First attempt to the petrogenesis and the classification of granitic pegmatites of the Itremo Region (central Madagascar)

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Central Madagascar is characterized by the presence of a series of pegmatite fields rich in gem-bearing and rare-element pegmatites (e.g. Pezzotta, 2001). In a tectonic unit known as the Itremo Group, pegmatites are characterized by rather unique geochemical and mineralogical features, such as a large quantity of danburite formed at the magmatic stage, and a variety of rare boron-rich and borate minerals (Simmons et al., 2002, Pezzotta et al., 2004). For studying the petrogenesis of such unusual intrusives, it is necessary to consider the Neoproterozoic geologic history of the crystalline basement of Central Madagascar, which represents an axial portion of the Neoproterozoic East African Orogen.

The geologic reconstruction reported here below has been elaborated trough the study of the available geological maps of the area, a series of new structural, petrological, geochemical and geochronological data reported in recent literature, and the results of field works of the author.

Pegmatite fields in Central Madagascar are distributed over a large area of about 75.000 square kilometers (limited N-E-S-W by the areas respectively of: Itasy, Ambositra, Fianarantsoa, Betsiriry) and they are hosted in two main tectonic domains: the *Antananarivo block* (Collins, 2000) characterizing the northern and the eastern parts of the area, and the *Itremo sheet* characterizing the remaining part of the area, composed by an upper anphibolite to granulite facies unit structurally underlying a greenschist to anphibolite facies metasedimentary unit (Moine, 1974, Fernandez et al., 2003). Moreover, some pegmatite fields probably extends to south-west up to the high-grade tectonic unit known as Southern Madagascar (Martelat et al., 1997).

Crystalline basement of central Madagascar is characterized by two main magmatic cycles, an older one of early Neoproterozoic age (790-800 Ma), forming a north-south belt 450 km long and composed by large gabbros and sienite intrusions that show suprasubdaction-zone geochemical affinities (Nédélec et al., 1995, Handke et al., 1999), and a more recent one of late Neoproterozoic age (570-540 Ma) forming sparse sienite and granite plutons (Handke et al., 1997, Kröner et al., 2000), emplaced in an extensional tectonic regime. The magmas of the older magmatic cycle are coeval with a significant regional metamorphic event which produced medium to high grade metamorphism in the rocks of the Antananarivo block. Nevertheless, this tectono-magmatic event generated mostly contact metamorphism and probably very low-grade regional metamorphism in the metasedimentary rocks composing the so called Itremo Group characterizing east Itremo (Fernandez et al., 2003).

During such early Neoproterozoic tectono-magmatic event, the metasedimentary sequence of Itremo Group experienced its first phase of deformation (D1) and it was transported toward E to NE into a fold-and-trust belt on top of the migmatitic rocks of the Antananarivo bloc. The late Neoproterozoic granites of the second magmatic cycle truncate the first phase structures in the Itremo Group (Fernandez et al., 2003) and very likely are coeval with a second phase of deformation (D2), associated with thermal metamorphism (upper-greenshists to low anphibolite facies), forming large scale N-S trending folds with steeply dipping axial planes, and affecting respectively: the fold-and-trust belt, the structurally underlying units, and the early Neoproterozoic intrusives. Unfortunately, very few geochemical and structural data exist in literature concerning such younger granites. Moreover, in the available geological maps of the area, a certain confusion exist between the mapping of the products of the two different magmatic cycles. Indeed, the more or less sin-kinematic emplacement of the intrusives of both magmatic cycles and the consequent frequent magmatic foliation of the granitoids, the typical not homogeneous partitioning of the strain during metamorphism, and the poor exposure of the outcrops due to the deep weathering, are among the main difficulties in correctly mapping (and consequently correctly genetically classifying) such rocks. Depending on the data available in literature and on the author field structural observations and mapping it seems confirmed that granitic pegmatites of central Madagascar are related to the second magmatic cycle.

Pegmatite fields in central Madagascar, despite they are related to the same magmatic cycle, they show great structural, geochemical and mineralogical differences between those occurring in the Antananarivo block, those in the medium to high grade rocks of the lower unit of the Itremo sheet, and those in the low grade metasedimentary rocks of the Itremo Group. Probably, the most significant similarity between all such pegmatites is a general “mixed” geochemical character between the two (NYF and LCT) geochemical pegmatite families of the P. Černý’s classification.

In the Itremo Group, distinctly different pegmatite populations are intruded (1) in ≈800 Ma gabbroic rocks, (2) in quartzites, and (3) in marbles.

(1) In pegmatites hosted in gabbros, rather no reaction between pegmatite and host rock is evident, except for a narrow band of fluids alteration at the exocontacts. Dikes form large irregular masses, frequently filling network of fractures of the hosting rock. The border zones contain perthite (mesoperthite), graphic quartz-perthite aggregates, and tapering crystals of black mica (mainly annite). Very coarse grained pegmatite cores, with masses of gray to pink quartz, contain large prism of deep-blue to greenish beryl. Vivid-green amazonite is locally present. Local concentrations of accessory phases include: zircon, allanite, monazite, ferrocolumbite, betafite-pyrochlore, ilmenorutile, fersmite, samarskite, fergussonite, etc. A typical pegmatite of such group is the Tsaramanga pegmatite, close to the Mahaiza village.

(2) Pegmatites in quartzites seem to be concentrated mostly at the axial plane of the megascale tectonic folds characterizing east Itremo. Because of the minor economic interest of such pegmatites, mining activities are rare and only limited exposures are available. Such pegmatites seem to have greatly reacted with the host rock with the formation of extensive “reaction zones” characterized at the exocontacts by an increase of the quartzite grain-size, and the local formation of abundant K-feldspar, black tourmaline (schorl-dravite with occasionally significant Ca contents), and locally white mica. Such “reaction zones” can extend in length up to one hundred meters, with local pegmatitic pods characterized by large quartz masses. Quartz-tourmaline-danburite veins can be associated to “altered” quartzites. Mineralizations are scarce and they include greenish and yellow beryl, rare chrysoberyl, and mostly ilmenorutile among Nb-Ta minerals. Occasional high-geochemically evolved LCT concentrations allow the formation of low quality green-red elbaite-liddicoatite crystals and Li-bearing micas.

(3) Rather all the most important gem-bearing pegmatites of the Itremo region are hosted in marbles. Such pegmatites are by far the most numerous in the area. The main pegmatite fields are, from E to W: Sahatany, Tetezantsio-Andoabatokely, Manapa, Ampanivana, Lohandany, Anvohitrakanga, Anjanabonoina (e.g. Pezzotta, 2001). A further pegmatite field occur south in the Ambalamahatsara area. The distribution of the dikes seem not to be directly geometrically related to the (570-540 Ma)-granitic intrusions, nevertheless, plutons, stocks and dikes of such granitoids are sparsely distributed in the basement of all east Itremo. Larger dikes show evidences of emplacement in rather active tectonic environment.

Close to granitic intrusions, some pegmatites hosted in marbles show typical NYF geochemical features (e.g. the Imalo pegmatite), containing in the core zones abundant deep-azure-green amazonite, zircon, allanite, monazite, ferrocolumbite, betafite and phenakite. The abundant presence of boron is shown by abundant schorl-dravite and danburite.

A second category of pegmatites in the marbles is represented by rather large dikes with “mixed” LCT-NYF features, containing miarolitic, high-geochemically evolved core zones rich in LCT minerals (elbaite-liddicoatite, Li-rich micas, spodumene, hambergite, pink-beryl, microlite, etc.), and portions in which typical NYF minerals are present (amazonite, betafite-pyrochlore, zircon, monazite, allanite, phenakite, etc.). An important pegmatite representative of such category is Anjanabonoina (De Vito et al., 2005).

A third category of pegmatites in marbles is represented by rather narrow, locally miarolitic dikes (from a few centimeters up to a few meters wide) extending up to many hundred meters in length, with an unusual very high geochemically evolved LCT mineralogy, characterized by extreme boron enrichment, as confirmed by the presence of danburite, tourmaline-group minerals, "rhodizites", Ta-Nb borates, dumortierite, hambergite. "Comb-like" textures of many minerals including tourmaline-group, K-feldspar, and danburite occur at the contacts with the hosting rock. Such pegmatites were classified in Pezzotta (2001) in a new category called "Danburite Subtype".

Pegmatites in marbles show locally significant reactions, and very likely significant contamination, with the hosting rocks. Indeed, skarn-minerals such as grossular, pyroxenes and amphiboles (unstudied), green micas, locally together with (Ca-rich)-schorl-dravite and apatite, are present at the exocontacts.

It is difficult to propose a "classic" genetic model for pegmatites occurring in the rocks of the Itremo Group. Even if many more mineralogical, structural, geochemical and isotopic studies are required, a possible "partially not conventional" genetic model can be summarized as follow:

- (570-540 Ma)-granitic liquids, of the NYF geochemical family, were emplaced under an active tectonic environment in a sedimentary sequence experiencing its first significant thermal metamorphism (upper green-schists to lower anphibolite facies).
- Relatively hot crustal thermal regime allowed to pegmatitic liquids to migrate at rather long distances from their parent granites. Pegmatites were preferentially emplaced along axial planes of megascale tectonic folds in quartzites, and in rocks characterized by brittle, or rather brittle, reology such as the gabbroic masses and mainly the marbles .
- Abundant boron-rich fluids of LCT geochemical signature, liberated by the sedimentary sequence experiencing metamorphism, interacted saturating and contaminating at various degrees the NYF pegmatite liquids expulsed by the crystallizing granitic masses. Abundant B concentration in the protholith of the Itremo Group is confirmed by the presence of large quartzite volumes rich in abundant accessory schorl-dravite and dumortierite (locally associated with lazulite).
- The nature of the hosting rocks significantly conditioned the crystallization of the dikes. Gabbros "entrapped" pegmatitic melts preventing further contamination during crystallization. Quartzites resulted very permeable to fluids allowing great interaction and contamination, bringing pegmatitic liquids to very aluminous compositions. Marbles produced very significant Ca contamination and a chemical quench of the pegmatitic liquid due to the reaction with the wall-rock, with the precipitation of locally very abundant tourmaline-group minerals and danburite, more or less associated with dumortierite. Deep contamination of pegmatitic liquids with boron-rich, LCT-fluids of metamorphic origin, expulsed by the metasedimentary sequence, gave to pegmatites a LCT geochemical overprint.
- Skarn formation in the exocontacts are related to the presence of fluids during pegmatite crystallization which allowed geochemical mobility and the activation of mineral reactions.
- The active tectonic regime, responsible of multiple movements of the faults/fractures along which the pegmatites were emplaced, generated in larger dikes a complex process of crystallization under fluctuating closed and open system conditions.

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