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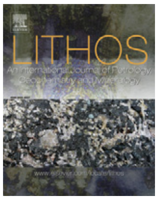

A-type granites from the Pan-African orogenic belt in south-western Chad constrained using geochemistry, Sr–Nd isotopes and U–Pb geochronology

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ABSTRACT

The Zabili granitic pluton (SW Chad) exposed in the Mayo Kebbi massif is dominated by a coarse-grained hornblende biotite granite grading into a fine-grained biotite granite along its southern margin. Petrologic (micrographic intergrowth of quartz and alkali feldspars, granophyric microstructures, the presence of fluorite and bastnaesite as accessory minerals) and geochemical data (high silica, alkalis and Fe/Mg, depletions in CaO, MgO, TiO_2; high Ga, Nb, Zr, Ga/Al, REE, depletions in Ba, Sr, Eu and compatible elements) indicate that this pluton consists of A-type granites crystallized from hot (apatite and zircon saturation temperatures ranging from 744 °C to 923 °C), extremely differentiated magmas. U–Pb zircon geochronology indicates that the magmas crystallized at 567 ± 10 Ma and reveals the presence of older Neoproterozoic xenocrystic zircons at 668 ± 5 Ma in both facies. Within the fine-grained biotite granite, discordant zircons with U–Pb and Pb–Pb ages ranging from Neoproterozoic to Archaean are also reported. The 668 ± 5 Ma old zircons are considered to derive from country-rocks while discordant zircons, characterized by angular shapes, internal fractures and inherited cores, are likely to represent multi-sources detrital crystals that have recorded at least one metamorphic event. Old pre-Neoproterozoic zircons are reported for the first time for rocks of the Mayo Kebbi massif and they attest to the contribution of an old basement (likely to be the Eastern Nigeria basement and/or the Congo craton) involved in a collisional event with a juvenile Neoproterozoic crust prior to the emplacement of the Zabili granitic pluton. Initial εNd values calculated for the Zabili pluton range from +2.6 to +7.0, the highest value recorded by one sample from the coarse-grained hornblende-biotite granite being close to the one of the depleted mantle at 570 Ma (εNd = +7.4). Combining geochronology, Nd isotopes composition and geochemical modeling, leads us to suggest the following model for the origin of the Zabili granitic pluton: (i) contribution of juvenile magmas or partial melting of a juvenile basaltic protolith characterized by a short crustal residence time; (ii) interaction of granitic magmas with older continental materials as suggested by the presence of pre-Neoproterozoic zircons and lower initial εNd values of the fine-grained biotite granite; and (iii) fractional crystallization of feldspars and ferromagnesians to produce the observed geochemical features of sample GAB-B, from which an initial εNd value of +7.0 has been calculated.

1. Introduction

A-type granites where first defined from the Pikes Peak batholith of Colorado (USA), the White Mountain Magma Series of New Hampshire (USA), the Nigerian Younger Granites, and the Gardar Province (Greenland) by Loiselle and Wones (1979). According to these authors, A-type granites are characterized by high K_2O, high Fe/(Fe + Mg) and K_2O/Na_2O; high REE, Zr, Nb, Ta, and low compatible trace elements. Following this first definition, the term "A-type granite" has been applied to a broad spectrum of granitoids, and Collins et al. (1982) proposed that a high Ga/Al should be used as a diagnostic feature while Eby (1992) distinguished A1-type and A2-type granites based on Nb, Ce, Y and Ga abundances. A1-type granites are anorogenic granites of mantle origin while A2-type granites, derived from mantle or crustal protoliths, occur in a wide variety of tectonic settings ranging from late-orogenic to anorogenic.

As a consequence, several genetic models have been proposed for A-type granites. These models, reviewed by Collins et al. (1982), Clemens et al. (1986), Whalen et al. (1987) and more recently by Frost and Frost (2011), include:

(i) Extreme fractionation of mantle derived alkali basalts to produce residual granitic liquids, with or without crustal interactions (Loiselle and Wones, 1979).

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(ii) Assimilation of crustal rocks by mantle-derived alkaline magmas giving syenitic liquids followed by fractional crystallization to produce a granitic composition has been first introduced in the Oslo Rift by Barth (1945). This model has been rejected and it was demonstrated that contamination has been effective only in the most extreme silicic rocks (Andersen and Knudsen, 2000).

(iii) Peralkaline granitic liquids produced by small scale immiscibility in basaltic magmas (Eby, 1979; Philipotts, 1976).

(iv) Differentiation of I-type magmas, involving fractional crystallization or "thermogravitational diffusion" (Shaw et al., 1976), to produce A-type residual liquids was discussed and rejected by Collins et al. (1982) based on their observations from the Gabo and Mumbulla granitic suites in south-eastern Australia. The process of "thermogravitational diffusion" resulting in the concentration of the high field strength elements (Zr, Nb…) at the top of an I-type magma chamber.

(v) Partial melting of a granulitic protolith to produce A-type granites was proposed by Bailey (1974), Collins et al. (1982) and White and Chappell (1983). Collins et al. (1982) suggested that partial melting of such a protolith, requiring high temperatures, is expected to produce relatively anhydrous melts enriched in halides, high field strength elements (Zr, Nb) and REE but depleted in large ion lithophiles elements such as Rb. However, Creaser et al. (1991) indicated that such a granulitic crust is characterized by low silica and potassium; it has lower Fe/Mg than its original protolith. Once partially melted, this granulitic crust is expected to produce liquids with these geochemical features, which are opposite to those observed in A-type granites.

(vi) A metasomatic model involving the role of CO_2 and halogen-rich fluids was proposed to account for the specific composition of the Topsails peralkaline granites in western Newfoundland by Taylor et al. (1980).

In this paper, we use field, petrologic, geochemical and isotopes data from the Zabili granitic pluton in order to propose a petrogenetic model for its generation and emplacement in the frame of the Pan-African orogeny. Hence, this work is a contribution to the origin of A-type granites to which this pluton is related and it provides some insights into the Pan-African orogeny from the poorly investigated Mayo Kebbi massif in southwestern Chad.

In the following, the term "source" is used to designate the crustal, mantle or mixed derivation of a magma, while the term "protolith" will refer to the nature of the rock submitted to physical transformations such as partial melting. The term "origin" involves ideally a description of the source, of the protolith and of the conditions of partial melting, differentiation and crystallization.

2. Geological setting

The geology of Chad comprises a Phanerozoic cover overlying a Precambrian basement outcropping in five distinct massifs (Fig. 1): the Mayo Kebbi massif in the southwest, the Tibesti massif in the north, the Ouaddaï massif in the east, the Guera massif in the centre and the Yade massif in the south. Three of these massifs, the Tibesti massif, the Ouaddaï massif and the Guera massif, are part of a large, poorly investigated area, described as the Saharan Metacraton by Abdelsalam et al. (2002), a metacraton being "a craton that has been remobilized during an orogenic event but that is still recognizable dominantly through its rheological, geochronological and isotopic characteristics" (Abdelsalam et al., 2002). The Mayo Kebbi massif is described as a juvenile Neoproterozoic crust (Penaye et al., 2006; Pouclet et al., 2006) which belongs, together with the Yade massif, to the Central African Orogenic Belt (CAOB). The Central African Orogenic Belt is part of the Pan-African belt and results from the collision between the Congo craton, the West-African craton (Toteu et al., 2004) and the enigmatic Saharan Metacraton (Ngako and Njonfang, 2011). This belt includes juvenile Neoproterozoic crust and pre-Neoproterozoic reworked crust outcropping north of the Congo craton (Toteu et al., 2001, 2004, 2006a, 2006b). The links between juvenile and reworked crustal segments are not clearly assessed at the scale of the Central African Orogenic Belt (Nzenti et al., 1994). Such links are useful in order to understand the origin and evolution of the continental crust exposed in the CAOB and surrounding cratons. Hence, the geology of Chad is of special interest regarding the geodynamic significance of the Pan-African orogeny north of the Congo craton as it may provide us with some insights into the generation and evolution of the continental crust during the Neoproterozoic.

The Zabili granitic pluton is exposed in the Mayo Kebbi massif straddling the border between Chad and Cameroon (Fig. 2). The Mayo Kebbi massif comprises (1) mafic metaplutonic and metavolcanic rocks associated with metasediments and metavolcaniclastics of the Zalbi and Goueygoudoum groups, (2) mafic to intermediate metavolcanic–plutonic associations, (3) Neoproterozoic granitoids intruding the mafic and intermediate rocks (Doumnang, 2006; Kasser, 1995; Penaye et al., 2006; Pouclet et al., 2006). The magmatic rocks outcropping in the Mayo Kebbi massif have been recently interpreted as resulting from Neoproterozoic juvenile accretion in an arc setting (Kasser, 1995; Pouclet et al., 2006). However, little is known about the last stages of the Pan-African orogeny in this part of the CAOB located at the triple junction among the Congo craton, the West African craton and the so-called "Saharan Metacraton" (Abdelsalam et al., 2002).

The Zabili granitic pluton is one of the least studied intrusions of the Pan-African orogenic belt in Chad. Kasser (1995) distinguished, on the basis of field observations, petrology and major element geochemistry a (i) fine-grained pinkish biotite granite in the south and (ii) a coarse grained two mica granite in the north, which are separated by (iii) a 2.5 km wide E–W trending mylonitic shear zone characterized by metasomatic alteration of the granite into episyenites and albitites. Rb–Sr isotopes data yielded an imprecise isochron age of 683 ± 172 Ma (Kasser, 1995). These preliminary results were supplemented by trace element data for the southern part of the pluton by Doumnang (2006) and Pouclet et al. (2006). These authors described a peraluminous and highly fractionated ($SiO_2 > 74$ wt.%; $Eu/Eu^* = 0.2$) potassic granite related to post-tectonic intrusions of the Mayo Kebbi massif.

3. Petrology

3.1. Field observations

The Zabili granitic pluton (Fig. 3) is intrusive within the metasedimentary and metavolcanic rocks of the Zalbi group. These metavolcanic and metasedimentary rocks are recrystallized under greenschist facies conditions (Doumnang, 2006; Kasser, 1995; Penaye et al., 2006; Pouclet et al., 2006). The Zalbi group is affected by polyphased deformation characterized by three superimposed structures. A composite NNE–SSW trending steeply dipping foliation corresponds to transposition of the bedding surface S_0 into S_1 and S_2 schistosities in association with isoclinal folds. This foliation is cross-cut by E–W trending subvertical shear bands associated with kinematic criteria consistent with a dextral sense of shear. Intrusive contacts are preserved along the northern and southern margins of the Zabili granitic pluton, whereas the eastern and western boundaries are transposed into foliation in accordance to the $S_{0/1-2}$ foliation of the host metasedimentary and metavolcanic rocks. The pluton comprises a variety of textures and compositions ranging from pink, fine-grained biotite granite outcropping at its southern margin, to a light colored, coarse-grained hornblende-biotite granite towards the north. The coarse-grained hornblende-biotite granite is truncated by E–W trending shear bands. Large metasedimentary xenoliths are found within the fine-grained biotite granite close to the pluton margin. These xenoliths are similar to the host metasediments and attest for the intrusive nature of the pluton.