems mainly controlled by migmatitic domes and shear zones.

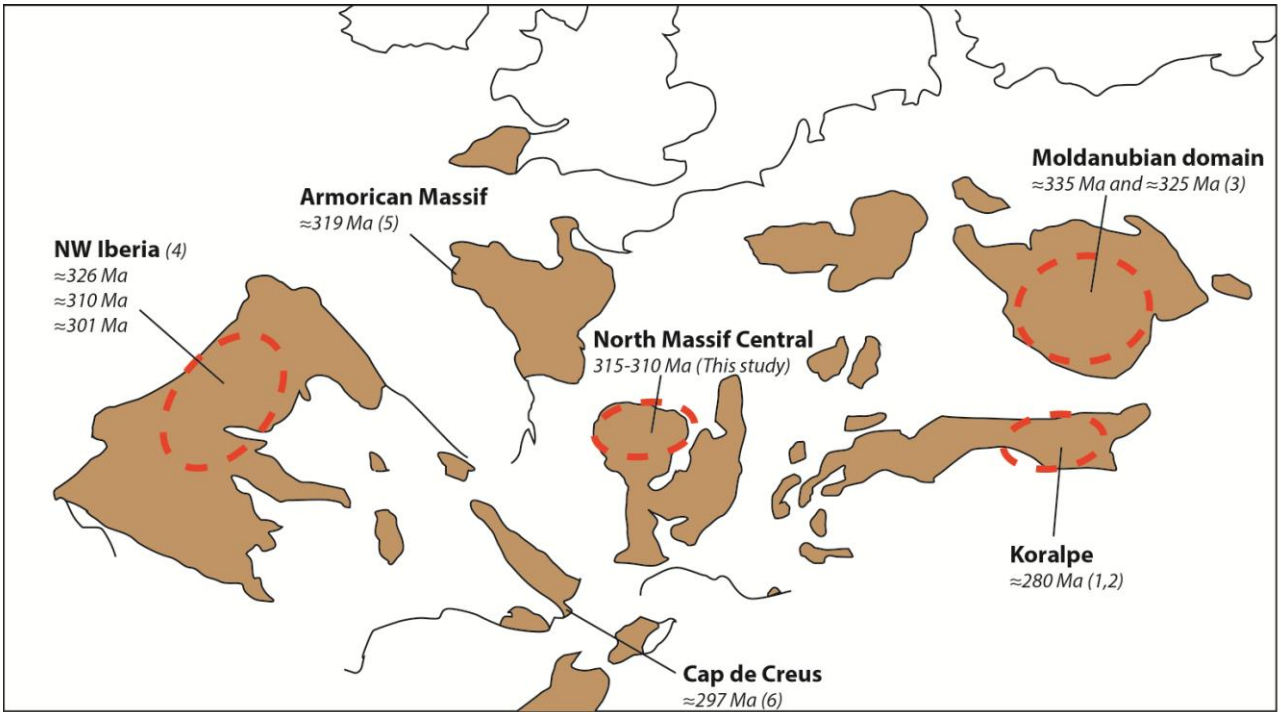

Figure 1. Location of the main districts of rare-elements pegmatites and granites within the European Variscan belt.Ages are from (1) Göd (1989); (2) Thöni et al. (2008); (3) Melleton et al. (2012); (4) Melleton et al. (*submitted*); (5) Branquet et al. (*inprep*.) (6) Grand'Homme (2012). All geochronological data are U-Pb on colombite-group minerals ages except for Koralpe where Rb-Sr (Göd, 1989) and U-Pb on zircon, monazite and xenotime have been performed (Thöni et al., 2008), and on colombite-group minerals and zircon for Cap de Creus pegmatites (Grand'Homme, 2012).

Two emplacements ages have been documented in the Moldanubian domain (U-Pb ages on colombite and tantalite; Melleton et al., 2012). The older at ~ 333 ± 3 Ma just follow HT-MP event of the end of the Moravo-Moldanubian phase and the younger at ~ 325 ± 4 Ma is contemporaneous with beginning of the Bavarian phase. The emplacement of Li-bearing rare-element pegmatites in the Moldanubian domain is the oldest known rare-element magmatic event during Variscan orogeny.

2.2 The French Massif Central

In the FMC, most of the actually known rare-elements magmatic bodies form a province in the North Limousin area (Marignac&Cuney, 1999), which represents the northwestern part of the FMC.The structure of FMC is a stack of metamorphic nappes, with, from bottom to top, four main tectonic units (Faure et al, 2009; and references therein): (i) the Para-autochthonous Unit consists ofNeoproterozoic to Ordovician metapelite-metagraywacke series with somequartzite beds and volcanic rocks metamorphosed;ii) theLower Gneiss Unit (LGU) contains numerous Early Cambrianand Early Ordovician alkaline granitoids intruded inparaderived host rocks; (iii) the Upper Gneiss Unit (UGU) contains eclogiteboudins, and mafic or felsic granulites lenses hosted by migmatiticparagneiss, metasediments and orthogneiss; (iv) and the Thiviers-Payzac Unit (TPU) formed by Cambrian metagraywakes, rhyolites and quartzites intruded by Ordovician granites. All these units are intruded by granitoids from the Late Devonian to the Late Carboniferous.The "rare-metals" province of north FMC is composed by three types of intrusions showing equivalent geochemical characteristics and trends (i) the Beauvoir and Montebras rare-elements granites (ii) the Richemont rhyolite and (iii) the Mont d'Ambazac rare-elements pegmatites field. In these latter, several types of pegmatites have been recognized (Raimbault, 1998; Deveaud et al., 2013), but we consider here the Chèdeville pegmatite which belongs to the *lepidolite*-subclass. The Chèdeville dyke is the most important with 3 m thick, more than 100 m long and a layered internal structure, with an important development of aplitic textures. The Beauvoir granite, which emplaced in the Para-autochthonous unit and the Montebras granite (emplaced in a peraluminousbatholotih), have been extensively described by Aubert (1969) and Cuney et al. (1992).

U-Pb dating of columbite-group minerals from Beauvoir, Montebras and Chèdeville rare-elements magmatic bodies has been performed using laser ablation system connected to a single collector SF-ICP-MS (description of the analytical protocol is presented in Melleton et al., 2012). The Beauvoir granite leads to an emplacement age of 317 ± 6 Ma (fig. 2)which is significantly older than previous ^{40}Ar-^{39}Ar age on *lepidolite* at 308 ± 2 (Cheilletz et al., 1992). Conversely, our U/Pb ages of 314 ± 4 Ma and 309 ± 5 Ma obtained for Montebras granite and Chèdeville pegmatite are identical within the uncertainties with previous published ^{40}Ar-^{39}Ar at 310 ± 1 Ma and 309 ± 1 Marespectively, but also with the Richemont rhyolite dated at 313 ± 3 Ma (Cheilletz et al., 1992; Cuney et al., 2002). The Marche fault system, which crosscuts in a general E-W trend all the northern part of the Limousin, seems to be a key-structure for the rare-elements magmatism of the area, since it appears as a hyphen between all bodies. Moreover, the Marche fault system is coeval with the rare-element magmatism as evidenced by ^{40}Ar-^{39}Ar ages ranging from 316 ± 5 Ma to 312 ± 2 Ma (Gébelin et al., 2007). Contemporaneous cordierite-bearing migmatitic gneisses dated at 316 ± 2 Ma also mark a discrete migmatitic event in the North of the Limousin (Gébelinet al., 2009).

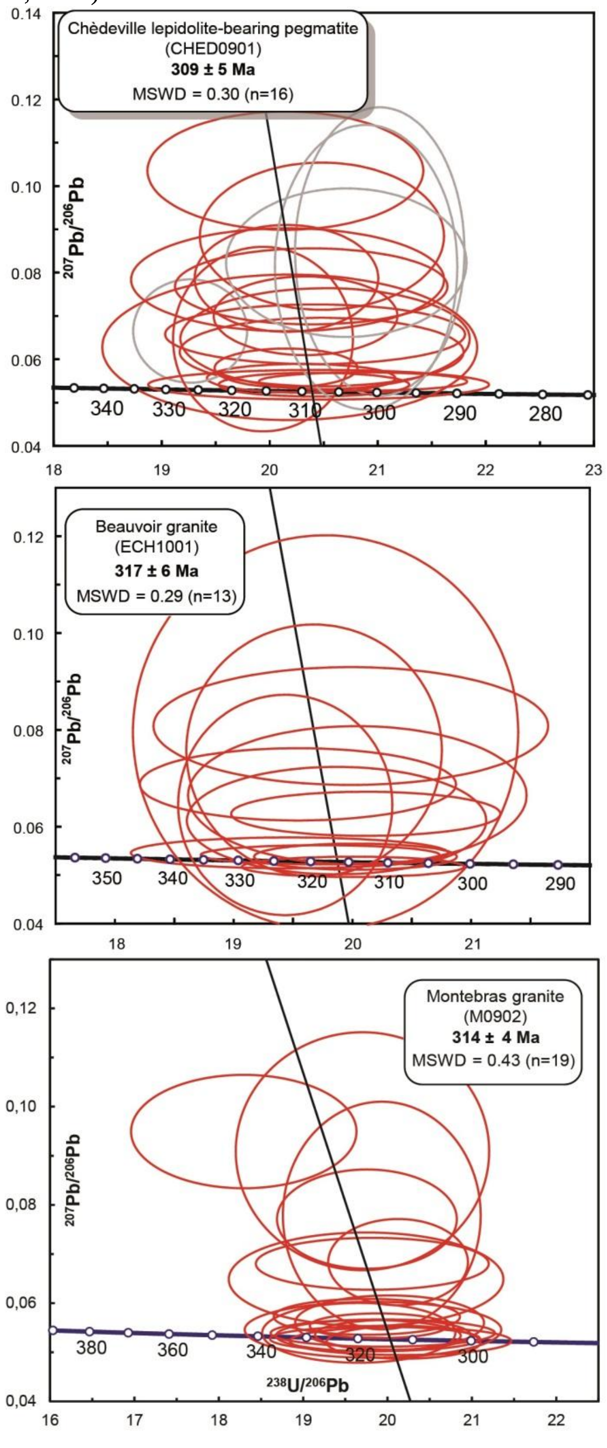

Figure 2. New U-Pb ages on colombite-group minerals from the North FMCdistrict.

2.4 Iberia

Although rare-elements pegmatites are spread in otherVariscan massifs of Iberia, such as in Cap de Creus, the northwest part of the Iberian Variscan belt contains numerous fields that represent the first economic targets in Europe. It is subdivided into four main zones: (i) the Cantabrian domain; (ii) the West Asturian Leones Zone; (iii) the Galicia-Trás-os-Montes Zone (GTOMZ); (iv) the Central Iberian Zone (CIZ) (Julivert et al., 1974; Farias et al., 1987). These last two zones particularly exhibit importantrare-elements pegmatites fields. Most of these dykes exhibit no or very discrete layered internal structures, and correspond to huge bodies of several meters thick and up to several hundred meters long. In the CIZ, the Argemela granite corresponds to the only rare-elements granite known in Iberia (Charoy& Noronha, 1991; 1996). Three events of rare-elements magmatism have been recognized in Northwest Iberia (U-Pb on colombite and tantalite; Melleton et al., submitted): (i)emplacement of the Argemela rare-element granite, in the Central Iberian Zone (CIZ), with an age of 326 ± 3 Ma; (ii) intrusion of rare-element pegmatites from the Galicia-Trás-os-Montes Zone (GTOMZ), at an average age of 310 ± 5 Ma; (iii)emplacements of rare-element pegmatites in the CIZ and in the southern GTOMZ at about 301 ± 3 Ma. These two last events are coeval to the two age peaks of the late orogenic magmatism at ca. 308 Ma and 299 Ma, and all dated rare-element pegmatites clearly emplaced during the late-orogenic evolution of the Variscan belt.Coevalfields of rare-element pegmatites are settled in belts following those formed by similar granitoids suites. Pegmatites fields from both the GTOMZ and the CIZ reveal a southward propagation of ages of emplacement, which matches the observed propagation of deformation, metamorphism and magmatism in the two different geotectonic zones. Moreover, the location of the main rare-elements pegmatites fields suggests a strong correlation between their emplacement and activity of major crustal shear-zones.

4 Origin of the rare-elements magmatism

Following the most accepted genetic model for rare-elements granites and pegmatites, these bodies representthelate withdrawal of residual melts enriched in fluxing elements(Li, F, B) and rare-elements (Ta, Nb, Be, Cs but also Sn and W) from the crystallization of parent granite (Černý et al., 2005; London, 2008).

Nevertheless, another hypothesis for rare-element enrichment proposes the extraction of metasomatic fluids during lower crustal metamorphic processes (HP-HT) to explain the abnormal enrichment of fluxing elements (Li, F, B, Be) and HFSE (Marignac&Cuney, 1999; Cuney et al., 2002; Cuney&Barbey, 2014). This hypothesis is based mainly on geochronological results (^{40}Ar-^{39}Ar on *lepidolite* and muscovite) from the North French Massif Central, where rare-element bodies would emplaced simultaneouslyat about 310 Ma, i.e. when a HP-HT metamorphism event affected the lower crust of the French Massif Central. The depleted geochemical compositions in such elements, recorded in some granulite terrains, were also used to supportthis assumption (Cuney&Barbey, 2014).

Although our results confirm coeval emplacement ages for rare-elements bodies from the FMC and the HP-HT metamorphic event, comparison with other massifs, in particular for NW Iberia where several rare-elements magmatic events are recognized, leads to discuss this last hypothesis. Indeed, the succession of events in NW Iberia might suggest that HP-HT metamorphism would occur several times in the same tectonic domain and in a short time interval. This appears to us unlikely in a general tectonic context of lateral movements rather than vertical structuration. Moreover, rare-elements pegmatites emplacement in the Moldanubian domain of the Bohemian massif clearly postpones the known HP-HT event, and marks the end of migmatitic doming and exhumation of HP units.

Another argument is the strong spatial location of rare-elements pegmatites fields, which more implies specific local conditions like particular sources, favorable tectonic processes and thermic regimes, rather than larger processes controlled by deep crustal events like delamination of the lower crust.

5 Classification of rare-elements pegmatites

The actual classification of pegmatites mostly usedhas been proposed by Černý&Ercit (2005). It is based on the depth of emplacement, the geochemistry and the mineral composition. Although it represents a useful tool for the description and comparison of rare-elements pegmatites, it does not take into account the internal structure of the dykes. Such a lack brings to group objects with similar mineralogy and geochemistry, but very different with respect to their internal organization, in the same class. Under this point of view, the classification of Černý&Ercit (2005) does not properly reflect the origin of the pegmatites. For example, the *lepidolite*-subclass pegmatites of the Moldanubian domain of the Bohemian massif show concentric organization, with the more differentiated zones in the center of the object. Geochemistry of these pegmatites is then very heterogeneous and their rare-elements characters are partly acquired by the internal evolution of the dykes. In another hand, the *lepidolite*-subclass pegmatites from NW Iberia, or the Chèdeville pegmatite in FMC, expose very similar layered organization, which suppose common processes for their origin.The geochemistry of these bodies is more homogeneous than in the case of Moldanubian pegmatites, which means that melts were already originally enriched in rare-elements.

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