Geochemistry of Granites from Chail Group of Garhwal Region, Lesser Himalaya, NW India

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Abstract: Paleoproterozoic granites are well exposed in the Chail group of Garhwal region, Lesser Himalaya crystalline sequences (LCHS). These granites are less studied in terms of geochemical classification and tectonic settings. In the present work, we carried out the geochemical analysis of granites of the Chail group from the Chirbatiya-Khal and Ghuttu areas. All the samples have high SiO2 (73.24–79.1 wt %), Al2O3 (11.2–12.95 wt %), K2O (3.8–5.9 wt %) and low P2O5 (0.11–0.24 wt %), CaO (0.21–1.02 wt %), and Na2O (2.2–3.03 wt %; exceptionally low in one sample, that is 0.009 wt %) contents. The A/CNK values for the samples are range from 1.19 to 2.91, characteristic of S-type granites. REE patterns for these granites are moderately fractionated with an average (La/Yb)N= 8.21 and europium anomaly (Eu/Eu*)= 0.15. The tectonic settings of the studied granite suggest that they are formed in syn-collision tectonic environments.

Keywords: Granites, Himalaya, geochemistry, Paleoproterozoic, Garhwal Himalaya

Introduction

Granites are the most abundant rocks in the Earth's crust. Therefore, understanding the origin of the Earth requires a thorough understanding of the evolution and reworking of the upper continental crust. Granites have a vast range of mineral composition, geochemistry, petrogenesis, and tectonics, as evidenced by extensive studies undertaken around the world. In general, it is now believed that a significant number of granites, such as those seen along active continental margins, can result from fractional crystallization of basaltic magma. In addition, under variable temperature and pressure conditions, partial melting of crustal protoliths during regional metamorphism in orogenic collisions also creates varied granites.

This paper aims to present the whole-rock geochemistry from Chail group granites in the Garhwal region of LHCS. We suggest that these Paleoproterozoic granites are S-type in origin and formed in syn-collision tectonic settings, based on their geochemical characteristics.

Geological background

In the 2400 km long Himalayan belt, four primary tectonic zones accrete from south to north: 1) Sub-Himalaya (SH); 2) Lesser Himalaya (LH); 3) Higher Himalayan Crystalline (HHC); and 4) Tethyan Himalaya (TH) (Heim & Gansser, 1975). (Fig. 1a). The SH, which is made up of Miocene to Pleistocene molasses and Himalayan sediments, thrusts over the Indo-Gangetic
plane along the Main Frontal Thrust (MFT) (Thakur, 1992). Paleoproterozoic to lower Cambrian rocks make up the LH sequence, which is thrust above the SH along the Main Boundary Thrust (MBT) (Valdiya, 1980). The Main Central Thrust (MCT), a north-dipping intra-continental shear zone with an inverse metamorphic gradient, is one of the most important tectonic features in the Himalayas (Metcalfe, 1993). MCT distinguishes LH from HHC. The HHC is made up of medium- to high-grade metamorphic stages ranging from greenschist to upper amphibolite facies (Thakur, 1992), as well as Ordovician (ca. 485–440 Ma) and early Miocene (ca. 22 Ma) granites.

The study area is constituted by granite, quartzite, schist, gneisses and meta-basic rocks (Fig. 1b). The undeformed granite exposed around Chirbatiya-Khal area is considered as Bhatwari (= Chail/ Ramgarh) group (Valdiya 1980; Saklani et.al., 1991). This rock unit has sheared up to several 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).

The granites, in the study area, generally show porphyritic texture with abundance of feldspar crystals. Large tourmaline crystals can be observed in the Chirbatiya-Khal granites (Fig. 3a). Muscovite and biotite are also present in the granites. Granites from Ghuttu area are also shows porphyritic characteristics (Fig. 3b). At some places, boudins of quartz can also be observed.

Fig. 1 (a) General tectonic map of Himalaya after Gansser (1964), and (b) General tectonic map of Garhwal Himalaya after Valdiya (1980), MCT-I, II, III after; Saklani et.al., 1991).
Fig. 2 Photographs of granites from the study area (a) Chirbatiya-Khal granites, a big tourmaline crystal can be seen; (b) Ghattu granites.

**Materials and Methods**

We collected granite rocks from the Chirbatiya-Khal and Ghattu area of the Garhwal region for geochemical analysis (Fig. 2). Table 1 presents the geochemistry of the granites. The Testing and Matter Analysis Centre, Institute of Geology, KarRC, RAS, Petrozavodsk, Russia, analyzed the chemical composition of the rocks using ICP-MS X Series 2 (*Thermo Fischer Scientific, Massachusetts, USA*). Svetov et al. (2015) and Singh and Slabunov (2015) outline the methods and precision in depth which is followed for the analysis. To determine the amounts of rock-forming elements, sample powder was melted with sodium carbonate and then leached with dilute hydrochloric acid. The percentage of SiO$_2$ in the final solution was calculated using the gravimetric technique after it was precipitated with gelatin. The concentrations of Al, Fe, Ca, and Mg in the solution were then estimated complexometrically. At the same time, Ti and P concentrations were estimated photometrically. The allowable variation between the findings of two parallel estimations, which does not exceed 0.7 percent for Si, 0.5 percent for Al, Fe, Ca, and Mg, and 0.3 percent for Ti and P, was used to determine calculation accuracy.

**Results**

The K-rich granites from Chirbatiya-Khal and Ghattu area are mostly calc-alkaline in nature classified as granite in Total alkali silica (TAS) diagram, Middlemost (1994) (Fig. 3a). The normative feldspar classification diagrams [Albite (Ab)–Orthoclase (Or)–Anorthite (An), O’Connor, 1965 and Barker, 1979] indicate that the sample falls in granite field (Fig. 3b). In granitoids Na$_2$O is low and varies from 2.2 to 3.3 wt.% (exceptionally low in one sample, that is 0.009 wt %), and K$_2$O content varies from 3.8 to 5.9 wt.%. The Al$_2$O$_3$ content varies from 11.2 to 12.95 wt.%. The rocks are highly rich in SiO$_2$ having range from 73.25 to 79.1 wt.% . Alumina content (Al$_2$O$_3$ : Avg. 11.89 wt.% in the granitoids is greater than the total alkalies (Na$_2$O+K$_2$O : Avg. 7.37 wt. %), the Titania (TiO$_2$) content in the granitoids is low ranging from 0.1 to 0.34 wt.%. The granites belong to high-K calc alkaline magma series, with mostly peraluminous in nature.

The samples are enriched in LREE and moderately depleted HREE along with a pronounced negative Eu anomaly (Eu/Eu* = 0.06 to 0.31) (Fig. 4a). The chondrite normalized rare earth element distribution pattern (Boydton, 1984) is low to high fractionated La$_N$/Lu$_N$ = (2.23 to 22.88). A primitive mantle normalized (Sun and McDonough, 1995) multi-element diagram (Fig. 4b) showed a wide range in the concentration of the trace elements. Most of the samples show enrichment of large-ion lithophile elements (LILE) but depletion of Nb, and Ti (McDonough and Sun, 1995).
The negative Nb anomalies and a positive Pb anomaly are related crustal thickening and/or related magmatism, and also suggested no clear evidence exist for collision-related crustal thickening and/or deformation.

It is noted that the studied granites are characterized by Ba and Sr -poor, while Rb, Th, U, and Pb are enriched. The negative Nb anomalies and a positive Pb anomaly are generally interpreted as subduction-related magma generation. While, Miller et al., (2000) discard subduction-related magmatism, and

Table 1 Major, trace and rare earth elements (in ppm) for the analyzed sample of granites

| Sample | HM-18-11 | HM-18-13a | HM-18-13b | HM-18-14 | HM-18-16 | HM-18-17 |
|--------|-----------|-----------|-----------|-----------|-----------|-----------|
| Locality | Chirbatiyakhal | Chirbatiyakhal | Chirbatiyakhal | Chirbatiyakhal | Ghutti | Ghutti |
| SiO₂ | 79.1 | 73.65 | 75.02 | 74.9 | 75.16 | 73.24 |
| TiO₂ | 0.12 | 0.11 | 0.11 | 0.13 | 0.12 | 0.34 |
| Al₂O₃ | 11.7 | 12.3 | 11.2 | 11.94 | 12.95 | 11.3 |
| Fe₂O₃ | 0.1 | 0.37 | 0.52 | 0.27 | 0.07 | 0.78 |
| FeO | 0.28 | 1.14 | 1 | 0.86 | 0.14 | 1.14 |
| MnO | 0.004 | 0.028 | 0.031 | 0.017 | 0.01 | 0.029 |
| MgO | 2.4 | 1.45 | 1.54 | 1.63 | 1.6 | 1.78 |
| CaO | 0.21 | 1.022 | 0.72 | 0.72 | 0.58 | 1.57 |
| Na₂O | 0.009 | 3.03 | 2.2 | 2.6 | 3.56 | 2.34 |
| K₂O | 3.8 | 5.27 | 5.9 | 5.5 | 4.47 | 5.59 |
| P₂O₅ | 0.17 | 0.24 | 0.19 | 0.2 | 0.11 | 0.21 |
| H₂O | 0.26 | 0.12 | 0.12 | 0.15 | 0.35 | 0.3 |
| LOI | 1.7 | 1.2 | 1.4 | 1.07 | 0.83 | 1.34 |
| Total | 98.153 | 98.71 | 98.551 | 98.917 | 99.12 | 98.619 |
| FeO/Total | 0.38 | 1.47 | 1.47 | 1.1 | 0.21 | 1.84 |
| A/ÇNK | 2.91 | 1.32 | 1.27 | 1.35 | 1.50 | 1.19 |
| P | 615.90 | 884.40 | 645.40 | 700.10 | 557.40 | 563.50 |
| Ti | 680.50 | 594.50 | 587.20 | 437.70 | 166.00 | 1627.00 |
| Rb | 428.10 | 697.70 | 835.80 | 606.30 | 247.80 | 457.70 |
| Sr | 3.95 | 12.28 | 8.49 | 10.98 | 33.16 | 55.41 |
| Y | 37.70 | 47.63 | 12.77 | 29.80 | 15.47 | 32.72 |
| Zr | 73.42 | 107.20 | 2.76 | 70.01 | 0.96 | 1.57 |
| Nb | 12.44 | 18.40 | 17.31 | 13.97 | 5.07 | 13.49 |
| Cs | 23.12 | 34.53 | 29.47 | 13.29 | 4.76 | 21.33 |
| Ba | 35.93 | 38.04 | 25.96 | 51.01 | 67.51 | 258.00 |
| La | 10.90 | 19.14 | 15.39 | 18.59 | 4.52 | 40.34 |
| Ce | 24.11 | 40.02 | 28.90 | 42.34 | 8.73 | 63.99 |
| Pr | 3.08 | 5.05 | 3.56 | 4.88 | 1.21 | 7.80 |
| Nd | 11.26 | 17.23 | 13.33 | 15.93 | 4.23 | 29.73 |
| Sm | 2.99 | 4.53 | 3.67 | 4.26 | 1.81 | 6.66 |
| Eu | 0.27 | 0.16 | 0.07 | 0.11 | 0.06 | 0.63 |
| Gd | 4.40 | 5.85 | 3.20 | 4.45 | 1.57 | 5.86 |
| Tb | 1.01 | 1.34 | 0.63 | 0.98 | 0.49 | 1.16 |
| Dy | 6.45 | 8.34 | 3.22 | 5.72 | 3.13 | 6.44 |
| Ho | 1.25 | 1.57 | 0.48 | 1.03 | 0.55 | 1.09 |
| Er | 3.11 | 3.95 | 0.86 | 2.46 | 1.61 | 2.74 |
| Tm | 0.42 | 0.54 | 0.33 | 0.25 | 0.34 |
| Yb | 2.48 | 3.07 | 0.53 | 1.93 | 1.77 | 1.90 |
| Lu | 0.29 | 0.37 | 0.07 | 0.24 | 0.21 | 0.21 |
| Ta | 2.51 | 3.37 | 2.64 | 2.38 | 1.13 | 1.36 |
| Pb | 6.05 | 17.76 | 26.91 | 18.66 | 45.94 | 45.63 |
| Th | 24.48 | 29.68 | 31.11 | 21.99 | 10.20 | 31.85 |
| U | 4.83 | 2.93 | 3.94 | 9.02 | 6.80 | 4.15 |
| ∑REE | 72.01 | 111.15 | 73.90 | 103.24 | 30.13 | 168.86 |
| Eu/Eu* | 0.23 | 0.1 | 0.06 | 0.08 | 0.11 | 0.31 |
Fig. 3. Classification diagram (a) TAS diagram after Middlemost (1994) (b) Feldspar Triangle after O’Connor (1965).

Fig. 4 (a) REE plot after Boynton 1984 (b) Primitive mantle plot after McDonough and Sun (1995).

Fig. 5(a) Rb vs. Y+Nb tectonic discrimination diagram after Pearce et.al., 1984 (b) tectonic discrimination diagrams after Batchelor and Bowden (1985).

In the Yb + Ta versus Rb discrimination diagram of Pearce et.al., (1984), the granites mostly plot within the syn-collision granite fields (Fig. 5a). The R1 - R2 [R1 = 4Si+...
The Proterozoic granitoids rocks from the NW Himalaya are enriched in LREE and relatively deficient in HREE, with prominent negative Eu anomalies and high Rb, Th, and U content, as well as negative Ba, Nb, Sr, P, and Ti anomalies (Miller et al., 2000). The high initial 87Sr/86Sr ratios (0.711-0.721) and initial epsilon Nd values of -5.8 to -8.8 suggest large-scale reworking of Archean sialic protolith, according to the Sr and Nd isotopic properties of these rocks (Miller et al., 2000). According to Singh (2011), granites from the Lesser and Higher Himalayas can be linked to a tectono-thermal (collisional) event that occurred around 1.9-1.8 Ga in the Bundelkhand craton (Slabunov et al., 2017), which is located in the southern section of the Garhwal Himalaya. Similar felsic granitic magmatism appears to occur in the Lesser Garhwal Himalaya, and more research is needed to determine whether the remobilization of Archean crust occurred in the Bundelkhand craton.

Discussion

The granitoids from the Chiplakot Crystalline Belt, Kumaun Himalaya, have been linked to the Columbia supercontinent subduction system in the Paleoproterozoic, according to Phukon et al., (2018). For the Bandal and Sainj granites, Frank et al., (1977) ascribes a whole rock Rb-Sr age of 1840 + 70 Ma, demonstrating the presence of Proterozoic granitic magmatism in the Himalaya. According to Islam et al., (2005), the Proterozoic granites of the Lesser Himalaya are rich in silica and K2O, have a high A/CNK value (>1.1), and contain normative corundum. Islam et al., (2005) also noted that granite, granitic gneisses, and associated metasedimentary rocks in the NW Himalaya underwent up to upper amphibolites facies metamorphism, suggesting that Proterozoic granitic gneisses were generated as basement slivers from the middle crustal level (a probable extension of the northern Indian craton). According to Singh et al., (2009), Paleoproterozoic (ca. 1860 Ma) felsic magmatic rocks are widespread in the Lesser Himalayan Zone to the basal part of the Higher Himalayan Crystallines (HHC), implying that older crustal material exhumed due to collisional tectonics during the Himalayan orogeny was remobilized.
more studies to understand 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 craton?

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