Tectonochemistry and $p$-$t$ Conditions of Ramgarh and Almora Gneisses from Asokt Klippe, Kumaun Lesser Himalaya

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Abstract: The chemical and petrological correlation of metamorphic nappes and klippes overlying the Proterozoic sedimentary units in the Kumaun Himalaya is still debated. The Ramgarh and Almora gneisses, not previously distinguished in the Asokt Klippe, show distinct field, petrological and chemical signatures markedly similar to the tectonostratigraphic disposition of the Almora Nappe. A negative Eu anomaly in the Ramgarh granitic gneisses indicates lesser plagioclase fractionation while the Eu anomaly in the Almora pelitic gneisses is likely to have been controlled by feldspar crystallization in restites. During the anatexis at $>776^\circ$C temperature and $>6.6$ kbar pressure, the melt moved slightly away to its crystallization sites. The Rb/Sr ratio $\sim 0.54$ and Nb $\sim 10$ ppm is consistent with the granodioritic composition. The negative Sr anomaly in the underlying Ramgarh granitic gneisses indicates a distinct mantle derived source/plagioclase fractionation with a notable correspondence to other late orogenic granites, particularly the basement Uller gneisses from the Nepal Himalaya. Ramgarh gneisses plot in the late- and post-COLG field. The Asokt ensemble is likely to be the tectonometamorphically reworked basement, viz. the Ramgarh Group along with its meta-pelitic cover of the Almora Group, together comprising southward thrust remnants of the leading edge of the Indian Plate that collided with Tibet during the Tertiary Himalayan orogeny.

Key words: geochemistry, thermobarometry, Almora gneiss, Ramgarh gneiss, Almora Nappe, Asokt Klippe

1 Introduction

Himalayan continental collision was responsible for the geological reworking of the rocks comprising the leading edge of the Indian Plate. Sequentially deciphering India’s paleoposition during the geological past and its location vis a vis the ever-changing configurations of supercontinents demands that the Pre-Tertiary lithological and structural elements are studied in a time-space perspective. Association and dissociation of supercontinents impelled by tectonic processes have a known periodicity of 400-500 Ma (Wilson, 1963; Nance et al., 1988). Cui (1997) suggested that the time and velocity constrained subduction of the Indian plate during Himalayan continental collision led to the thickening in south of the subduction and the consequent thermal – uplift extension, which were the key mechanisms for uplifting the collision zone. Columbia, one of the oldest supercontinents in the geological history of the earth, coalesced between 2.1 to 1.7 Ga ago (Rogers, 2000; Condie, 2002; Rogers and Santosh, 2002; Meert and Santosh, 2017). Study of the Lesser Himalayan igneous, sedimentary and metamorphic sequences has a key role in supercontinent reconstructions in southeast Asia, which has been attempted by Gansser (1964), Le Fort (1975), Valdiya (1980, 2009), Yin (2006) and others. The Lesser Himalayan rocks have undergone a tortuous deformation history, culminating in three major orogenetic parallel thrusts viz. the Main Central Thrust, the Musiari Thrust and the Ramgarh Thrust, along with the brittle crustal scale North Almora Fault (Joshi, 1999; Joshi et al., 2019), intersecting the area. The Lesser Himalaya essentially consists of Pre-Himalayan or Pre-Tertiary sedimentary (Valdiya, 1980, 2009; DeCelles et al., 2001) and igneous rocks that are capped by detached tectonic outliers essentially comprising a metapelitic cover that invariably overlies mylonitized igneous rocks, with an intervening thrust.

Despite several workers arguing for Pre Tertiary orogenic events (e.g. Fuchs, 1968; Srikantia, 1977; Bhargava, 1980, 2011; Bhargava and Bassi, 1994; Valdiya, 1995; Joshi et al., 1994; Joshi, 1999; Gehrels et al., 2003; Joshi and Tiwari, 2004, 2009) in the Lesser Himalaya, the idea somehow still does not have a wide acceptance. In fact, Baig et al. (1988) proposed a late Cambrian orogeny from the Pakistan Himalaya, while Gehrels et al. (2003) suggested a Late Cambrian-Middle Ordovician thrusting from the Nepal Himalaya. Gehrels et al. (2006) discussed regional metamorphism that at least reached garnet-grade, and associated regional folding related to an Early Palaeozoic tectonic event, ratifying Joshi et al. (1994) and Joshi and Tiwari (2005), who documented a Pre-Cambrian amphibolite facies metamorphic event from the adjacent Kumaun Himalaya. There is evidence suggesting that the Palaeo-proterozoic (1800-1900Ma) has been a particularly active period in terms of igneous activity in the Lesser

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Himalayan sequences. Though the area has not been extensively dated employing well constrained U-Pb and Pb-Pb dating, Kohn et al. (2010) suggested a date of 1830±50 Ma based on U-Pb zircon dating for the edge of a palaeocontinental arc in the Lesser Himalaya. A crystallization age for a granite–granodiorite gneiss has been determined at 1856±1.0 Ma (±19 Ma), and a crystallization age of 1878±2.4 Ma (±19 Ma) has been suggested for a biotite augen gneiss, using U-Pb zircon dating for the Askot area in the Kumaun Himalaya by Mandal et al. (2016).

The present study is essentially focused on two aspects, viz. the tectonochemistry of the gneissic rocks comprising the igneous basal part of the Askot Klippe, and the chemistry and the petrotectonic evolution of a hitherto unexplored metamorphic cover for its relationships with rocks of similar stratigraphic disposition within the Himalaya, for better regional comprehension, in the context of its possible relationships with the Columbian supercontinent.

During the Tertiary continental collision, the Main Central Thrust transported the quartzite-schist-granite gneiss ensemble southwards from its root zone in the Higher Himalaya (Heim and Gansser, 1939; Valdiya, 1980, 2010 and others). Askot Klippe is one of the smaller remnants of this large thrust sheet, similar in its architecture to the Almora Nappe, which is the southernmost extension of a once continuous larger thrust sheet (Fig.1a). Striking resemblance in lithology, structural history, tectonic setting and metamorphic evolution renders the crystallines of Almora Nappe and Baijnath, Askot, Chhiplakot and Lansdowne klippes almost indistinguishable (Valdiya, 1980; Celerier et al., 2009; Patel et al., 2011, 2015).

The Ramgarh gneisses can be correlated largely after Valdiya (1980, 1983 and 2010) and Singh (2010) with other gneisses along the Himalayan strike. Thus, the Ramgarh gneisses can be correlated with the Bhatwari Formation farther north in the Kumaun Himalaya, the Himachal Himalaya, the Dhauladhar gneisses in Kashmir, the augen gneisses of the Bhimphedi Group in western Nepal, the Ulli gneisses in Central Nepal (Le Fort and Rai, 1999), migmatitic gneisses of the Tumlingtar Group in Eastern Nepal, the Bomdila Mylonitic Gneisses in the western Arunachal Himalaya (Singh, 2010), the Lingaste augen gneiss of the Darjeeling-Sikkim Himalaya (Sinha-Roy, 1980) and with gneisses of the Shumar Formation of the Bhutan Himalaya (Dasgupta, 1995).

The present attempt addresses the petrochemistry of Askot Klippe, in order to understand the evolution of the area, and to discriminate between the petrotectonic settings of the Ramgarh and the Almora gneisses. We focus on deciphering the compositional similarities of the Ramgarh granite gneisses with similar granites from other parts of the Himalaya and the world, in order to understand their tectonic setting and regional correlations.

2 Regional Geology

Askot Klippe resulted from the southward thrusting of the metamorphics from the Higher Himalayan Crystallines over the Main Central Thrust (MCT). Valdiya (1983), however, suggested that these basement gneisses have been thrust southwards. It is strikingly similar to the Almora Nappe, both in terms of structure and metamorphism. The Klippe has a slightly asymmetric structural disposition, with the northern limb dipping 30°–35° due south while the southern limb dips 20°–25° due north. The longer axis of the rhomboid Askot Klippe on the map is oriented roughly E–W.

For the first time, we present evidence that Askot Klippe consists of two tectonostratigraphic units, viz. the basal Ramgarh Group and the overlying Almora Group. We mapped an asymmetric overturned antiform in the central part of the klippe that exposes pelitic gneisses, with its southern limb steeply dipping (50°–71°) due north and the northern limb dipping relatively gently (22°–35°) due south (Fig. 1b). The absence of an adjacent synform could be explained through truncation by the Almora Thrust. The fold axis of this doubly-plunging fold is oriented broadly E–W and it exposes K-feldspar-sillimanite-cordierite gneisses, reported here for the first time. Shear sense indicators suggest that the general sense of movement for mylonites in the klippe is from top-to-south. We consider the top-to-north sense of shears recorded by Mandal et al. (2016) in the southern contact of the Klippe to be minor exceptions due to lagging behind by some tectonic slices within the dominant top-to-south tectonic transport in the shear zone, likely due to a back thrust. In Askot Klippe, like the Almora Nappe, the outer periphery of the klippe comprises Ramgarh Group rocks, which are separated from the underlying sedimentary rocks of the Damtha and Tejam groups by the Ramgarh Thrust (RT) of Joshi (1999) in its northern and southern flank, as identified in the Almora Nappe. Like the Almora Nappe, Almora Group rocks exposed in the central parts of the nappe are separated from the underlying Ramgarh Group rocks by the Almora Thrust (AT) in its northern and southern flank.

Based on the rock types, the Almora and Ramgarh groups are separated by the Ramgarh Thrust within northern and southern exposures. The Basal Shear Zone of the Almora Nappe is characterized by the presence of granitic mylonites and ultramylonites of greenschist facies and rare proto-mylonites. The Ramgarh Group is characterized by the presence of dark grey granitic gneisses, whereas the Almora Group is distinguished by the presence of light coloured gneisses. Gneisses of the Almora Group are pelitic in nature and comprise garnet, cordierite, kyanite, sillimanite and K-feldspar. The Askot Klippe is bound in the north by schistose phyllites and limestones of the Mandhal Formation, locally known as the Tejam Group (Valdiya, 1980; Celerier et al., 2009), and to the south by quartzites of the Jaunsar and Beraing formations (Valdiya, 1980).

Large scale displacement over a single thrust resulted in the larger Almora Nappe and a number of smaller klippes in the Kumaun Lesser Himalaya, such as the Askot Klippe and the Chhiplakot Klippe. The Askot Klippe tectonically rests on the dolomites and the dolomitic limestones of the Damtha and Tejam groups. The Ramgarh Group consists of ultramylonites, mylonites and protomylonites, after the
Fig. 1. Simplified geological map of the Kumaun Lesser Himalaya (after Valdiya, 1980; Joshi, 1999).
(a) Various thrust contacts. Black open rectangle indicates the study location; (b) lithological map of the studied location, characterizing various thrust contacts and lithologies from bottom to top.
granite gneisses that are exposed at the base of the kippe. These are followed upwards by mylonitized schistose phyllites, quartzites and/or schistose quartzites. Further up the section, the equivalent of the Almora Thrust is marked by the first appearance of garnets and chlorite-biotite-muscovite-garnet schists, garnet-biotite-kyanite schists, K-feldspar-sillimanite gneisses interbanded with psammitic bands and amphibolite sills. A post-orogenic intrusive granitic-granodioritic body which appears gneissose due to mylonitization has also been observed.

3 Petrography

3.1 Almora Group

The Almora Group rocks are essentially pelitic, comprising white, greenish grey, bluish grey and brown, fine to medium-grained schists, micaceous quartzites, amphibolites and gneisses (Fig. 2). Different varieties of schist are recognized, such as chlorite schists, biotite-sericite schists, graphitic schists and garnet-mica schists. The schistosity is defined by the preferred alignment of the micas. Locally-developed porphyroblastic garnet is quite common, particularly in the mica schists. The pelitic augen gneisses occur in the central parts of the kippe in an anticlinal exposure (Fig. 2a).

The pelitic gneisses are rich in biotite and contain porphyroblasts of plagioclase and K-feldspar. The schists are interbanded with quartzites and gneisses. Near the periphery of the kippe, the low grade schists are underlain by protomylonites, mylonites and ultramylonites, after the dark-colored Ramgarh gneisses. The porphyroblastic pelitic gneisses exposed in the core of the kippe are mylonitized towards the periphery with the degree of mylonitization increasing as the equivalent of the Almora Thrust is approached. The augen gneisses of the Almora Group in the Askot Crystallines have a distinctive character, and consist of large porphyroblastic feldspar augens. The high grade K-feldspar-sillimanite gneisses are restricted to the central parts of the kippe. The thick pile of gneisses is exposed between the schists due to a later overturned folding event. The locally-interbanded nature of schist-gneiss-schist is observed, suggesting melting in the more albitic layers that produced the gneisses.

Microscopically, the mica schists and garnetiferous mica schists are characterized by the dominant S2 schistosity that defines the regional trend. Relicts of an older schistosity (S1) are also present. The schistosity is defined by the preferred orientation of chlorite, biotite and

Fig. 2. Megascopephotographs of the Almora Group.
(a) Feldspar porphyroblasts in augen gneiss; (b) South Almora Thrust near Oglia, showing the underlying Ramgarh mylonites and the mylonitized garnet mica schists of the Almora Group; (c) asymmetric quartz-feldspathic veins showing top-to-south movement in the Almora gneisses. Arrow shows the direction of shearing; (d) contact of gneiss and amphibolite.
muscovite. In the pelitic gneisses of the Almora Group, plagioclase, garnet, quartz and rare kyanite blades and sillimanite needles are present within the K-feldspar. The plagioclase occurs as laths and shows lamellar twinning. Polysynthetic twinning is observed. In places, the plagioclase grains are highly saussuritized and converted to dense aggregates of sericite, epidote and calcite. The feldspar length is truncated by the S-plane and the mica flakes are also truncated by the foliation plane. The S-C fabrics are well-developed in the garnet-mica schists at the base of the Almora Group (Fig. 3b). The plagioclase generally shows polysynthetic twinning and, in places, oscillatory zoning. Biotites are irregularly-shaped and heterogeneously distributed in the rock, and occur as uneven masses. Myrmekitic intergrowths of plagioclase with quartz are common. The other accessory minerals include epidote, zircon, apatite, sphene, tourmaline, clinozoisite and opaques.


Chlorite in the schists of the Askot Crystallines is generally a retrogression product, and chloritized garnet is common at the base of the Almora Group rocks, comprising the shear zone of the Almora Thrust. Muscovites and biotites of two generations, viz. one of coarser size, define the S2-foliation and the other cross-cutting finer one defines a later foliation. Biotite grains are strongly pleochroic from yellow-brown to deep reddish-brown. Randomly oriented biotite flakes in the pelitic gneisses suggest that, due to extreme temperature, partial melting was initiated, and the physical conditions of the rock changed to a semi-plastic state with consequent hydrostatic pressure.

Two types of garnet have been observed in the pelitic gneisses of the Almora Group. Garnet-I are syn-kinematic crystals that developed during the deformation. The sigmoidal disposition of the quartz grains in the central part of the garnet indicates rotation during growth. Internal schistosity (S3) in the core is oblique to the external schistosity (S2), while S, close to the garnet rim is parallel to S3 (Fig. 3c). Garnet-II crystals, with an idioblastic outline are post-kinematic and developed after the cessation of deformation (Fig. 3g-h). This suggests that the garnet core developed during a synkinematic recrystallization, while the inclusion-free rim developed when the directional stresses ceased. Evidently the metamorphism in the area outlasted the deformation. The micas and other minerals appear to flow around the garnet. Hematite is observed along the cracks and margins of the garnet. Inclusions of quartz and iron oxides are commonly observed in the garnets. Highly chloritized garnets are observed, due to retrogression near the thrust (Almora Thrust) at the base of the Almora Group.

The pelitic gneisses of the Askot Klippe are medium-to-coarse grained, crudely foliated, biotite gneisses. Foliation is defined by planar blebs and streaks of biotite. The main constituents are garnet, cordierite, quartz, K-feldspar, plagioclase, biotite and sillimanite. Random orientation of biotite is observed due to the development of hydrostatic stresses during anatexis in the gneisses at peak metamorphic conditions. Microperthites in the pelitic gneisses indicate locally strong deformations and interlocking of the grains. Cordierite is reported here for the first time from any of the klippe/nappes in the Kumaun Lesser Himalaya. The reaction between garnet and biotite indicates the onset of granulite facies metamorphism in the pelitic gneisses (Fig. 3e-f). Plagioclase is mostly subhedral and euhedral and commonly shows albite, albite-carlsbad and albite-pericline complex twinning. In some of the samples, the laths of plagioclase are truncated by the S-planes. Inclusions of quartz, biotite, muscovite, sericite and zircon are observed within the plagioclase. Plagioclase also occurs as small grains and as inclusions within the biotite.

3.2 Ramgarh Group

Ramgarh Group rocks are essentially granitic and have been subjected to intense mylonitization, leading to the development of mylonites and ultramylonites under greenschist facies conditions with the characteristic development of chlorite (Fig. 4).

The rocks of the Ramgarh Group, which constitute the basal part of the klippe, show more intense shearing compared to those of the overlying Almora Group. Broadly speaking, the degree of mylonitization increases as the basal Ramgarh Thrust is approached. The mylonites are generally dark in colour, due to the predominance of ferromagnesian minerals. Chlorite-rich mylonites and ultramylonites after the mica schists are exposed at the base of the Almora Group rocks overlying the Ramgarh mylonites in the Ogla-Rangana section.

Under the microscope, the granite gneisses of the Askot Klippe can be seen to be medium-to-coarse grained mylonitized biotite gneisses, characteristically lacking gneisses. Orthoclase is usually fractured with veins of quartz and plagioclase showing combination twinning and strong saussuritization. Mortar texture is commonly developed, due to intense mylonitization (Fig. 5b). In some places, myrmekitic intergrowths are characteristically developed (Fig. 5c). Microfolding is common. Porphyroblastic crystals of orthoclase and subordinate plagioclase which are twinned and highly saussuritized can be observed. The main mineral assemblages, viz. quartz, feldspar, muscovite and biotite, are unevenly distributed within the rocks. Near the Almora Thrust, mortar texture is displayed by K-feldspar. Chessboard twinning in plagioclase is also common. The mineral assemblages are: muscovite-biotite-plagioclase-quartz, muscovite-biotite-plagioclase-K-feldspar-quartz and muscovite-biotite-plagioclase-K-feldspar-quartz.

Quartz occurs as fresh grains with sharp outlines, having inclusions of biotite, muscovite, chlorite, sericite, euhedral zircons and opaques. Quartz also occurs as inclusions within the K-feldspar, plagioclase and mica. Brown biotite is the dominant mica in these rocks. Biotite, muscovite and quartz fiber are the common minerals developed in the asymmetric pressure shadow zones around the feldspar porphyroclasts. The K-feldspar has undergone sericitization, likely as a result of ingress of
Fig. 3. Photomicrographs of the Almora Group, a, c are in XPL and b, d are in PPL.
(a) Random orientation of biotite flakes; (b) shows the S-C fabric; (c) garnet porphyroclast surrounded by retrograded chlorite with symmetric neutral pressure shadow; (d) tourmaline crystal embedded in the ground mass of feldspar; (e) garnet-biotite reaction in PPL; (f) same in XPL; (g) and (h) show synkinematic and postkinematic garnet in the kyanite-garnet-mica schists of the Almora Group.
water during shearing. Inclusions of quartz, biotite, muscovite, sericite and zircon are observed within the plagioclase.

The grains of plagioclase are highly saussuritized near the marginal area. The plagioclase shows chessboard twinning (Fig. 5a) in some of the samples, due to local shearing. Metasomatism in local shear zones is brought about by hydrothermal fluids that reduce the temperature and result in such tiled textures (Exner, 1949). Microlithons retaining the original fabric of the precursor rock are also present. The rocks of the Ramgarh Group are mainly granitic and characteristically devoid of any garnet. The presence of green biotite in the mylonites of the Ramgarh Group (Fig. 5d) indicates the basic character of the rocks, with a relatively higher Fe₂O₃ content and (FeO+MgO) and a lower Al₂O₃ content (Sakai, 1981). The green biotites are formed at a slightly lower temperature and pressure than the brown biotites (Sakai, 1981).

4 Sampling and Methods

The pelitic gneisses and granitic mylonites of both the Almora and Ramgarh groups were analyzed for their geochemical characteristics. A total of thirty samples were subjected to whole rock analysis using XRF (SIEMENS SRS 3000 at Wadia Institute of Himalayan Geology, Dehradun, India), to determine the major oxide chemistry of the rocks. Eleven of the samples were analyzed at the Activation Laboratory, Canada, for both the trace element characteristics and the REE behaviour of the rocks. The values for these elements were determined by fusion ICP-MS. Cu, Pb, Zn, Ni, Ag, As, Sb, W, Cr and Sn content were also analyzed (Table 1).

The mineral chemistry for the gneisses of the Almora Group was carried out employing the Electron Probe Micro Analyzer (EPMA) in the EPMA Laboratory, Department of Geology, Institute of Science, Banaras Hindu University. Polished thin sections were coated with a 20 nm thin layer of carbon for electron probe micro analyses using the LEICA-EM ACE200 instrument. The Cameca SXFive instrument was operated by SXFive Software at a voltage of 15 kV and a current of 10 nA, with a LaB6 source in the electron gun for generation of the electron beam (Table 2).

5 Discussion

5.1 Petrochemistry of both the Almora and Ramgarh Groups

Geochemical analyses of the Almora and Ramgarh
gneisses show distinctive geochemical characteristics. In the Ramgarh granitic gneisses, the ΣREE ranges from 152.24 to 265.53, while in the Almora pelitic gneisses the ΣREE ranges from 144.91 to 155.12. Thus the ΣREE is significantly lower for the Almora pelitic gneisses, which clearly distinguish the two geochemically.

For the Almora pelitic gneisses, the (La/Lu)_N was restricted to between 12.60 and 17.45, while for the Ramgarh granitic gneisses it varied from 17.66 to 22.53, again characterizing the two clearly. However, both of them indicate a typical continental margin setting (Cullers and Graf, 1983). To determine the tectonic setting, both the rock groups were plotted on the diagram of Pearce et al. (1984).

The Eu/Eu* ratio in the Ramgarh granitic gneisses varied from 0.29 to 0.78, showing a moderate negative Eu anomaly. In contrast, the Eu/Eu* ratio for the Almora pelitic gneisses varied from 0.15 to 0.54, showing a more pronounced negative Eu anomaly for the rocks. The negative Eu anomaly for the Almora pelitic gneisses (Fig. 8a) signifies a somewhat higher degree of fractionation in the plagioclase. The Eu anomaly is controlled by feldspar, particularly in felsic magmas, as Eu (present as Eu²⁺) is compatible in plagioclase and potassium feldspar in contrast to Eu³⁺, which is incompatible. Thus, the removal of feldspar from a felsic melt by crustal fractionation or the partial melting of rocks, in which feldspar was retained in the source to give rise to a (−ve) Eu anomaly in the melt (Rollinson, 1983), is likely.

However, in the Askot Klippe the pelitic schists imperceptibly grade into the Almora pelitic gneisses and the reactions muscovite+albite=quartz+K-feldspar+sillimanite+H₂O (Thompson, 1974) and muscovite+quartz = sillimanite+K-feldspar+H₂O (Turner and Verhoogen, 1960 and Winkler, 1978) have been petrographically identified in the thin sections. Thus, the large negative spike of the Eu anomaly is likely to be a reflection of the removal of the melt from the adjacent schists that eventually solidified as the gneisses. This suggests that the source rocks, viz. schists, are likely to have melted, leaving a feldspar rich restite and producing a melt with a negative Eu anomaly.

The Rb/Sr ratio varies from 0.43 to 9.22 for the Ramgarh gneisses and from 13.94 to 82.75 for the Almora gneisses, which once again distinguishes the two. The unexpected increase in the Rb/Sr ratio and decreasing Sr content in the Almora gneisses can be related to fractional crystallization.

In contrast, samples of the Ramgarh Group of rocks
### Table 1: Major oxides (wt%) and trace elements (ppm) of XRF analysis of the selected samples from the Ramgarh and Almora Groups

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<td>2.71</td>
<td>2.40</td>
<td>2.82</td>
<td>2.77</td>
<td>2.51</td>
<td>0.59</td>
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<td>K₂O</td>
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<td>5.98</td>
<td>2.77</td>
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<td>3.74</td>
<td>6.13</td>
<td>5.55</td>
<td>6.03</td>
<td>5.37</td>
<td>5.96</td>
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<td>4.49</td>
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<td>TiO₂</td>
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<td>0.34</td>
<td>0.28</td>
<td>0.32</td>
<td>0.50</td>
<td>0.22</td>
<td>0.71</td>
<td>0.31</td>
<td>0.36</td>
<td>0.21</td>
<td>0.20</td>
<td>0.30</td>
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<tr>
<td>P₂O₅</td>
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<td>0.16</td>
<td>0.11</td>
<td>0.13</td>
<td>0.15</td>
<td>0.12</td>
<td>0.20</td>
<td>0.15</td>
<td>0.16</td>
<td>0.13</td>
<td>0.10</td>
<td>0.15</td>
<td>0.13</td>
<td>0.21</td>
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<tr>
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<td>99.52</td>
<td>100.66</td>
<td>99.88</td>
<td>99.51</td>
<td>100.49</td>
<td>99.12</td>
<td>100.8</td>
<td>99.91</td>
<td>99.92</td>
<td>99.93</td>
<td>98.69</td>
<td>100.41</td>
<td>101.62</td>
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### Table 2: Probe analysis of selected mineral grains from the Almora Group

<table>
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<th>ASK-79</th>
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<td>Sro</td>
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<tr>
<td>Cr₂O₃</td>
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<td>0.18</td>
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<tr>
<td>Al₂O₃</td>
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<td>19.87</td>
</tr>
<tr>
<td>Cr₂O₃</td>
<td>0.11</td>
<td>0.11</td>
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<tr>
<td>FeO</td>
<td>18.94</td>
<td>21.18</td>
</tr>
<tr>
<td>MnO</td>
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</tr>
<tr>
<td>MgO</td>
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<td>0.28</td>
</tr>
<tr>
<td>CaO</td>
<td>14.85</td>
<td>14.35</td>
</tr>
<tr>
<td>Na₂O</td>
<td>0.01</td>
<td>0.01</td>
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<tr>
<td>K₂O</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>P₂O₅</td>
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<td>0.04</td>
</tr>
<tr>
<td>Total</td>
<td>99.86</td>
<td>98.78</td>
</tr>
</tbody>
</table>

Oxygen atoms: 12.00  22.00  8.00  18.00  12.00  22.00  8.00
viz., CB-5, LG-26, LG-5 show a decreasing Rb/Sr ratio and increasing Sr content. The average Rb/Sr ratio is ~0.54 and Nb ~10 ppm in these three samples, characterizing a granitic magma that produced the granodiorite (Henderson, 1980).

In the Harker variation diagrams, Al₂O₃, CaO, TiO₂, P₂O₅ and FeO show a negative relationship with the SiO₂, while MgO, Na₂O and K₂O did not show any relationship with the SiO₂ (Fig. 6). The A/CNK and K₂O/Na₂O and the trace elements Ni and Cr did not show any relationship with the SiO₂, while the trace element Rb shows a positive relationship with the SiO₂ and Sr shows a negative correlation with the SiO₂. The mgₖ shows a negative correlation with SiO₂ for the Ramgarh gneisses while it shows no relationship with the SiO₂ for the Almora gneisses (Fig. 7). Some of the pelitic gneisses of

the Almora Group, viz. OA-10 and ON-3, have high Al₂O₃ and K₂O, but low CaO and Na₂O. Such variations in the pelitic gneisses are also known from other parts of the world (Chinner, 1960, Malisa, 2005). Low Ca content in the granitic gneisses of the Ramgarh Group suggests that these granites may have anorogenic tectonic affinities (Chappell and White, 2001).

Both the Ramgarh and Almora gneisses show large REE variations from the primordial mantle composition (Fig. 8), but have been treated separately here, consistent with the field and petrographic evidence elaborated previously. The Ramgarh gneisses are likely to have evolved from assimilation and fractional crystallization, while the K-feldspar-sillimanite-cordierite bearing Almora gneisses formed due to melting under the highest metamorphic grade conditions. Both groups have a

Fig. 6. Harker diagrams showing SiO₂ (wt%) variation with major oxides (wt%) of Almora and Ramgarh Gneisses from Askot Klippe.
Red circles: Ramgarh gneisses; blue diamonds: Almora gneisses; green triangles: Debguru Porphyroids; black square: Uleri gneiss.
negative Sr anomaly and a negative Nb anomaly. The negative Sr anomaly indicates the distinctive mantle derived source/plagioclase fractionation. In some of the gneisses of the Ramgarh Group, the Ni concentration is between 20–40 ppm, indicating a modern ocean arc setting (Smith et al., 1997). The relative enrichment of LILEs to REEs and the depletion of Nb and P is suggestive of the arc environment for the genesis of the Ramgarh gneisses, and is expected to be the configuration of the bulk continental crust. On the Rb/30 vs. Hf vs. Ta*5 plot of Harris et al. (1986), the granitic rocks of the Ramgarh Group lie within the field of the volcanic arc and the late-and post-COLG field (Fig. 9). The gneisses of the Almora Group lie within the fields of Syn-Collisional and within-plate tectonic settings, which appear consistent with their metamorphic origin.

Of the four types of peraluminous granites identifiable in the A-B multi-cationic diagram of Villaseca et al. (1998), modified after Debon and Le Fort (1983), granite gneisses of the Askot Klippe show two distinct clusters, viz. the highly felsic peraluminous granites (f-P) equivalent to the Almora Group and the highly peraluminous granitoids (h-P) of the Ramgarh Group. The Almora gneisses show most of the characteristics of the highly felsic peraluminous granitoids and show a marked absence of mafic minerals. These lay close to their source region and contain cordierite, almandine-pyrope garnet and sillimanite, as described by Villaseca et al. (1998). The Ramgarh gneisses, however, are characterized by an increase in peraluminosity with increasing mafic content, consistent with field observations (Fig. 10). Surprisingly, none of the Ramgarh gneisses plot in the metaluminous field, as reported by previous workers (Rao and Sharma, 2009, 2011; Mandal et al., 2016).

In the tectonic discrimination diagrams of Pearce et al. (1984), the Almora gneisses invariably plot in the Syn-COLG field with only one exception plotting in the WPG field, which is consistent with their behaviour in the other diagrams discussed above. The Ramgarh gneisses, however, show a more mixed nature, falling in the VAG, Syn-COLG, and at the boundary with the WPG field (Fig. 11).

The Na₂O+K₂O – CaO vs. SiO₂ plot of Frost et al. (2001) also clearly distinguishes the calc-alkaline S-type Almora gneisses from the alkali-calcic I-type Ramgarh gneisses (Fig. 12). The S-type granites are characterized by their peraluminous nature, while the I-type granites are almost invariably metaluminous. That the Almora gneisses are of pelitic origin and distinctly different from the Ramgarh gneisses is once again brought out by their plotting in the S-type field in the Frost et al. (2001) diagrams. Present analyses for the Ramgarh gneisses, however, plot in the I-type field, which is generally the metaluminous field.

5.2 Mineral chemistry and phase equilibria of the Almora Group gneisses

The mineral chemistry shows that the biotites of the gneisses of the Almora Group are siderophyllites enriched in Al₂O₃ and FeO, but depleted in SiO₂ and MgO. The Fe⁺/Fe³⁺+Mg in biotites of gneisses vary from 0.65 to 0.74. The MgO content of biotite in the rock varies from 5.22 to 6.86 wt%, whereas the Al₂O₃ content varies from 16.30 to 20.67 and the FeO content varies from 22.32 to 26.10 (Fig. 13a–b). The siderophyllite variety of biotite is generally not known from Lesser Himalayan metapelitic sequences. Although siderophyllite is generally not a common mineral in gneisses of metapelitic origin, it has nonetheless been recorded in the garnet-orthopyroxene-cordierite-biotite-quartz-plagioclase-perthite=sillimanite assemblage from the Karimangar area of the Eastern Dharwar Craton, India (Sharma and Prakash, 2007).
Siderophyllite is also recorded from pelitic gneisses from the Geis Magmatic Arc, Brazil (Navarro et al., 2013). Interestingly, the Karimangar assemblage is identical to the pelitic gneisses from the Askot area, albeit with the difference that orthopyroxene is inferred at the reaction boundary between the garnet and biotite in the current area under discussion.

The BSE image and its subsequent compositional plot of garnet show the zoning profile of Ca, Mg, Mn and Fe from core to rim. XCa represents Ca/(Ca+Mg+Fe+Mn), XMg represents Mg/(Fe+Mg), XFe represents Fe/(Fe+Mg) and XMn represents Mn/(Ca+Mg+Fe+Mn). Garnet zoning in the metapelitic gneisses of the Almora Group shows the variation in Ca, Mg, Fe and Mn from core to rim (Fig. 14). XMn shows a slightly bowl-shaped profile and increases from core to rim. However, XFe and XMn are more or less flat. On the other hand, XCa shows a slightly plateau-shaped profile and decreases from core to rim. Partial re-equilibration in the P-T conditions of the metapelitic Almora gneisses resulted in some flattening in the elemental composition profile of the garnets.

Phase section modelling is one of the better tools to compute the P-T conditions. The reliability of the results is based on the internally consistent thermodynamic dataset. The phase section model was drawn by the Perple X 6.7.5 (database: hp02ve.dat) (Connolly, 2005) in the NCMnKFMASHT system for the garnet-cordierite-K-feldspar-sillimanite bearing gneisses of the Almora Group. The amount of H2O taken for the calculations of phase section modelling was estimated by the ‘Loss on Ignition’ (LOI) value in the whole rock analysis. The phase section modelling was drawn with the help of the internally consistent thermodynamic dataset and equation of state for H2O (Holland and Powell, 1998). The solution models of Bio (HP), Gt (HP), hCrd, Chl (HP), Mica (CHA), Ilm (WPH), melt (HP) and feldspar are used to...
Fig. 11. \((Na_3O+K_2O) - CaO vs. SiO_2\) plot of Frost et al. (2001), clearly distinguishing the calcic S-type Almora gneisses from the alkali-calcic I-type Ramgarh gneisses.

<table>
<thead>
<tr>
<th>Table 3 Thermodynamic dataset for phase diagram calculations</th>
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<tbody>
<tr>
<td>Symbol in Perple_X solution model</td>
</tr>
<tr>
<td>Bis(HP)</td>
</tr>
<tr>
<td>Gt(HP)</td>
</tr>
<tr>
<td>Crd</td>
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<td>Chl(HP)</td>
</tr>
<tr>
<td>Mica(CHA)</td>
</tr>
<tr>
<td>Melt(HP)</td>
</tr>
<tr>
<td>Feldspar</td>
</tr>
<tr>
<td>Ilm(WPH)</td>
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</table>
Fig. 12. Tectonic discrimination diagrams after Pearce et al. (1984) for the Almora and Ramgarh gneisses. Symbols are same as Fig. 8.

draw the phase section diagram (Table 3). Compositional isopleths have been drawn in the calculation to decipher the P-T path. The isopleth contours for the garnet were calculated in the cordierite-K-feldspar-garnet bearing gneisses as shown in Fig. 15. Through the intersection of the $X_F$, $X_{Ca}$ and $X_{Mg}$ isopleths, the temperatures and pressures are estimated.

The software PTCALC (Ferry and Spear, 1978 and Lal, 1991) and QBASIC (after Wu et al., 2004) were used to estimate the average temperature and pressure from the mineral chemistry of the rocks from the study area. In the observed petrogenetic grid system, the garnet-cordierite-biotite gneisses yielded average temperatures around 776°C and pressures around 6.6 kbar, as calculated by preferred thermobarometric models (Thompson, 1976; Holdaway & Lee, 1977; Ferry and Spear, 1978; Perchuk and Lavrenteva, 1983 for temperature and Lai, 1991; Wu et al., 2004 for pressure). These P-T conditions are the minimum estimates of the P-T reached by the gneisses. This is corroborated by the temperatures estimated for the core and rim of the garnets, viz. 665°C and 776°C respectively (Table 4). The corroded garnet-biotite contact suggests the onset of granulite facies metamorphism, which is corroborated by temperature estimates of around 776°C for the garnet rims. The data were intrapolated within the Petrogenetic Grid System (PGS) (modified after Spear and Cheney, 1989; Spear et al., 1999), which is a closed system with the calculated pressure-temperature path (Fig. 16).

The temperature of Ferry and Spear (1978) and pressure of Lal (1991) were chosen, based on the petrographic observations and the petrogenetic grid. The petrogenetic grid is one of the easiest ways to document changes through mineral reactions during the progress of metamorphism. The estimated temperatures and pressures were plotted in the NcMnKFMASHT system (Fig. 16). The persistently corroded boundary between garnet and biotite suggests dehydration melting of biotite under the ambient P-T conditions and the estimated P-T estimates are clear evidence for the onset of granulite facies metamorphism. These gneisses are characterized by the common presence of fresh muscovite and biotite overprinting the regional foliation. The recrystallization of the fresh later-generation micas is interpreted as being due to their development past the peak metamorphic conditions during the regressive arm of the prograde metamorphism. The temperature of 776°C was recorded when the rock was cooling. The system was a closed system and flushed with water. Upon the solidification of the anatectic melt, slightly away from the restite, water was released and used up in giving rise to the fresh alteration of sillimanite-K-feldspar to coarse high-T muscovite. There was little melt in the system due to the intermittent presence of hydrous minerals in the rock, and consequently the melt did not escape the system in a sizable quantity. This segregated $H_2O$ was one of the reactants for the later development of fresh assemblages containing coarse muscovite. Looking at the fresh muscovite at the regressive arms of the metamorphic field gradient, it is apparent that the rocks were sent to temperatures exceeding 770°C and pressures around 6.5 kbar, i.e. to depths exceeding 25 km and were then

Fig. 13. Chemical discrimination diagram of biotites from the Almora Group. (a) FeFeMg vs. Al² diagram (after Deer et al., 1965) for biotites of Almora gneisses; (b) FeO-MgO-Al₂O₃ diagram of biotites of Almora gneisses. Fields are after Abdel-Rehman (1994).
exhumed due to the erosion of the upper surface.

5.3 Implications for tectonic setting

In Askot Klippe, the SiO$_2$ shows a discrete relationship with most of the trace elements, such as Rb, Sr and Ni in both the Almora and Ramgarh group gneisses. The SiO$_2$ vs. Al$_2$O$_3$ and K$_2$O vs. Na$_2$O ratios indicate the evolutionary changes in the average composition of the continental crust (Schwab, 1978) and the source.

Metapelitic gneisses in the central parts of the Klippe chemically show a syn-collisional tectonic setting, while the signatures for the Ramgarh gneisses fall in both the late- and post-COLG fields. The data from different parts of the world have been correlated with the present data on the Ramgarh Group, employing the plot of Pearce et al. (1984), and our data show a marked correspondence with the data of Roger and Greenberg (1990), Neymark et al. (1994) and Liu et al. (2005). Some of the data plot outside the expected field due to some aberration, such as contamination during data processing, flexibility in the analyzed values and the somewhat non-ideal nature of the samples. Most pelitic gneisses of the Almora Group fall in the syn-COLG field, while the Ramgarh gneisses yield mixed signatures and plot in the late- and post-COLG fields (Harris et al., 1986). The ΣREE ranges from 152.24 to 265.53 in the Ramgarh Group gneisses and 144.91 to 155.12 in the Almora Group gneisses, clearly ratifying the field and petrographic observations that the two gneisses
are of distinctly different origins. The negative Eu anomaly in the Ramgarh gneisses indicates lower plagioclase fractionation.

In contrast, the Eu anomaly in the Almora gneisses is likely to have been controlled by feldspar crystallization in the restites during anatexis and movement of the melt away to its crystallization site (Rollinson, 1983). It is obvious that the Eu depletion in the Almora gneisses is a likely artifact of the melting of the albite-rich precursors. The variation in the negative Eu anomaly spikes likely reflects various stages of melt evolution. The unexpected increase in the Rb/Sr ratio and decreasing Sr content in the Almora gneisses is likely due to fractional crystallization of the anatectic melt. The Rb/Sr ratio of ~0.54 and Nb ~10 ppm is consistent with their granodioritic composition. The negative Sr anomaly for the Ramgarh gneisses indicates a distinctive mantle derived source/plagioclase fractionation. However, a moderate negative Sr anomaly in the Almora gneisses corresponds well with a moderate negative Eu anomaly, both of which are likely to be related to plagioclase fractionation.

The Rb/Sr vs. Sr plots (Fig. 17) again show two distinctly different trends viz. fractional crystallization for the Almora gneisses and assimilation and fractional crystallization for the Ramgarh gneisses. The analyses for the Debgaru granites (Singh and Joshi, 2001), located close to the type area of Ramgarh (Valdiya, 1980), merge imperceptibly with the Ramgarh gneisses from the Askot Klippe, further strengthening the hypothesis that the two are closely related. Singh and Joshi (2001) characterized the Debgaru granites as S-type, with the caveat that “it was not possible to characterize the source rock unequivocally with the available data”.

Based on Fe3+/Fe2+ = Mg vs. Alp and the FeO/MgO ratio, the biotite in the rock is mainly siderophyllic in composition (Deer et al., 1963) and peraluminous (S-type) in character. In a ternary plot of FeO-MgO-Al2O3, the gneisses of the Almora Group have an affinity towards the
crystallized phase in the peraluminous (S-type) suite.

The Almora gneisses and the Ramgarh gneisses are also clearly distinguished in the classification diagram of Whalen et al. (1987) (Fig.18). The Almora gneisses plot in the FG field (fractionated felsic granite), while the Ramgarh gneisses plot in the OGT field (non-fractionated granite). Interestingly, one sample of Ulleri gneiss (Celerier et al., 2009) from the Ramgarh Group in the Nepal Himalaya also plots in the OGT field. The Ramgarh gneisses correspond well with gneisses of other parts of
Table 4. P-T conditions of Almora pelitic gneisses

<table>
<thead>
<tr>
<th>Models</th>
<th>Calculated temp in °C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Core</td>
</tr>
<tr>
<td>Thompson (1976)</td>
<td>651</td>
</tr>
<tr>
<td>Holdaway &amp; Lee (1977)</td>
<td>664</td>
</tr>
<tr>
<td>Ferry &amp; Spear (1978)</td>
<td>615</td>
</tr>
<tr>
<td>Pigage &amp; Greenwood (1982)</td>
<td>662</td>
</tr>
<tr>
<td>Hodges &amp; Spear (1982)</td>
<td>722</td>
</tr>
<tr>
<td>Perchuk et al. (1985)</td>
<td>749</td>
</tr>
<tr>
<td>Perchuk &amp; Lavrenteva (1983)</td>
<td>666</td>
</tr>
<tr>
<td>Aranovich et al. (1988)</td>
<td>698</td>
</tr>
<tr>
<td>Hoinkes (1986)</td>
<td>589</td>
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<tr>
<td>Bhattacharyya et al. (1992), (H&amp;W) &amp; (G&amp;S)</td>
<td>634</td>
</tr>
<tr>
<td>Average temperature</td>
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</tbody>
</table>

Geobarometry based on Garnet - Cordierite - Sillimanite - Quartz geobarometry estimated at 600°C temperature.

<table>
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<td>Lai (1991)</td>
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</tr>
<tr>
<td>Harris &amp; Holland (1984)</td>
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</tr>
<tr>
<td>Newton (1978)</td>
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</tr>
<tr>
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<td>Aranovich &amp; Podlesnik (1983, 1989)</td>
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<tr>
<td>Average pressure</td>
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</table>

Based on GBOPII estimated temperature in 600 degree C

<table>
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<tr>
<th>Models</th>
<th>Calculated pressure in kbar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wu et al. (2004)</td>
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</tr>
</tbody>
</table>

the Himalaya, viz. gneisses from NW Himalaya and the Nepal Himalaya by Sharma and Rashid (2001); Islam et al. (2011); Regmi and Arita (2008) and Miller et al. (2000). We feel that the compositional similarities between the Ramgarh gneisses from Askot Klippe and the data on granites from different parts of the world by Rogers and Greenberg (1990), Neymark et al. (1994), Liu et al. (2005), Celerier et al. (2009), are acceptable and lend further support to our identification of the Ramgarh gneisses from the basal part of the Askot Klippe.

For the Almora Group, the biotites are mainly siderophyllitic in nature, and fall in peraluminous field. Thus, the broad tectonostratigraphic disposition of the Askot Klippe and the Almora Nappe are similar, lending further support to their being remnants of the same thrust sheet, with its root zone in the Higher Himalaya, which moved over the MCT at one point of time to cover large parts of the Kumaun Himalaya over the Lesser Himalayan sediments with a Basal Shear Zone (Joshi, 1999), equivalent to the MCT.

Unlike Rao and Sharma (2009), we found that most of our Ramgarh gneiss samples fell in the late- and post-COLG tectonic setting. This is consistent with our hypothesis that the Ramgarh gneisses comprise the lowermost units in the Askot Klippe, which, as elsewhere in the Lesser Himalaya (Valdiya, 1983), represent tectonically transported basement. Temperatures around 300-400°C and pressures in 5-7.5 kbar range have been suggested for equivalents of Ramgarh rocks, viz. the Dailing rocks in the Darjeeling-Sikkim area by Sinha-Roy (1976), while no P-T estimates are available for the

Fig. 19. Simplified cross-section of the Kumaun Lesser Himalaya along X-Y from north to south (after Valdiya, 1980; Celerier et al., 2009).
Ramgarh gneisses from the Kumaun Himalaya.

6 Conclusions

Askot Klippe resembles a synform, with its central part comprising an asymmetrically overturned fold with a gentle northern limb and a steep southern limb. The two tectonostratigraphic units are being distinguished for the first time from the Askot Klippe, viz. the basal Ramgarh Group and the overlying Almora Group as the supracrustals. The Almora Thrust has been identified for the first time from the klippe. Garnet-K-feldspar-sillimanite-cordierite bearing gneisses in the central part of the klippe reached granulite facies conditions and record the highest grade of metamorphism from any of the Lesser Himalayan nappes and klippes. The Ramgarh Group rocks have been distinguished from the Almora Group rocks physically, petrochemically and tectonically. The Almora Group has been affected by crustal anatexis and solidification of anatectic magma under fluid-present conditions, whereas the Ramgarh Group has been affected by subduction metamorphism governed by mantle-derived fractional crystallization, as evidenced by a negative ‘Sr’ anomaly. The Almora pelitic gneisses are syn-Collisional, whereas the Ramgarh granitic gneisses are post- and late-Collisional volcanic arc granites. The Almora Group pelitic gneisses are felsic-peraluminous, whereas the Ramgarh Group of rocks are highly peraluminous in character. The Almora pelitic gneisses are basically S-type, whereas the Ramgarh granitic gneisses are basically I-type. Metamorphism in the Almora pelitic gneisses exceeded a temperature of 776°C and pressure of 6.6 kbar, indicating the onset of granulite facies conditions, as demonstrated by phase section modelling and the Petrogenetic Grid System (PGS). The Almora pelitic gneisses underwent fractional crystallization, while the Ramgarh granite gneisses underwent assimilation and fractional crystallization. The Ramgarh Group is correlatable with many of the Palaeoproterozoic granites of other parts of the Himalaya, including NW Himalaya and the Nepal Himalaya, all of which show an anorogenic and non-fractionated felsic granitic nature.

A simplified cross-section kinematics model (Fig. 19) has been prepared, modifying Celerier et al. (2009). There is a significant increase in the intensity of deformation due to the proximity of the Askot Klippe to the MCT, as shown by the increase in the number and width of the bands comprising ultramylonites after the Ramgarh gneisses at the base of the Askot Klippe, as compared to the mylonitized Ramgarh gneisses at the base of the Almora Nappe, located farther south. Sometime during the middle part of the Indo-Asian collision, the Main Central Thrust (MCT) is likely to have been juxtaposed over the Bhatwari Thrust (BT), and the package comprising the basement Ramgarh gneisses overlain by the greenschist to granulite facies metapelitic cover, viz. the Almora Group, moved southwards. The Chiplakot and Askot klippes and the Almora Nappe are tectonostratigraphically identical, detached tectonic outliers of this once-continuous thrust sheet. The slivers of the granitic gneisses of around 1875±90 Ma (Rb-Sr whole rock; Trivedi et al., 1984) representing the Ramgarh Group at the base of the Almora Group in the Almora Nappe, along with their equivalents dated at 1878±19 Ma (U-Pb zircon; Mandal et al., 2016) from the Askot Klippe, are likely to represent the Precambrian basement of the Indian Craton. Although the pelitic Almora gneisses discussed above and the Ramgarh granitic gneisses were not distinguished by Mandal et al. (2016) in the klippe, the 1865±60 Ma Almora gneisses (Rb-Sr whole rock; Trivedi et al., 1984) in the Almora Nappe and the 1857±19 Ma (U-Pb zircon; Mandal, 2016) pelitic gneisses from the core of the Askot Klippe belong to the metapelitic cover of the leading edge of the Indian Plate. The edge of a Palaeocontinental arc in the Lesser Himalaya yielded an age of 1830±50 Ma based on U-Pb zircon dating after Kohn et al. (2010). The ‘thick-bedded rusty quartzite’ picked up from the ‘central part’ of the Almora Nappe has been assigned a maximum depositional age of 850 Ma by Mandal et al. (2014) and may well represent the Higher Himalayan elements sensu stricto, which are missing in Askot, due to a deeper level of erosion.

Based on the bulk rock and elemental geochemistry of both the pelitic gneisses of the Almora Group and the granitic gneisses of the Ramgarh Group, it can be concluded that the Ramgarh granites are continental arc granites, likely to be associated with the Palaeoproterozoic amalgamation of the Columbia supercontinent, based on ages given by Mandal et al. (2016), and these are products of subduction-related midercrustal anatexit. The Almora Group was deposed and metamorphosed as a supracrustal cover.

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