Contrasting Styles of Metamorphic to Metasomatic Deposits of Gemstones in Cabo Delgado, Northern Mozambique

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http://doi.org/10.29227/IM-2024-01-02

Submission date: *14.2.2023* | Review date: *5.4.2023*

Abstract

From a conceptual point of view, in some ruby and garnet deposits of the Lalamo Supergroup – Cabo Delgado Nappes Complex, Northern Mozambique – the structural control of the primary mineralization seems to be spatially and geochemically related to the genesis of calcsilicate rocks, also with gemstones. Two main locations, with contrasting paragenesis, were studied in detail – Miteda area and Micute to N'Djekwa sector. Structural and paragenetic analysis, departing from high-resolution cartography, fabric microanalysis, SEM microscopy and mineral identification by X-ray diffractometry, were used with a major incidence in outcrops and small-scale mine diggings. Regional Neoproterozoic formations, especially its metacarbonate members, host Mg, B - rich skarns, bearing dravite and B-Mg-calc-silicate gemstones, especially in Micute and N'Djekwa area. Following the composition of the probable lithological precursor, these minerals, consistently, reveal a geochemical Mg - B signature that could have been inherited from an evaporite type ancestor, inter-stratified with carbonate rocks in the protolithic Lalamo sequence. The focus of hydrothermal circulation in multistage shear zones is invoked as the main pathway to interpret the complex mineralization observed in Miteda. In this case, the structure of a corundum + garnet major spot is coherent with a pull-a- part dilation associated with sinistral shear. There is a relation between red color saturation of ruby and the content of Cr in corundum. Cr can be leached from the meta-ultramafic host-rocks as a byproduct of desilication. Calcsilicate metasomatism could trigger Si sequester, producing metamorphic desilicated fluids. The focus of hydrothermal circulation in shear zones is invoked as the main pathway for the entrapment of metamorphic and metasomatic gem deposits. These occur in corridors of anomalous host-lithologies and vein swarms where peraluminous paragenesis are located inside highly modified meta-ultramafic or metacarbonate rocks. Skarn like lithologies result from reaction with a sedimentary carbonate protolith and gem deposition is mainly metasomatic. Veining affecting metaultramafic sequences of amphibolitic to granulitic facies show occasional, metasomatically affected, eclogite. For the contrasting styles of deposits represented in Micute – N'Djekwa and in Miteda, although the corresponding paragenesis are separated in space, their deposition can be situated in a conceptual model characterized by a geochemical interdependency and time proximity.

Keywords: gemstone, minerals, deposits, cabo delgado, northern mozambique

Introduction

In the last decade the exploitation of rubies in Cabo Delgado and Niassa provinces, in Mozambique, has reached significant values, both in terms of the number of regular companies and informal prospectors involved, as well as, in the monetary amounts that characterize local and international transactions of these gemstones. It turns out that, in most cases, mining works focus on the so-called secondary deposits, alluvial placers being considered as the most interesting ([1, 2]). Nevertheless, some companies begin to devote some attention to primary deposits. Recent field studies of the small-scale mining in the Messalo river basin, revealed the presence of ruby and a vast diversity of other gemstones, which primary genesis, hypothetically, depend on atypical processes, having in common, the structural relation with strike-slip and over-thrust shear and the geochemical dependency on acidic metasomatism of mafic or carbonate protoliths. Two representative locations were selected for the study of its mode of occurrence: Miteda, for peraluminous gemstones, Micute – N'Djekwa for calcsilicate noble minerals. Both sites are located in the supergroup or complex of Lalamo (Fig. 1), which is a suite of Neoproterozoic rocks, corresponding to gneissic-migmatitic members, distinguished by lithology, metamorphic grade, structure and age. Often the contacts are of tectonic type and were established till the Pan African Orogeny. The main lithologies correspond to mesocrustal components. The metamorphic features vary from low grade to amphibolite and granulitic facies [3].

In Lalamo the widespread gneisses are predominantly felsic to intermediate. They occur at lower tectono-stratigraphic levels but were segmented, indented or carried over other formations. Some representative lithotypes are discriminated in Fig. 2. The contiguity of these formations is attributed to tectonic transport and carriage overlap.

Departing from the ideas of [1] and [4], [5] presented a synthesis of the main conceptual models that may be involved in the origin and structural control of primary mineralization of peraluminous gemstones (mainly ruby and garnet), and listed some other noble materials, which could be obtained, as byproducts, from the ruby and garnet mining.

As a main goal the present study considers the multiplicity of formations hosting the different gemstones and enhances the major features of the structure and paragenesis of the mineralized spots, which may contribute to enlarge the set of data and mechanisms invoked to understand the link between hiperaluminous and calcsilicate deposition of noble minerals.

Materials and Methods

Starting from the above mentioned, terrane organization (Fig. 1), fieldwork was dedicated to the detailed structural and paragenetic analysis of gem occurrences, considering samples of noble minerals, carrier mineral assemblages and host rocks. These samples were studied by optical (polished thin sections) and electron microscopy (SEM) and x-ray diffractometry and the noble species were subjected to carving, polishing and stone enhancement assays to confirm their gemmological adequacy. In the case of pink to red corundum, Cr_2O_3 contents, were estimated by electron microprobe analysis, only dedicated to this oxide, using standards of a known Cr-rich ruby and chromite.

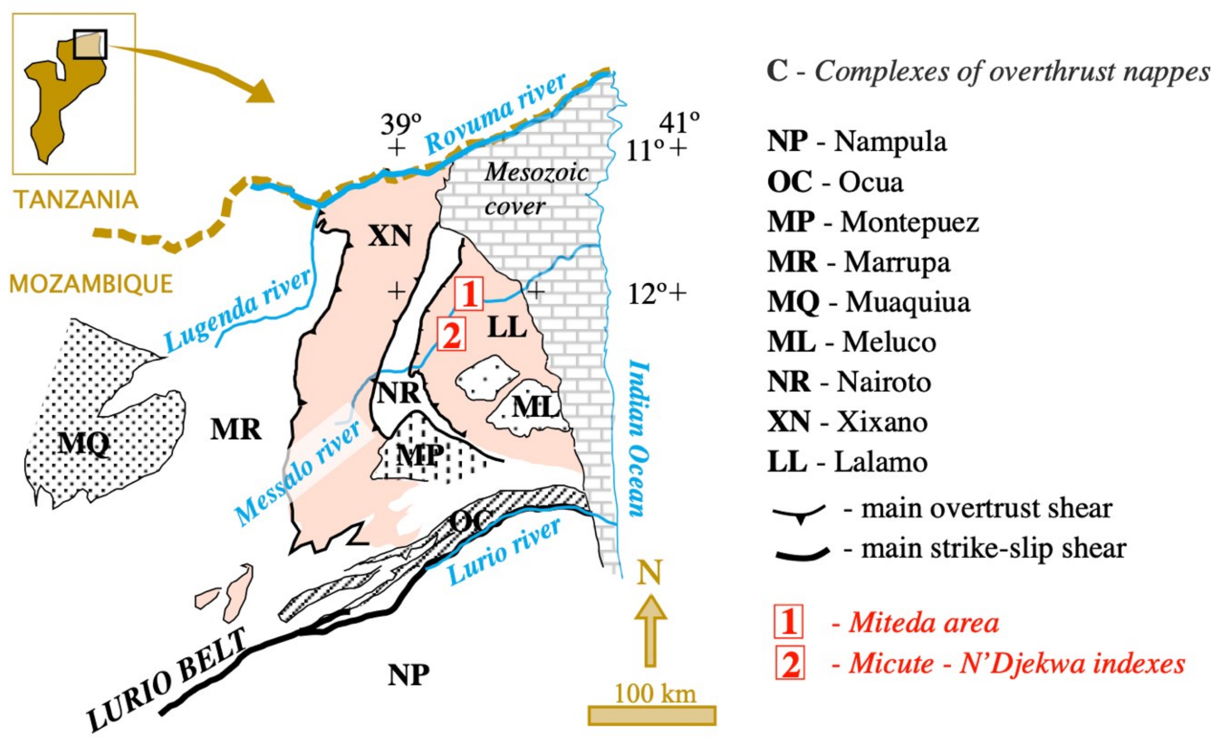

Fig. 1. Paleogeographic and tectonic organization of the Cabo Delgado Proterozoic terranes (modified from [6] and [7]) – Location of the main gem-deposits considered in the present study – Miteda (1) and Micute-N'Djekwa (2).

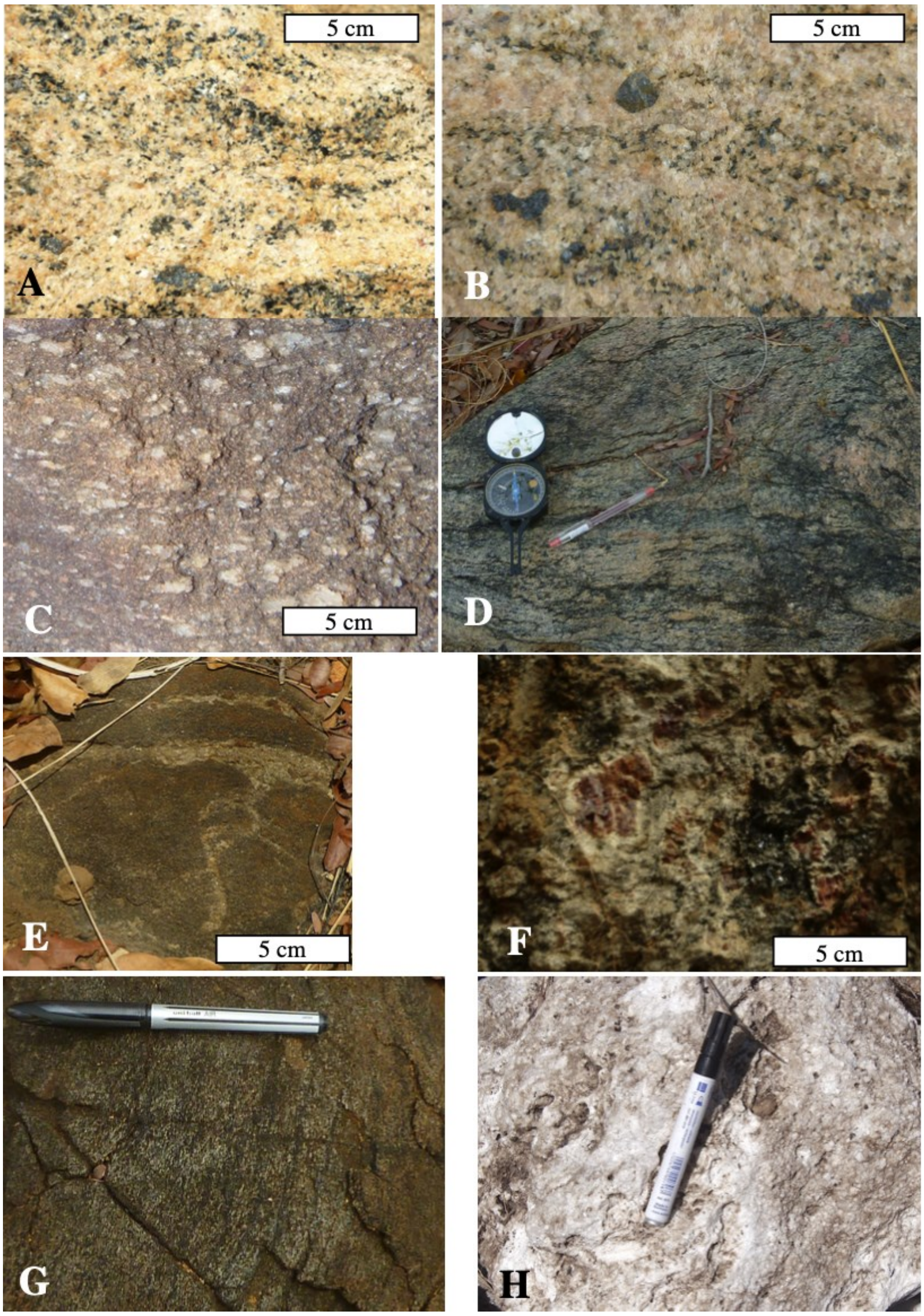

Fig. 2. Main lithotypes of the Lalamo complex that outcrop at Miteda and Micute to N'Djekwa areas. A – alkaline gneiss with graphite; B - alkaline gneiss with magnetite megacrysts and some enderbitic lenses; C - sillimanite hyper-aluminous gneiss, strongly foliated, with some cataclastic domains; D – meta-ultramafic rock with intermediate plagioclase and orthopyroxene; E – granulitic member with segregation veins of amphibole + plagioclase and garnet megacrysts; F – eclogitic type rock, associated with metamorphism and metasomatism (strongly related to ruby + rodholite garnet mineralization in biotitic lenses); G – amphibolite with foliation defined by hornblende and fracture controlled, metasomatism, with associated tourmaline; H – siliceous meta-carbonate rock tremolite-rich, with some lenses of magnesite plus dolomite and also fluorite.

Results and Discussions

The base resources of gemstones that were confirmed in the region include minerals of dubious nature present in secondary deposits but with uncertain primary source. Nevertheless, the survey of the most probable primary - secondary linkages, allowed to attribute the hypothetical origin of these gem clasts to metasomatic skarn outcrops and mafic metasomatic rock-products, at the transition granulite – eclogite – amphibolite.

From the detailed inspection of small-scale pits and trenches, we deduce that the gem mineralization is quite heterogeneous. In the case of Micute-N'Djekwa there is a tendency for their dispersion in the silicate-rich meta-carbonate rock and occasional concentration in typical skarn horizons, currently showing dravite tourmaline, Ca, Mg, Fe - varieties of garnet, epidote, kornerupine and spinel. The most prevalent gemstones correspond to dravite tourmaline. In the case of Miteda there is a tendency for a concentration of gem corundum (occasionally, ruby) and rodholite garnet in the biotite-rich product of recurrent metasomatism departing from inner-gneissic mafic to ultramafic formations.

Results for Micute to N'Djekwa

Some specimens of corundum and chrysoberyl were collected from amphibole rich formations that occur close to the main skarn outcrops, which have been the object of informal mine diggings. However scarce, its presence can be used to stablish a paragenetic link with the productivity of the Miteda deposit, much more developed in what concerns these hyper-aluminous minerals.

Ilvaite, axinite, scapolite, holmquistite, titanite and spodumene are present, especially in Micute, suggesting a defined relation of the metasomatism with a thin pegmatite that crosscuts the skarn-like lithologies.

Fig. 3, concerning N'Djekwa, synthesizes the internal structure and paragenesis of the banded skarn formations, typically laying between metacarbonate rocks and gneiss to migmatite, under the coverage of glacis or placer type deposits. It is apparent the transition stage between progressive and regressive stages of a typical skarn generation. The concomitant metamorphic peak, materializes a threshold suitable for the main gemstones trapping in voids related to shear (Fig. 4).

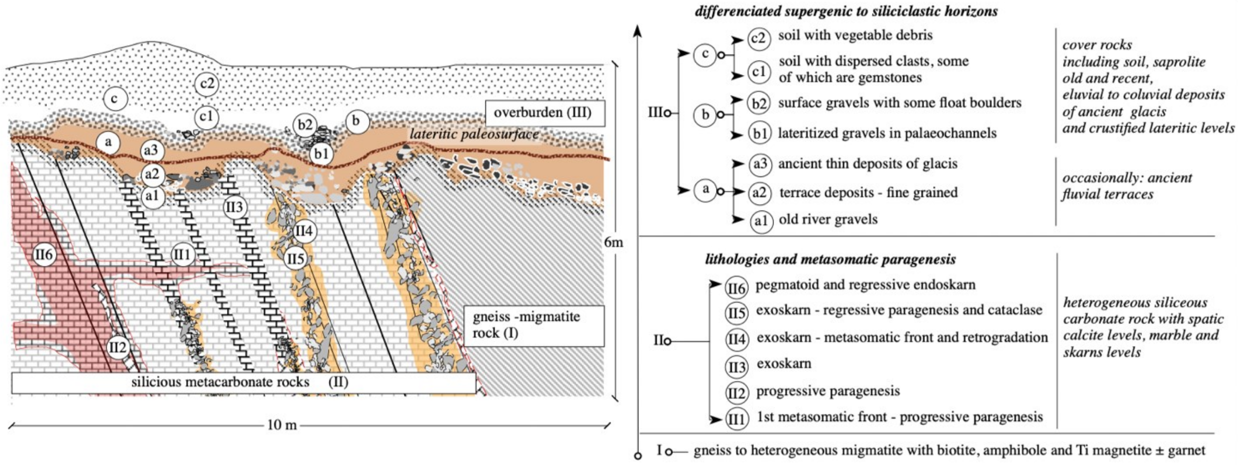

Fig. 3. Holistic sketch-profile for a NE-SW traverse, deduced from trenches representative of N'Djekwa and Micute - geometric analysis of structure and paragenesis of the main calcsilicate occurrences.

Fig. 4 also enhances de multistage character of the deposition of gem minerals. Hydrothermal alteration and precipitation focused on shear zones and associated dilatational volumes are critical mechanisms, not only for the deposition but also for the maintenance of the gem quality, after the deposition.

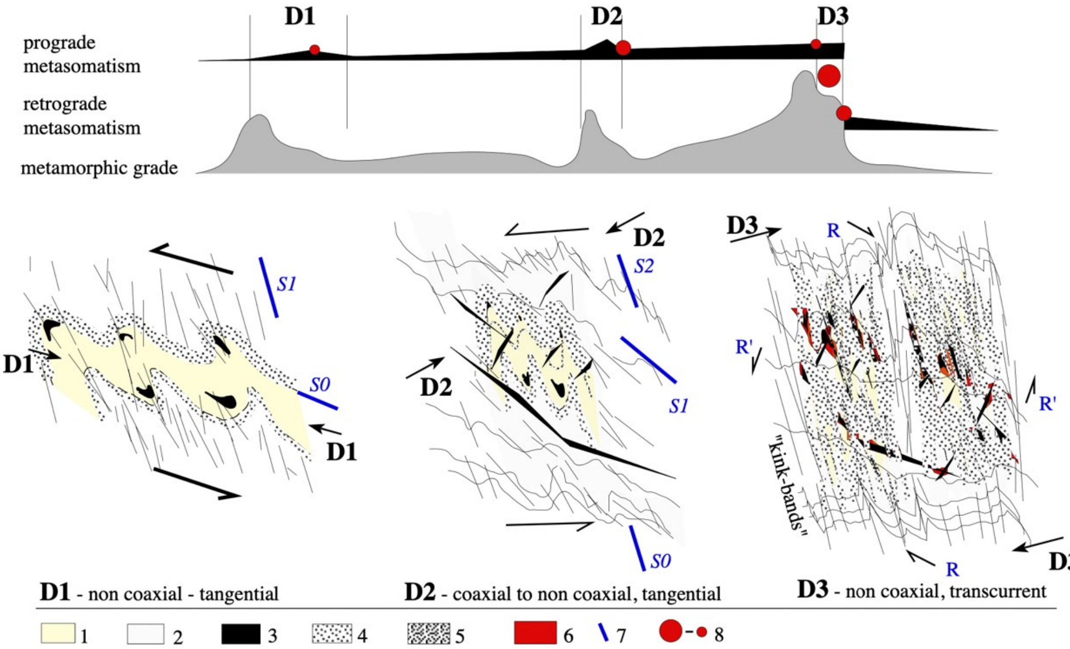

Fig. 4. Conceptual model for the generation of Mg - Al - B - calcsilicate gemstones – dependent on fluid / rock interaction in the presence of tangential to transcurrent shear deformation. 1 – calc- magnesian silicious metacarbonate rock; 2 - magnesian calcsilicate rock; 3 - dilatational environments, occasionally miarolitic; 4 - masses of deformed inosilicates and phyllosilicates with newly formed blasts; 5 - cataclasite and mylonite; 6 - deposition sites for noble minerals; 7 - metamorphic surfaces; 8 - probable chronological position for the genesis of gemstones, with the relative importance, qualitatively indicated by the diameter of the representative circle.

From a geological point of view the most interesting mode of deposition is the miarolitic precipitation in contaminated pegmatites and dilatational volumes associated with shear, inside true skarn lenses; also, interfaces and reaction fronts are good reception sites for typical gem minerals resulting from metasomatic reactions.

Dravite is the gem with the greatest diversity of locations, and its hydrothermal concentration in dilatational sites is likely to be the most favorable for the development of larger crystals with the best gem quality.

From these observations stands out the importance of shear displacement to the opening of empty porosity for fluid percolation followed by voids occlusion and trapping of noble crystalline products (Fig. 5). Metasomatic reactivity results from the interaction of acidic fluids with B-enriched metacarbonate rocks. It is expressed as products enriched in Al, B - silicates and the original Mg excess of carbonate protoliths reaches the terminal calcsilicate sequence in the form of dolomite and magnesite rich layers and veins.

grossular (hessonite) kornerupine epidote spinel tourmaline (dravite)

Fig. 5. Gem minerals deposited in tremolite-rich skarns, essentially in reaction fronts, occurring as in equilibrium final porphyroblasts. Size interval of the figured gem blasts is 0.5 to 2 cm.

The genesis of Al, B - silicates must be attributed to the particularities of the primary composition of the protoliths, the substituted calcsilicate facies and the process of evolution, limestone - marble – silica rich metacarbonate - skarn. The substitution between Mg and Fe, as well as Al, Si and B in complex silicates is determined by the substituted minerals (eg magnesite and pyroxenes) and is expressed in the tourmaline (product) and later silicates.

Kornerupine is a typomorphic mineral, characteristic of deep bimetasomatic skarns. Kornerupine and tourmaline probably crystallize during a late stage of the evolution of boron mineralization, in contact with the sequences of magnesian carbonates and desilicated Al-rich rocks. There is also a good potential for the occurrence of garnet deposits hosted in this type of skarns and siliceous marbles, especially in high-grade metamorphic crustal domains, and thus also in this case.

Results for Miteda

From the combined approach, cartography and petrology, it was deduced that Miteda occurs in the more amphibolitic gneisse terranes, being a spot positioned inside a prior mafic to ultramafic protolith (Fig. 6).

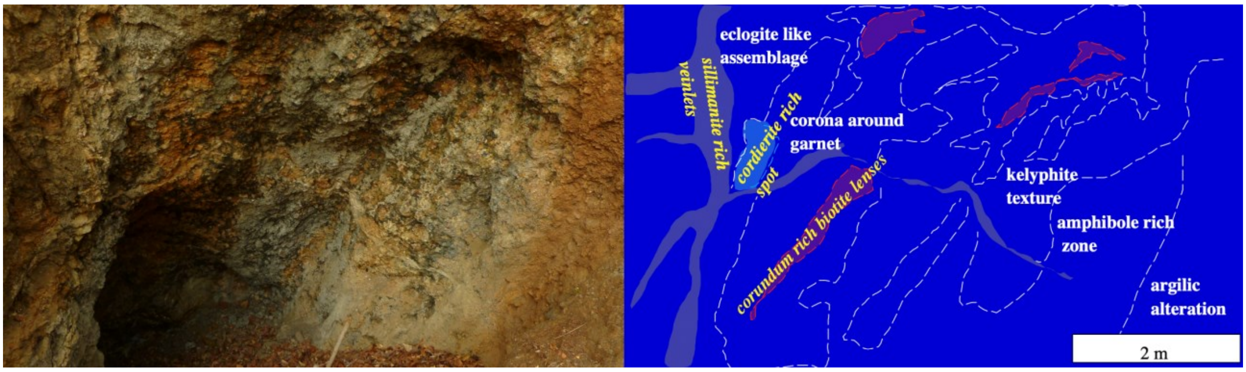

Fig. 6. Miteda corundum – rodholite – iolite spot as a prior ultramafic volume that acquired an inner-zoned lenticular shape in response to strike-slip shear and associated dilation pull-a- part.

Metamorphic paragenesis typical of the granulitic facies are widespread, with the variations of the stability fields of $Al_2 Si O_5$ being located between sillimanite and kyanite. The metamorphic P / T stability field admits a granulite - amphibolite transition, due to temperature and lithostatic pressure variations in the sillimanite field - and a granulite - eclogite transition, more dependent on pressure variations - sillimanite => kyanite, transition. This might be facilitated by increased stress, related to progressive shear (tangential to transcurrent) and by fluid circulation focused on the same deformational corridors that control regional to local metasomatism.

From paragenetic analysis of the regional metamorphic rocks it emerges a pattern of regional metamorphic evolution, showing the following trends: A - pressure and temperature increase that allows the transition of the monovariant boundary between amphibolite facies and granulite facies - regional metamorphism in the sillimanite stability field; B - pressure increase, in conjunction with fluid circulation, originating an eclogitic transition from the granulitic facies (Fig. 7); the transition seems to be controlled by shear corridors with cartographic expression. Such corridors may include tectonic accidents and shear zones ductile to fragile, both tangential and transcurrent. This conjugated structures, control a dynamic metamorphism in the transition from sillimanite to kyanite stability field to which metasomatism is also associated.

At the same corridors, siliceous magnesite marble, with fluorite-rich layers and skarn lithologies, similar to those from Micute and N'Djekwa, seem to be related to the same deformation stages.

The most valuable noble minerals detected were translucent, cabochon-grade, rubies and pink-sapphires (Fig. 8) and also transparent, in various shades of red, almandine - rhodolite - pyrope garnet and iolite variety of cordierite. Typical rubies, with the higher concentrations of Cr_2O_3 (as in Fig. 9), are rare. Apparently, the more adequate gem colors (intense red) coincide with varieties with higher contents of chromium in the crystal lattice and without chromite inclusions or overgrowths.

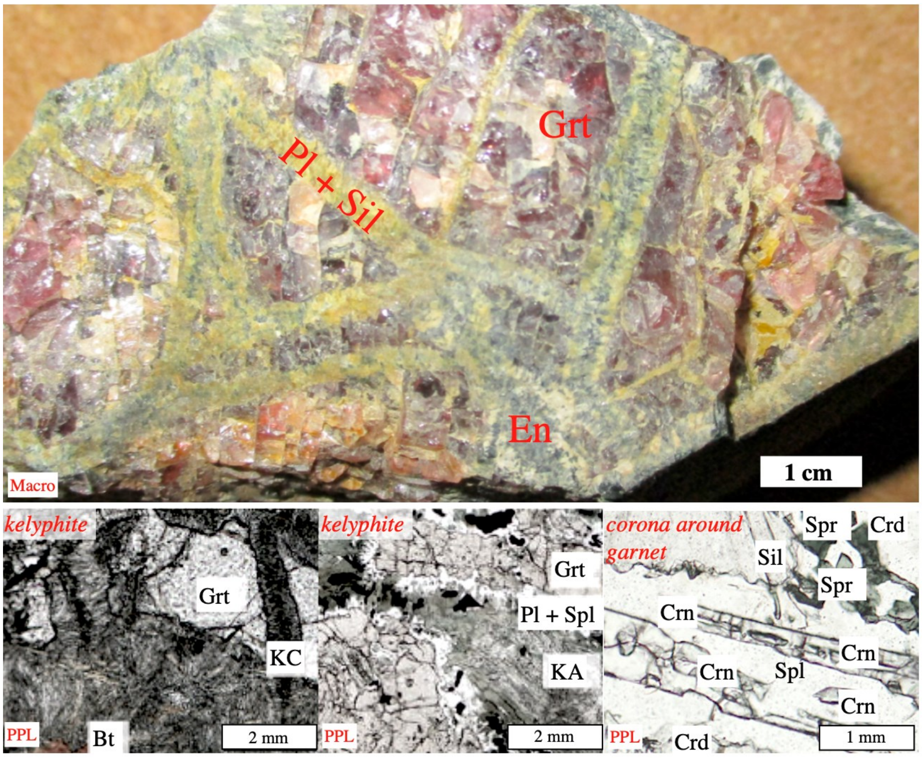

Fig. 7. Textural expression of some metamorphic reactions in eclogite type lithologies - keliphytic to coronitic intergrowths of garnet and pyroxene. Macro – macroimage; PPL - transmitted light micrographs obtained in plane-polarized light. Grt – garnet; En - enstatite; Sil - sillimanite; Bt - biotite; PL – plagioclase; Spl – spinel; Spr - sapphirine; Crd – cordierite; Crn – corundum; *KC* - kelyphite coronas or reaction laths with major enstatite; *KA* - keliphyte fine assemblage with diopside + albite + omphacite.

A B C

Fig. 8. Corundum varieties of Miteda. A – typical texture that includes porphyroblasts of pink corundum in a biotite metasomatic rock resulting from the latest stage reactions – larger side of photo = 10 cm; B – predominant colors and "cabochon" assays - larger side of each photo = 3 cm; C – the same "cabochon" in transmitted light incidence and in short wave ultraviolet incidence - larger side of each photo = 2 cm.

Conclusion

In both sites studied, mineralized host-rocks occur along shear corridors. Special lithologies related to the presence of the diverse types of gemstones are: coronitic – kelyphitic metasomatic eclogites and lenses of biotitites with some flogopite; tremolite skarns and magnesite calcsilicate rocks. Mineralogy of gemmological interest includes: garnet (rhodolite and pyrope), corundum (ruby and pink sapphire) and cordierite (iolite), in Miteda; dravite, kornerupine, epidote, hessonite and spinel in Micute and N'Djekwa.

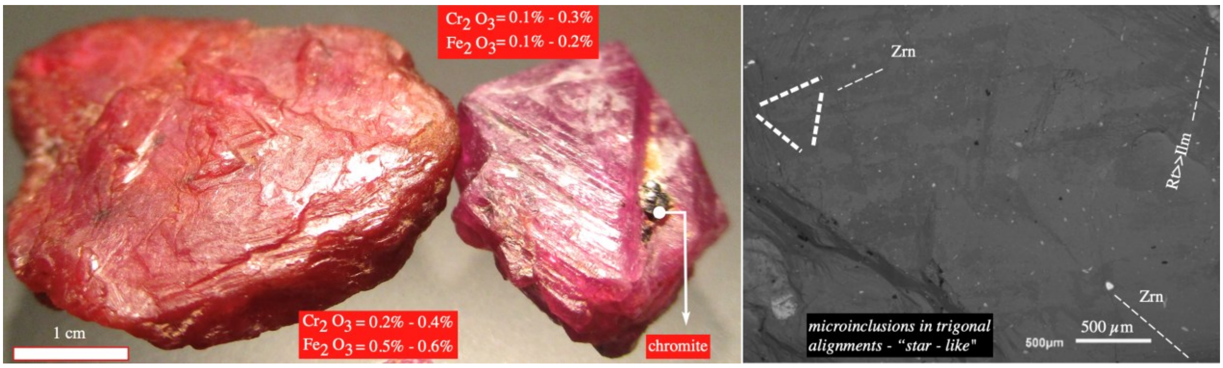

Fig. 9. Results of electron microprobe analysis for Cr content in polished slabs of specimens similar to those present in the left photo and back-scattered electron image of a Cr-rich slab showing oriented inclusions of rutile (Rt), zircon (Zrn) and ilmenite (Ilm) but without chromite (right photo).

Considering the observed typomorphic minerals, the estimated peak of metamorphism related to gem deposition could be situated at the reference conditions of T ± 630 °C and P ± 5.5 kb. These are consistent with the development of the metamorphic facies, amphibolitic to granulitic. In the studies of petrofabric and also in geological recognition in the field, it was possible to discriminate elements of at least three deformation phases in relation to the prograde and retrograde metasomatic textures. This combination of processes would have captured the noble minerals.

The case of Miteda reveals a new structural and paragenetic scenario where it is necessary to consider the strict spatial and probably, genetic relation of productive shear with eclogite transition in high-grade metamorphic terrenes, with a preferential hosting of the corundum gemstones in the transtensive or transpressive spots of the shear zones adjacent to the eclogitic transition.

The desilication of fluids that generate the ultra-aluminous signature may have been caused by loss of silica in the same metasomatic reactions that also produced calcsilicate minerals - in contact with metacarbonated rocks or in contact with metaultramaphic rocks, hosted in granulitic sequences. Fluids and melts predictably segregated near the contact of this rocks are more deficient in silica when compared to fluids that would be secreted from normal granulitic metamorphic sequences. The more or less coronitic to kelyphitic eclogitic facies, which are closer to the biotitic micaceous schlierens, present also the rhodolite with the best gem quality. The association ruby + rhodolite + iolite is indicated by the lithological guide, biotitite (Fig. 10 A). The same regional Neoproterozoic suites in Micute and N'Djekwa region, especially its calcsilicate members (tremolite-rich), host dravite (Fig. 10 B).

As in Miteda the metasomatic / metamorphic layering expressing the gem content, show structural trends coherent with the same deformation stage. Once again, the focus of hydrothermal circulation in multistage shear zones is a main pathway for the follow up of the diverse mineralizations.

There is a relation between red color saturation of rubi and the content of Cr in corundum. Cr could have been leached from the meta-ultramafic host-rocks as a byproduct of desilication.

At the vicinity of Miteda a meta-carbonate level also exists holding tremolite + calcite + fluorite + magnesite, suggesting an evaporitic ancestor.

It seems credible the existence of an evaporitic signature for the carbonated protoliths, considering the mineral-chemical composition biased to a magnesian and borated geochemical inheritance. The prevalence of late B and Mg gemstones, including dravite-uvite series, is consistent with this hypothesis for at least some of the protoliths of the Lalamo sequence.

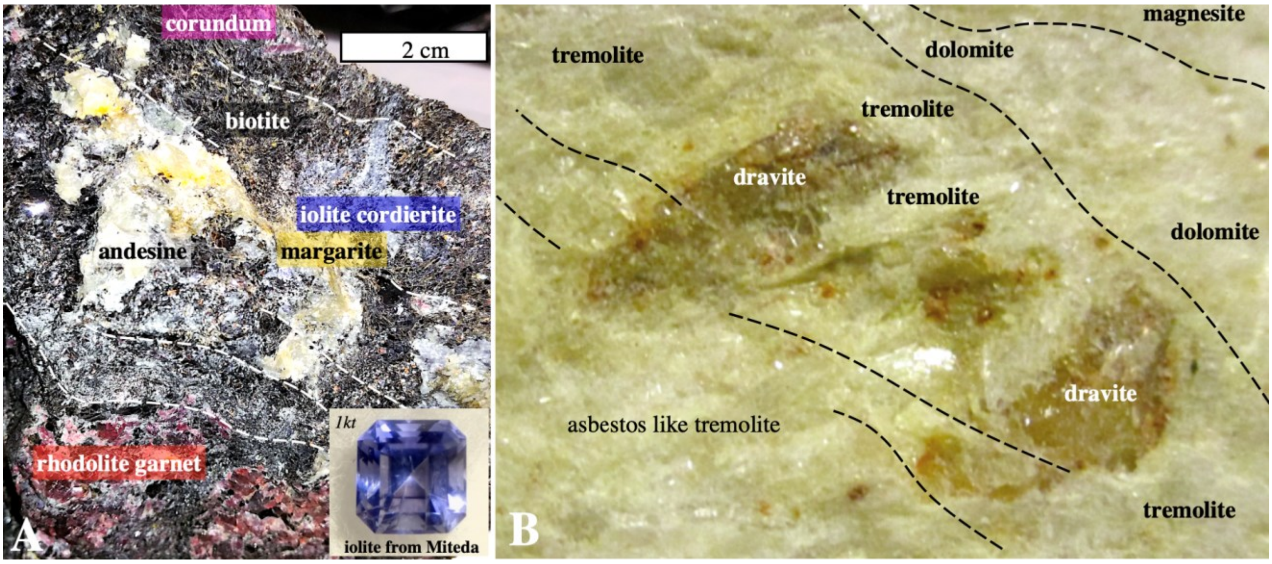

Fig. 10. Layering of the different mineral assemblages holding gemstones. A - zoning and layering of Miteda paragenesis (faceted colorful iolite in inset). B – zoning and layering of Micute – n'Djekwa paragenesis with dravite situated at the metasomatic front between Mg-carbonates and tremolite.

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