Geochemistry and geodynamic setting of Paleoproterozoic granites of Lesser Garhwal Himalaya, India

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Abstract
The granite and gneisses rocks are well exposed around Toneta, Tilwara and Chirbatiyakhal region in the Lesser Garhwal Himalaya have less studied which consider as Paleoproterozoic era. The granites from Toneta area are classified as K-rich peraluminous granite with low Na₂O content of 0.74 to 2.4 wt.%; and high K₂O content varies from 5.0 to 6.91 wt.%. The average Al₂O₃ (12.7 wt.%) in the granite is greater than the total alkalies (Na₂O+K₂O = Av. 7.62 wt.%), the TiO₂ content is low ranging from 0.1 to 0.28 wt. % in the Y + Nb – Rb, Y – Nb, Ta + Yb – Rb, and Yb – Ta discrimination diagram of Pearce et al. (1984) show that the Toneta granites mostly plots within the syn-collision granite fields. This is typical collisional granite.

Keywords: Paleoproterozoic granite, Garhwal Himalaya, syn-collision granite, geodynamic setting, Lesser Himalaya

1. Introduction
To Granites have provided a constant focus for controversy among geologists on account of their inherent diversity and their association with very wide spectrum of geological phenomenon since the beginning of geology in the modern sense which can be arbitrarily judged to date from 1838 with the publication of Lyell’s “Principles of Geology” (in Islam et al., 2005).

The Himalayan mountain belt has evolved due to the collision of the Eurasian and Indian Plates and extends along an arc having a convexity towards south (Patriat and Achache, 1984). It measures for about 2400 km in length with a width of about 320 km. The Himalaya is broadly classified as i) Sub-Himalaya, ii) Lesser Himalaya, iii) Higher Himalaya, iv) Tethys Himalaya, and v) Trans Himalaya (Fig. 1a). Lesser Himalayan sequence is separated from the Higher Himalayan crystalline by a deep seated tectonic lineament called Main Central Thrust (MCT; Heim and Gansser, 1939). Fuchs and Sinha (1978), Sinha (1989), Thakur (1992), Gansser (1993) and Saklani (1993) suggest that the MCT is not a single thrust in the Garhwal region, but composed of three tectonic planes i.e. MCT-I, -II and –III developed by the duplex mechanism of thrust tectonics (Fig. 1b; Saklani et al., 1991). The extensive work of Vaidiya (1980) from Kumaon Himalaya show that several Palaeoproterozoic granites bodies occur in Lesser Himalayan sequence and it found all along the 2000 km Himalayan belt starting from Besham in Swat valley (NW Himalaya) to the Bomdila gneiss in the NE Himalaya (Islam et al., 2005; Phukon et al., 2018 and references therein). The granites occurring in the Himalaya are classified in to four groups (Islam et al., 2005): i) Proterozoic granites (2200 - 1800 Ma; 1400 - 1200 Ma; from Lesser and Higher Himalaya), ii) Early Palæozoic granites (600 - 500 Ma), iii) intrusive phases of Ladakh plutonic complex (102 ± 3 Ma and 42 - 30 Ma), and iv) Tertiary leucogranites (30 - 12 Ma).

Granitic gneisses and granitic augen gneisses exposed in the Lesser Himalayan zone have extended as Proterozoic ages (2200 - 1800 Ma; Table 1). These rocks from Lesser and Higher Himalaya are considering as part of the peninsular India, and the occurrences of granites from Lesser Himalayan sequence are well exposed in Himachal and Garhwal - Kumaon regions (Saklani et al., 1991; Saklani, 1993; Singh et al., 1998). The Outer Himalaya and Indo-Gangetic plain formed, after eroded material from Higher Himalaya during Himalayan orogeny, towards south of Lesser Himalaya.
Fig. 1. (a) General tectonic map of Himalaya after Gansser (1964), and (b) General tectonic map of Garhwal Himalaya after Valdiya (1980).

Table 1. Summarized geochronological ages of Himalayan Proterozoic granites (after Islam et al., 2005; Singh et al., 2009).

| Locality                          | Age               | References                          |
|-----------------------------------|-------------------|-------------------------------------|
| Jeori–Wangtu                      | 1860 Ma           | Miller et al., (2000)               |
| Wangtu, Sutlej                    | 2025 to 2075 Ma   | Kwatra et al., (1986)               |
| Wangtu                            | 1895±64 Ma        | Rao et al., (1995)                  |
| Wangtu                            | 1866±10 Ma (U-Pb Zr) | Singh et al., (1994)           |
| Magladgad                         | 2068±5 Ma (U-Pb Zr) |                          |
| Bandal                            | 1840±0.0027 Ma    | Frank et al., (1977)                |
| Nirath-Baragaon                   | 1430±150 Ma       | Bhanot et al., (1978)               |
| Bandal                            | 1220±100 Ma       | Bhanot et al., (1979)               |
| Dhakuri                           | 2315±35 Ma        | Pandey et al., (1981)               |
| Chailli, Bilangna valley          | 2121±60 Ma        | Raju et al., (1982)                 |
| Rihee-Gangi, Bilangna valley      | 1841±86 Ma        | Singh et al., (1986)                |
| Ghuttu, Bilangna valley           | 1763±16 Ma        | Singh et al., (1985)                |
| Chirpatiyakhal, Bilangna valley   | 1708±31 Ma        |                                    |
| Amritpur                          | 1585±192 Ma       |                                    |
| Joshimath-Guptakashi              | 1950±200 Ma       | Pandey et al., (1981)               |
| Naitwar, Tons valley              | 1811±33 Ma        | Singh et al., (1986)                |
| Hanumanchatti, Yamuna valley      | 1972±102 Ma       |                                    |
| Bhatwari, Bhagirathi valley       | 2047±119 Ma       |                                    |
| Musiari                           | 1830 to 1890 Ma   | Bhanot et al., (1977)               |
| Rameshwar granite                 | 1820±130 Ma       | Trivedi et al., (1984)              |
| Chiplakot Crystalline Belt (granite gneiss) | 1920.7 ±4.2 Ma | Phukon et al., (2018)               |
| Namik                             | 1910±48 Ma        |                                    |
| Tawaghanh                         | 1906±220 Ma       | Singh et al., (1985)                |
| Almora–Askot                      | 1620±90 Ma        | Powell et al., (1979)               |
| Askot Dharamgarh                  | 1795±30 Ma        | Pandey et al., (1981)               |
| Ramgarh granite                   | 1765±60 Ma        | Trivedi et al., (1984)              |
| Gwaldam granite                   | 1300±80 Ma        | Pandey et al., (1981)               |
| Lingse granite, NE Himalaya       | 1678 Ma (Rb–Sr whole rock) | Paul et al., (1996)               |
| Darjeling–Sikkim, granite gneiss  | 1792 Ma (Pb–Pb age) |                          |
| Bomdila gneiss                    | 1874±24 Ma (U–Pb Zr) | Rao, (1998)                          |
|                                  | 1827±95 Ma (U–Pb Zr) |                          |
The Lesser Himalayan zone comprises Paleoproterozoic granite, Paleozoic sediments (e.g., slates, phyllites, quartzites) with contemporaneous mafic volcanic (1.83 - 1.88 Ga Sm-Nd T-CHUR modal ages; Miller et al., 2000). There is a period of felsic volcanism and granite emplacement occurred around 1.86 - 1.84 Ga in NW Himalaya. Nd model ages for these granitic rocks extend to 2.63 Ga, indicating recycling of Archean continental crust (Miller et al., 2000). Still more studies are required especially from Garhwal Himalaya where limited data are available to set up Proterozoic magmatism. Therefore, Palaeoproterozoic granites are selected from Toneta area, Tilwara section for whole rock geochemical analysis to establish tectonic environment and geodynamic setting.

2. Geology of the area

It is supposed that the Indian crust was imbricated and different parautochthonous of deeper rocks from various tectonic levels by the duplex mechanism and thrust on metasedimentary rocks of the Lesser Himalayan sequence. The study area is constituted by granite, quartzite, schist, gneisses and metabasics (Fig. 2). The undeformed granite exposed around Toneta area is considered as Bhatwari (= Chail/ Ramgarh) group (Valdiya 1980; Saklani et al., 1991). This rock unit has sheared up to 500 meters having brittle ductile deformation (mainly Indian plates basement rocks medium to high metamorphic grade) consider as characteristics of MCT-III zone in the Lesser Himalayan sequence. The rocks of Chail group are tectonically separated by Chail thrust (MCT-III) with massive white quartzite of the Garhwal group towards south (Valdiya, 1980; Saklani et al., 1991; Singh et al., 1998).

Fig. 2. Geological map of the area around Toneta, Rudraprayag, Lesser Garhwal Himalaya (after Valdiya, 1980). Analysed granite samples are given in Table 2.

The Toneta granites extend from 1.5 km west of Tilwara to Chirbatiyakhal in the east. They are well exposed around Toneta village and hence the name (Negi et al., 1980). These granitic rocks sometime associated with tourmaline granite, gneiss and quartz - sericite - schist (Fig. 3a). Tourmaline granite is medium to coarse grained with feldspar and quartz having subordinate tourmaline and biotite. The sample N-4, N-5 and N-6 are medium to coarse grained containing feldspar (microcline and plagioclase) and quartz, and accessory minerals are biotite and tourmaline. It is typical for MPG (Muscovite-bearing Peraluminous Granitoids) which common for collisional setting (Barbarin, 1999). Striation in tourmaline grains is seen near Toneta, where the grains are 0.5 cm ×0.3 cm
The granite-gneiss (sample No. S-1, S-4 and S-5) are exposed around Mayali having quartz and felsic minerals. About 1 km south east of Mayali, augen gneisses are observed and some boudinage of quartzites are exposed in the granite gneiss. Similar structures are also reported by Negi et al. (1980) along the Helang-gad fault and the rocks are highly scattered. The fine to medium grained quartz-talc-schist is reported by Negi et al. (1980) from Toneta to Mayali traverse which extending further towards North and have elongated quartz grains. Quartz-sericite schist is well developed in sheared zones, particularly along the Alaknanda thrust and in the upper Lasar gad valley and correlated with MCT-III of Saklani et al. (1991) which show thrusted contact with quartzite at southern side. These granites have well developed joint system and also traversed by epidiorites.

3. Sampling and analytical techniques

Based on criteria least alteration, seven representative samples of granite were analysed. The chemical composition of the rocks was determined at the Testing and Matter Analysis Centre, Institute o

4. Geochemistry and tectonic settings

The K-rich granites from Toneta area are mostly calc-alkaline in nature classified as granite (Fig. 4a). The normative feldspar classification diagrams [Albite (Ab)—Orthoclase (Or)—Anorthite (An), O’Connor, 1965 and Barker, 1979] indicate that the Toneta granite falls in granite field (Fig. 4b). In granitoids Na₂O is low and varies from 0.74 to 2.4 wt.% and K₂O content varies from 5.0 to 6.91 wt.%. The Al₂O₃ content varies from 11.67 to 13.7 wt.% except sample N-9 (95% silica). The rocks are highly rich in SiO₂, having range from 71.84 to 76.68 wt.%. Alumina content (Al₂O₃; Av. 12.7 wt.% in the granitoids is greater than the total aluminas (Na₂O+K₂O; Av. 7.62 wt. %), the TiO₂ content in the granitoids is low ranging from 0.1 to 0.28 wt.% CIPW norms calculations, all the samples show normative cordierite values ranging from 0.37 to 3.89 which is a typical in all granite samples of the Lesser Garhwal Himalaya with high normative Orthoclase and less normative Albite-Anorthite feldspar minerals (Table 2). The granites belong to high-K calc alkaline and shoshonite series (Fig. 5a), with mostly peraluminous in nature (Fig. 5b).

Table 3. Trace elements (in ppm) analytical data of the granites, Tilwara, Lesser Garhwal Himalaya.

| Sample Name | S-1 | S-4 | S-5 | N-4 | N-6 | N-5 | N-9 |
|-------------|-----|-----|-----|-----|-----|-----|-----|
| Cr          | 20.2| 23.01| 18.33| 40.12| 23.09| 25.92| 43.66|
| Ni          | 12.03| 9.53| 10.15| 8.34| 13.24| 15.28| 20.91|
| Co          | 1.78| 1.13| 1.73| 1.65| 2.24| 4.88| 2.19|
| Sc          | 5.05| 6.23| 6.22| 6.69| 6.85| 7.78| 4.70|
| V           | 26.03| 49.46| 44.97| 47.01| 25.59| 109.80| 57.32|
| Cu          | 5.13| 4.83| 8.18| 7.51| 18.74| 10.56| 5.49|
| Pb          | 11.84| 19.72| 39.24| 16.47| 32.29| 22.40| 3.37|
| Zn          | 21.82| 24.13| 39.95| 29.65| 87.93| 44.35| 9.23|
| Bi          | 1.59| 0.93| 0.57| 1.88| 37.93| 0.25| 0.19|
| Cd          | 0.09| 0.07| 0.14| 0.14| 0.14| 0.08| 0.06|
| Sn          | 23.79| 27.83| 13.06| 11.76| 14.51| 9.51| 5.28|
| W           | 3.75| 5.26| 6.36| 3.97| 4.76| 3.90| 5.02|
| Mo          | 0.36| 0.46| 0.31| 0.44| 0.46| 0.59| 0.91|
| Nb          | 0.27| 0.27| 0.23| 0.41| 0.32| 0.24| 0.27|
| Cs          | 386.7| 434.8| 374.8| 301.5| 438.| 333.1| 21.2|
| Ba          | 161.1| 64.18| 179.8| 155.| 275.40| 491.6| 34.4|
| Sr          | 15.11| 15.30| 40.68| 16.31| 18.31| 45.68| 10.57|
| Ti          | 1.94| 2.06| 1.94| 1.38| 2.54| 1.84| 0.14|
| Ga          | 18.28| 17.90| 17.23| 17.14| 18.06| 19.43| 3.31|
| U           | 13.44| 8.71| 9.02| 18.23| 13.13| 14.07| 3.82|
| Ta          | 1.66| 2.28| 1.56| 1.95| 1.61| 0.95| 0.48|
| Nb          | 10.77| 10.69| 11.27| 12.60| 12.28| 11.03| 4.93|
| Hf          | 2.73| 2.32| 2.70| 3.52| 4.70| <PO| 1.91|
| Zr          | 63.08| 50.20| 70.74| 93.74| 117.10| 1.89| 57.89|
| Y           | 25.38| 27.23| 23.70| 26.93| 41.93| 16.21| 5.75|
| Th          | 25.74| 23.93| 20.55| 25.03| 25.66| 50.98| 19.50|
| U           | 9.88| 12.97| 3.52| 6.83| 9.27| 3.28| 6.22|
| La          | 25.85| 14.59| 22.10| 28.79| 31.37| 66.33| 19.22|
| Ce          | 61.83| 33.25| 44.93| 59.19| 62.66| 137.60| 37.84|
| Pr          | 7.21| 3.59| 5.38| 7.07| 7.44| 15.67| 4.28|
| Nd          | 24.75| 12.47| 18.61| 24.16| 26.14| 53.84| 14.18|
| Sm          | 4.23| 2.90| 2.88| 3.55| 3.67| 7.16| 2.70|
| Eu          | 0.37| 0.19| 0.47| 0.42| 0.51| 0.83| 0.39|
| Gd          | 5.76| 3.74| 4.51| 5.50| 6.24| 7.17| 2.38|
| Tb          | 1.00| 0.79| 0.80| 0.94| 1.15| 0.96| 0.32|
| Dy          | 5.20| 4.99| 4.49| 5.13| 7.24| 4.03| 1.44|
| Ho          | 0.91| 0.96| 0.85| 0.96| 1.42| 0.66| 0.23|
| Er          | 2.01| 2.44| 2.06| 2.27| 3.77| 1.34| 0.58|
| Tm          | 0.26| 0.34| 0.29| 0.32| 0.53| 0.13| 0.08|
| Yb          | 1.37| 2.00| 1.62| 1.61| 3.16| 0.66| 0.49|
| Lu          | 0.18| 0.26| 0.21| 0.23| 0.42| 0.07| 0.07|
| Be          | 2.85| 2.08| 3.71| 2.26| 2.23| 1.95| 1.72|

Chondrite–normalized rare earth-element patterns (McDonough & Sun 1995) of the granitoids show pronounced negative Eu anomaly (Eu/Eu⁺ = 0.18 to 0.36, Fig. 6a), pronounced enrichment in LREE and highly fractionation of heavy rare elements (HREE; La/Nd/Lu = (5.81 to 101.34). These rocks are also rich in LILE: Cs, Rb, Th, U, and Pb (see primitive mantle normalized, McDonough & Sun 1995, Fig. 6b) and display negative Nb–Ti anomalies (Fig. 6b).
In the Yb + Ta versus Rb and Nb versus Y discrimination diagram of Pearce et al. (1984), the Toneta granites mostly plots within the syn-collision granite fields (Fig. 7). The $R_1 - R_2$ [$R_1 = 4\text{Si}^{4+} - 11(\text{Na}^{+} + \text{K}^{+}) - 2(\text{Fe}^{3+} + \text{Ti}^{4+})$, molar; $R_2 = 6\text{Ca}^{2+} + 2\text{Mg}^{2+} + \text{Al}^{3+}$, molar] tectonic discrimination diagram show syn-collision to post-orogeny field tectonic setting (Fig. 8).

![Discrimination Diagram](image)

Fig. 4. (a) Total alkalis (Na$_2$O + K$_2$O) versus silica (SiO$_2$) diagram (after Middlemost, 1994) for Paleoproterozoic granitoids of Toneta area of Lesser Garhwal Himalaya, (b) Normative feldspar classification diagrams [Albite (Ab)–Orthoclase (Or)–Anorthite (An)], (after O’Connor, 1965 and Barker, 1979).

![Classification Diagrams](image)

5. Discussion

Phukon et al. (2018) discussed that the granitoids from the Chiplakot Crystalline Belt, Kumaun Himalaya are associated with the Columbia supercontinent subduction system in the Paleoproterozoic. Frank et al. (1977) assign a whole rock Rb-Sr age of 1840 + 70 Ma for Bandal and Sainj granites, documenting an existence of Proterozoic granitic magmatism in the Himalaya. Islam et al. (2005) stated that the Proterozoic granites of the Lesser Himalaya are silica and K$_2$O enriched with high A/CNK value (>1.1) and show presence of normative corundum. Islam et al. (2005) also pointed out that the granite, granitic gneisses and associated metasedimentary rocks in NW Himalaya experienced up to upper amphibolites facies metamorphism which might suggest that the Proterozoic granitic gneisses were derived as basement slivers from middle crustal level (a probable extension of the northern Indian craton). Singh et al. (2009) also indicated that the Paleoproterozoic (ca. 1860 Ma) felsic magmatic rocks are widespread in the Lesser Himalayan Zone to basal part of the Higher
Himalayan Crystalline (HHC) probably remobilization of older crustal material which exhumed due to collisional tectonics during the Himalayan orogeny.

The Proterozoic tourmaline-bearing granitoids rocks from NW Himalaya have typical for collisional MPG (Barbarin, 1999) petrography. They are enriched in LREE and moderately depleted HREE along with a pronounced negative Eu anomalies and characterized by negative Ba, Nb, Sr, P and Ti anomalies and high Rb, Th and U content (Miller et al., 2000). The Sr and Nd isotopic characteristics of these rocks show their high initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios (0.711-0.721) and initial epsilon Nd values are -5.8 to -8.8 which suggest large-scale reworking of Archean sialic protolith (Miller et al., 2000). Singh (2011) suggested that 1800-2000 Ma granites from Lesser and Higher Himalaya can be correlated for tectono-thermal (collisional) event which also noticed as huge hydrothermal activity occur ca. 1.9-1.8 Ga in Bundelkhand Craton (Slabunov et al., 2017), southern adjacent part of Garhwal Himalaya. It seems to be similar granitic magmatism occurs in the Lesser Garhwal Himalaya and further studies are needed to establish the remobilization of Archean crust could be of Bundelkhand or Aravalli Cratons.

![REE Plot](image1.png)
![Multi Element Spider](image2.png)

Fig. 6. (a) The chondrite normalized (after McDonough and Sun, 1995) REE plot for Toneta granites. (b) Mantle normalized multi element spider diagram of Toneta granites (after McDonough and Sun, 1995).
Fig. 7. Discrimination diagram of Rb-Y+Nb, Nb-Y (Pearce et al., 1984) for the Toneta granites ORG: Ocean Ridge Granites; syn-COLG: Syn-Collision Granites; VAG: Volcanic Arc Granites; WPG: Within Plate Granites.

Fig. 8. R1-R2 multicationic variation diagram \[ R_1 = 4Si^{4+} - 11(Na^+ + K^+) - (Fe^{3+} + Ti^{4+}), \text{ molar; } R_2 = 6Ca^{2+} + 2Mg^{2+} + Al^{3+}, \text{ molar} \], (Batchelor and Bowden, 1985).
6. Conclusions

To the collision tectonics nature of granites exists in Garhwal Himalaya demonstrate felsic magmatic phase implication occur during Paleoproterozoic ages.

The Lesser Garhwal Himalaya Toneta granites formed syn-collision to post-orogeny tectonic environment, which resemble with ca. 1800-1900 Ma existing hydrothermal activity in Bundelkhand Craton suggest a possible linkage to it.

However, the questions are still unanswered and required more studies to understand about the nature of granitic rocks of Garhwal Himalaya whether these rocks have formed due to the melting and recrystallization of pre existing Archean continental crust of Bundelkhand or Aravalli Cratons?

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