International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2020): 7.803

Origin and Emplacement Conditions of the Dibilo Lithiniferous Mineralization (Liptako, Western Niger)

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Abstract: ***The Dibilo Lithium pegmatites are located in the Téra - Ayorou pluton, 4 km from the contact zone with the Diagorou - Darbani greenstone belt in the Niger Liptako province (Northeastern part of Man Shield, West African Craton). The main objective of this study is to specify the main geological characteristics of the lithium mineralization in the Dibilo pegmatites and to propose a metallogenic model of their emplacement. The methodology used consisted of fieldwork, laboratory work, and the use of discriminating reference diagrams. The Dibilo lithium pegmatites can be classified as Rare Element (RE), complex type, spodumene sub - type, and Lithium - Cesium - Tantalum family pegmatites. Four (4) types of pegmatites have been identified: (1) sterile pegmatites; (2) Li, Ta, W pegmatites; (3) Mo, Ta pegmatites; and (4) Mo, Ta, W, Be, Au pegmatites. Lithium mineralization occurs mainly as spodumene and secondarily as lepidolite and holmquistite. This lithium mineralization could result of a residual magmatic liquid from the fractional crystallization of the adjoining biotite - granite which corresponds to late magmatic liquids could result from the magmatic differentiation of the granodiorites. These granodiorites are thought to be the product of partial melting of metasomatized oceanic crust in the "lower amphibolite" facies, in an oceanic subduction context.***

Keywords: Pegmatites, Dibilo, NigerienLiptako, Spodumene, Fractional Crystallization

1. Introduction

Rare element granitic pegmatites of the LCT type have been widely studied throughout the world [1]– [4], [4]– [7], [7]–[16], the most important deposits are exploited in Canada [17], Zimbabwe [18], Australia [19], Mozambique, Namibia, Spain, Finland and China [20]. The most complete classification of granitic pegmatites is that provided by [21]. This classification of pegmatites is based on mineralogical, geochemical, geological (depth of emplacement, degree of enclosing metamorphism), and economic criteria.

In Niger, four (4) lithiniferous showings have been identified by [22]– [24]in the Precambrian of the Nigrien Liptako, precisely in the Dibilo sector, Téra zone. These showings are hosted by pegmatite veins, near the western contact between the Diagorou Darbani greenstone belt and the Téra - Ayorou granitic pluton. Only the Dibilo showing appears to be of economic interest because of its high LiO_2 content and the extent of the outcropping mineralized zone. Since the reconnaissance work of [24], no detailed study has been carried out on the geological context and typology of the Dibilo lithiniferous mineralization. The main objective of this study is to specify the main geological characteristics of the lithium mineralization of the Dibilo pegmatites and to propose a metallogenic model of their emplacement. Specifically, it aims to:

- To refine the geological mapping of the South - East Dibilo zone;
- To conduct a petro - structural study of the geological context of the lithium mineralization of the Dibilo pegmatites;
- To make a typological classification of the lithiniferous pegmatites allowing the origin of the mineralization to be traced.

2. Geological Context

The Dibilo sector (about 20km NNE of Téra) is located in the NW Zone of the Nigerien Liptako, which corresponds to the NE extremity of the Man Dorsal (West African Craton), stabilized since 1700 Ma [25]. The Nigerien Liptako has been the subject of numerous studies, from geological reconnaissance works [22]– [24], [26], [27]to the most recent works [28]– [40]. All these studies have allowed an advance and an improvement of the knowledge on the geology of Liptako. The synthesis of the studies carried out in the Liptako allows us to distinguish two main groups:

- The basement, of Paleoproterozoic age 2300 to 2000 Ma [33]which includes granitic plutons alternating with greenstone belts oriented globally NE - SW (**Fig.1**);
- The sedimentary cover which includes infracambrian, Tertiary (post - Eocene) terminal continental, and Quaternary formations.

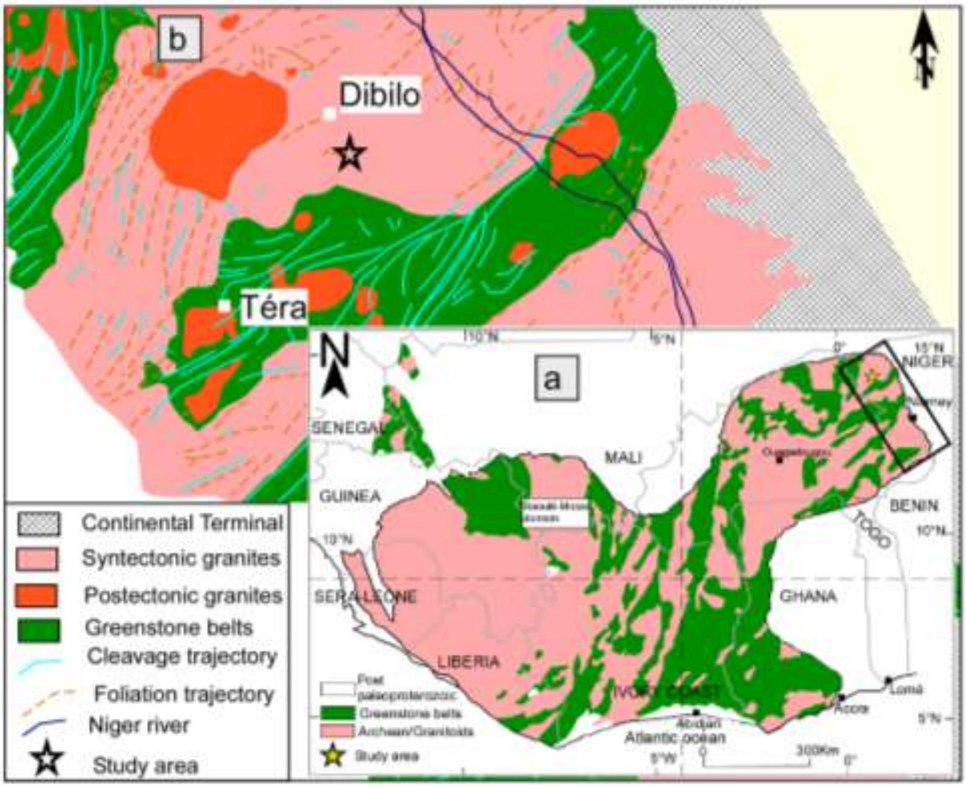

Figure 1: **(a)** Nigerien Liptako in the context of the West African Craton; **(b)** Location of the study area on the map extract from [27].

2.1 Geological of the study area

The study area is located within the foliated granitic pluton of Téra - Ayarou dated at 2158 Ma ± 9 [41], [42]. This study area is located 7 km SE of Dibilo, not far from the contact zone with the Diagorou - Darbani greenstone belt. The geology of the study area is represented by:

- Greenstone belt formations: talc - schists, talc - chloritoschists, metasediments, and metavolcanosediments;
- The formations of the granitic pluton: migmatites, granodiorites, calc - alkaline granites with biotite or 2 micas, rich in basic and ultrabasic enclaves of amphibolite and pyroxenite which testify to the intrusion in force of the granitic pluton of Téra - Ayorou. These rocks are cut by late quartz, pegmatite, and dolerite veins (**Fig.2**).

The Dibilo pegmatites are hosted in a foliated biotite - granite located at the edge of the Téra - Ayorou pluton.

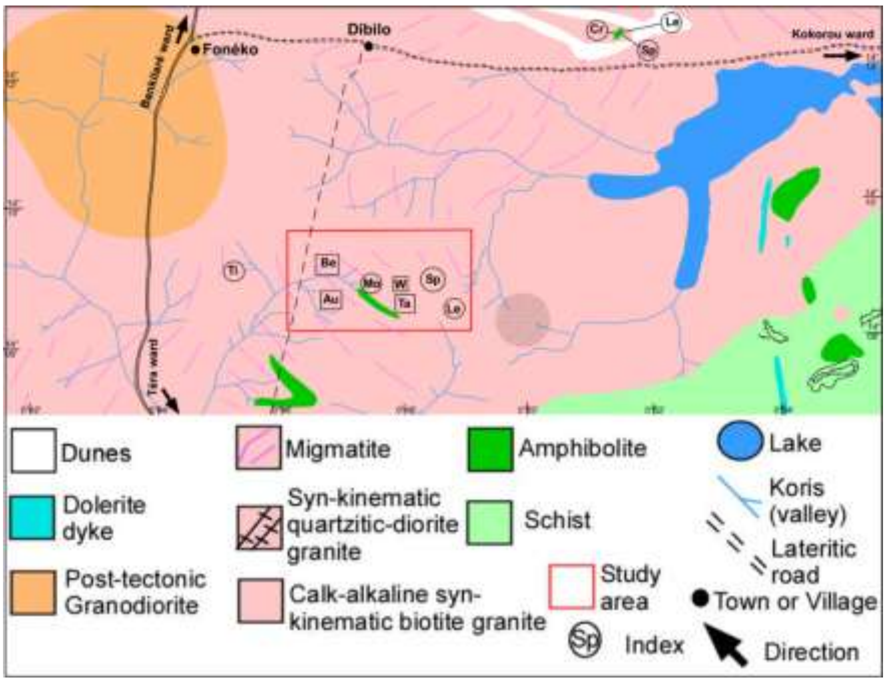

Figure 2: Extract of mineralization map North Téra sheet [22].

3. Methodological Approach

The methodology implemented to carry out this study consisted:

a) Fieldwork which allowed the realization of a geological map of the sector of study, geological sections as well as to establish a spatial distribution of pegmatites inside of the granite;
b) Laboratory work which consisted of microscopic analyses;
   - The use of pre - existing geochemical data to estimate reserves.
   - The use of discriminating reference diagrams (formation conditions and origin of lithium mineralization).

4. Results and Discussion

4.1 Petro - structural characteristics of the Dibilo birimian formations

4.1.1 Dibilo biotite - granite

The rare element pegmatites of Dibilo are hosted in a light grey to whitish, medium - grained biotite - granite with a grano - lepidoblastic texture. It has a foliationof N90° to N130° orientation with variable dips (**Fig.3a**). Locally this biotite - granite is mylonitic. This biotite - granite also shows magmatic segregations that are materialized by a local banding. It is cut by two shear zones with dextral components N100° to N110° (**Fig.3c**) or sinistral components N25° to N45° (**Fig.3b**), which appear as quartz vein fillings. The dimensions of these shear zones vary from a few centimeters to several hundred meters. The biotite - granite is also affected by tension cracks (**Figs.3d, 3e)** and mineral lineations of N110° direction having caused the orientation of feldspar minerals and quartz (**Fig.3**). Hydrothermal alteration phenomena related to the circulation of very hot fluids (**Fig.3f**). The biotite - granite is characterized by a lithological and metallogenic zonation. The SE part of the granite is represented by 18 intragranitic pegmatite veins mineralized in lithium and columbite - tantalite, while the NW part is represented by pegmatite veins mineralized in molybdenite.

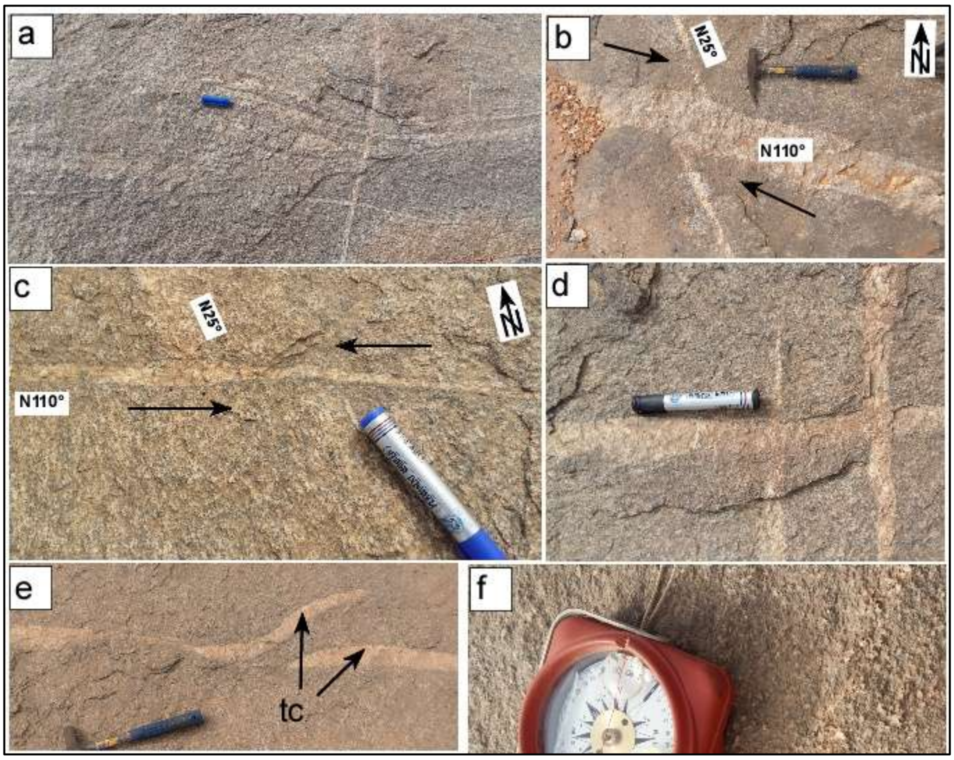

Figure 3: Biotite - granite. **(a)** schistosity/foliation; (**b and c)** dextral and sinistral conjugate fractures; (**d and e)** tension cracks (tc); **(f)** vacuoles that show hydrothermal alteration

Microscopic observation of the biotite - granite shows a granoblastic to grano - lepidoblastic texture with quartz, plagioclase, and biotite as constituent minerals. Two generations of quartz were observed, a first - generation formed by large xenomorphic crystals with rolling extinction and sometimes fractured (**Figs.4a, 4b**) and a second - generation formed by small crystals with uniform extinction in the primary patches, in the plagioclases or arranged on their edges and also constitute microfracture fillings (**Figs.4c, 4d**). Plagioclase occurs as large sub - automorphic crystals (**Figs.4b, 4d**). Biotite is brown and occurs as isolated lamellae or arranged in beds defining foliation/schistosity planes (**Figs.4a, 4c**).

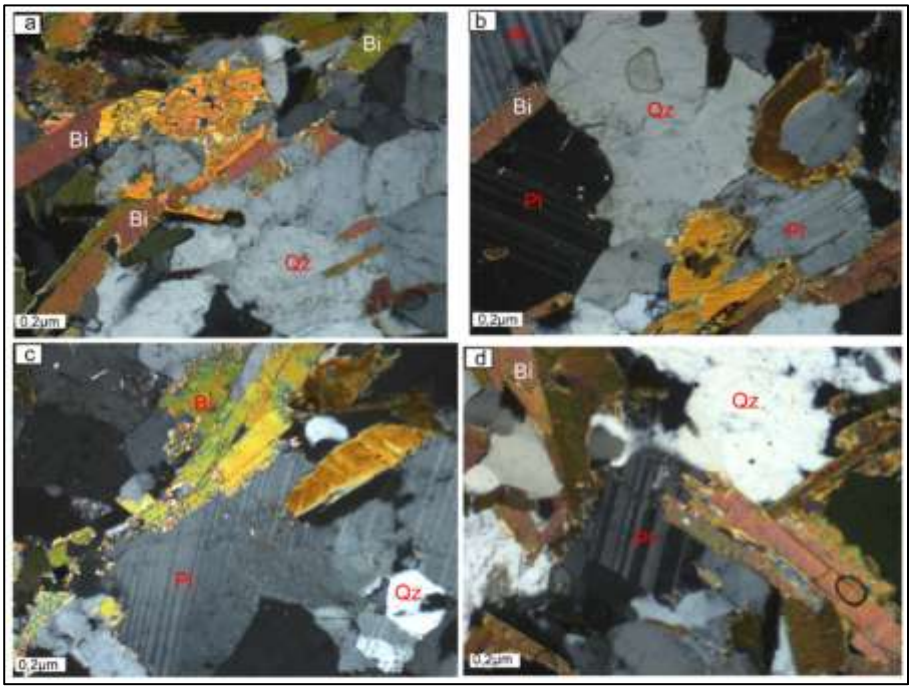

Figure 4: Polarized and Analyzed Light (PAL) observation of thin sections of biotite - granite (**a, b, c and d). (a)** beginning of foliation; (**b)** Plagioclase (Pl) and Quartz (Qz) intersect Biotite (Bi); (**c and d)** the appearance of small Quartz crystals in Plagioclase

4.1.2. Dibilo pegmatites

4.1.2.1. Geological characteristics of the Li pegmatites of Dibilo

The main geological characteristics of the study area were highlighted by the production of a geological map (**Fig.5**) and geological sections of the study area (**Figs.6, 9, 14, and 17**).

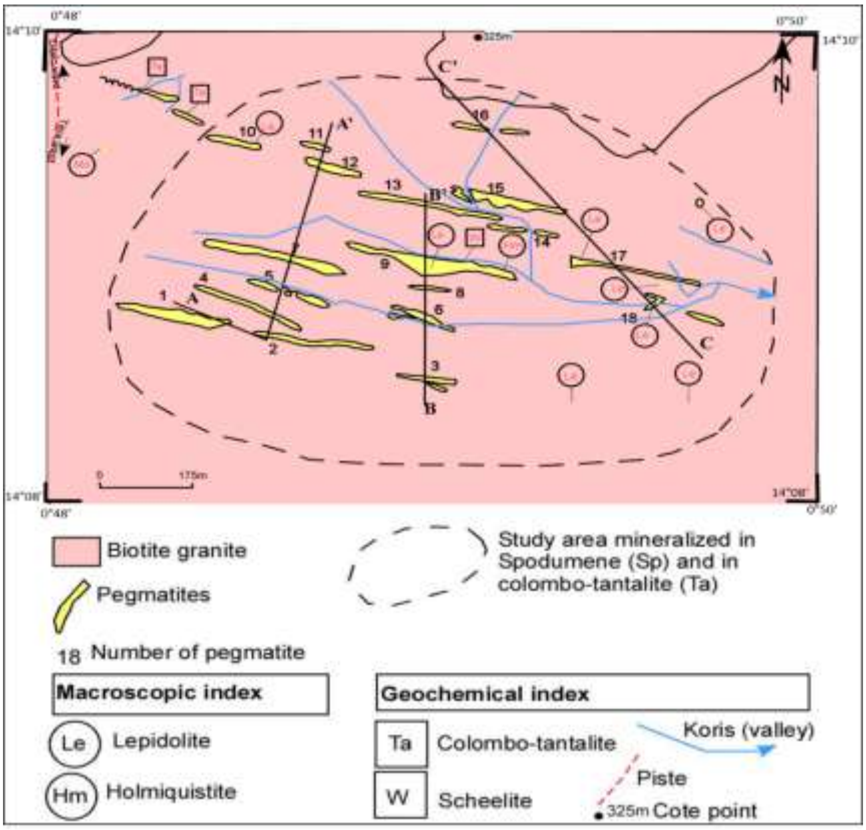

Figure 5: Simplified geological map of the study area [22], with the location of the different geological sections surveyed (**A - A', B - B', and C - C').**

Section A - A' shows seven pegmatite veins that are intrusive in a biotite - granite (**Fig.6**), pegmatite N° 1 is strongly mineralized in spodumene with crystals measuring 25 to 30 cm long (**Fig.7b**). The spodumene crystallized inter - growth with quartz, feldspar, and muscovite (**Figs.7c, 7d).** The contact between pegmatite N°1 and the host rock is clean (**Fig.7a**). Colombo - tantalite has been identified in the concentrates [22].

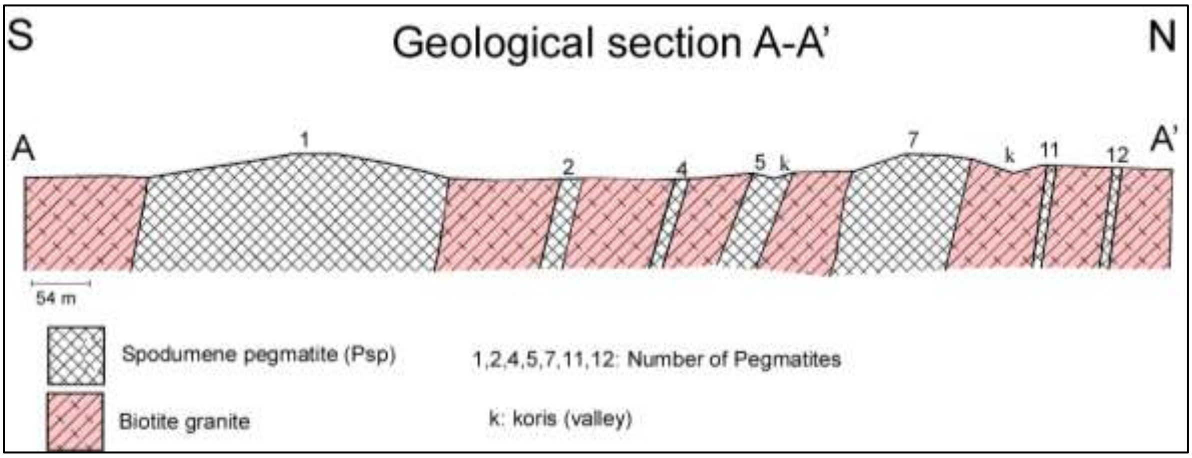

Figure 6: Geological section A - A'

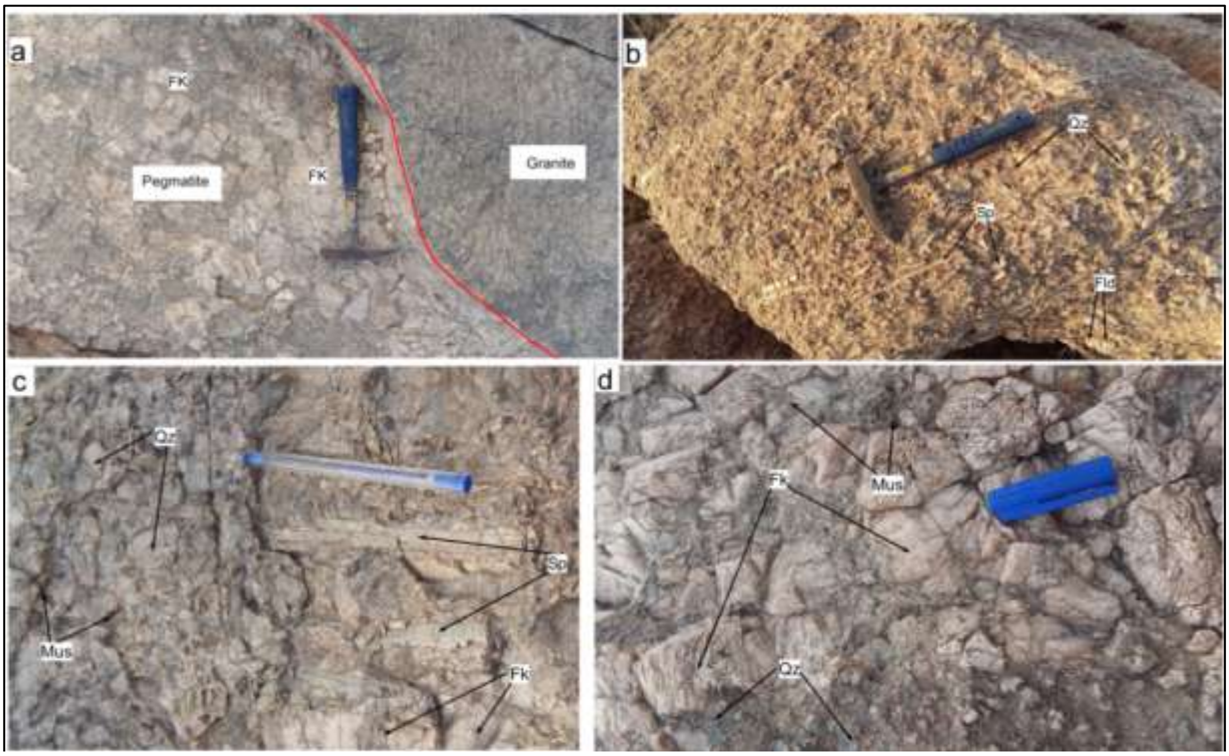

Figure 7: Pegmatite vein N°1, (**a)** Pegmatite/granite contact; (**b)** Spodumene (Sp) crystals measuring 25 to 30cm long; (**c)** and (**d).** Spodumene crystals intergrowth with quartz minerals and feldspars

Microscopic observation of Lode N°1 revealed Spodumene, Quartz, Plagioclase, and Muscovite. The texture is pegmatitic (Fig.8). In thin section, Spodumene (Sp) occurs as very large elongated prismatic and automorphic crystals that have crystallized with Quartz (Qz) (**Figs.8a, 8b, 8d, 8g, 8h**), Plagioclase (Pl) (**Figs.8c, 8g, 8h, 8i**) and Muscovite (Mus) (**Figs.8d, 8i**).

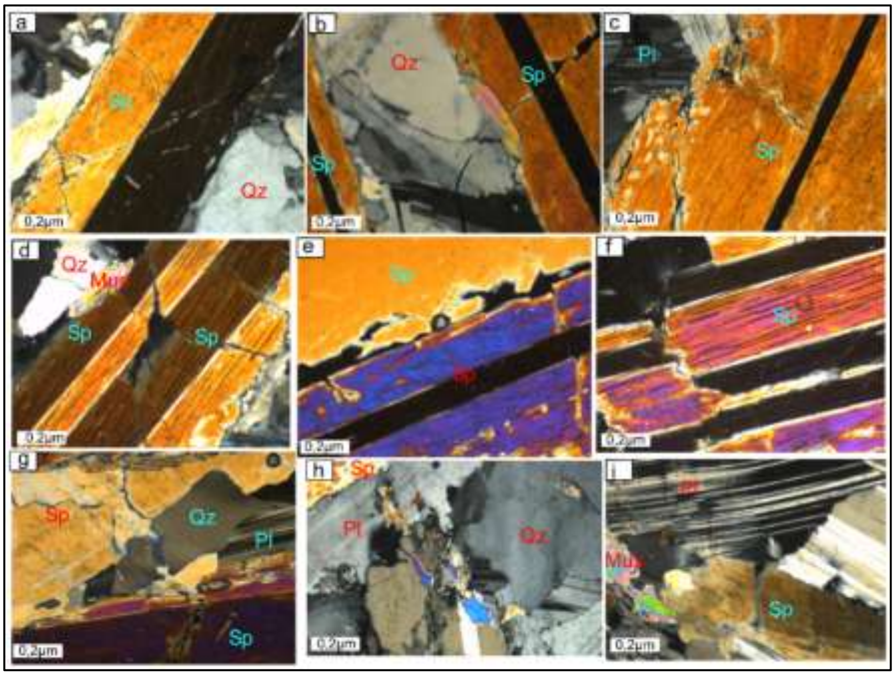

Figure 8: Polarized and Analyzed Light (PAL) observation of thin sections of pegmatite N°1 (**a, b, c, d, e, f, g, h, and i). (a, and b)** Spodumene (Sp) intergrowth with Quartz (Qz); (**c)** Spodumene with Plagioclase (Pl); (**d)** association between Spodumene, Quartz and, Muscovite (Mus); (**e, and f)** Spodumene; (**g)** Spodumene with Plagioclase and Quartz; (**h, and i)** Spodumene - Plagioclase - Quartz - Muscovite.

Section B - B' shows five pegmatite veins intruding the foliated biotite - granite (**Fig.9**). At the contact of vein N°9, the biotite - granite has been enriched in Holmquistite by metasomatism (**Figs.10b, 10c**), which shows a contribution of Lithium to the granite in replacement of Na. This metasomatism is explained by the interaction of the granite wall with the fluids from the pegmatite (**Fig.10a**).

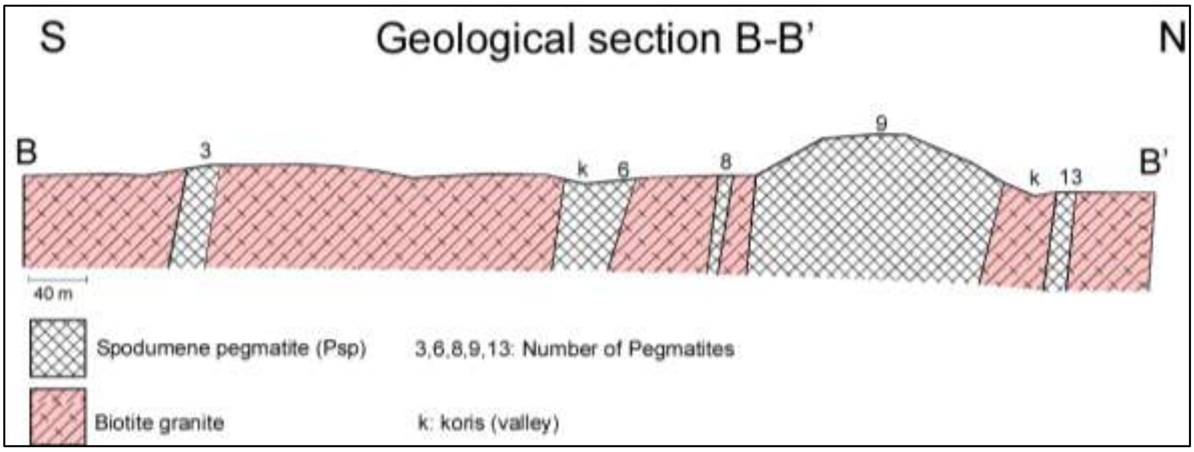

Figure 9: Geological section B - B'.

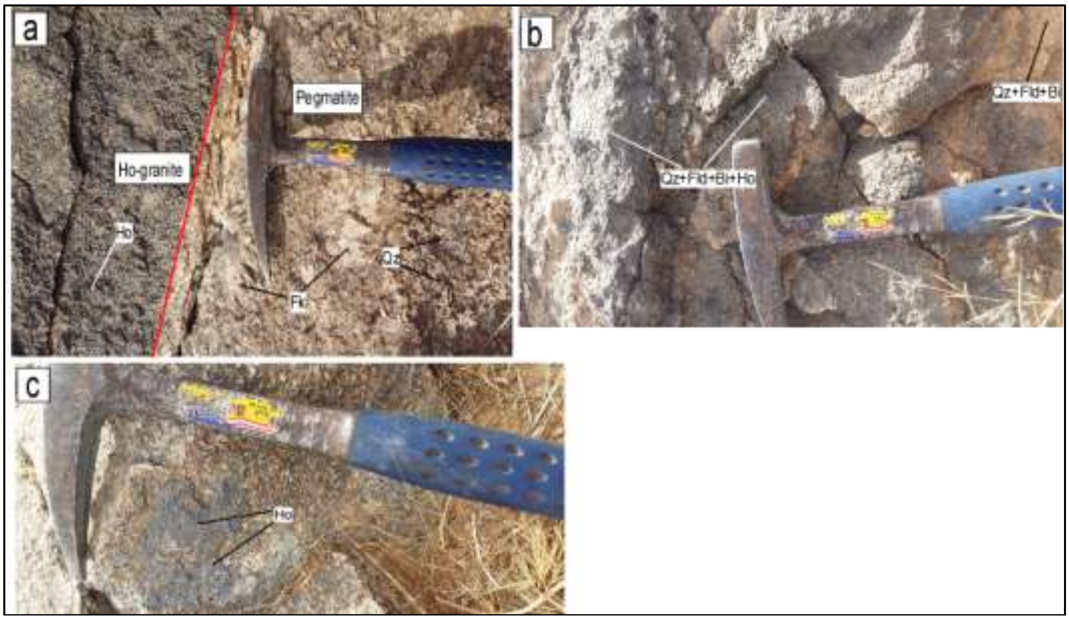

Figure 10: Biotite - granite (**a**) Pegmatite/Holmquistite granite contact; (**b**) Holmquistite granite; (**c**) Holmquistite - enriched biotite - granite (Ho).

Microscopic observation reveals a grano - lepidoblastic texture with holmquistite, quartz, plagioclase, spodumene, and biotite as constituent minerals. The holmquistite occurs in the form of elongated crystals or in patches replacing the biotite (**Figs.11a, 11b, 11c, 11d, 11e, 11f, 11g, 11h**). The biotite appears as jagged lamellae in Holmquistite, locally, a holmquistization of the biotite is observed by metasomatism, this holmquistization starts on the edges and in the cleavages (**Figs.11a, 11b, 11c, 11d, 11e, 11f, 11g, 11h**). Quartz occurs in two generations: a first - generation formed of large xenomorphic crystals with rolling extinction and sometimes fractured; and a second - generation formed of small crystals with uniform extinction in the primary patches, in the plagioclases or arranged on their margins and also constitute microfracture fillings (**Fig.11i**). Spodumene occurs as subautomorphic crystals. Plagioclase occurs as large subautomorphic crystals (**Fig.11i**).

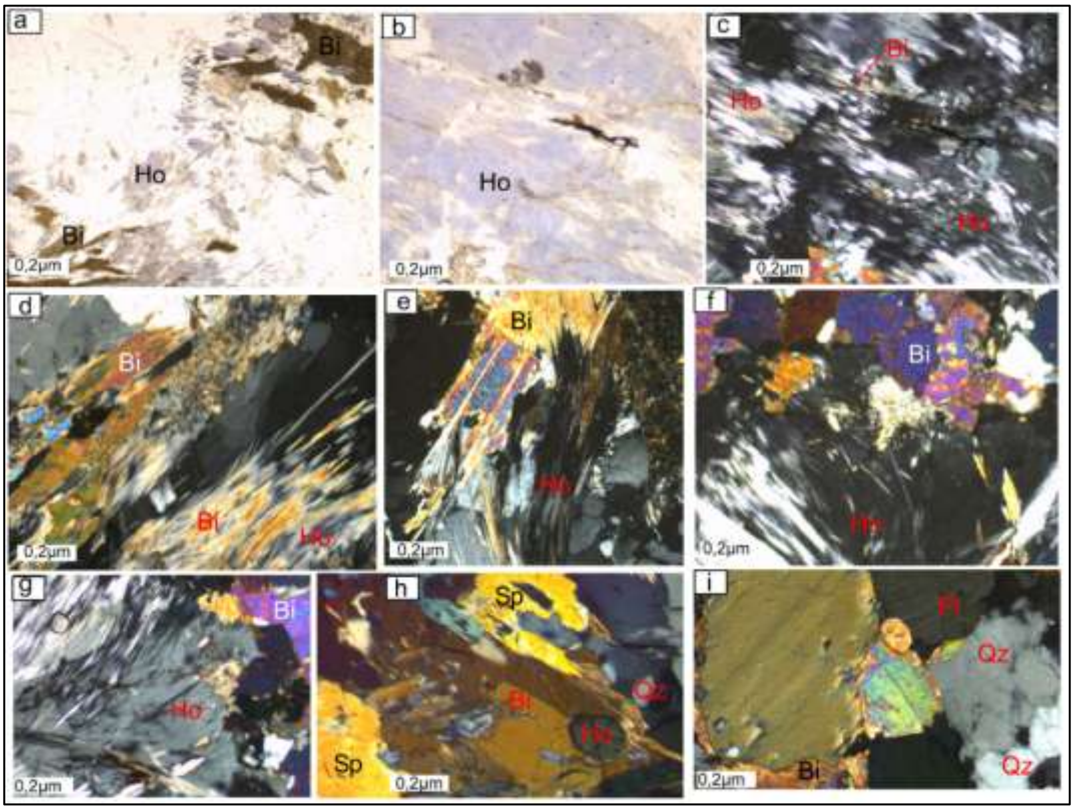

Figure 11: Polarized and Analyzed Light (PAL) observation of biotite - granite thin sections (**c, d, e, f, g, h, and i);** Polarized and Unanalyzed Light (PLN) observation (**a, and b).** (**a, b, c, d, e, f, and g)** Transformation of Biotite (Bi) into Holmquistite (Ho) by metasomatism; (**h)** Enrichment of the granite in spodumene and association between quartz, spodumene, and holmquistite; (**i)** Association between Biotite, Quartz (Qz), Plagioclase (Pl), and Holmquistite.

Pegmatite N°9 is strongly mineralized in spodumene (**Figs.12b, 12c**) and secondarily in Lepidolite having crystallized with quartz, feldspar, and muscovite (**Figs.12c, 12d**). Scheelite and columbite - tantalite have been highlighted by geochemical analysis [22]. The contact with the surrounding granite is frank (**Fig.12a**).

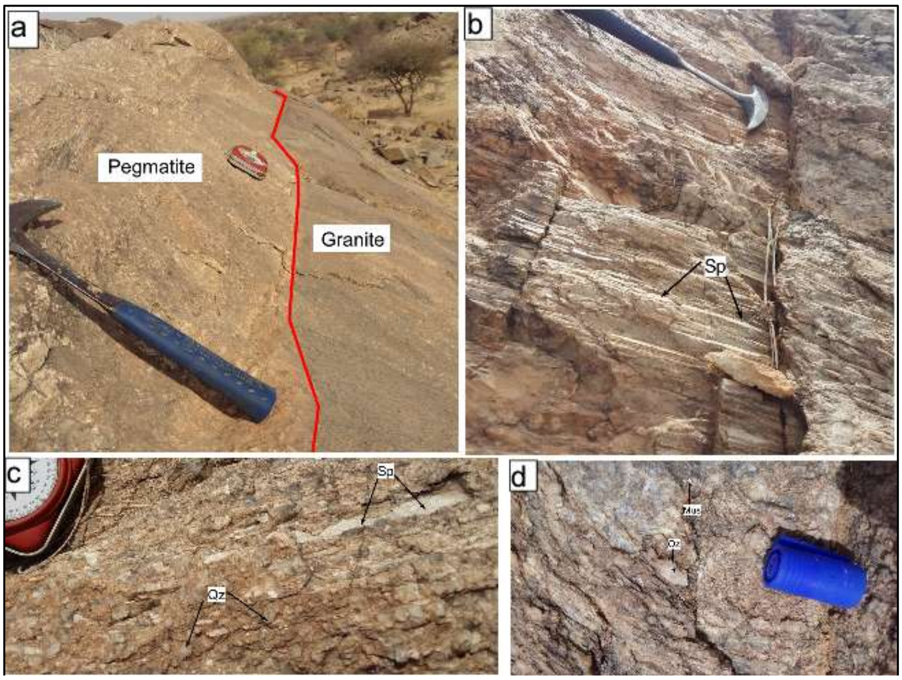

Figure 12: Pegmatite Lode N°9, (**a**) Granite/Pegmatite contact; (**b and c**) Centimetric spodumene crystals; (**d**) Spodumene intergrowth with quartz.

Microscopic observation of vein N°9 revealed spodumene, lepidolite, quartz, and plagioclase. The texture is pegmatitic (**Fig.13**). Spodumene occurs as very large elongated prismatic and automorphic crystals intergrown with quartz (**Figs.13a, 13b, 13c, 13d, 13e**). Lepidolite occurs in lamellae (**Figs.13f, 13g**). Quartz occurs in two generations: a first - generation formed of large xenomorphic crystals with rolling extinction and sometimes fractured; and a second - generation formed of small crystals with uniform extinction in the primary patches, in the Spodumene or arranged on their margins and also constitute fillings of microfractures (**Figs.13d, 13h)** Plagioclase is very abundant and occurs as subautomorphic crystals (**Fig.13h**).

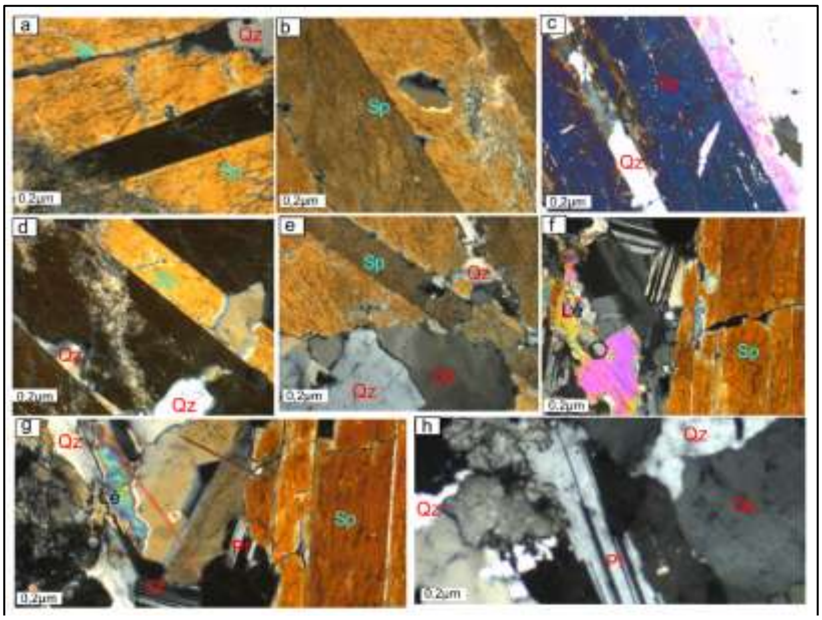

Figure 13: Polarized and Analyzed Light (PAL) observation of thin sections of pegmatite N°9 (**a, b, c, d, e, f, g, and h). (a, b, and c)** Prismatic crystals of Spodumene (Sp); (**d and e)** Spodumene intergrowth with Quartz (Qz); (**f and g)** Spodumene with Plagioclase (Pl), Quartz and Lepidolite (Lé); (**h)** Plagioclase - quartz.

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Section C - C', shows five pegmatite veins that are intrusive in the foliated biotite - granite (**Fig.14**).

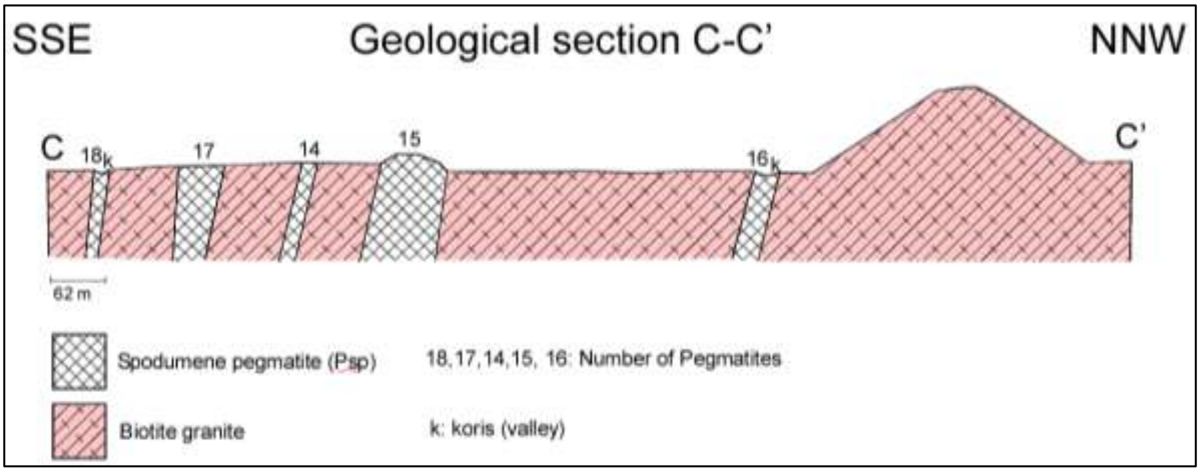

Figure 14: Geological section C - C'.

The pegmatite N°18 is moderately mineralized in Spodumene and Lepidolite (**Fig.15**).

Microscopic observation of Lode N°18 has allowed the detection of Lepidolite, Spodumene, Quartz, Microcline. The texture is pegmatitic. Lepidolite occurs in lamellae. The microcline occurs in the form of large crystals. Quartz is found in the form of small xenomorphic patches.

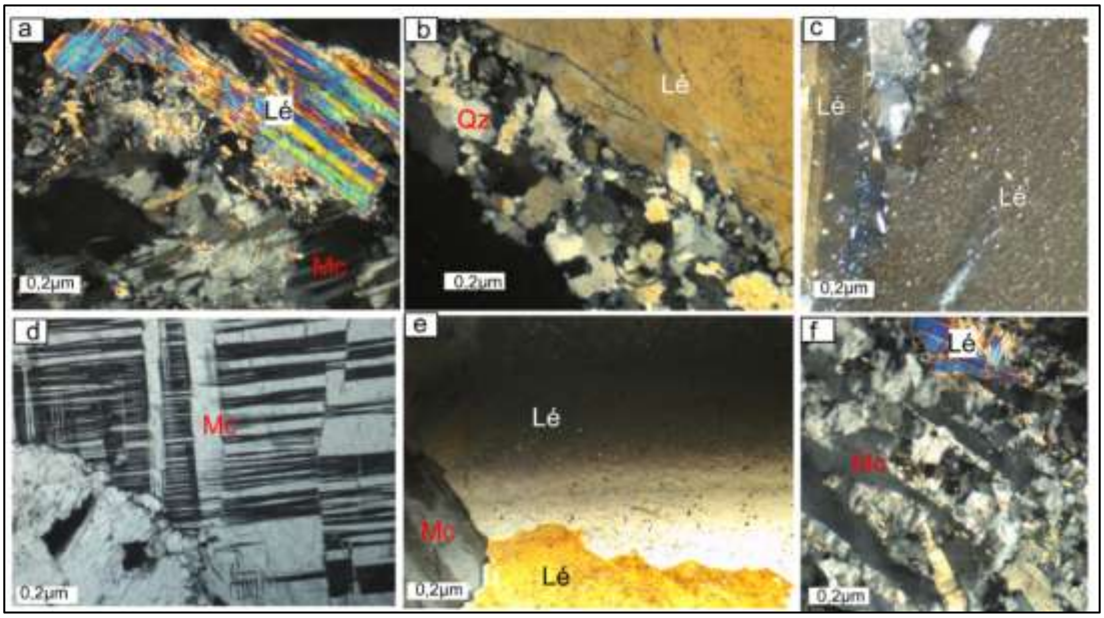

Figure 15: Polarized and Analyzed Light (PAL) observation of thin sections of pegmatite N°18 (**a, b, c, d, e, and f). (a, e and f)** Lepidolite (Le) and Microcline (Mc); (**b and c)** Lepidolite and Quartz (Qz); (**d)** Microcline

The pegmatitic vein N°15 is strongly mineralized in spodumene having crystallized with quartz, feldspar, and muscovite (**Fig.16**). Microscopic observation of Lode N°15 revealed Spodumene, Quartz, and Plagioclase. The texture is pegmatitic. Spodumene occurs as elongated prismatic and automorphic crystals in patches inter - growing with quartz. Quartz occurs in two generations: a first - generation formed of large xenomorphic crystals with rolling extinction and sometimes fractured; and a second - generation formed of small crystals with uniform extinction in the primary patches, in the Spodumene or arranged on their edges and also constitute fillings of microfractures. Plagioclase is very abundant and occurs in subautomorphic crystals.

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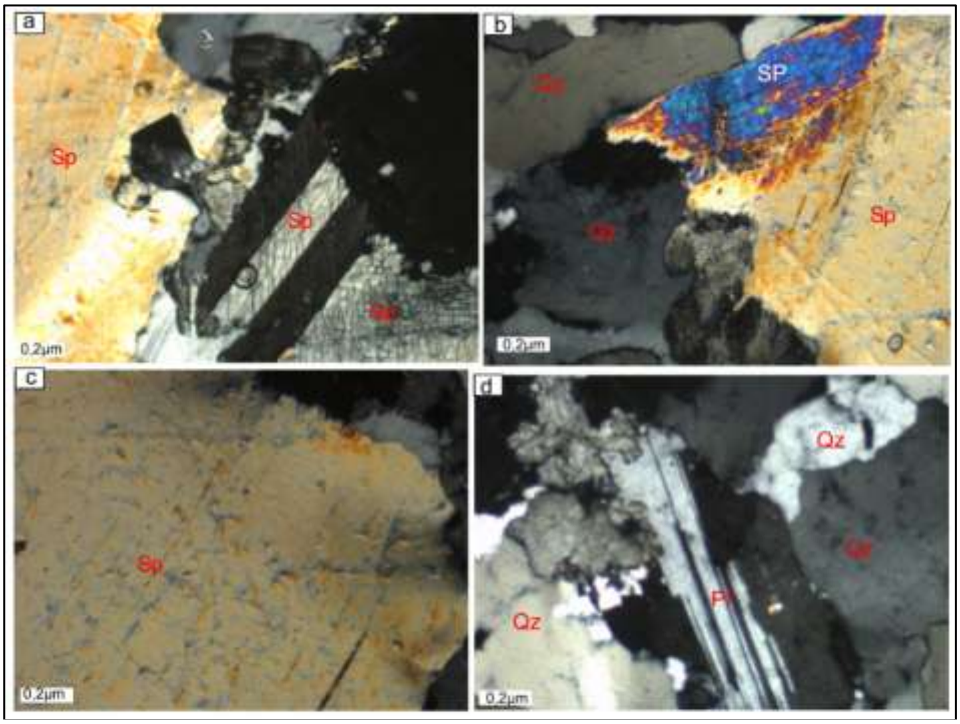

Figure 16: Polarized and Analyzed Light (PAL) observation of thin sections of pegmatite N° 15 (**a, b, c and d). (a)** Spodumene (Sp) in prismatic crystals and in patches; (**b)** Spodumene associated with Quartz (Qz); (**c)** Spodumene in patches; (**d)** Quartz and Plagioclase (Pl).

The synthesis section highlights the three most mineralized pegmatites in the Dibilo field (**Fig.17**). The total reserves of these three veins are estimated at 166, 000 tonnes of ore grading approximately 2% LiO_2. The 15 other lodes have lower reserves, and we estimate the reserves of the Dibilo sector at 300, 000 to 350, 000 tonnes grading between 1.4% and 2% LiO_2 [22].

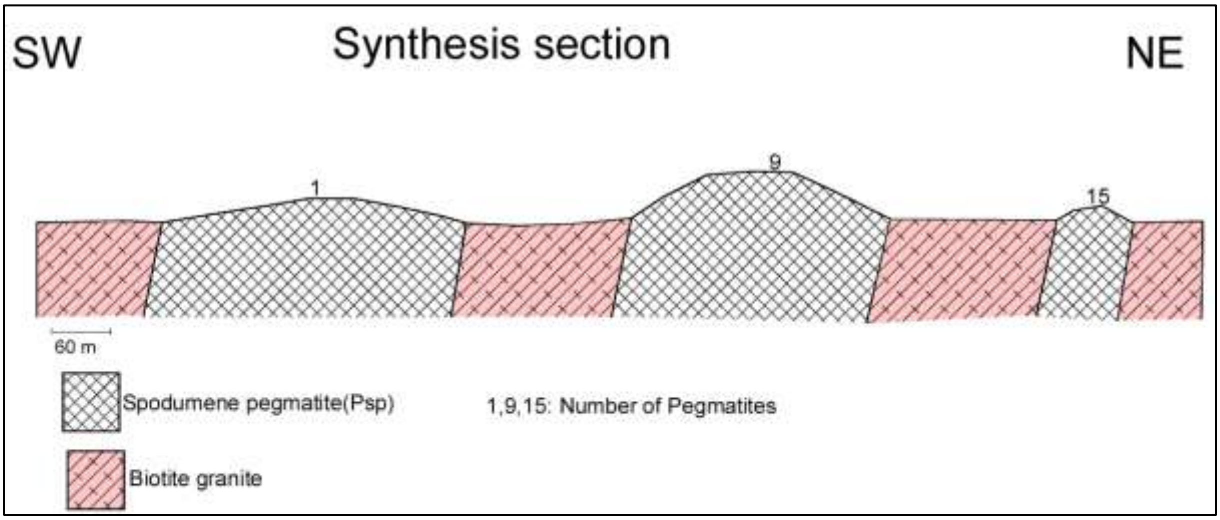

Figure 17: Synthesis section showing the three most mineralized pegmatites of the Dibilo field.

4.1.2.2. Spatial distribution of pegmatites within the granite

The Dibilo pegmatites show a distribution within the biotite - granite. This spatial distribution is marked by a progressive enrichment in useful elements and an increase in complexity within the granite. Thus, from a spatial distribution point of view of the Dibilo rare element pegmatites within the parent granite, four (4) types of pegmatites have been identified: Sterile pegmatites; Li, Ta, W pegmatites; Mo, Ta pegmatites; Mo, Ta, W, Be, Au pegmatites (**Fig.18**).

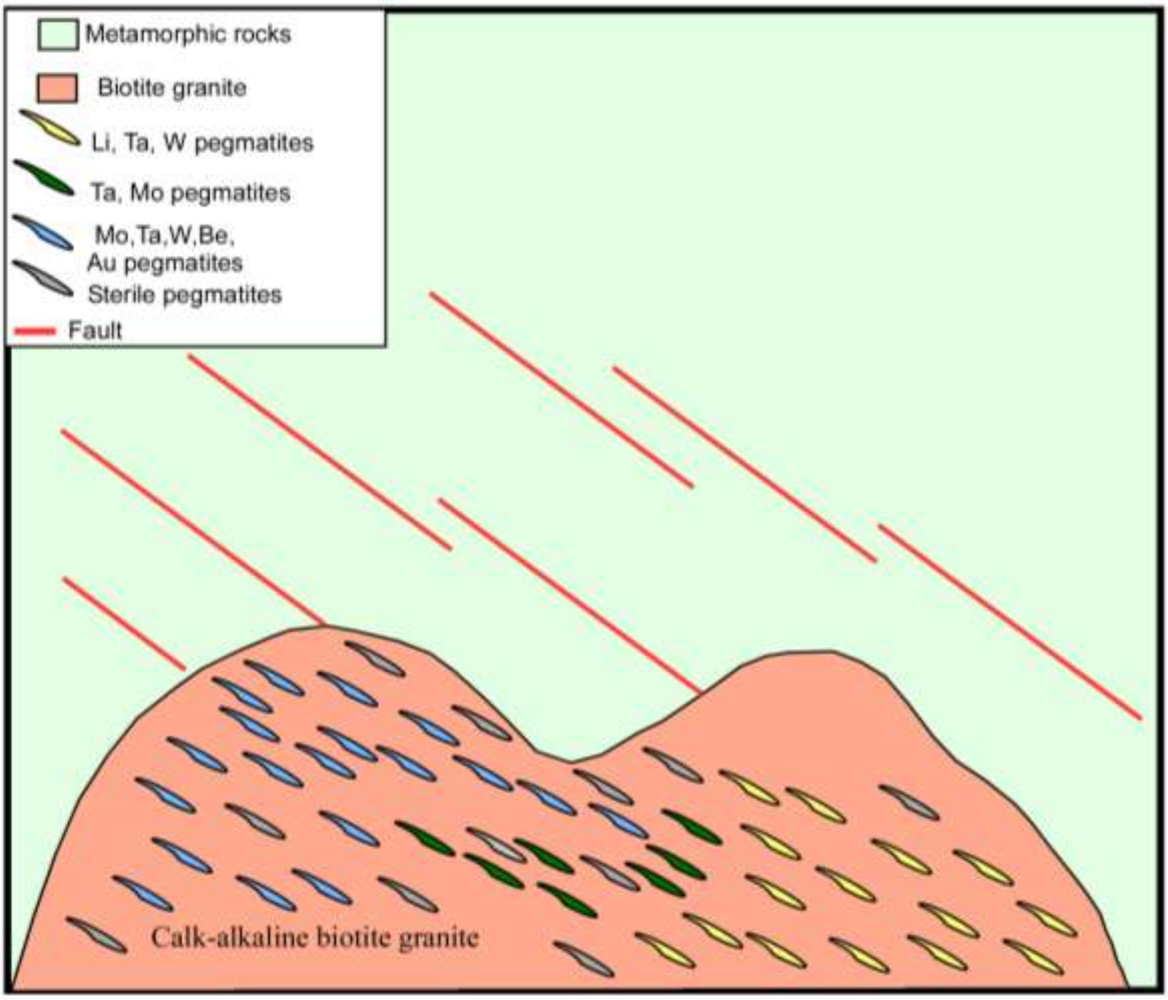

Figure 18: Spatial distribution of Dibilo rare element pegmatites within the parent granite. Four (4) types of pegmatites have been identified: Sterile pegmatites; Li, Ta, W pegmatites; Mo, Ta pegmatites; Mo, Ta, W, Be, Au pegmatites

4.1.2.3 Mineralogy and internal zonation of the Dibilo pegmatites

In the Dibilo area, more than 50 intragranitic pegmatite veins trending N110° to N100°, 40 of which are mineralized, have been recorded by [22]. The length of the veins varies between 30 and 700 m, their width between 1 and 5 m, with a dip of 30° to the North. Mineralization occurs as spodumene ([SiO3]$_2$ LiAl), molybdenite, lepidolite ([Si$_3$ (Si, Al) O$_{10}$ $_{(}$OH, F) $_2$] KAl (Li, Fe, Al)), Holmquistite (Li$_2$ (Mg, Fe$_2$+) $_3$Al$_2$Si$_8$O$_{22}$ (OH) 2), scheelite colombo - tantalite, beryl and gold [22]. In the Dibilo pegmatites, the lithiniferous mineralization is essentially in the form of tapered crystals of spodumene, the largest individuals being up to 25 to 30 cm long by 2 cm thick, having crystallized in inter - growth with quartz [22], [24]. They are generally concentrated in the median part of the veins, either oriented parallel to the spurs, or arranged perpendicular to them and in this case, they frequently appear bent [24]. Not all veins are uniformly mineralized along their entire length. Laterally the concentrations of spodumene crystals can vary from a few % to 70 % in the richest sections. The lithiniferous minerals accompanying the spodumene are the punctual lepidolite noted in only a few veins and Holmquistite, which is a lithiniferous amphibole. Common minerals are quartz, muscovite, feldspar, and accessory garnet. Spodumene and petalite represent different phases of the Li_2O - Al_2O_3 - SiO_2 system [43]and can provide a rigorous paleobarometer (**Fig.19**). The spodumene subtype is the most common of the complex pegmatites, crystallizing largely at relatively high pressures (~3 to 4 kbar), with low temperatures. In contrast, the less common petalite subtype consolidates at somewhat higher temperatures with lower pressures (~1.5 to 3 kbar) [43]– [45]. The Dibilo pegmatites can be classified as Rare Element (RE) class pegmatites, complex type, spodumene subtype, and Lithium Cesium Tantalum (LCT) family.

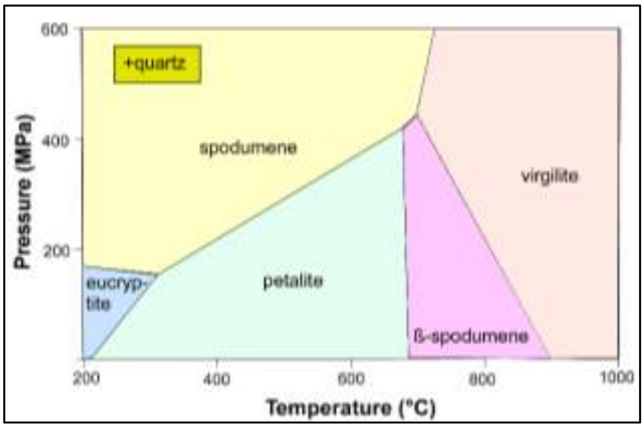

Figure 19: Phase diagram of lithium silicates under quartz saturation conditions [44], [45].

4.2 Characterization of the deformation phases

The structural analysis carried out in the field and in the laboratory allowed to highlight two major phases of deformation noted D1 and D2: The first phase of deformation D1, is characterized by a schistosity/foliation (S1) of orientation N20° to N50° with a westward dip. In the granitoids, this phase is highlighted by the orientation of amphibole, biotite, muscovite, and feldspar crystals and by the elongation of mafic enclaves. The projection of the foliation plane measurements, in the Win - Tensor software (version 5.8.9) by the right dihedral method, indicates an NW - SE shortening (average shortening N122°) (**Fig.20a**).

The second phase of deformation D2 is associated with the operation of dextral (N100° to N110°) and sinistral (N25° to N45°) shear corridors that affected the granitoid. These shear corridors would result from the rotation of the D1 regional stress from NW to NNW, in relation to the emplacement and swelling of the Téra - Ayorou pluton. This observation is in agreement with the work of [28], [29]. In the Dibilo area, these two shear corridors are combined, which could have favored the emplacement of the Dibilo biotite - granite and its pegmatites [28], [29], [38]. The projection of the shear zone measurements, in the Win - Tensor software (version 5.8.9) by the right dihedral method, indicates an NNW - SSE shortening, for the dextral shear zones and WSW - ENE for the sinter zones (**Fig.20b**).

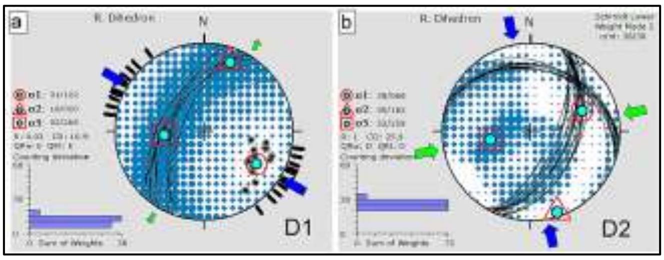

Figure 20: (**a**) Projection of the Schistosity/Foliation (S1) planes of the Dibilo area; (**b**) Dextral and sinistral shear corridors of the D2 phase, NNW - SSE and WSW - ENE compression, respectively.

4.3. Discussion

4.3.1. Genesis of rare element pegmatites

From a genesis point of view, two models are mainly used to justify the presence of rare element granitic pegmatites:

The crustal anatexis model: This model, has been proposed by many authors, to link rare element pegmatites to crustal rocks undergoing partial melting [46]. It has also been suggested to justify: the clustering phenomenon of certain types of pegmatites (typical mineralization associated with each cluster); the wide extent of pegmatite fields compared to granitic plutons (Black Hills pegmatite fields and the associated Harney Peak granite in South Dakota, [47]; Pegmatite fields in the absence of a parent granite; The existing temporal gaps between granites and pegmatites [48]; The non - continuity of magmatic fractionation between granites and the most evolved pegmatites [49];

The parent granite model: this is the most common model, which assumes the consolidation of granite, most often hyper luminous with two micas, from which the residual pegmatitic magmas enriched in volatile and incompatible elements would escape from its dome [1], [10], [50]. According to [10], the further the pegmatitic magmas are from their parent granitic source, the more they are enriched in rare and volatile elements (Li, Nb, Ta, F, B, H_2O). This model is based on physico - chemical conditions [3]– [5], [9]namely: observable physical links between mineralized pegmatites and their granitic parents; the geochemical continuity of granite - pegmatitic suites; the granitic composition of rare - element pegmatitic magmas; the regional zonation observable around certain granitic plutons (hyper luminous granites of the HHP type). The continuity of magmatic fractionation, based on K/Rb, Li/Cs type indicators, between granites and overlying pegmatites has been the main argument to justify the genetic relationships between these granites and rare elements pegmatites.

At Dibilo, the granite - parent model is best suited to explain the emplacement of the lithium pegmatites. According to this model, the rare - element pegmatites are either injected into the surrounding metamorphic rocks or occur as segregations within the granitic plutons. In the Dibilo pegmatitic field, all pegmatites are intragranitic and mineralized with lithiniferous minerals. The fact that the pegmatites are located within the granite is explained by its depth of emplacement and its cooling temperature. According to the granite - parent model presented by [10], the more distant the pegmatitic magmas are from their parent granite source, the more they are enriched in rare and volatile elements (Li, Nb, Ta, F, B, H2O) (**Fig.21**). Thus, according to the "London" model, most often intragranitic pegmatites are sterile and extragranitic pegmatites are enriched in rare elements.

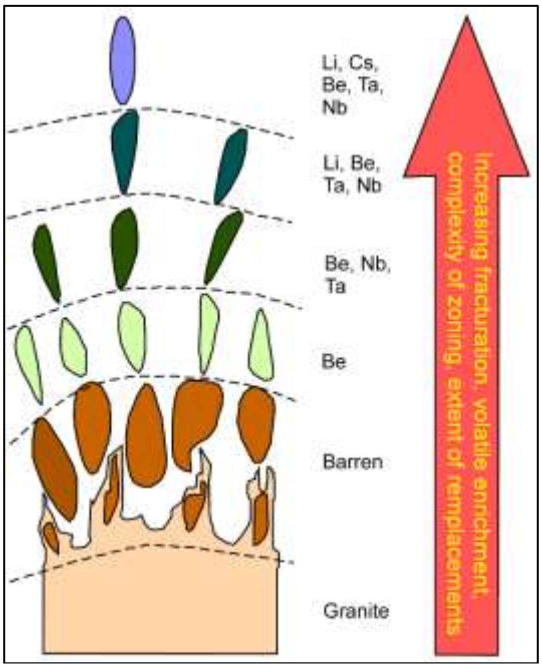

Figure 21: Parent granite model revisited by [10].

Most pegmatitic fields conform to this "London" model, but in the case where pegmatites occur as segregations within granitic plutons this spatial distribution changes to within the granite (**Fig.18**). It should be noted that the fields where pegmatites occur as segregations within granitic plutons are very rare, we can cite among others the pegmatites of the Greer Lake leucogranite in Canada [51], the Maniema pegmatites in the Democratic Republic of Congo (DRC) [52], the Kenieba pegmatites in Senegal [53]and the Himalayan pegmatites. The Dibilo field is one of these fields that occur as segregations within granitic plutons and whose enrichment in rare elements is related to magmatic differentiation.

4.3.2. Genetic model of the Dibilo pegmatites

The origin of this lithium mineralization has long been a subject of controversy. According to [22], lithiniferous mineralization is related to the emplacement of pneumatolytic occurrences, which post - date synkinematic - late granite differentiation but originate from the same granitic magma as the latter, and whose emplacement has been favored by pre - existing tectonics. On the other hand [24]suggest that the emplacement of the lithium pegmatitic veins is explained by a partial fusion of the remains of a metasedimentary sequence that manifests itself in the form of pegmatitic differentiations (neosome) intersecting in the form of veins the framework of the paragneiss, realized under the conditions of metamorphism, generally of the lower amphibolite type. The hypothesis of a partial fusion and remobilization of basic rocks can in these conditions be invoked to explain the formation of lithiniferous veins and for which metamorphism would be responsible. In this case, the lithium would have its source in the host metabasites and would have been concentrated during the remobilization phenomenon.

Based on the Birimian geodynamic model in the Liptako, which suggests that the Birimian rocks of the Liptako are emplaced in an oceanic arc environment [30], in an oceanic arc and back - arc basin [33], in an oceanic arc and back - arc basin with a strong influence of depleted mantle metasomatism in the genesis of metabasalts and amphibolites [35]or in subduction zones, with an early Paleoproterozoic magmatic event [36]. According to this last model, the partial melting of a metasomatized mantle slab generated the calc - alkaline affinity granitoids, whereas the granitoids with TTG (tonalite - trondhjemite - granodiorite) characters could have been produced by direct partial melting of the subducted oceanic crust (partial melting of a garnet amphibolite [36], [54]. Based on this geodynamic model of Liptako we propose a model taking into account the emplacement of granitic plutons and lithiniferous mineralization of the Dibilo pegmatites, in 3 major stages (**Fig.22**):

Stage 1: 2200Ma to 2190Ma: Partial melting, of the former seafloor and arc magmas by metamorphism into lower amphibolite facies and production of a primitive granitic magma. These seafloor rocks and arc magmas were metasomatized by aqueous fluids enriched in incompatible elements (P, Sr, Rb, and Ba) and light earth (La, Ce, Nd, and Sm). This metasomatism could have occurred in a subduction zone by alkali - rich fluids from dehydration of a subducting oceanic plate [33]. The fluids coming from the dehydration of the subducted oceanic plate will cause the lowering of the melting point of the mantle peridotites, thus provoking a partial melting and the production of a metasomatized basaltic magma.

Stage 2: from 2190Ma to 2150Ma: The granitic and basaltic magmas thus produced coalesce and give rise to a mixed magma of the M type which is set up in magma chambers where the process of fractional crystallization begins [33]. These magmas being granitic and rich in H_2O are organized in plutons which migrate rapidly by density effect towards the basaltic crust by assimilating only a small proportion of this basaltic crust given their relatively low initial temperature (600 °C) [33]. The intrusion in force of granitic plutons is explained by the presence of numerous enclaves of metavolcanic and metasedimentary rocks, schistosity, foliation, and folding [29]. It is during this interval of time that the foliated granodiorites were developed, corresponding to the early granitic suite. The internal chemical evolution of this early suite was largely controlled by fractional crystallization processes. The crystallization and separation of minerals such as clinopyroxene, calcic plagioclase, and amphibole lead to the depletion of Ca, Mg, Fe, Cr, Ni, Sr and the progressive increase in Si, Ba, Rb/Sr, La/Sm from the dioritic magmas to the granodiorites [55], [56].

Stage 3: from 2150Ma to 2000Ma: Development of calc - alkaline biotite or two - mica granites, sometimes late mylonitic. According to geochemical studies (major and trace elements, Sm - Nd isotopes, unpublished data) foliated granodiorites and biotite or two - mica granites could be cogenetic [29], [41], [57]. According to these authors, biotite - granites correspond to late granitic liquids, trapped in partially crystallized granodiorites, expelled during differential movements affecting granodiorites, the argument in favor of this hypothesis is the ribboning often observed in the plutons. As the fractional crystallization of biotite - granites proceeds, compatible (lithophilic) elements concentrate in the crystals while incompatible (magmatophilic) elements (Li, Cs, Rb, Ta, Nb, and W), volatile phases, and H_2O concentrate in the residual magma fluid. When the residual magma is sufficiently enriched in incompatible elements, traces, volatile phases and is supersaturated in H_2O, there is then an increase in pressure and expulsion of aqueous phases (rich in Li, Rb, and Cs) accompanied by a silicate magma that is injected in the form of pegmatites in the cracks and diaclases of the biotite - granite.

The pegmatitic magmas thus expelled initiate an internal differentiation leading to an internal zonation of the Dibilo pegmatites. This internal differentiation is centripetal and begins with the crystallization of the albite and biotite - rich granitic rim, then crystallizes the quartz, albite, and muscovite - rich pegmatite wall. As the internal differentiation of the magmatic liquid occurs the crystallization of the replacement zone is rich in quartz, albite, muscovite, and lepidolite. At the end of the pegmatitic differentiation, there is a crystallization of the intermediate zone and the heart of the pegmatite where spodumene is abundantly concentrated and lepidolite in the state of traces. These pegmatites have high Li concentrations. The majority of the pegmatites form thin dykes that have undergone high internal differentiation, which explains the zonality observed in the Dibilo pegmatites. On the other hand, some of the Li, Cs, and Rb rich aqueous phases are expelled into the cracks during the

Paper ID: SR21917211430 DOI: 10.21275/SR21917211430

consolidation of the pegmatite, forming the holmquistite halos in the biotite - granite. This model could explain, among other things, the coarse chemical and mineralogical zonation observed in the pegmatitic envelope associated with the Dibilo biotite - granite.

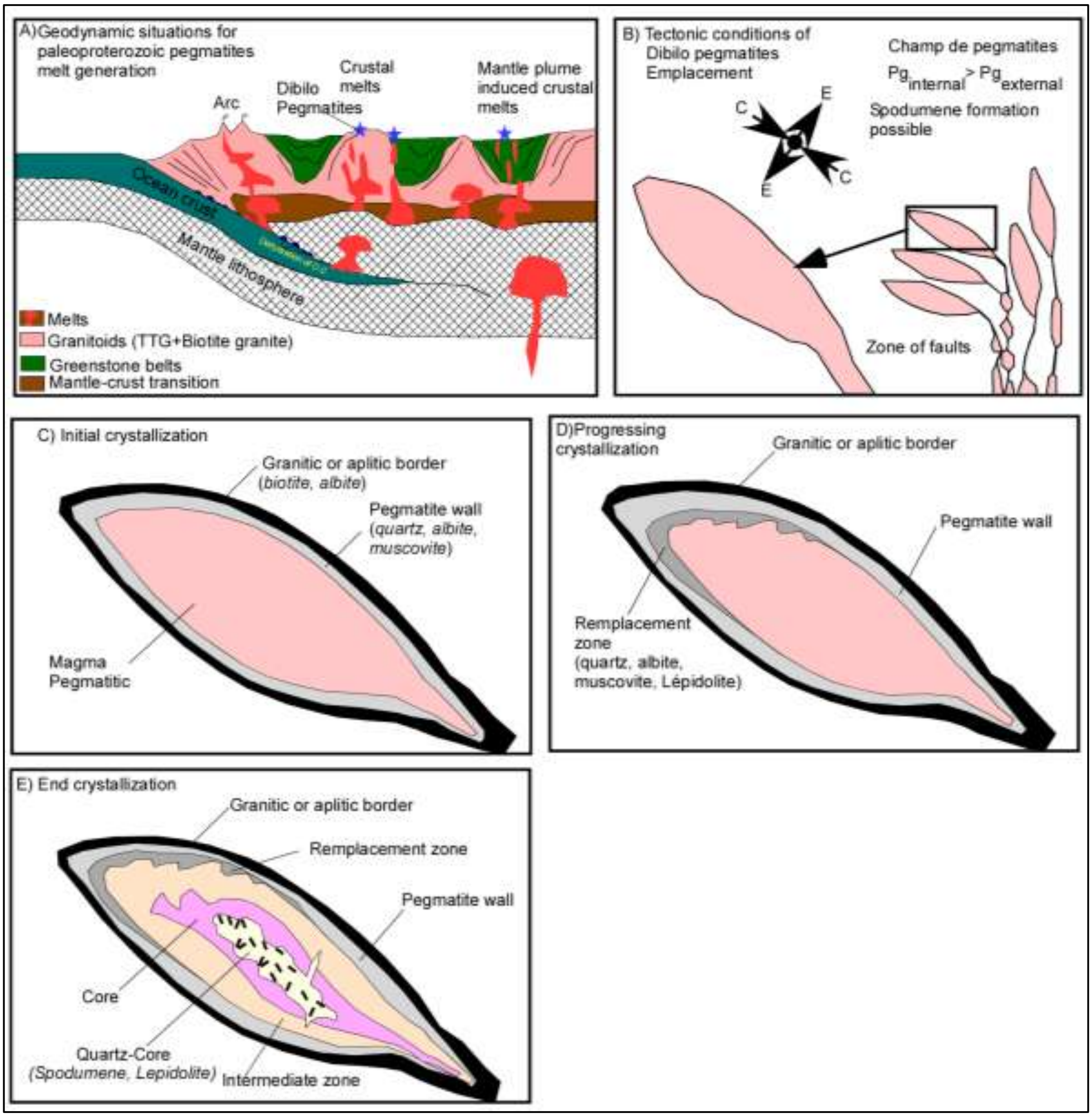

Figure 22: Genetic model of the Dibilo lithium pegmatites (inspired by [59])

This model for the emplacement of Li mineralization in SE Dibilo is comparable to that of [58], [59], the Greer Lake leucogranite pegmatites in Canada [51], the Maniema pegmatites in the Democratic Republic of Congo (DRC) [52], the Kenieba pegmatites in Senegal [53]and the Himalayan pegmatites [15].

5. Conclusion

The study of the Dibilo lithium deposit allows us to specify that:

The Dibilo lithium pegmatites correspond to residual magmatic liquids resulting from the fractional crystallization of the late foliated biotite - granite of Dibilo located at the edge of the Téra - Ayorou pluton. This biotite - granite corresponds to late magmatic liquids resulting from the magmatic differentiation of granodiorites. The latter result from the partial melting of a metasomatized oceanic crust by metamorphism in the facies of lower amphibolites, in an oceanic context of subduction.

The Dibilo lithium pegmatites can be classified as Rare Element (RE) pegmatites, complex type, spodumene subtype, and Lithium - Cesium - Tantalum (LCT) family;

Four (4) types of pegmatites have been identified: sterile type pegmatites; Li, Ta, W pegmatites; Mo, Ta pegmatites; and Mo, Ta, W, Be, Au pegmatites;

Lithium mineralization occurs mainly as spodumene and secondarily as lepidolite. This lithiniferous mineralization corresponds to residual magmatic liquids enriched in rare elements, resulting from the fractional crystallization of biotite - granite. The emplacement of the Dibilo lithium - bearing pegmatites within the granite was favored by the operation of the dexter and sinister shear corridors during the D2 deformation phase.

The LiO_2 content obtained by geochemical analysis varies between 1.4% and 2% for reserves estimated at 300, 000 and 350, 000 tons of ore [22].

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