Palaeoproterozoic Khetabari Formation of Bomdila Group in Arunachal Pradesh, India is an N–S to NE–SW trending volcano-sedimentary sequence. It stratigraphically overlies the Se La Group and is exposed in the western limb of Siang antiform (Figure 1a). The Khetabari Formation comprises calc–silicate rocks/marble, carbonaceous phyllite, magnetite quartzite, quartzite/schistose quartzite marble, carbonaceous phyllite, magnetite–calcite schist, and mica schist (Figure 1a) with some concordant and discordant basic intrusions. It is thrusted over the Palaeoproterozoic Tenga Formation in the eastern margin. Intrusive Ziro granite gneiss (1536–1914 Ma) is exposed along its western margin. Multiple episodes of deformation have affected the Khetabari Formation. F1 folds well-preserved in massive and schistose quartzites, show tight to isoclinal, reclined to recumbent geometry and their axial planes generally show N–S to NNE–SSW strike. The most pervasive planar fabric S1 is developed parallel to the axial plane of the F1 folds, and is predominantly parallel to the S0 plane. The F2 folds have co-axially refolded the axial planes of F1 folds giving rise to type-III interference patterns. Crenulation cleavage (S2) is related to F2 folding. Steeply plunging, inclined, open folds of the third generation superposed on earlier folds have N–S axial planes. N–S to NNE–SSW trending fault has given rise to fault breccia. Sigmoidal magnetite grains indicate sinistral shearing. In the shear zones, elongated quartz grains and S–C fabrics are noted. These structures have played a vital role in the circulation of mineralizing fluids in the Khetabari Formation, and have served as locales for uranium and associated polymetallic mineralization (Figure 2a and b).

Exploration efforts over the last few decades in Arunachal Pradesh by the Atomic Minerals Directorate for Exploration and Research, Shillong have resulted in locating several uranium and associated polymetallic occurrences in the Khetabari Formation. Sie Rimi-Noko–Nala–Kardo–Badak area has established subsurface continuity of uranium mineralization in magnetite–calcite schist. The uranium mineralization of LGM-1 is hosted by breccia and is located in the first-order creek section about 900 m SSW of Laggi Gamlin village. The 1–10 m wide mineralization zone here is traced along the N–S strike over a length of 150 m. The strike coincides with the axial plane strike of F3 folds in the area. The breccia consists of few millimetres to more than 5 cm-sized calcite clasts cemented by ferruginous matter (Figure 2a). The study reveals that ferruginous cement is radioactive. Thirteen samples of ferruginous breccia have assayed 0.009–0.027 (av. 0.012) %U3O8 and thickness up to 0.005% ThO2.

Petromineralogical study shows that breccia has developed from precursor calc–silicate rock/marble. It has angular clasts of calcitic marble which are cemented by a matrix composed of magnetite, hematite, K-feldspar and quartz (Figure 3a). Accessory minerals are pyrite, chalcopyrite and rutile. Uranium occurs in the adsorbed state in magnetite and hematite in the matrix/cement of the brecciated marble.

The LGM-2 uranium mineralization is in sheared magnetite quartzite. Uranium mineralization (Figure 3a) in sheared magnetite quartzite (Laggi Gamlin-2; LGM-2) at Laggi Gamlin, West Siang district, Arunachal Pradesh (Figure 1). The uranium mineralization of LGM-1 and in sheared magnetite quartzite (Laggi Gamlin-1; LGM-1) and in sheared magnetite–calcite schist of the Khetabari Formation. Subsurface exploration at Noko Nala–Kardo–Badak area has established subsurface continuity of uranium mineralization in magnetite–calcite schist over a strike length of 1200 m with grade up to 0.036 %U3O8 and thickness up to 8.1 m (ref. 4).

Here we provide details of recently located uranium and associated sulphide mineralization in a breccia zone (Laggi Gamlin-1; LGM-1) and in sheared magnetite quartzite (Laggi Gamlin-2; LGM-2) at Laggi Gamlin, West Siang district, Arunachal Pradesh (Figure 1).
mineralization is observed in a 60 m × 4 m area which is located about 20 m NW of LGM-1. The host rock magnetite quartzite is folded into a N–S antiform with limbs dipping about 50° westerly and easterly. Magnetite quartzite consists of quartz grains set in siliceous and ferruginous cement. It shows intensive shearing related to F3 deformation episode. The shearing is represented by sigmoidal magnetite grains (Figure 2b), elongated quartz grains, S–C fabric and extensive development of micaceous minerals. Magnetite, tourmaline, chlorite and quartzofeldspathic veins are emplaced along the shear planes. The emplacement of magnetite-bearing quartzofeldspathic veins has played a major role in uranium mineralization, because uranium has precipitated along such veins as indicated by the chromogram test. Grab sample (n = 09) of sheared magnetite quartzite have been radiometrically assayed 0.013–0.390 %U₃O₈ (av. 0.154%) and <0.010 %ThO₂.

Sheared magnetite quartzite dominantly consists of quartz, magnetite and muscovite with few flakes of biotite. In addition, pyrite, monazite, zircon and apatite occur as accessory minerals. The S-planes are well developed by layering of muscovite flakes (Figure 3b). Microscopic evidences of shearing are
represented by sigmoidal poikiloblastic magnetite grains, S–C fabric and mica fishes. Magnetite, tourmaline (Figure 3 c and d), fluorite (Figure 3 d), chlorite and quartzo-feldspathic veins are evidences of subsequent hydrothermal activity. Uraninite is the main uranium-bearing ore mineral identified in sheared magnetite quartzite and is closely associated with hydrothermal magnetite-bearing quartzo-feldspathic veins (Figure 3 e and f). Hematite has developed along the boundary of these veins. Adsorbed uranium associated with hematite shows linear, dense α-tracks in the cellulose nitrate (CN) film (Figure 3 g). Secondary uranium minerals show fluorescence. Under the microscope, secondary uranium minerals occur as bright-coloured and show dense α-tracks in the CN film (Figure 3 h).

Uraninite is confirmed by X-ray diffraction. Other radioactive minerals like schoepite, monazite, xenotime and zircon have also been identified. Unit-cell dimension of uraninite (a₀) = 5.4660 ± 0.0006 Å and unit cell volume (V) = 163.316 Å³ correspond to that found in hydrothermal vein-type deposits.

Geochemically, brecciated marble (n = 13) is characterized by higher values of Fe₂O₃ (15.2–54.33%), CaO (0.27–43.09%), TiO₂ (0.10–5.02%), and low values of SiO₂ (8.35–23.28%), Al₂O₃ (1.46–8.26%), MgO (0.26–0.94%), MnO (<0.01–0.14%), Na₂O (<0.01–2.09%), K₂O (0.37–0.84%) and P₂O₅ (<0.01–0.11%). Higher Fe₂O₃ content in the rock is due to the presence of magnetite and hematite in the matrix/cement, and higher CaO content is mainly due to calcite clasts. Higher TiO₂ content is attributed to the presence of rutile. Significant positive correlation (r = +0.85) between U₃O₈ and Fe₂O₃ confirms the role of iron in uranium mineralization. The concentration of associated trace elements in ferruginous breccia is 2216–10100 ppm Cu, 50–70 ppm Co, 22–600 ppm Ni, 35–76 ppm Zn, <10–90 ppm Mo, 150–800 ppb Au and 1899–5003 ppm ΣREE. They justify the polymetallic nature of mineralization.

Sheared magnetite quartzite (n = 9) has higher Fe₂O₃ (6.99–41.54%), Al₂O₃ (10.47–17.98%), K₂O (2.08–6.00%), and low to moderate SiO₂ (37.40–69.41%), Na₂O (<0.01–3.7%), TiO₂ (0.34–0.72%), MgO (0.15–3.71%), MnO (<0.01–0.64%), CaO (<0.01–3.7%) and P₂O₅ (<0.01–0.51%). Higher Fe₂O₃ content in magnetite quartzite is due to the presence of detrital magnetite grains and magnetite veins. Higher K₂O and Al₂O₃ are due to muscovite, biotite and K-feldspar. Trace elements in magnetite quartzite (n = 9) are 8–23 ppm Cu, 48–52 ppm Co, <10–25 ppm Ni, 15–35 ppm Zn, <10–18 ppm Mo and 234–1479 ppm ΣREE. Such trace elemental association indicates significant role of hydrothermal fluid activity in bringing about uranium and rare earth mineralization hosted in the sheared magnetite quartzite. The intrinsic uranium content of non-mineralized magnetite quartzite (2–74 ppm, av.
27 ppm, \( n = 19 \) is higher than other litho-units of the Khetabari Formation (Table 1). This suggests that uranium might have been derived from the fertile Se La Group granitoids (12–60 ppm). Uranium mineralization in the Khetabari Formation involves two distinct processes: (i) syngenetic and (ii) epigenetic. Non-mineralized magnetite quartzite shows uranium abundance in the range 2–74 ppm (Table 1). Such high values are unusual, and may be due to derivation of uranium from fertile granite gneiss provenance belonging to the Se La Group. The fertile gneisses of Se La Group have high abundances of uranium ranging from 12 to 60 ppm. Iron associated with magnetite quartzite could help in the precipitation of uranium from sea water during its deposition. The epigenetic hydrothermal process is evidenced by uraniferous magnetite-bearing quartzofeldspathic veins (Figure 2a). The epigenetic hydrothermal mineralization has played a vital role in enrichment of uranium. The Ziro granite with 5–45 ppm, av. 16 ppm uranium content intruding the Khetabari Formation might have facilitated enrichment of uranium in the Formation. Fractures/faults/shear planes (Figure 3e and f) acted as conduits and locales for uranium precipitation, as evident from vein-type uranium mineralization. Uranium is precipitated in the ferruginous breccia and sheared magnetite quartzite under the influence of reducing agents like sulphide and iron oxide.

The geological setting, presence of higher intrinsic uranium content in country rocks, prevailing fractures, faults and shears as conduits, hydrothermal alterations and favourable geochemical signatures suggest that Laggi Gamlin and adjoining areas are potential targets for multi-metal (U–Fe–Cu–Au–REEs)-type uranium mineralization. This finding opens up a novel target area for uranium exploration in the Khetabari Formation.


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