Lithium and tungsten mineralization in Sewariya pluton, South Delhi Fold Belt, Rajasthan: Evidences for preferential host rock affinity

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'Sewariya batholith', the largest of Erinpura granite intrusions in the South Delhi Fold Belt is evolved from a two-stage subduction process. The Sewariya granitoids comprise three major mineralogical varieties, viz. hornblende–biotite granite, biotite granite and leucogranite. The hornblende–biotite granite is a deep-level I-type granite, whereas the other two are orogenic, S-type anatectic granites formed by partial melting of the same source material under varying physicochemical conditions. These two granite types also host the tungsten and lithium mineralization. The W and Li minerals show perfect separation and host rock discrimination. The W minerals are associated with biotite granite, whereas the leucogranite hosts the Li mineralization.

THE folded rock sequences of northwestern part of the Indian shield in the state of Rajasthan contain two principal well-defined Proterozoic fold belts, the early Proterozoic Aravalli and the Middle to Late Proterozoic Delhi Fold Belt. The Delhi Belt extending from Delhi in the northeast to northern Gujarat in the southwest is exposed in two discrete sectors[1], viz. North Delhi Fold Belt (NDFB) in northeastern Rajasthan and South Delhi Fold Belt (SDFB) towards southwest, with its best development in the main Aravalli hill range near Ajmer and in western Mewar. The Delhi sequence has been traced into southwestern Rajasthan but its physical continuity is interrupted by a vast expanse of alluvium, resulting in tremendous correlation uncertainties. Orogenic activities manifested by continuous polyphase acid magmatism have been documented in NDFB by 1600–1500 Ma granites and by 850–700 Ma plutonic belt in SDFB, overlapped and followed by the Malani igneous activity (740–430 Ma). The SDFB is intruded by a number of granitoid bodies ranging from minor intrusions to composite batholiths. The 22 mile long and 4 mile wide Sewariya batholith is the largest of the Erinpura granite intrusions in the northern half of the Delhi synclinorium[1].

Location and geological setting

The present work deals with the evidences of typical mutual association of specific granitoid host *vis-à-vis* tungsten and lithium mineralization in the area south of Luni river in northwestern flank of SDFB (26°30″ to 26°32′N and 74°05′ to 74°22′E) around village Sewariya in district Pali, Rajasthan (Figure 1). The geological setting of the area is shown in the detailed lithologic map (Figure 1) and the stratigraphic sequence is summarized in Table 1.

The oldest rocks encountered in the area are the Pre-Delhi metamorphites comprising mica schist, gneisses and amphibolites. These are overlain by two thick bands of marble, commonly known as 'Ras Marble'. The contact between Ras Marble and Pre-Delhi rocks is either concealed by alluvium or infested by pegmatites. The Ras Marble is coarse-grained, light grey and thickly bedded massive carbonate rock containing minor quantities of quartz, felspar along with epidote, zoisite, diopside and tremolite as accessories. A volcano-sedimentary assemblage constituting the Barotiya Group containing meta-argillite (+/– autoclastic conglomerate), tourmalinite, meta-basic volcanics, meta-gabbro, meta-arkose, marble and chert overlies the Ras sequence. The contact between Barotiya group of rocks and the Pre-Delhi metamorphites/Ras Marble is obliterated and occupied by Sewariya granitoids (SG). The meta-argillite contains quartz, biotite, plagioclase, garnet, tourmaline, staurolite, andalusite, sillimanite (fibrolite), apatite and magnetite. Tourmalinite contains mainly tourmaline and quartz besides minor opaques and biotite as accessories. The meta-volcanics of the Barotiya group exhibit bimodal composition[2]. In the present area only the mafic component having actinolite, plagioclase (andesine), quartz, sodic hornblende, epidote, apatite, leucoxene and opaques is exposed. Relict pyroxene cleavage is observed in the amphiboles. Alteration of hornblende into chlorite and plagioclase into saussurite is also seen. Three petrographic variants of meta-gabbroid bodies have been identified in the field. Marble contains discrete clasts of anhedral quartz in fine micritic mass along with zoisite, clinozoisite and apatite as common accessory minerals. Meta-arkose is dirty-white-coloured, medium-grained rock containing mainly quartz and felspars besides muscovite and apatite along with minor opaques. Meta-chert occurs as thin linear bands within meta-arkose unit in the area.

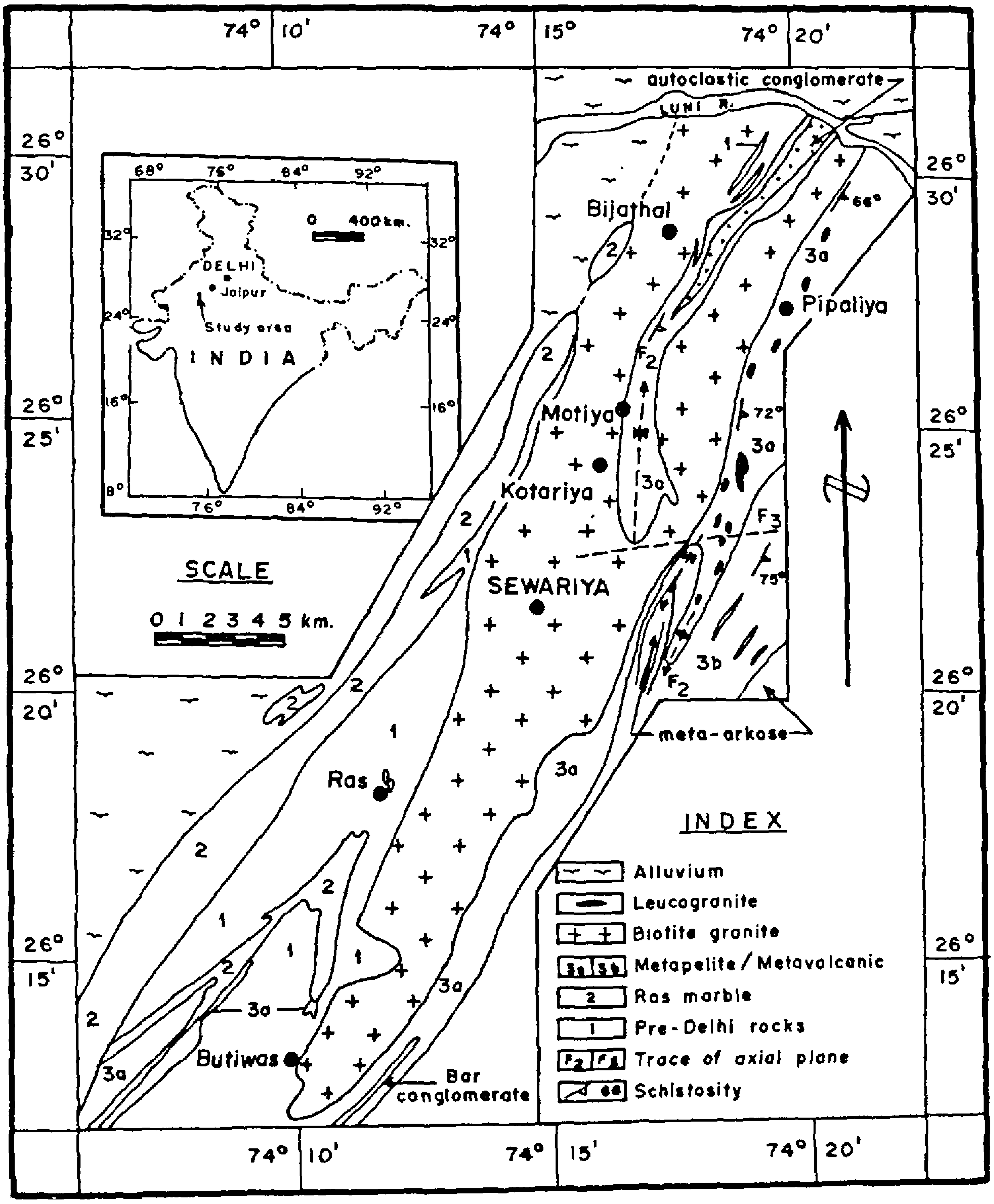

Figure 1. Lithostratigraphic map of the Sewariya region Map of India showing the location of the study area is also given in the inset

Various structural elements recorded in the area are *in harmony* with the deformations related to SDFB. The overall strike pattern, litho-contacts and linear shears of the area are in conformity with NNE–SSW-trending Aravalli orographic axis. Three generations of conformable deformational structures have been recognized in both Ras and Barotiya group of rocks, while one more phase of earlier folding is also recorded in the Pre-Delhi rocks. Shears usually follow the zones of weakness and contribute prominent linearity to the overall outcrop pattern.

The area of the present study has undergone two progressive metamorphic phases involving lower greenschist to sillimanite–almandine subfacies of amphibolite facies and subsequent anatexis, followed by a retrogressive phase of metamorphism under lower greenschist facies. The grade of metamorphism in this sector increases westwards and the isograds are parallel to the regional planar fabric.

Table 1. Stratigraphic succession of the Sewariya region

Syn- to Post-Delhi intrusives		Pegmatites, quartz tourmaline, quartz andalusite, quartz felspar and quartz veins
		Leucogranite; biotite granite; hornblende–biotite granite
Intrusive contact		
Delhi super group	Barotiya group	Marble, meta-chert, meta-arkose; tourmalinite; meta-volcanics; meta gabbro; mica schist (+/- autoclastic conglomerate)
	Ras sequence	Marble
Structural hiatus		
Pre-Delhi		Metamorphites

Table 2. Major and trace element analysis of Sewariya granitoids. The major oxides are represented as wt% and the trace elements in ppm

	Range	Average[1]	Average[2]
SiO_2	67.71–80 18	71 83	73 62
TiO_2	0 07–0.50	0.22	< 0 05
Al_2O_3	9.67–15 60	13 13	14 88
Fe_2O_3	0 40–4.70	1.93	0 76
FeO	1 08–3 17	1.80	0 90
MnO	0 01–0 10	0 04	0 04
MgO	0.05–1.3	0 64	0.04
CaO	0.56–2.48	1 36	0.41
Na_2O	0 14–4 64	2 57	4.86
K_2O	3.72–6 05	4.91	3.53
P_2O_5	0 03–0.22	0.12	0.22
Trace elements			
Ni	10–20	13	< 10
Zr	20–50	28	< 20
Li	20–900	135	65
W	20–100	50	< 50

[1]Average of 15 biotite granites.
[2]Average of 2 leucogranites.
< = Below detection limit.

Granitoids and metallogeny

Three types of granitoids, viz. leucogranite, biotite granite and hornblende–biotite granite, are exposed in the present area. The latter two granite types and their associated W +/– Li +/– Sn mineralization have already been studied in detail[3]. During the present study the authors have identified the leucogranite variety and have also successfully discriminated exclusive association of tungsten mineralization with biotite granite and lithium with leucogranite–pegmatoid phase. The hornblende–biotite granite seems to be absolutely devoid of any mineralization.

Leucogranite is a fine- to medium-grained, white- to dirty-white-coloured rock occurring as small pods and irregular bodies of extremely variable size, in the eastern part of the area within meta- argillites. The smaller bodies and pegmatite veins lie concordant to the planar fabric and are often boudinaged. The typical mineral assemblage of this rock is quartz, plagioclase (mainly albite), K-felspar, muscovite, tourmaline and garnet with small amounts of apatite. Tourmaline occurs either as irregular masses or as euhedral prisms with 10–15% modal abundance. The leucogranite does not contain a single flake of biotite.

The biotite granite and the leucogranite are meta- to per-aluminous, highly fractionated in character, showing depletion of compatible elements like Fe, Mg, Ti, Ca, Ni, etc. (Table 2). The relatively more fractionated (high SiO_2, very low MgO and CaO and higher alkalies), homogeneous leucogranite has characteristic absence of biotite and zircon, implying efficient separation of melt from solid residual phases[4]. The low Li content of leucogranite (65 ppm) can be attributed to the partitioning of Li into the residual melt phase during fractionation and its ultimate segregation as Li phosphate minerals in the late-stage pegmatoid phase associated with leucogranite. The low W content of leucogranite is due to the absence of biotite phase, which is the carrier and the most suitable locale for W concentration.

The biotite granite is heterogeneous in nature, with composition comparable to the metasediments of the area[4]. It is well differentiated, per-aluminous, orogenic, S-type granite with calc-alkaline affinities[3]. The initial I_{Sr} of 0.74552 indicates its crustal derivation from metasedimentary source rock[5]. The higher concentration of W is due to the presence of biotite as an important constituent. Higher values of Li as compared to the leucogranite (host for Li mineralization) is a result of regular partitioning of Li in the crystal phases during fractionation, resulting in its depletion in the residual melt. As such, the quartz and pegmatite veins associated with the biotite granite are devoid of any Li mineralization.

The crustal anatexis and recycling of pre-existent crustal material plays a dominant role in granitoid petrogenesis. Consequent to progressive regional metamorphism under sillimanite–almandine subfacies of amphibolite facies, anatexis takes place, giving rise to different types of granitic magmas depending mainly upon the composition of the source material, its formation level difference and the percentage of partial melting. In this context the leucogranite appears to have been formed at higher crustal levels, generated by comparatively lower percentage of partial fusion of supracrustals[6] with simultaneous removal of melt from the melting zone under water-rich conditions as evident by the presence of extensive pegmatite veins. The melt initially segregated into small bodies, which subsequently united together to form larger bodies and intruded the overlying rocks in the eastern part of the study area.

The SDFB with an ensialic rifting history contains profuse Post-Delhi granites, the older Sendra granite and the younger Sewariya granite developed in response to the subduction process[7]. A perfect matching of the geological setting and lithological characters of the present area with pyrenes[8,9] indicates that localized rifting events associated with strike–slip motion in SDFB have affected the basin[10]. Deep circulation of ground waters also influenced the anatectic process by controlling the solidus–liquidus temperature and promoted higher percentage of partial melting to produce such a huge biotite granite pluton (Sewariya batholith), the 'largest of Erinpura granite intrusions'. The biotite granite of the area appears to have been derived from the same source material at relatively deeper levels compared to the leucogranite, involving higher percentage of partial melting under essentially 'wet' melting conditions[6].

Both leucogranite and biotite granite are high-level, syn-metamorphic and syn- to post-kinematic, anatectic granites, but the third variety, i.e. the nonfoliated hornblende–biotite granite is post-metamorphic 'deep-level' granite possibly formed either exclusively from deeper crustal material or by mixing of mantle-derived mafic magma and assimilated crustal lithologies.

The western Indian craton and its fold belts have provided important clues to the understanding of different metallotects for various mineral commodities. Incidence of wolframite was first recorded within Sewariya pluton by Rajasthan State Tungsten Development Corporation in 1987 and later a 14 km long tungsten mineralization belt was identified between Kalni in the north and Kotariya in the south[11]. The W +/– Sn +/– Li metallogeny associated with metallogenetically specialized biotite granite has been compared with similar metallogenesis of the Cordilleran arc system[3]. However, the present study reveals that the tungsten metallogeny in the eastern part of the area associated with meta-argillites (viz. Pipaliya and Pipaliya village prospects) seems to be exhalative strata-bound type. Subsequent enrichment in W content during progressive metamorphism is evidenced by enhanced W values in NNE–SSW- trending dewatering quartz veins emplaced along axial plane schistosity (S2). Evidences of later remobilization and enrichment in quartz veins associated with NNE–SSW-trending shear zones near and along the contact between Barotiya group of rocks and anatectic biotite granite have also been observed. In contrast, at Motiya, Kotariya, Bijathal, etc., the host quartz and pegmatite veins are associated with granitization process emplaced in and through channelways in the shear zones. Tungsten mineralization accompanied by greissenization and as placer deposits in Motiya block, has also been identified. The lithium phosphate minerals (sicklerite, ferrisicklerite and triphylite) bearing zoned pegmatoid and quartz veins associated with leucogranite phase occur concordantly within meta-argillites in the eastern part of the present area as an 18 km long belt. The younger discordant veins show remobilization and enrichment. Similar phosphate species of sicklerite–triphylite also occur as important accessory minerals in numerous granitic pegmatites in the Pala area[12]. The phosphate mineralogy and alteration history of these minerals indicate their crystallization at a relatively shallow depth[13]. The crystallization was facilitated by the presence of a coexisting, exsolved, volatile-rich fluid within the pegmatite magma in the upper intermediate zone only[14]. The phosphate–silicate liquid immiscibility is not essential for lithium phosphate formation under water-saturated conditions[15].

Discussion and conclusion

The relationship between leucogranite and the biotite granite in the present area is not clear as the former is occupying the synformal cores and the latter is emplaced in antiformal cores of the same deformation (DF2). Leucogranite does not contain biotite as well as tungsten, whereas biotite is the main mafic mineral in tungsten-bearing biotite granite. Pegmatitic phase is ubiquitous in leucogranite and contains lithium phosphate minerals. Though a few pegmatite veins are associated with biotite granite, they are devoid of any lithium phosphate mineralization. Pneumatolytic quartz veins are a very common feature of biotite granite, which hosts the bulk of the tungsten mineralization.

The absence of biotite and certain elements in well-differentiated leucogranite implies efficient selective separation of melt from solid residual phases during anatexis. The tungsten normally partitions along with biotite and hornblende in a granitic melt[16], consequently, the biotite-free leucogranite of the present area is devoid of any associated tungsten. The absence of absolute pegmatitic conditions and essential exsolved volatile-rich fluid phase in biotite granite have constrained it to host the lithium mineralization. The present area is characterized by three phases of Erinpura granitic activity. The leucogranite and the biotite granite are high-level, syn-metamorphic and syn- to post- kinematic, S-type granite generated by anatexis of Barotiya group supracrustals at different formation levels involving varying percentages of partial melting. Though supracrustals of the area were the source for both leucogranite and biotite granite, effective selective separation during anatexis has caused lithium phosphate mineralization in extremely well-differentiated leucogranite under absolute pegmatitic conditions along with essential coexisting exsolved volatile-rich fluid phase. For want of such suitable conditions the biotite granite could host only the tungsten mineralization. In Stewart pegmatite, only the upper intermediate zone contains Li mineralization, while simultaneously formed lower intermediate zone is devoid of mineralization due to the absence of exsolved fluid phase, essential for mineralization[15]. These observations also warn about uncertain chances of Li mineralization at deeper levels in the present area. The hornblende–biotite granite in this area seems to be devoid of any mineralization; however, further studies are underway to explore the possibility of its contribution in the metallogeny of the area.

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