# Significant Values of Rare Earth Element, Uranium and Thorium in Felsic Tuff from the Koira Group of Western Iron Ore Group, Singhbhum Craton, Eastern India

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**Abstract:** ***The aim of the present study to shows the occurrences of two bands of felsic tuff having dacitic to rhyodacitic in composition which is hosted the rare earth element, uranium, and thorium mineralization belonging to the Western Iron Ore Group, Singhbhum Craton, Eastern India. The petrographic study suggests that it is predominantly comprised of quartz, plagioclase, microcline, muscovite, biotite, chlorite, epidote, zircon, monazite, allanite, apatite, pyrite, and opaques which are mainly embedded in the devitrified groundmass. Petrochemically, it is characterised by high $SiO_2$, $Al_2O_3$, and low $Na_2O$, $K_2O$, and $TiO_2$ contents. The analysed samples show higher values of La and Ce which vary from 30 ppm to 319.79 ppm (average of 186.65 ppm) and 68.04 ppm to 428.87 ppm (average of 295.07 ppm) respectively. These average values are approximately five times higher than the crustal abundance of La and Ce. Pr is ranging from 8.74 ppm to 44.97 ppm and Nd values vary from 44.05 ppm to 167.87 ppm which is higher than the crustal abundance. Values of Sm (5.83 - 28.52 ppm), Gd (5.32 - 31.11 ppm), Dy (4.25 - 28.53 ppm), and Yb (1.63 - 15.97 ppm) are also noteworthy. The ∑REE varies from 174.03 ppm to 1056.99 ppm (average of 681.3 ppm) which is approximately five times higher than the crustal abundance. Besides, uranium (U) values vary from 5 ppm to 35 ppm with an average of 16.08 ppm which is approximately nine times more than the crustal abundance values of U (1.8 ppm). The value of thorium (Th) is varying from 7 ppm to 69 ppm (average of 38.58) which is more or less five times higher than the crustal abundance of Th (7.2 ppm).***

**Keywords:** Felsic tuff, REE-U-Th mineralisation, Western Iron Ore Group (WIOG), Singhbhum Craton, Eastern India

## 1. Introduction

A group of seventeen elements comprising the fifteen elements in the lanthanide group, plus scandium and yttrium was identified by The International Union of Pure and Applied Chemistry which defines as the Rare Earth Elements (REEs). The lighter rare earth elements are represented by lanthanum - La; cerium - Ce; praseodymium - Pr; neodymium -Nd; samarium - Sm; europium - Eu. Heavy rare earth elements are defined by gadolinium - Gd; terbium -Tb; dysprosium - Dy; holmium - Ho; erbium - Er; thulium - Tm; ytterbium - Yb; lutetium - Lu; scandium - Sc; promethium - Pm, and yttrium - Y. Currently, these metals have become very critical and are of huge importance in modern industry for producing various functional materials such as cellular telephones, computer hard drives, electric and hybrid vehicles, flat-screen monitors, televisions, permanent magnets, rechargeable batteries, catalysts, and lamp phosphors because of their unique magnetic and electronic properties. Many workers have reported the occurrence of these metals in the Earth's crust, their mineralogy, different types of deposits both on land and oceans (Long et al., 2010; Chakhmouradian and Wall, 2012). In India, occurrences of rare earth element-uranium-thorium bearing felsic tuff is predominantly reported from the greenstone belts of the Proterozoic and the Phanerozoic Era and scanty occurrences in the Archaean greenstone belt, South India (Patranabis-Deb et al., 2007; Mishra and Sen, 2008; Das et al., 2009; Pal et al., 2010; Dharma Rao et al., 2012; Saha and Tripathy, 2012; Singh and Singh, 2012; Kacmaz, 2016; Roverato et al., 2016; Zhao et al., 2017). Mukhopadhyay et al., 2008 and 2011 reported the felsic tuff, dacitic lava, and pyroclastics rocks from the southern Iron Ore Group (SIOG) in the Singhbhum Craton.

The study area forms a part of the Bonai - Kendujhar belt (BKB) which is belonging to the Western Iron Ore Group (WIOG) (Jones, 1934, Dunn and Dey, 1942). The lithostratigraphy of WIOG is classified under the Koira Group (Murthy and Acharya, 1975) which comprises mainly basal sandstone-quartzite, mafic volcanic formation, lower shale formation, banded iron formation, upper shale formation, and Kolhan Group. The entire area is folded into a series of asymmetrical / slightly overturned anticlines and synclines. Massive, laminated, shaly, powdery, and flaky types of iron ores are predominantly found in the area. The basement-cover relationship between the Singhbhum Granite Phase - B, the Bonai Granite, and the Koira Group has been established in the study area by earlier workers like Mukhopadhyay, 2001; Mukhopadhyay et al., 2008, 2016; Basu et al., 2008. The rocks of the Bonai-Kendujhar belt is flanked by mafic lavas like Dangoaposi lavas, Nuakot volcanics, Jagannathpur lavas, and Malangtoli lavas (Dunn, 1940; Banerjee, 1982; Iyengar and Murthy, 1982; Saha, 1994; Sengupta et al., 1997; Sahu et al., 1998; Rajanikanta et al., 2017). Two bands of felsic tuff of the Koira Group hosted rare earth element-uranium-thorium (REE-U-Th) mineralization are recorded to the south of Malda village, Keonjhar district, Odisha. These are continuously exposed in the lower flank of the hills over a strike length of ~2 km trending N45°W - S45°E direction and width vary from 30 to 50 m.

**Regional Geological Setting**

The Singhbhum Craton is bounded by Chhottanagpur Gneissic Complex in the north (an extension of Central Indian Tectonic Zone = Satpura Mobile Belt), the Eastern Ghats Mobile Belt (EGMB) in the south, the Bastar cratonic block in the west, and the vast tract of alluvium in the east. The Older Metamorphic Group (OMG) is dated ~3.5 - 3.6 Ga by Misra et al., 1999 which is represented the oldest member of the Singhbhum Craton (SC) and comprises pelitic schist, arenite, para, and ortho- amphibolites. The rocks of the OMG are intruded by Older Metamorphic Tonalite Gneiss (OMTG) which represents the first stable continental crust, is dated around 3.44 Ga**.** Both the OMG and OMTG are intruded by an early phase of Singhbhum Granitoid which consists of five distinct plutons emplaced around 3.3 Ga **(**Misra et al,. 1999). The Palaeo-Mesoarchaean sedimentation in the Singhbhum Craton began with the deposition of the IOG rocks which is represented by low-grade volcano-sedimentary successions comprising meta-volcanics, felsic and intermediate volcanics (Yadav and Das, 2019a; Yadav et al., 2020a), ultramafics, spinifex textured peridotitic komatiite (Yadav et al. 2015, 2016; Chaudhuri et al. 2015, 2017; Yadav and Das, 2017b, 2020b), quartz-pebble conglomerate (Yadav et al., 2016; Yadav, 2017a; Yadav and Das, 2019b, 2020c) quartzites, banded iron formation, and metachert with minor carbonate rocks. The greenstone successions of the IOG occur in three detached synformal outcrop belts, namely, the Eastern (Gorumahisani-Badampahar greenstone belt or EIOG), Western (Noamundi-Jamda-Koira greenstone belt or WIOG), and Southern (Tomka-Daitari greenstone belt or SIOG) which is exposed on the eastern, western, and southern periphery of the Singhbhum Granite pluton (Saha, 1994; Fig. 1). Geochronological data from the Iron Ore greenstone successions are given a minimum age of ~3.1Ga which was assumed that the Iron Ore Group of rocks was laterally intruded by Singhbhum granitoids and these belts are detached into three outcrop belts (Misra et al., 1999; Fig.1). 3.4 Ga U-Pb zircon age from the volcanic rocks of the western IOG in the Noamundi- Koira valley was reported by Basu et al., 2008. SHRIMP U-Pb zircon age of 3507±2 Ma for dacitic lavas which interlayered with sedimentary rocks of the southern IOG has been reported by Mukhopadhyay et al., 2008. The observation establishes a Paleoarchean age of the greenstone belts. These recently obtained ages warrant considerable modifications in the Singhbhum stratigraphy and suggest that the greenstone successions of western and southern IOGs are older than the OMTG or Singhbhum Granitoids. It may be equivalents to other smaller enclaves of metasedimentary and metavolcanic rocks within OMTG or Singhbhum Granite, collectively known as the Older Metamorphic Group (OMG) (Basu et al., 2008; Mukhopadhyay et al., 2008; Upadhyay, et al., 2014).

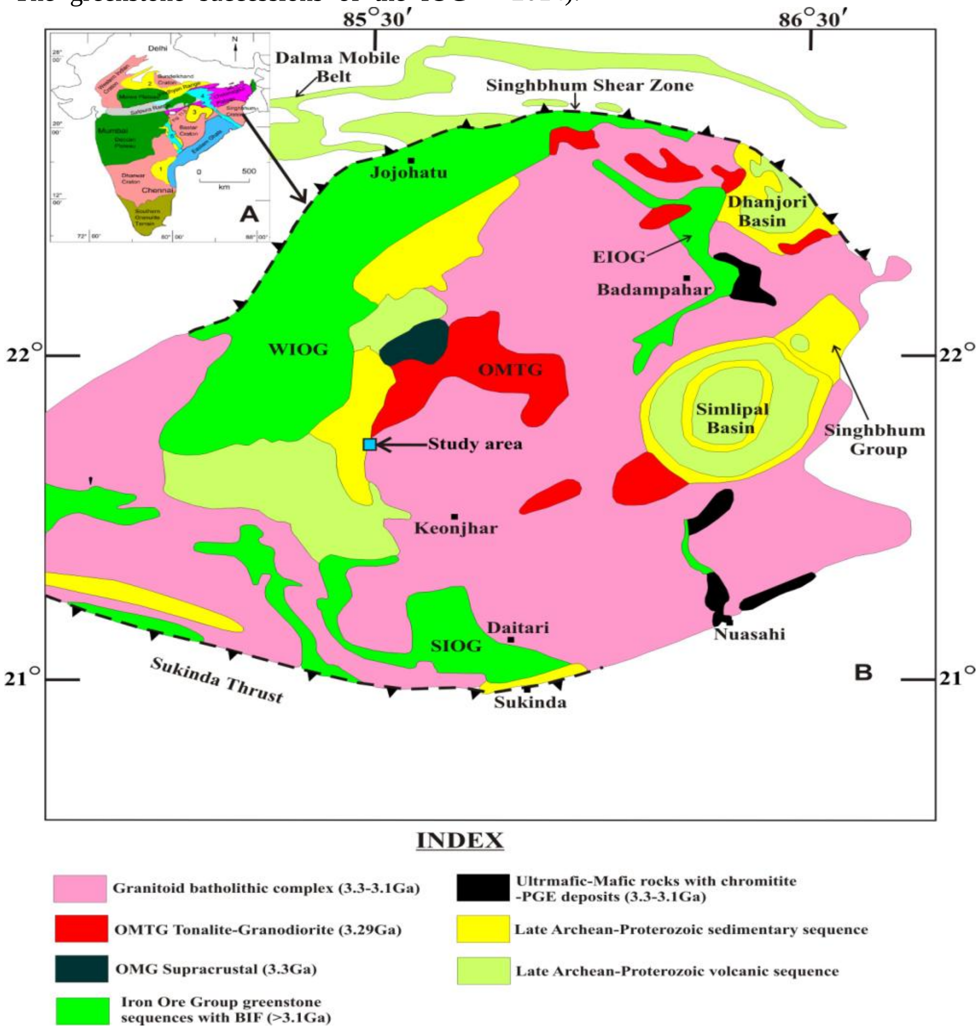



**Figure 1: (A)** Tectonic map of India, **(B)** Generalized geological map of central Singhbhum Craton, North Odisha (modified after Saha, 1994) showing location of the study area.

**Geology of the study area**

The studied area exposes three different types of litho-assemblages viz. (i) litho-assemblages belonging to older supracrustal "Badampahar Group", (ii) litho-assemblages represented by "Koira Group" i.e. younger supracrustal, and (iii) Singhbhum Granitoids. The Badampahar Group of rocks is represented by amphibolites and peridotite which are exposed in the central part. The litho-assemblages of Koira Group are represented by a quartz-pebble conglomerate (QPC), quartzite, gritty quartzite, amygdular basalt, and felsic tuff which are feebly metamorphosed. The Eastern part is mostly occupied by equigranular granodiorite which shows the intrusive relationship with the Badampahar Group of rocks and forming a basement for the Koira Group of rocks (Fig. 2; Yadav et al., 2016; Yadav and Das, 2019b).

Amphibolite is observed near Malda and Sana Kaliapala areas which occur both in the plain land and hilly terrain. It is melanocratic, foliated, medium to coarse-grained, (at places it reaches very coarse-grained), and composed predominantly of hornblende and plagioclase along with quartz and epidote (mostly derived from plagioclase). Besides, few stubby grains of pyroxenes and magnetite are also noticed. At places, equal distribution of felsic minerals (plagioclase and quartz) and mafic mineral (amphibole) are noticed within it which defines the salt and pepper texture. This rock is well foliated and often characterized by mineral lineation (Fig. 3a) which is defined by the alignment of plagioclase and hornblende. Peridotite is observed to the east of Malda village which occupies the plain and hilly terrains. It is melanocratic, fine to medium-grained, feebly foliated, and composed chiefly of olivine, serpentine, pyroxenes and amphiboles, and magnetite as an accessory mineral. Needles of pyroxenes and olivine (now altered to serpentine and secondary magnetite) are randomly orientated (Fig. 3b) and vary in size from 5 - 30 cm and 1 - 7 mm respectively. The eastern part of the mapped area is mostly occupied by granodiorite which is exposed near Kandraposi and Kosira areas as irregular patchy occurrences in the widely soil-covered area. It is leucocratic, medium to coarse-grained, massive to highly jointed (Fig. 3c), and chiefly composed of quartz, plagioclase, and K-feldspar with biotite and muscovite as ferromagnesian and epidote as accessories. Tonalite-granodiorite gneiss is intruded by granodiorite and tongue and apophyses of granodiorite are also noticed in the tonalite-granodiorite gneiss. This granodiorite is intruded by numbers of quartz, pegmatite, and aplite veins. Two prominent joint sets are noticed and the attitude of these joint sets are N80ºW / vertical and N15ºE / vertical (Fig. 3c).

The dominant part of the mapped area is occupied by the Koira Group of rocks which is represented by a quartz-pebble conglomerate (QPC), quartzite, gritty quartzite, amygdular basalt, and felsic tuff (Fig. 2). Three nos. of small bodies of quartz-pebble conglomerate (QPC) are mapped to the west of Kosira and these are interbedded with the quartzite (Fig. 2). As the name implies, the quartz-pebble conglomerate contains clasts of quartz embedded within an arenaceous matrix (Fig. 3d). The clast and matrix ratio of quartz-pebble conglomerate is varying from 70:30 to 60:40 (Fig. 3d). However, in some cases, it is matrix-supported with a clast/matrix ratio of 30:70. Overall, 90% of the clasts are made up of quartz which is rounded, subrounded and elliptical and made up of white, smoky, and reddish quartz. The clast size ranges from less than a cm to 4 cm with the largest clasts up to 6 cm. Quartzite forms high hilly terrains in the mapped area which is represented by white, grayish, greenish, and reddish, medium to coarse-grained, massive to feebly foliated, and predominantly composed of quartz along with muscovite and opaques. Near Malda, trough-cross bedding is observed in ferruginous quartzite (Fig. 3e). Outcrop of amygdular basalt is marked near Balabhadrapur village which is melanocratic, massive, fine-grained and comprises plagioclase and pyroxenes as essential minerals. Magnetite, quartz, and chalcedony occur as accessory minerals. At places, vesicles are filled with quartz (Fig. 3f).

Two bands of felsic tuff having dacitic to rhyodacitic in the composition are mapped near Malda, Keonjhar district, Odisha with a strike length of ~2 km trending N45°W - S45°E direction and width varies from 30 m to 50 m (Fig. 2). It is mainly white, pale purple at places, fine to medium-grained, and massive to feebly foliated (Fig. 3g & 3h). The upper part of the tuff appears as a more compact, weather-resistant horizon with alternate medium to fine-grained and mostly shows ferruginous enrichment. The tuff beds show lateral variation in thickness varies from 5 cm to 2 m. Petrographically, it is mostly composed of glass and quartz shards with a variable amount of crystal fragments. The crystal fragments include quartz (including euhedral to subhedral and pyramidal form), plagioclase, microcline, muscovite, chlorite, zircon, monazite, pyrite, and opaques which are mainly embedded in the devitrified groundmass (Fig. 3i). Glass shards are altered to chlorite and quartz at places. Platy, sickle, bicuspate, tricuspate, crescent, and horn shape of glass and quartz shards (2 - 10 mm) is noticed in the tuff. At places, inclusions of monazite in K-feldspar are also observed (Fig. 3j).

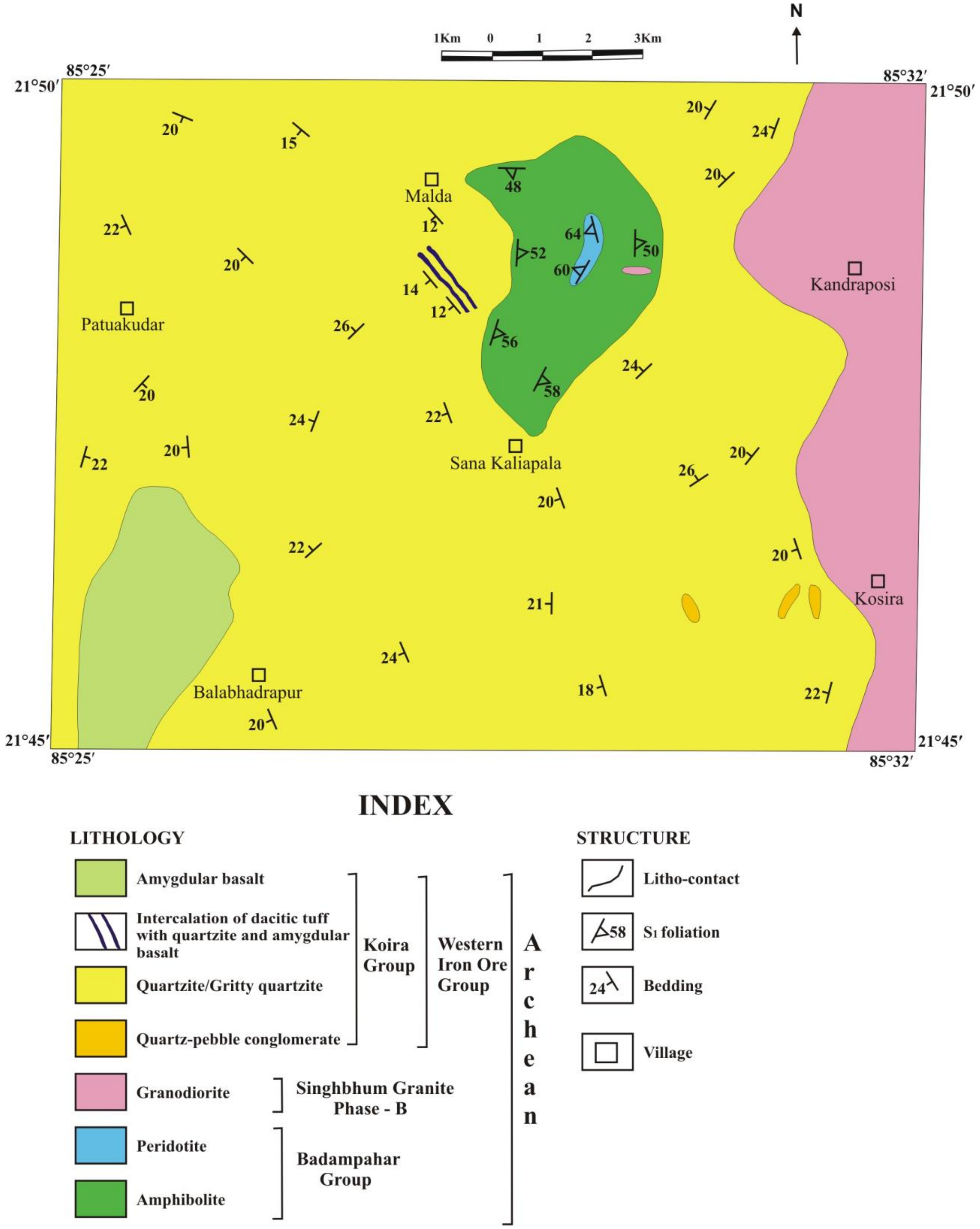
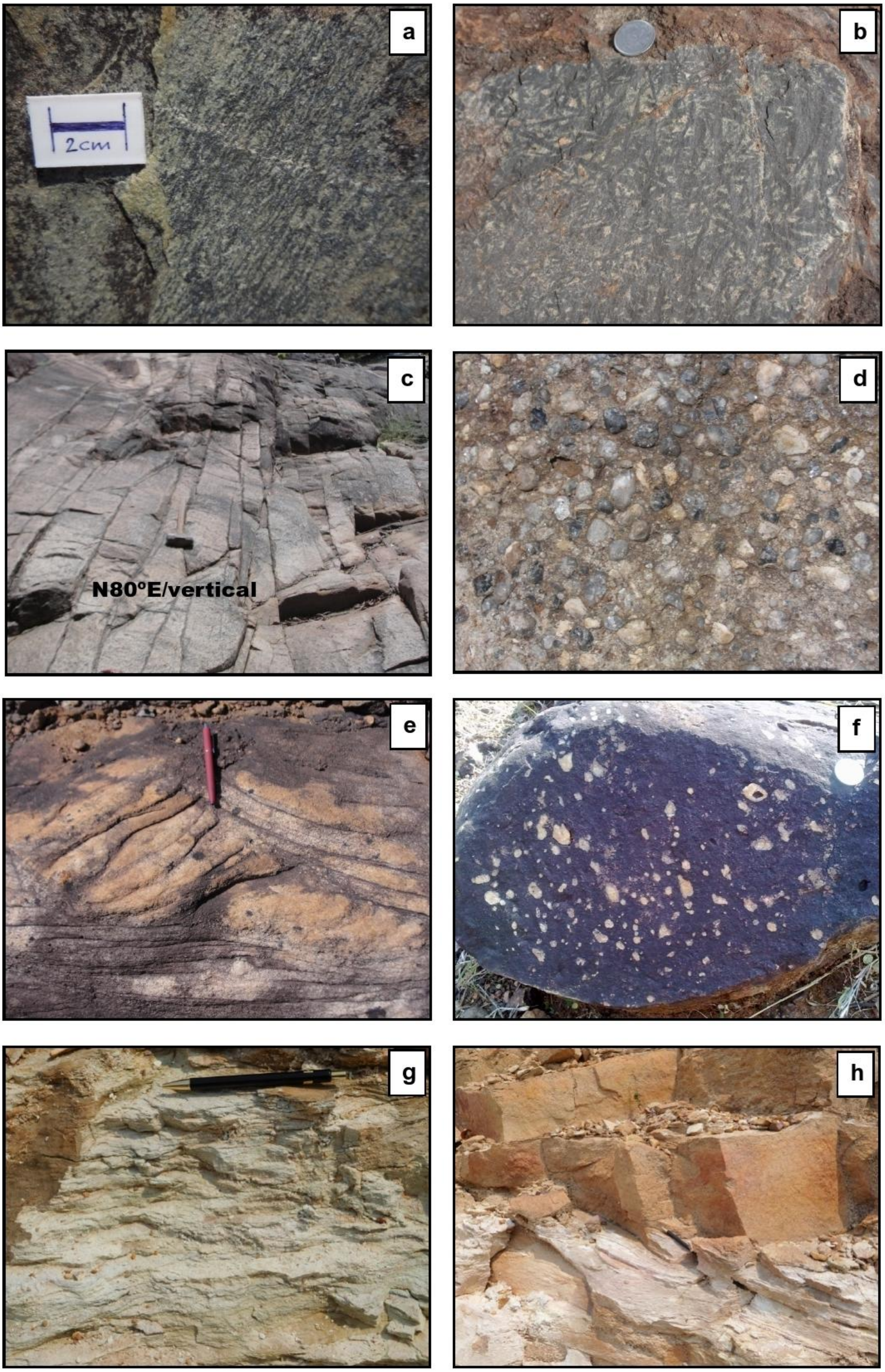



**Figure 2:** Geological map of the study area showing the occurrence of felsic tuff in south of Malda, Keonjhar district, Odisha (Yadav et al., 2016; Yadav and Das, 2019b).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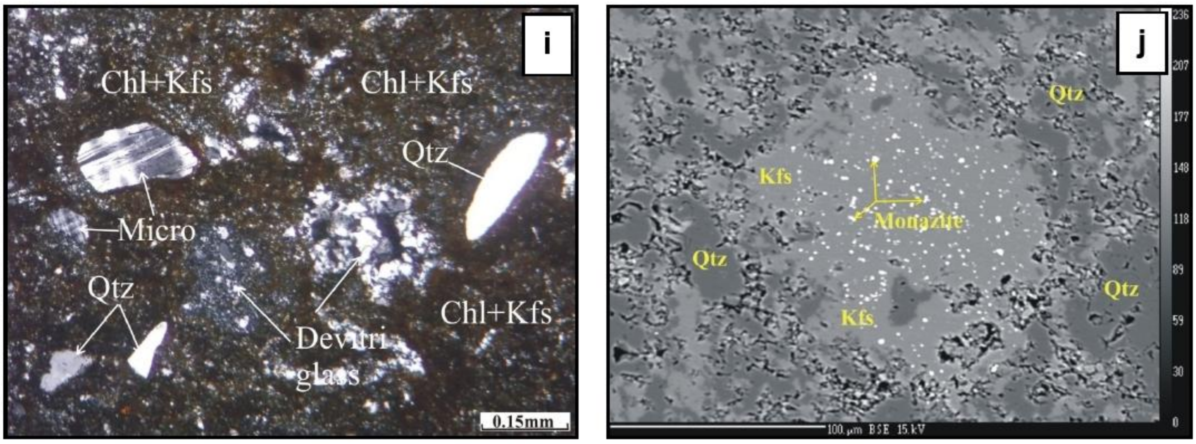


**Figure 3: (a)** Mineral lineation defined by parallel alignment of felsic minerals (plagioclase and quartz) and mafic mineral (amphibole) in amphibolite. **(b)** Peridotite display randomly orientated needles of pyroxenes and olivines. **(c)** Exposure of highly jointed granodiorite is observed near Kadraposi. **(d)** Sub-rounded to sub-angular clasts of smoky and white quartz embedded in an arenaceous matrix of the quartz-pebble conglomerate. **(e)** Trough-cross bedding in ferruginous quartzite. **(f)** Amygdules of quartz preserved in amygdular basalt. **(g & h)** Tuff showing the change from massive to feebly foliated. **(i)** Tuff predominantly comprises microcline, plagioclase, quartz shards, devitrified glass, and groundmass made up of chlorite and alkali feldspar (Cross Polarized Light). **(j)** BSE image shows an inclusion of monazite in alkali feldspar.

**Sampling and Analytical techniques**

Appropriate care has been taken in selecting the least altered samples for chemical analysis after the detailed petrographic examination. About five hundred grams of sample was collected and crushed with an iron mortar and then pulverized with an agate mortar and finally processed through -80 mesh and -200 mesh. Two sets of samples (original and duplicate) were prepared through coning and quartering. Twelve nos. of samples (9 nos. of analytical results from sample no. KL-648 to KL-656 were collected from Yadav and Das, 2019b; 3 nos. of new analytical results from FT-1 to FT-3 are incorporated in this paper which is showing high values of REE, U, and Th) from the felsic tuff of the Koira Group were collected for analysis of major oxides, trace elements, and REE. Major oxides and trace elements were analyzed by X-Ray Fluorescence (XRF) and REE by Inductively Coupled Plasma Mass Spectrometer (ICP-MS) instruments at Geological Survey of India, Eastern Region, Kolkata, India. The analytical result of felsic tuff is given in Table 1.

## 2. Results and Discussion

**Geochemistry and classification of felsic tuff**

The composition of tuff is ranging from dacitic to rhyodacitic and is characterised by $SiO_2$ content ranging from 63.76 to 72.58 wt. % with an average value of 70.05 wt. %, high $Al_2O_3$ (21.22 - 27.91 wt. %, average 23.16 wt. %), and high $TiO_2$ (0.23 - 1.09 wt. %, average 0.75 wt. %). $Na_2O$ and $K_2O$ values vary from respectively in tuff which is suggested that the rocks are rich in alkalis (Table 1). Apart from that, values of FeO (T) (0.09 - 0.72 wt. %), CaO (0.07 - 0.10 wt. %), MgO (0.10 - 1.57 wt. %) and P2O5 from 0.02 to 0.10 wt. % is also notable. The analytical results of trace elements show some noteworthy values which are presented in Table 1. All samples reveal ∑REE contents, ranging from 174.03 to 1056.99 ppm, with an average of 681.3 ppm (Table 1). The analysed samples of tuff are classified as dacite (Fig. 4a) while plotted in TAS (Total Alkali-Silica) diagram of Middlemost (1994). $Zr/TiO_2$ versus Nb/Y diagram of Winchester and Floyd, 1977 is used for classification of tuff which comes under the rhyodacite-rhyolite field (Fig. 5b).

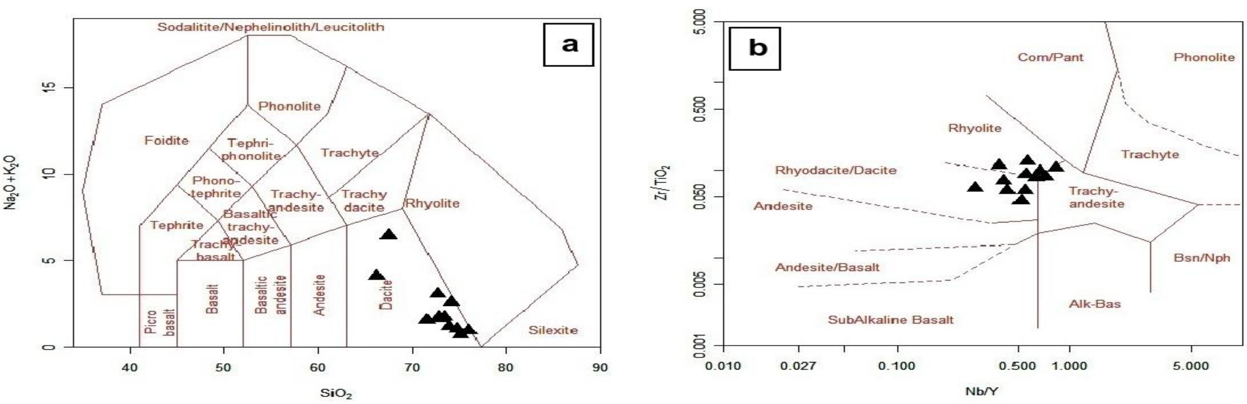


**Figure 4: (a)** TAS diagram shows the dacitic composition of tuff. **(b)** Tuff plotted in the $Zr/TiO_2$ versus Nb/Y diagram of Winchester and Floyd, 1977 which comes under the rhyodacite-rhyolite field.

**Significant values of Rare Earth Element, Uranium, and Thorium**

The main purpose of the paper has brought to light an array of Rare Earth Element (REE) mineralisation with promising values, hosted in felsic tuff. The analysed samples show high values of light REE like La, Ce, Pr, Nd, and Eu along with some significant values of Sm, Gd, Dy, and Yb (Table 1). The lanthanum (La) value ranges from 30 ppm to 319.79 ppm with an average of 186.65 ppm (n = 12) which is six times predominantly above the crustal abundance of La (30 ppm; Krauskopf, 1967). Four samples show higher values of La i.e. 319.79 ppm, 278.90 ppm, 268.78 ppm, and 268.04 ppm respectively which is approximately nine times higher than the crustal abundance. The value of cerium (Ce) is ranging from 68.04 ppm to 428.87 ppm with an average of 295.07 ppm which is around five times higher than the crustal abundance of Ce (60 ppm; Krauskopf, 1967). Three samples are showing seven times higher value of Ce than the crustal abundance viz. 428.87 ppm, 422.65 ppm, and 421.43 ppm respectively. Praseodymium (Pr) value varies from 8.74 ppm to 44.75 ppm (average of 45.87 ppm) which is five times more than the value of crustal abundance (Pr -8.2 ppm; Krauskopf, 1967) and neodymium (Nd) vary from 44.05 ppm to 167.87 ppm with an average of 107.54 ppm. The average values of Nd are approximately four times higher than the crustal value of Nd (28 ppm; Krauskopf, 1967). Besides, values of Sm (5.83 - 28.52 ppm), Gd (5.32 - 31.11 ppm), Dy (4.25 - 28.53 ppm), and Yb (1.63 - 15.97 ppm) are also remarkable. In this unit, the value of ∑REE is varying from 174.03 ppm to 1056.97 ppm with an average of 681.3 ppm which is approximately five times higher than the crustal abundance values i.e. 151.1 ppm (Krauskopf, 1967).

Besides, high values of trace elements like Ba, Rb, Cr, U, Th, Y, V, and Zr are also noticed. Uranium (U) values vary from 5 ppm to 35 ppm with an average of 16.08 ppm which is approximately nine times more than the crustal abundance values of U (1.8 ppm; Krauskopf, 1967). Three samples of U are showing an eleven times higher value than the crustal abundance viz. 21 ppm, 22 ppm, and 25 ppm respectively, and one sample have 35 ppm value which is around twenty times more than the crustal abundance. The value of thorium (Th) is varying from 7 ppm to 69 ppm (average of 38.58) which is more or less five times higher than the crustal abundance of Th (7.2 ppm). Three samples show higher values of Th i.e. 62 ppm, 67 ppm, and 69 ppm respectively which is around nine times higher than the crustal abundance. Besides, noteworthy values of chromium (Cr) are also recorded which ranges from 333 ppm to 1825 ppm with an average of 1095.34 ppm and the average value is around eleven times more than the crustal abundance of Cr (100 ppm). Zirconium (Zr) values are ranging from 143 ppm to 950 ppm with an average of 625.75 ppm which is significantly greater than the crustal abundance of Zr (165 ppm). Four samples are displaying higher values of Zr i.e. 843 ppm, 850 ppm, 925 ppm, and 950 ppm respectively which is approximately five times more than the crustal abundance. Values of Ba (322 - 1449 ppm), Rb (10 - 198 ppm), Y (17 - 38 ppm) and V (42 - 207 ppm) are also showing noteworthy and these are distinctly higher than the crustal abundance values.

**Table 1:** Major oxides, trace elements and REE data of felsic tuff belonging to the Koira Group

| Sample Nos. | KL-648 | KL-649 | KL-650 | KL-651 | KL-652 | KL-653 | KL-654 | KL-655 | KL-656 | FT-1 | FT-2 | FT-3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 63.76 | 70.42 | 70.21 | 71.07 | 74.02 | 71.86 | 72.58 | 70.42 | 65.54 | 69.07 | 71.67 | 70.01 |
| $Al_2O_3$ | 22.30 | 22.97 | 21.22 | 22.94 | 21.32 | 22.43 | 22.29 | 23.13 | 27.91 | 24.94 | 22.98 | 23.45 |
| $Fe_2O_3$(T) | 0.72 | 0.28 | 0.20 | 0.11 | 0.12 | 0.30 | 0.09 | 0.41 | 0.38 | 0.11 | 0.05 | 0.12 |
| MnO | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| MgO | 1.57 | 0.16 | 0.23 | 0.11 | 0.10 | 0.10 | 0.10 | 0.28 | 0.30 | 0.11 | 0.23 | 0.10 |
| CaO | 0.07 | 0.07 | 0.09 | 0.07 | 0.07 | 0.07 | 0.07 | 0.09 | 0.10 | 0.07 | 0.07 | 0.05 |
| $Na_2O$ | 0.56 | 1.13 | 1.11 | 0.44 | 0.36 | 0.26 | 0.39 | 0.46 | 1.02 | 0.44 | 0.36 | 1.12 |
| $K_2O$ | 5.53 | 1.83 | 1.34 | 0.67 | 0.52 | 0.38 | 0.58 | 1.11 | 3.01 | 1.04 | 1.32 | 0.52 |
| $TiO_2$ | 0.71 | 0.23 | 0.40 | 0.75 | 0.88 | 0.50 | 0.91 | 1.09 | 1.01 | 0.75 | 0.88 | 0.88 |
| $P_2O_5$ | 0.05 | 0.03 | 0.03 | 0.10 | 0.09 | 0.05 | 0.08 | 0.03 | 0.02 | 0.10 | 0.09 | 0.09 |
| Total | 95.28 | 97.13 | 94.84 | 96.27 | 97.49 | 95.96 | 97.10 | 97.03 | 99.30 | 96.64 | 97.66 | 96.35 |
| Trace and REE (ppm) | | | | | | | | | | | | |
| Ba | 573 | 322 | 639 | 909 | 712 | 432 | 614 | 1051 | 1449 | 789 | 898 | 1245 |
| Co | 17 | 6 | 14 | 5 | 5 | 11 | 8 | 7 | 5 | 8 | 9 | 10 |
| Cr | 965 | 333 | 483 | 1825 | 1354 | 1032 | 1402 | 1240 | 1036 | 1423 | 687 | 1364 |
| Cu | 94 | 39 | 49 | 61 | 46 | 95 | 42 | 49 | 17 | 54 | 47 | 67 |
| Ga | 24 | 19 | 24 | 23 | 20 | 20 | 20 | 22 | 27 | 23 | 20 | 20 |
| Nb | 15 | 6 | 11 | 13 | 22 | 13 | 19 | 13 | 13 | 13 | 21 | 14 |
| Ni | 68 | 12 | 18 | 14 | 15 | 8 | 9 | 8 | 8 | 11 | 15 | 8 |
| Pb | 8 | 11 | 11 | 20 | 15 | 26 | 23 | 9 | 9 | 20 | 16 | 12 |
| Rb | 138 | 50 | 113 | 15 | 10 | 10 | 13 | 196 | 198 | 38 | 78 | 19 |
| Sc | 7 | 5 | 5 | 10 | 5 | 7 | 8 | 19 | 16 | 10 | 5 | 5 |
| Sr | 53 | 64 | 112 | 70 | 53 | 36 | 47 | 50 | 51 | 69 | 64 | 45 |
| Th | 32 | 7 | 13 | 67 | 69 | 30 | 50 | 14 | 26 | 62 | 56 | 37 |
| U | 13 | 5 | 7 | 22 | 25 | 14 | 17 | 8 | 8 | 35 | 21 | 18 |
| V | 106 | 42 | 53 | 121 | 79 | 112 | 103 | 186 | 207 | 142 | 111 | 156 |
| Y | 36 | 21 | 20 | 33 | 33 | 18 | 30 | 25 | 30 | 23 | 38 | 17 |
| Zn | 17 | 11 | 15 | 43 | 35 | 18 | 46 | 15 | 12 | 41 | 29 | 27 |
| Zr | 534 | 143 | 236 | 843 | 850 | 418 | 745 | 485 | 590 | 950 | 790 | 925 |
| La | 97.02 | 30.00 | 54.82 | 268.78 | 268.04 | 216.77 | 116.42 | 175.50 | 156.93 | 278.90 | 319.79 | 256.88 |
| Ce | 171.66 | 68.04 | 107.35 | 421.43 | 422.65 | 337.30 | 201.60 | 288.52 | 291.59 | 428.87 | 412.44 | 389.33 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pr | 20.16 | 8.74 | 12.61 | 44.97 | 44.75 | 35.83 | 22.37 | 31.67 | 39.61 | 41.66 | 44.75 | 28.99 |
| Nd | 86.72 | 44.05 | 55.56 | 103.44 | 103.44 | 101.93 | 55.76 | 123.30 | 143.28 | 147.80 | 167.88 | 157.37 |
| Sm | 11.23 | 6.30 | 5.83 | 14.67 | 14.50 | 12.44 | 9.13 | 11.71 | 28.52 | 6.89 | 25.89 | 26.44 |
| Eu | 1.76 | 0.88 | 0.86 | 1.10 | 1.09 | 0.99 | 0.75 | 0.93 | 3.54 | 1.10 | 1.09 | 1.09 |
| Gd | 10.65 | 5.32 | 5.61 | 15.16 | 14.32 | 12.40 | 7.95 | 11.97 | 31.11 | 25.12 | 27.69 | 18.77 |
| Tb | 1.65 | 0.89 | 0.85 | 1.35 | 1.34 | 1.42 | 0.89 | 1.73 | 4.83 | 1.35 | 1.34 | 1.34 |
| Dy | 8.15 | 4.64 | 4.25 | 6.78 | 6.68 | 7.43 | 4.58 | 8.59 | 28.53 | 14.67 | 26.09 | 24.59 |
| Ho | 1.21 | 0.68 | 0.57 | 1.42 | 1.46 | 1.33 | 0.93 | 1.12 | 5.38 | 3.23 | 1.46 | 1.67 |
| Er | 3.60 | 1.86 | 1.75 | 4.47 | 4.46 | 4.25 | 2.77 | 3.46 | 16.25 | 6.78 | 11.89 | 7.88 |
| Tm | 0.61 | 0.50 | 0.50 | 0.78 | 0.76 | 0.73 | 0.50 | 0.59 | 2.65 | 0.78 | 0.76 | 0.76 |
| Yb | 4.11 | 1.63 | 2.06 | 5.16 | 5.12 | 4.88 | 3.02 | 3.97 | 15.97 | 5.28 | 13.25 | 12.56 |
| Lu | 0.64 | 0.50 | 0.50 | 0.82 | 0.81 | 0.81 | 0.50 | 0.64 | 2.38 | 1.34 | 2.67 | 1.23 |
| ∑REE | 419.16 | 174.03 | 253.11 | 890.34 | 889.40 | 738.50 | 427.15 | 663.69 | 770.55 | 963.78 | 1056.99 | 928.90 |

## 3. Conclusion

Two bands of dacitic to rhyodacitic composition of felsic tuff of the Koira Group belonging to the Bonai-Kendujhar belt are mapped near Malda, Keonjhar district, Odisha which shows an encouraging value of REE-U-Th. The analysed samples show mostly higher values of REE like La, Ce, Pr, Nd, Sm, Gd, Dy, and Yb. The value of ∑REE is varying from 174.03 ppm to 1056.97 ppm with an average of 681.3 ppm which is approximately five times higher than the crustal abundance values i.e. 151.1 ppm. In addition, high values of trace elements like Ba, Rb, Cr, U, Th, Y, V, and Zr are also observed which are distinctly higher than the crustal abundance values. Based on analytical results, it reveals that the felsic tuff may be a resource potential for rare earth element-uranium-thorium and polymetallic mineralization.

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