Open Journal of Applied Sciences, 2024, 14, 171-181
https://www.scirp.org/journal/ojapps
ISSN Online: 2165-3925
ISSN Print: 2165-3917

Rare-Element Pegmatites Rocks Rich and Li of the Aïr Massif of the Tchirozerine: Mineralogy and Chemical Composition Agadez Region-Northem Niger

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How to cite this paper: Mama, N., Bassara, H., Adama, A., Zéphyrin, A.P. and Limbisoa, N. (2024) Rare-Element Pegmatites Rocks Rich and Li of the Aïr Massif of the Tchirozerine: Mineralogy and Chemical Composition Agadez Region-Northem Niger. *Open Journal of Applied Sciences*, **14**, 171-181.
https://doi.org/10.4236/ojapps.2024.141013

Received: October 11, 2023
Accepted: January 28, 2024
Published: January 31, 2024

Abstract

The lithium potential in the Aïr massif is represented by mineral index of spodumene pegmatites and, lepidolite pegmatites. The mineral deposits of lithium occur in cluster or veins that cut the host rock or are located near the contact between the greenstone belt and granitic massif. The evidence of lithium is in the form of clusters or disseminated and stockwerk. Mineralogical characteristics show similarities between the Air Massif pegmatites and indicate the same homogenous source during the magma-generation process. The pegmatite rocks attracted the attention due to their wide exposure and composition, well appearance, and economically hosting of significant rare earth metals such as Sn and W. The mineralogical and petrographical investigations on the eight pegmatites rocks samples observed have a relative similarity, while a little difference in the shapes attributed to the ratio in the pegmatite rocks of the minerals. The occurrence of the kink band indicates the influence of the tectonic processes which affected the Aïr massif after the emplacement of late magmatic or post-magmatic pegmatites by injection into fractured rocks in the upper part of the crust. The Air Massif pegmatite has higher concentrations Li and of all trace elements except Hf and occasionally Zr, Ti, Sn and Mg of for the economic exploration.

Keywords

Pegmatite, Lithium, Rare Elements, Hydrothermal Processes, Aïr Massif

1. Introduction

The growing strategic importance of Li- and rare elements during the last decades due to the strong increase in energy consumption raises a particular interest to study of the Aïr massif for sustainable development. LCT-type pegmatites are rare-element pegmatites enriched in Li, Cs and Ta, and are often related petrogenetically to fertile, progenitor granites for classification of pegmatites [1]. Those granitic pegmatites in the Aïr massif, which are the source of many rare elements, can be source of gem rough in the case of the pegmatite exploration. Establishing the chemical composition of the granitic pegmatite provides important clues regarding its origin, geologic history, and relationships to other rock types or bedrocks. They are crystalline rocks that are often characterized by highly variable texture, giant-size crystals, unusual minerals, and concentrations of rare elements. Pegmatites originate from residual magmas derived by partial melting of crustal rocks or as products of the final stages of igneous crystallization [2] [3]. Although the Aïr massif is constituted by a variety petrography (rocks) and it shares the same basement composed of the metamorphic rocks and granitic rocks [4] [5]. Individual pegmatite of the Aïr massif is presented to demonstrate the remarkable similarities between rare elements pegmatites in rich Li in diverse parts compared of the world pegmatite. This work presents current knowledge concerning the mineralogy and chemical composition of those fascinating pegmatite in the ring complex of Aïr affected by very accentuated tectonic processes and understand granitic pegmatites and their distinctive features. We have not used the analysis to other rocks or bedrocks because only the concentration potential of lithium, some rare elements and granitic pegmatite feature are highlighted in order to classify the lithium resource of the Aïr and not the linked between the rocks type of the study area.

2. Geological Setting

The Aïr massif is one of the rigid blocs accreted during the Pan-African orogeny [6]. It is located at the northem Sahelian limit, in the village of Boudari (Northern Niger) and extends between 8˚1'12"E - 8˚6'36"E and 17˚33'12'''N - 17˚21'36"N (**Figure 1**). It is geologically linked to the eastern Hoggar, from which it is separated only by a narrow threshold of Devonian sediments Niger presents a geological context favorable to the occurrence of rare elements as well as the phanerozoic ring intrusions of the Aïr massif, Damagaram-Mounio massif, and the small anorogenic alkaline massif [7]. The Aïr volcanoes are located either on faults-oriented NW-SE or on annular faults linked to Devonian ring complexes [4]. The Aïr Massif is part of the mobile zone or orogenic belt of the West African

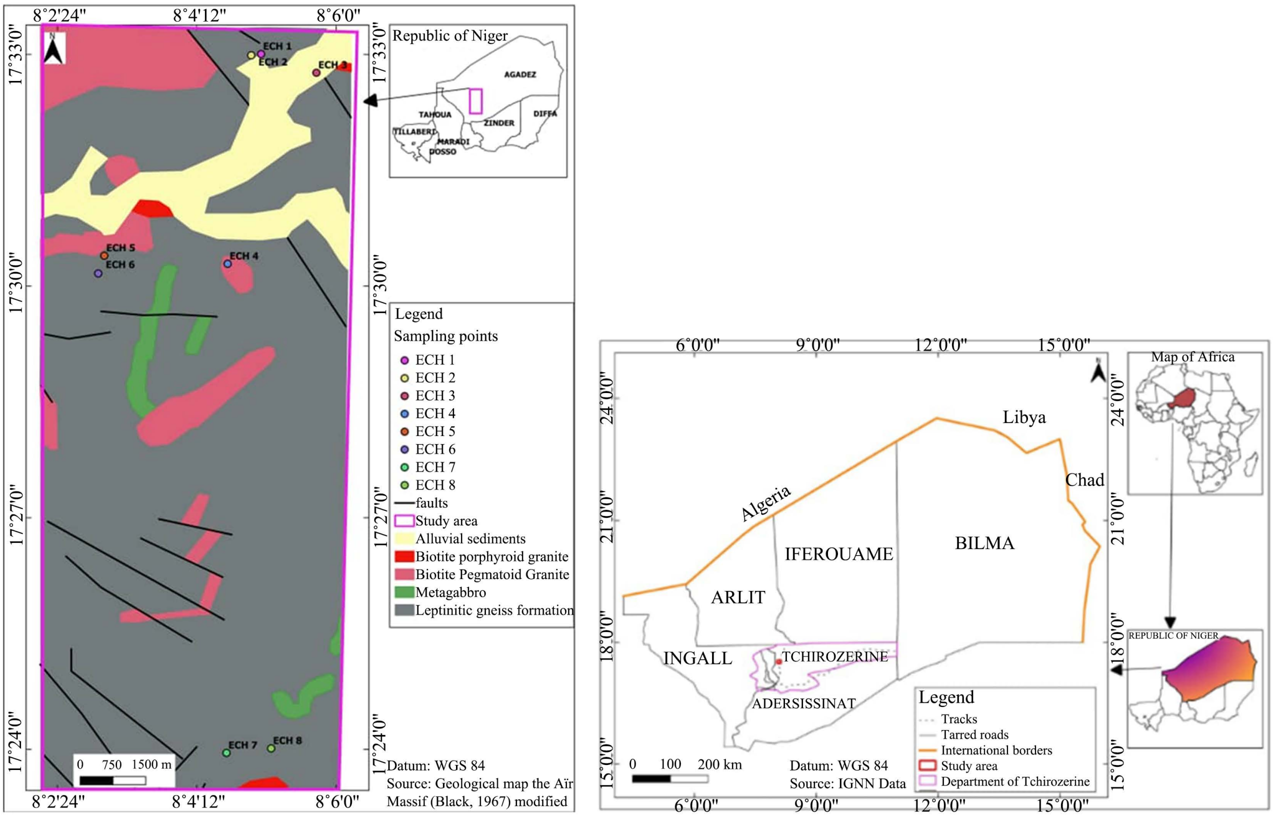

Figure 1. Geological map of the Aïr Massif modified after [4].

craton which completes the Iforas-Hoggar-Aïr mountain chain formation. This position, which borders the large Tim Mersoï basin, thus overflowing with uranium deposits, gives it a complexity of geological phenomena that have contributed to a diversity of rock groups. In the Aïr massif, lithium is related to Sn-W stanniferous and wolframite mineralization hosted in granites (CRGM, 2022). The uranium is believed to have been derived from erosion of the alkaline ring complexes in the Aïr Massif, and the current radiometrics data supports this; strong responses are generated by some units within the ring complexes, and by the basal sedimentary horizons lapping the Aïr Massif to the west. The uranium mines are situated outside the current survey area, but the radiometrics data and a number of reported uranium occurrences within the survey area lend potential to selected zones within the survey area (report of the Minister of Mines and Mining and geological research center). The interest of the Aïr ring massifs lies in the regional character of the distribution of such intrusions, on the scale of the African continent, and in their linear distribution in a meridional direction, in relation to deep in the basement. The Aïr massif is illustrated by tectonic structuration in three domains from North-South affected by some accidents in one domain [6]. Bedrocks are classified into different rocks formations with the metamorphic facies that are affected by eastward folding [4] [8]. The anorogenic ring complexes, emplaced at the end of the panafrican orogeny, present the result of volcano-plutonic magmatism with bimodal volcanism and plutonism of syenitic rock type and alkaline, peralkaline and some metaluminous granites [9] [10] [11] [12]. The Syntectonic granites are the most widespread panafrican granites belonging to the calc-alkaline series and whose ultimate facies is a two-mica granite [13]. The volcanism of the Aïr massif, whose emplacement at the level of ring faults linked to Devonian ring complexes [4] was favoured by reactivation near the Raghane shear zone at the end of the panafrican orogeny. The bimodal character of the Aïr Massif mafic lavas was manifested from Devonian through Cretaceous during the Phanerozoic to the present [4] [14] [15] [16]. Numerous late-magmatic structures are highlighted through the vein rocks (vein quartz filling faults, rhyolite, pegmatite, syenite and micrograined rock) [5]. The term pegmatite, then, primarily refers to the texture of a rock, that is, the size, shape, and arrangement of mineral grains. In practice, it can be applied to a wide range of rocks of igneous or metamorphic origin that exhibit large crystals. Pegmatites tend to be most common in particular geologic settings, generally where igneous or metamorphic rocks are exposed at the earth's surface [17] [18].

3. Analytical Methods

The complete description of the analytical methods is provided in this work. Eight refined polished thin sections were prepared for mineralogical and petrographic studies using optical polarizing microscope at the laboratory of the Department of Mining Geology at the School of Geology and Mining Engineering of the University of Ngaoundere, Meiganga. The identification of mineral inclusions and variety of oxide staining was determined using a standard petrographic microscope. Whole-rock analyses half of each of the eight samples collected was crushed, pulverized to 200 mesh and analyzed for trace-elements. Concentrate samples from different study area have been investigated (**Figure 1**). For details on the geographical coordinates of the sample locations and sample characteristics, the reader is referred (**Figure 2**).

(a) (b)

Figure 2. (a) Field photograph showing the sharp contact between the main granitic varieties of the Aïr Massif and (b) macroscopic observation of the pegmatite sample.

4. Results

4.1. Study of the Granitic Pegmatite in Field

The Aïr massif is crossed by an irregular band of muscovite-biotite pegmatite, which ranges from 6 m into the granite layer and gneiss. The contact of pegmatite with the other rocks is exposed and it is fairly well represented in our study zone dominated by the gneiss liptinitic. The structural study will not be developed in this work; as we observe that the emplacement of late magmatic or post-magmatic pegmatites by injection into fractured rocks in the upper part of the crust. The highest part of the hill, where the rocks are gneiss which strike slightly east of north and dip nearly vertical. The contact nearly parallels the trend of the gneiss leptinitic and the pegmatite is plainly intrusive, locally cutting across the gneiss and granite rocks (**Figure 2(a)**). Numerous pegmatites veins are similar orientation which vary between the N300˚ to N358˚ (CH01, CH04, CH05, CH06, CH07) excepted the CH02 and CH03 respectively N75˚ and N225˚. The CH02 and CH03 pegmatite veins present similar composition respectively the lepidolite pegmatite and the spodumene pegmatite. The tanslucent quartz intergrown with the penetrating nature of some crystals (circled) and euhedral outline of the quartz (dashed line) (**Figure 2(b)**). Numerous samples-stained grain of possible spodumene is pointed. Those orientations are not always similar of the main tectonic orientations in the Aïr Massif are N120˚ - N150˚ and N50˚ - 90˚, sometimes rhyolitic dykes and gabbros [4]. This quartz is typically dark grey to black in color and intergranular matrix to Spd megacrysts (**Figure 2(b)**). The mineral assemblage of numerous pegmatites of the Aïr Massif is similar compared to the rocks description by [19] and [20].

4.2. Petrography and Mineralogy

The pegmatite in the Aïr massif for detailed study shows feldspar crystals up and aggregates of feldspar crystals unmixed with other constituents and areas of smoky quartz one-half inch across. Although pegmatites are commonly thought of as very coarse-grained rocks, they actually vary considerably in grain size. The central part of the pegmatite CH07 and CH04 retains its very coarse-grained original texture (**Figure 3(b)** and **Figure 3(c)**). The Aïr massif is composed of the pegmatite (CH01, CH03 and CH08) consistent of two micas (muscovite, biotite). The others samples of this type are composed mainly of plagioclase, quartz, potash feldspar and minor subordinate biotite minerals (**Figure 3(d)** and **Figure 3(e)**). Quartz ranges from medium-to fine-grained crystals. It shows clear extension due to deformation processes (**Figure 3(e)** and **Figure 3(f)**). The muscovite is very abundant more than biotite. Muscovite has a pale yellowish green or even silver color or even silvery (CH08). Mineralogical assembly of pegmatite in the Aïr massif is identical with those of the granite and gneiss: orthoclase, quartz, microcline, oligoclase-albite with some border rims of albite, biotite, and muscovite. Plagioclase occurs as phenocrysts crystal mantled by coarse grained quartz and biotite forming porphyritic texture. This mica is transparent to

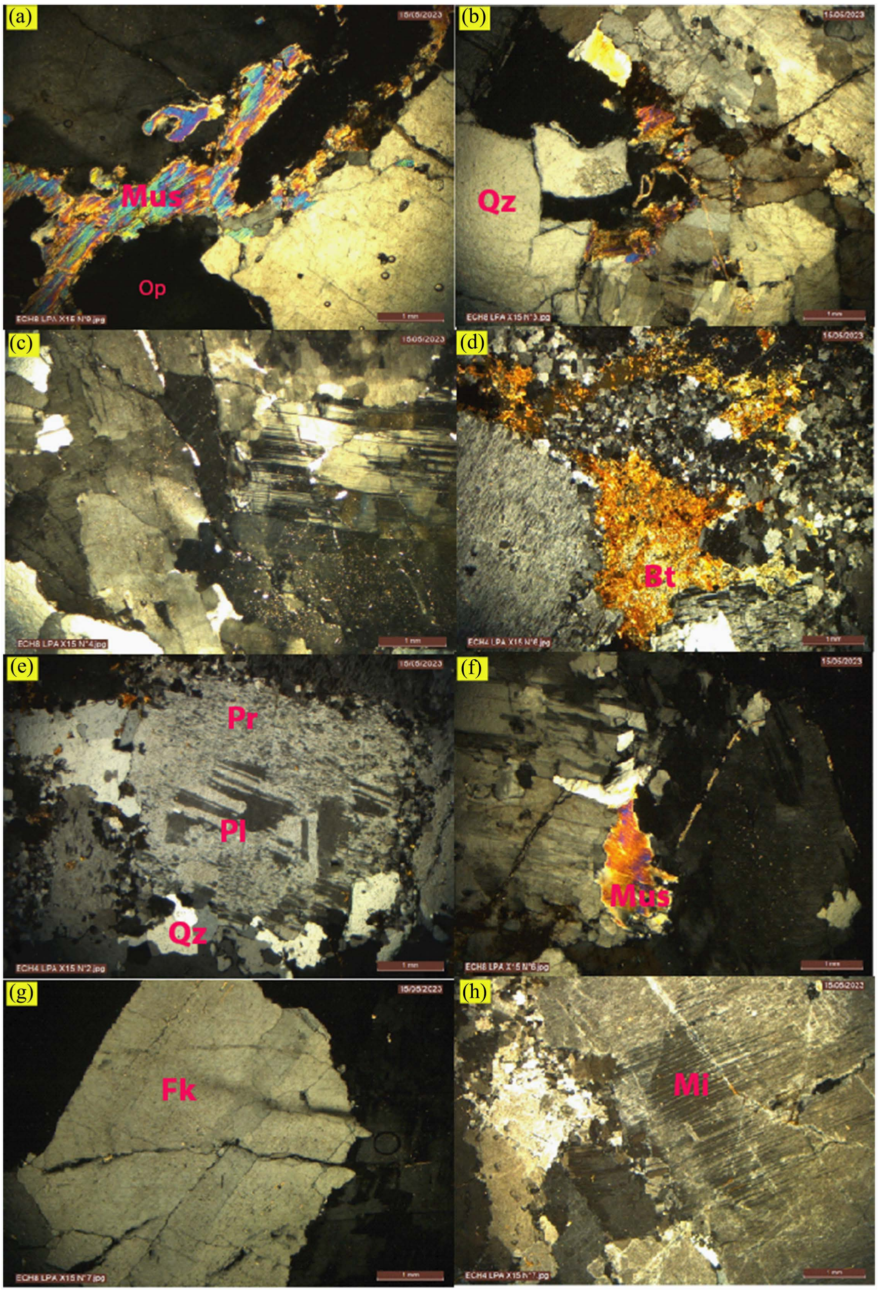

Figure 3. Photomicrographs reveals: (b) Coarse-grained orthoclase (F4); (c) Fractured coarse-grained orthoclase perthite that filed by secondary quartz (F7); (d) Extensive turbid surface of plagioclase crystals (F6); (e) Pyramid-like shape of perthite crystal surrounded by sericite (F6); and (f) Euhedral of quartz crystal (F5); (g) Well-formed kink band.

orange hue and tends to be subhedral to euhedral. Plagioclase crystals are not homogenous with the zonation and inclusion-free (**Figure 3(c)**). The feldspar also occurs here and there in crystals of large size. Microscopic study shows it to consist of the potash varieties, orthoclase and microcline, minutely (perthitically) intergrown with small amounts of the soda feldspar, albite. Perthite reveals a xenomorphic of patchy type that mostly engulfs plagioclase (**Figure 3(h)**). Large euhedral crystal of plagioclase occupies of the rock mass and presents medium relief between its minerals and with the presence of polysynthetic marks. The principal difference in their mineral composition is the much smaller quantity of biotite and muscovite present in the pegmatite. Biotite is minor constituent of some pegmatite, although it constitutes up to 5% of the mode of a few samples. It occurs as very fine to fine grained < 0.3 mm) pale green or brown crystals. The oxide may also be present as lager grains showing bladed habit. Muscovite is the one of the principal constituents in nearly some pegmatites (CH 01 - 05). Orthoclase, present with quartz in nearly all of the pegmatites shows the relative proportions. In the vast majority of deposits, the pegmatite minerals appear to be present in very nearly the same proportions as in the associated granites in the whole massif. The pegmatite becomes rich in feldspar and in the lithium minerals, lepidolite and spodumene. Quartz varies from white to dark gray in color and from opaque to beautifully transparent. The quartz obtained in the course of the pegmatite samples is white and very pure and is of excellent quality for which crystalline quartz is now used. It occurs as medium-grained crystals, reveals extensive exhibits lamellar. While shear fractures are abundant in most consolidated rocks, kink-bands occur only in rocks with a well-developed (**Figure 3(g)**).

5. Geochemical

The concentrations of trace elements on the same samples were determined by fire assay/AAS analysis fusion. The average results of the trace element of the studied pegmatite are shown in **Table 1**. The trace-element compositions within each sample of the study area are highly variable; however, several important features are observed. The whole-rock geochemistry reveals an important association of Mn and Cu portions of the pegmatite. However, as well as trace elements allow the distinction disproportion of some trace elements. The trace chemical elements of the pegmatite magma determine the nature of the abundant, first-formed minerals as feldspars, quartz, and micas. Evidence of this is found in mineralogical similarity, in the invariable presence of granite in all areas where pegmatite is found, and in many actually observed transitions from one to the other. Only 5% of the Ta and Sn resources are hosted in primary deposits (pegmatites and cassiterite-bearing quartz veins). Lithium contents (30 - 50 ppm) are relatively low in pegmatites in our study area. Maximum values don't exceed 369 ppm in Li-rich spodumene pegmatite (CH08) and concomitant in Mn with 867 and 936 for the CH07. Beryllium concentrations in the all pegmatite are very low. Elevated values from 2 to 12 ppm of the beryllium are found in several pegmatites. Beryllium concentrations do not show any correlation with Mn and Pb values. Lithium varies from 30 to 360 ppm, showing a broadly positive correlation with #Mn and a weak negative one with #Ta. The highest Zn concentrations in pegmatite (155 ppm Zn) occur in the CH08 sample in the south zone of the study area. This may indicate an external source of Zn in the

Table 1. Whole-rock analyses half of each of the eight samples collected was crushed, pulverized to 200 mesh and analyzed for trace-elements (ppm) except the Al content.

	ECH1	ECH2	ECH3	ECH4	ECH5	ECH6	ECH7	ECH8	Bik blank	Rep ECH5	Std OREAS906	Std AMS0355
Al	69122.00	74179.00	65975.00	66517.00	57282.00	65878.00	63804.00	46824.00				
Ba	420.00	362.00	93.00	66.00	371.00	256.00	44.00	22.00		356.00	2572.00	
Be	9.00	11.00	10.00	10.00	12.00	9.00	10.00	2.00	5.00			144.00
Co	22.00	31.00	18.00	15.00	12.00	24.00	25.00	50.00		25		248
Cu	15.00	15.00		25.00	40.00	25.00	15.00	90.00	10	35	2836	382
K	7.60	8.50	2.80	2.30	7.50	2.20	4.20	1.40		7.4	2.9	1.6
La	14.00	9.00	7.00	11.00	16.00	8.00	15.00	13.00			40	
Li	30.00	25.00	40.00	35.00	30.00	50.00	30.00	369.00	25	30	45	7254
Mn	69.00	50.00	155.00	239.00	50.00	89.00	938.00	867.00		45.00	333.00	899.00
Sn	44.00	29.00	52.00	61.0	32.00	60.00	111.00	1022.00	80			392
Mo	23.00	28.00	14.00	16.00	17.00	22.00	28.00	25.00				
NI	18.00	12.00	14.00	8.00	3.00	18.00	20.00	60.00				144
Pb	64.00	75.00	25.00	35.00	25.00	36.00	47.00	52.00				
Sr	144.00	150.00	20.00	40.00	64.00	154.00	15.00	111.00		60	144	60
Y	40.00	30.00	40.00	105.00	6.00	72.00	50.00	40.00			15	
Zn	15.00	20.00	30.00	30.00	35.00	20.00	30.00	155.00	25	25	129	74

hydrothermal fluids during the emplacement of pegmatite rocks (CH08). The southern zones of the study area are associated with elongated rafts of the host rock (liptinitic gneiss formation), oriented parallel to the pegmatite suggests that successive pulses of magma were injected along a structural feature (**Figure 1**). The highest Al content with sample CH01 (46824.00 ppm) showing a lower concentration than the rest of the sample, promote the stabilization of the orthoclase crystals in the pegmatite which represent the high proportion modal of the mineral assemblage (**Table 1**).

6. Discussion

The petrographic examination of pegmatite rocks was using a polarizing microscope to identify their mineralogical assembly. The textural features revel some significant processes affected these pegmatite rocks. The textural relationships indicate that the K-feldspar was syn- or post-crystallization relative to the others minerals. Based on the mineralogical composition and the main textural relationship, the pegmatite rocks of the Aïr massif show the gradation from one rock into the other indicate a common magmatic source. The pegmatite appears to have been intruded before the complete solidification of the granite. Our pegmatite zone as well other the vast majority of pegmatites in the world are found to be chemically and mineralogically similar to ordinary granites. Muscovite has a pale yellowish green or even silver color or even silvery, which usually indicates the existence of spodumene pegmatite. The veins are typically found as multistage networks, interpreted as forming because of high fluid pressures associated with intrusion and volatile release. This is an excellent example of a biotite-muscovite pegmatitic leucogranite unit with characteristic plumose segregations of muscovite-quartz or rocks crystal and megacrysts of quartz-orthoclase, K-feldspar-porphyritic biotite granitic pegmatite. The close petrologic relationship that is sometimes apparent between pegmatites and plutonic igneous rocks has been taken as evidence that most pegmatites themselves result from the crystallization of silicate magmas suggestion by [21]. The pegmatite granite was derived from a residual magma of the mantle source then the reactivation near the Raghane shear zone at the end of the panafrican orogeny coupled with the hydrothermal process. The main observations, however, suggest that the pegmatite studied in this paper did not form as a result of kink band development but that the kinking instead is reflecting with the preexisting pegmatite granite. Our thin section suggests the kinking zone rocks were deformed and many represent advanced stage of mineralization affected by hydrothermal processes. The kink band occurs suggest that the pegmatite was affected by syngenetic deformation in correlation with the same orientation of pegmatite veins which are affected by tectonic processes. The occurrence of pegmatite granite cutting across the foliations of both the gneiss and granitic rocks of the zone indicates indicate that the period of pegmatite emplacement overlapped with the period of development of the gneissic foliation and granite. The relation between crystallization of a particular mineral and the events of deformation may appear contradictory in the different thin sections of the same area or sometimes in different parts of the same thin section. The association of minerals assemblage suggests that magmatic-metasomatism from a low-density Li-rich melt may be the primary cause of sporadic enrichment of the pegmatite with certain trace elements.

7. Conclusion

The petrographic description of the studied pegmatite granite exhibited deformation effects expressed as fragmentation of quartz and plagioclase crystals. The mica occurrence and few rare elements in the pegmatites of the Aïr massif are characterized the pegmatites which are formed at depth and intermediate depths probably between 7 to 11 km similar of the pegmatites of the Black Hills, South Dakota [22] [23] [24]. Mineralization (Sn, Zn, W, Nb, Ta, C, Cu, Fe, Bi, U, REE) is confined to biotite granitic pegmatite affected by hydrothermal processes, which produced metasomatic disseminated of the minerals that present an enrichment of those elements. Mineralogical description presents two phases: major phases (quartz, plagioclase, microcline, muscovite and biotite) and minor phases (spodumene, beryl and apatite). It is difficult for us to determine the mechanism which contributes to the enrichment, those samples with the high-Li concentration. Trace element data have been used in formulating mixing hypotheses for the origin of those magmas. The major conclusion from the foregoing is that high-Li, the magma type must generally be derived as partial melt of felsic to metaignous rocks and characterized by a more enriched Li in the crust. The textural feature of the pegmatite rocks constitutes the important role played by aqueous fluid (hydrothermal).

Acknowledgements

The authors would like to thank for the reviews of this manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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