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Geochemical evolution of micas and Sn-, Nb-, Ta- mineralization associated with the rare metal pegmatite in Angwan Doka, central Nigeria

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The pegmatites in Angwan Doka, north central Nigeria are genetically related to the basement granites formed during the Pan-African orogeny, 550–530 Ma ago. They occur as sharply discordant dykes in the granitic and metasedimentary basement rocks. The pegmatite population comprises of mineralogically simple and complexly zoned types that are characterized by LCT (Li, Cs and Ta) geochemical signature. The host granitoids range in composition from hornblende, titanite-bearing to biotite–muscovite granodiorites. Analysis of geochemical data of whole rock and muscovite from the different zones reveals compositional variations and evolution across the pegmatite body from border zone to the lepidolite-quartz core zone. Fractionation of Rb, Cs, Sr, Li, F, B, Be Sn, Zn, Ta, Nb and Mn which increases from host granitoids, through the border zone to the central core, with decrease in Fe, Mg, Ti, Ba content, is typical and marks the magmatic crystallization trend of the pegmatites. Other distinctive attribute of the pegmatites is occurrence of cassiterite believed to have formed as a consequence of greisenization, albitization and late-stage metasomatism, which led to enrichment in Sn (up to 886 ppm) in the intermediate zone. Chemical composition of muscovite from the different zones of the pegmatite reveals high concentration of primary magmatic columbite-Fe (ferrocolumbite and ferrotantalite) in the border zone and tantalite-Mn (manganocolumbite and manganotantalite) in the core zone. Ta predominates (352 ppm) in the most evolved lepidolite (Li- and F-rich) zone while Nb was enriched (up to 714 ppm) in the border zone. These geochemical features are ascribed to undercooling of the melt and crystallization in boundary layers accompanied with increased accumulation of incompatible and fluxing components. With increasing fractionation, Nb/Ta and Fe/Mn ratio decreased and is accompanied with increase in Rb, Cs, Li, F and Be typical of crystallization from magmatic process. The sequence of zonation, origin and formation of the different pegmatite zones can be explained by a single path of fractional crystallization.

1. Introduction

Rare-element pegmatites are important resources for their economic concentrations of rare elements Sn, Li, Ta, Rb, and Cs, presence of high quality industrial minerals such as muscovite, spodumene, feldspar and mica, and occurrence of gem minerals (e.g. tourmaline, beryl). LCT-type pegmatites are rare-element pegmatites enriched in Li, Cs and Ta, and are often related petrogenetically to fertile, progenitor granites (Černý, 1991). Large percentages of pegmatites associated with granite form pods within the granite or coalesce upwards and segregate towards the roof of the granitic plutons. Pegmatites may also intrude in form of dykes into the surrounding rocks and emanate from the carapace of the pluton and are in this case defined as epigenetic pegmatites.

The pegmatites in Angwan Doka, north central Nigeria are a part of the large pegmatite belt containing hundreds of pegmatite dykes, which have been reported to be associated with tin and columbite-tantalite mineralizations in a large number of granitic bodies sporadically distributed in the Nigerian Basement (Garba, 2003; Okunlola, 2005). The pegmatites comprise of labyrinth of vertical and low lying horizontally dipping dykes in metasediments and granitoids belonging to the Older Granite suites, which have been dated 600 ± 150 Ma by Matheis and Caen-Vachette (1983).

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These pegmatite bodies vary in size and have been shown to be complex with varied mineralogical zonation and are Sn–Li-rich with subordinate Ta and Nb concentration (Okunlola and Ocan, 2009). In terms of chemistry, the host rock of the pegmatites in Angwan Doka is peraluminous, fractionated S-type granodiorite with ASI $\geq$ 1.1 (Akoh, 2014).

The importance of composition of muscovite as the best clue to internal evolution and as an exploration tool for Nb–Ta mineralization of pegmatite magma has been recognized by Černý (1982, Černý et al., 1985); Černý and Burt (1984); Jolliff et al. (1987); Roda et al. (2005), Van Lichtervelde et al. (2007). This paper describes the compositional and magmatic evolution across the pegmatite bodies in the Angwan Doka area and their geological and geochemical relationship to mineralization, using textural and compositional attributes of muscovite. This is aimed at providing valuable information on the petrogenetic evolution of the different zones of the pegmatites and the factors responsible for concentration of trace elements as chemically diverse as Li, F, Rb, Cs, Ta and Nb, to values that are hundreds of times their average crustal abundances. Attempt is also made to relate the mineralogical features, internal fabrics and compositions with the processes that control the distribution of Sn and Nb–Ta mineralizations in the pegmatite bodies. Using the compositional trend as it relates to the geochemical differentiation or evolution of the pegmatites, with particular emphasis on coexisting micas, the fractionation indices of these minerals, sequence of crystallization of pegmatite zones and details of mineral parageneses were also established and delineated.

1.1. Geological setting

Nigeria lies within the Upper Proterozoic-Lower Phanerozoic Pan-African reactivated mobile belt, east of the West African Craton. The reactivated belt, which extends from Algeria across the southern Sahara into Nigeria, Benin and Cameroon is interpreted to have evolved by plate tectonic processes involving continental collision between, the passive continental margin of the West African Craton and the active Pharusian continental margin about 600 Ma ago (Burke and Dewey, 1972; Bertrand and Caby, 1978; Black et al., 1979; Caby et al., 1981; Leblanc, 1981; Garba, 2002).

The Nigerian Basement Complex rocks are believed to be the results of at least three major orogenic cycles that were characterized by intense deformation and isoclinal folding accompanied by regional metamorphism followed by extensive migmatization corresponding to the Liberian (2700 Ma), the Eburnean (2000 Ma), and the Pan-African cycles (600 Ma). Three major petro-lithological units have been recognized (Fig. 1). They are:

i. Migmatite-gneiss complex, which comprises biotite and biotite hornblende gneisses, quartzites and quartz schist and small lenses of calc-silicate rocks
ii. Slightly migmatised to unmigmatised paraschists and metaigneous rocks which consist of pelitic schists, quartzites, amphibolites, talcose rocks, metaconglomerates, marbles and calc-silicate rocks
iii. Older Granites which comprise rocks varying in composition from granodiorites to true granites and potassic syenite.

The Older Granites believed to be pre- syn- and post-tectonic rocks cut and intrude both the migmatite-gneiss quartzite complex and the schists and metaigneous rocks. They represent a varied and long lasting (750–450 Ma) magmatic cycle associated with the Pan-African orogeny. Subduction and consequent collision at the eastern margin of the West African craton (McCurry and Wright, 1977; Turner, 1989) produced extensive melting of the older rock suites resulting in the emplacement of the mainly calc-alkaline granitoids and basaltic intrusions. The Older (Pan-African) Granites include a wide spectrum of rocks varying in composition from tonalite and diorite through granodiorite to true granite, syenite and charnockite (Ajibade and Wright, 1989).

On the basis of field relationship, mineralogy and texture, Jones and Hockey (1964) have recognized three phases of the Older Granite suite; an early phase comprising closely intermingled gabbroic rock, dolerites, granodiorites and quartz diorites, a main phase, which comprises coarse porphyritic hornblende granite, syenite and coarse porphyritic biotite granite, and late phase comprising homogenous granite, pegmatite and aplite dykes. In the light of field and geochemical evidences, however, Rahaman (1989), Dada and Respaut (1989), Dada et al. (1995), Ferré et al. (1998, 2002) have refuted the retention of dolerite as integral part of the early phase granites as reported by Jones and Hockey (1964). These authors are of the opinion that the unmetamorphosed doleritic rock, which cross-cuts the granitoids (granites, granodiorites, charnockites etc.), is the youngest of the Nigerian Basement Complex rocks.

The Angwan Doka area is underlain by the Basement Complex rocks comprising migmatitic gneiss, schist, granodiorite and pegmatite dykes (Fig. 2). The granodiorite is by far the most abundant rock of the intrusive unit. It is medium-coarse grained, mesocratic and range from titanite-to biotite-muscovite-bearing, in composition. In the contact zone with the pegmatite, the granodiorite has been altered mainly through albitization and greisenization as revealed by microscopic evidences of intense ductile and brittle deformation (e.g. intense dynamic recrystallization of quartz, deformation twins on orthoclase, microkinking and deformation of micas, abundant myrmekites).

Age determination of the Older Granite suite by Rb–Sr whole rock and U–Pb zircon shows their emplacement to have lasted at least 630 to 530 Ma while the barren and mineralized pegmatites have been dated 562–534 Ma (Matheis and Caen-Vachette, 1983; Dada, 2006). This indicates that emplacement of the pegmatites occurred, mainly after the peak of the Pan-African orogenic event. The late Pan-African tectonic granites were proposed by Akintola and Adekeye (2008) to be the parental rock to the highly mineralized pegmatites in this area. In their opinion the granites originated from anatexis of undepleted mica-rich metasediments at depth, followed by a magmatic fractionation of the fluid-rich melt as it ascended reactivated ancient fractures.

1.2. General geology and petrography of the pegmatites

The pegmatites in the Angwan Doka area consist of discrete dykes and veins that commonly coalesce to form large N–S-trending bodies. The dykes display advanced fractionation, manifested by irregular spatial zonation of mineral assemblages, abundant rare metal mineral phases and gemstones. The main strike directions of the pegmatite dykes is N–S (0–25° from N) while the minor set occurs in the E–W (78–90° from N). The pegmatite dykes are of varying dimensions up to 2 m and more in width and from a few metres to about 1 km and sometimes more in length. The dip of the dykes is highly variable and changes from nearly vertical to flat lying and undulating with pronounced pinch and swell structures. The contact between the pegmatite and the host rock is generally sharp and characterized by narrow zone of tourmalinization. The volume and number of occurrences of the pegmatites are highest within the contact zone of the granitic plutons with the metasediment (schist) and progressively reduce, away from the zone till an almost complete lack of the pegmatite is recorded at greater distances from Angwan Doka.

As revealed in a mining pit where the N–S and E–W trending