REPETITION OF ISOGRADS DUE TO FOLDING IN KAPHARKHAN AREA, KUMAUN LESSER HIMALAYA, INDIA

MALLICKARJUN JOSHI*, RASHMI*

ABSTRACT

The Lesser Himalayan crystalline nappes and klippes invariably occurring as detached thrust masses over the Lesser Himalayan low grade metasedimentaries are believed by most of the workers to be Inverted Metamorphic Sequences similar in nature to the Inverted Higher Himalayan Metamorphic Belt which is believed to be the root zone of the nappes and klippes. The former is characterized by Inverted Metamorphic Sequences that expose metamorphic rocks wherein the grade of metamorphism enigmatically increases upsection in the Higher Himalaya. Based on geological mapping and careful petrographic study the reaction isograds have been delineated for the Kapharkhan area and a lithological map along with a reaction isograd map has been prepared for the area. These maps show that the K-feldspar sillimanite bearing gneisses and the kyanite-biotite schists have been repeated at least thrice in the area along the northeast-southwest transect in contrast to the Higher Himalaya. It has been argued that this repetition is a consequence of a Precambrian post metamorphic regional tight to isoclinal F2 folding of the rocks along with the reaction isograds with roughly WNW-ESE to NW-SE trending fold axis. It is demonstrated that the hypothesis of Inverted Metamorphic Sequence is not valid for the northeastern part of the Almora Nappe and the apparent inversion observed by earlier workers may be an artifact of observing the area upsection from the base of metamorphics and closing the traverse on reaching the gneisses.

INTRODUCTION

Lesser Himalayan nappes are a consequence of crustal scale southward thrusting due to the Tertiary continental collision of the Indian Plate with the Tibetan Plate. The thrusting transported Higher Himalayan Metamorphics some 80-100 km south over the Precambrian sedimentary sequences of Lesser Himalaya. All along the length of Himalaya the detached metamorphic outliers occur resting over the sedimentaries with a thrust contact at their base. Middlemiss (1887) was among the first to study the igneous and metamorphic rocks of the Kumaun and Garhwal Himalaya. The thrusted Lesser Himalayan metamorphic sequences are crucial to understanding the Himalayan orogeny by providing constraints for geological modelling (Gansser, 1964; Le Fort1975; Valdiya 1980, 2009; Yin, 2006).

*Department of Geology, Banaras Hindu University, Varanasi-221005, India.
Correspondence E-mail Id: editor@eurekajournals.com

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The ductile Main Central Thrust, the Munsiai Thrust, the Ramgarh Thrust and the brittle North Almora Fault (Joshi, 1999) are the most important tectonic discontinuities crossing the area. A generalized geological map of Himalaya showing major tectonostratigraphic divisions of Himalaya is shown in Figure 1.


It is largely accepted that the Lesser Himalayan Crystalline Nappes are characterized by Inverted Metamorphic Sequences (Thakur, 1981, Sinha Roy, 1982, Srivastava and Mitra, 1996). The Inverted Metamorphic Sequences of Higher Himalaya have been discussed in quite some detail by Joshi and Rai (2003). However, this has been contested for the Almora Nappe by Joshi and Tiwari (2004, 2009) and his other associates, who believe that although close to the base of the Almora Nappe an apparent inverted sequence is exposed but the schists and gneisses are repeated upsection due to tight to isoclinal F2 regional folding particularly in the southern flank of the Almora Nappe. Folded metamorphic isograds in the Almora Nappe were delineated by Joshi and Tiwari (2007).

The Kumaun Lesser Himalaya is a thrust-bound sector delineated by two tectonic planes, viz. the Main Boundary Fault to the south and the Main Central Thrust to the north. There are two elongate tectonic belts of sedimentary/metasedimentary rocks separated by an ESE-WNW trending Dudhatoli - Almora Crystalline zone, which we prefer to call Almora Nappe.
The Outer Sedimentary Belt to the south of the crystalline mass is the Krol Belt while the Inner Sedimentary Belt to the north constitutes the Deoban-Tejam zone (Gansser, 1964), or the Jaunsar-Berinag Nappe (Valdiya, 1980). The studied area extends from Basoli in the North to Kalmatia in the south through Kapharkhan area.

Auden (1937) had identified a thrust fault in the Himalaya at the base of metamorphics with a minimum lateral movement of 80km. Based on this Heim and Gansser (1939) were the first to identify the Main Central Thrust (MCT) as the contact between the high grade metamorphics and the low grade metasedimentaries in the Kumaun Himalaya. Auden (1937) believed the Central Crystallines to be the root zone of Almora Nappe. Heim and Gansser (1939) had included the Ramgarh Group in the Almora Nappe but Gansser (1964) included it in the lower tectonic subdivision of the Almora Nappe and recognized it as a separate tectonic slab. One of the first discussions on Ramgarh Granite gneisses was by Pande (1956) in its type locality, viz. Ramgarh in Kumaun Lesser Himalaya, who called these rocks as migmatisites. On the basis of the structural setup and various shear sense indicators in the mylonites of the basal shear zone of the Almora Nappe, Joshi (1999) suggested a complex three stage tectonic evolution for the transport of the Almora Nappe. He demonstrated that the North Ramgarh Thrust which is entrenched as a high angle North Almora Thrust/Fault in the geological literature of Kumaun Himalaya is actually a low angle south dipping tectonic discontinuity.

Almora Nappe located in the Kumaun Himalaya (Uttarakhand) is one of the largest Nappes in the Himalaya. It formed as a consequence of tectonic transport of the Higher Himalayan Metamorphic Belt (HMB) to the Lesser Himalaya over the Main Central Thrust (MCT) during Eocene-Oligocene. Joshi and Tiwari (2004, 2007, and 2009) studied the Almora Nappe in detail and have suggested the tectono-metamorphic evolution of the area. Kfeldspar-Sillimanite grade rocks intruded by the Cambrian Granitoids dated at 560±20Ma by Trivedi et al. (1984) that were responsible for the still very much intact contact metamorphic aureoles (Joshi et al. 1994) from this part of the nappe have been documented by them for the first time demonstrating that the dominant metamorphism in the area is Precambrian (Joshi et al. 1994, 2004, Joshi and Tiwari, 2007, 2009).

In the present paper we have explored in detail a crucial part of the northern flank of the Almora Nappe located around Kalmatia area, located north of Almora town, for detailed geological mapping and for preparing a detailed reaction isograd map to better understand that whether the hypothesis of Inverted Metamorphic Sequence (Srivastava and Mitra, 1996) holds for the northern flank of the Almora Nappe.

The present work is an attempt towards delineation of metamorphic zones on the basis of reaction isograds in order to understand the nature and disposition of metamorphic zones in the northern flank of the eastern parts of the Almora Nappe. This is done on the basis of careful study of the minerals reactions in thin sections and preparation of an accurate reaction isograd map based on the reactions identified.

**GEOLOGY OF THE AREA**

The Almora Nappe comprises metapelites of Saryu and the Gumalikhet formations which have been metamorphosed from greenschist to upper amphibolite-granulite facies transition during Pre-Himalayan or likely Precambrian Period (Joshi and Tiwari, 2009). This metamorphic sequence has been intruded by Champawat Granitoids (Singh et al. 1993) or
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Champawat Granodiorite of Valdiya (1980) dated at 560±20Ma by (Trivedi et al. 1984). These are tectonically underlain by the highly mylonitized granite gneisses of the Ramgarh Group overlain by metapelites of Nathuakhan Formation. The Almora Thrust, with the North Almora Thrust and the South Almora Thrust as its northern and southern outcrops, separated the Almora Group from the Ramgarh Group which in turn is separated from the underlying quartzites of the Berinag /Nagthat Formation of the Jaunsar Group and Rautgara Formation of the Damtha Group by the Ramgarh Thrust (Valdiya, 1980) with the North Ramgarh thrust and the South Ramgarh Thrust as its northern and southern exposures respectively (Joshi, 1999).

Figure 2. Geological map of the area showing repetition of lithologies along a NE transect
The Almora Nappe consists of mylonitized rocks of the Basal Shear Zone exposed at both the northern and southern sides of the nappe over which the unmylonitized rocks of the Almora Group are transported through a shear zone (Joshi, 1999). The Basal Shear Zone of the Almora Nappe is constituted of the protomylonites, mylonites, and ultramylonites of the Ramgarh Group. Ramgarh Thrust is demarcated by the tectonic boundary of the Basal Shear Zone at its base and the Almora Thrust is located closer to the top of the Basal Shear Zone.

The area comprises garnet - mica schists, garnet - biotite kyanite schist, K-feldspar - sillimanite gneisses, migmatites and graphitic schists in the Kalmatia area. Detailed mapping brought out three gneissic bands that are folded by a tight to isoclinal F2 folding with roughly WNW-ESE to NW-SE axis, which is responsible for the repetition of the lithologies along a NE transect. The area is folded by an open F3 regional folding with roughly EW axis. As very similar sequence in southern flanks of the Almora Nappe is also folded with roughly identical fold geometries with the Cambria Champawat Granitoids (Singh et al., 1993) intruded into the sequence which has been responsible for a still very well preserved contact metamorphic aureoles unaffected by any later regional metamorphism (Joshi, 1994; Joshi and Tiwari, 2004, 2009), it can be reasonably inferred that the regional metamorphism in the northern flank of the nappe is also likely Precambrian.

**PETROGRAPHY**

Meticulously collected samples from the field were studied both megascopically as well as microscopically. Microscopic study includes identification of textures and mineral composition of rocks, along with the metamorphic reactions in the thin sections.

The three major rock types in the area are schists, graphite schist and gneisses. Mica schists and garnetiferous mica schists are the dominant rocks in the area. They are medium to coarse grained with well developed foliation defined by preferred orientation of micas. Dirty white, greenish grey, bluish grey and brown schists are observed in the area. The area is characterized by interbanded quartizes and schists. The yellow coloured quartizes are generally fine medium grained. However, near the Kapharkhan area very thick bands of quartizite are interbanded with mica schist layers.

The mica schists and garnetiferous mica schists are characterized by schistose lepidoblastic texture. The primary schistosity S1 is defined by the preferred orientation of Muscovite-I, Biotite-I, Chlorite-I and stretched Quartz-I. The secondary schistosity S2 is characterized by Muscovite-II, Biotite-II and Chlorite-II. The main constituents of schists are chlorite, biotite, muscovite, alkali feldspar, garnet and quartz. Magnetite and hematite occur as accessories.

The observed mineral assemblages are (1) Chlorite-Biotite-Muscovite-Garnet-Feldspar-Quartz, (2) Biotite-Muscovite-Garnet-Feldspar-Quartz and (3) Biotite-Muscovite-Garnet-Plagioclase-Quartz.

Two types of quartz have been identified in the schists, viz. medium to coarse quartz-I which has serrated boundaries and undulose extinction. The grains are anhedral to subhedral in shape. Inclusion of quartz-I are observed within garnet and micas. Quartz-II is strain free and shows sharp extinction. The grains are intact.

Among the two types of chlorite the chlorite-I occurs as relatively larger flakes and defines the S1 Schistosity plane while the finer chlorite-II shows a cross-cutting relationship with the chlorite-I and appears to have developed later
with the development of $S_2$ foliation. Likewise two types of muscovite have been distinguished. The lepidoblasts of muscovite-I are relatively coarser in size. The dominant $S_1$ foliation is defined by preferred alignment of muscovite-I lepidoblasts. Biotite-I is commonly interleaved with these muscovites and chlorite (Figure 3 left). Inclusions of quartz and opaque minerals are found within muscovite-I. The lepidoblasts of muscovite-II are somewhat finer sized than the muscovite-I. It is oriented at various angle to the $S_1$ schistosity and shows a crosscutting relationship with muscovite-I and develops parallel to the axial planar $S_2$ schistosity. Inclusion of quartz and iron oxide and tourmaline are commonly observed.

There are three distinct varieties of garnets which have been observed in the schists. Garnet-I are highly shattered anhedral pre-kinematic grains. Relatively later origin of hematite is observed along the cracks and margins of the garnets. Garnet-II is synkinematic (to $S_1$) garnet with $S$-shaped and $Z$-shaped inclusion trails of quartz and biotite. Hematite rims are seen at the boundary of garnet porphyroblast. Garnet-III is characterized by idioblastic shape and is post kinematic. It also occurs as idioblastic overgrowth on synkinematic garnet-II porphyroblast. An important feature associated typical garnet-III idioblast is that they have formed by pushing the schistosity away from them while they developed and they suggest that the metamorphism outlasted the deformation.

Figure 3. Left: Chlorite-muscovite-biotite in mica schist (near Kapharkhan); Right: Sillimanite needles inside K-feldspar evidencing the reaction muscovite + quartz = K-feldspar + sillimanite + melt (both near Kapharkhan)

Figure 4. Metamorphism outlasted deformation (Left) Idioblastic garnet pushing the existing foliation away; (Right) randomly oriented biotite lepidoblasts cutting across the prevailing foliation (Near Kapharkhan)
Sometimes in the garnet core inclusions are aligned crudely parallel to an earlier foliation. This core is followed by a mantle of inclusion free garnet rim which is post-kinematic. This is followed by an inclusion rich zone which is all likelihood represents synkinematic growth of garnet. The outermost idioblastic rim is characterized by lack of inclusion and formed after the deformation has ceased.

The gneisses are dirty white to light grey coloured, crudely foliated, medium to coarse grained rocks which have developed foliation due to preferred alignment of micas. The characteristic feldspar augen in the gneisses lie with their longest axes aligned parallel to the foliation. These are largely psammitic in composition with predominance of quartz, plagioclase and K-feldspar while muscovite (unstable), biotite, sillimanite and tourmaline are present in small modal amounts. Garnet-ilare anhedral in shape and occur as highly fragmented grains, while the Garnet-ilare idioblastic post-kinematic crystals. Haematite is seen along the margins of the garnet due to high oxygen fugacity(Figure.4).

The synkinematic garnets which are very common in the schists of the area are conspicuous by their absence in the gneisses. Quartz-I in gneisses are medium to coarse grained and show undulose extinction. In some thin section Quartz-I occurs as inclusion within the K-feldspar, plagioclase and garnet. Most of the Quartz-I grains are showing a reaction boundary with muscovite suggesting that the reaction muscovite + quartz = K-feldspar+ sillimanite+ Liquid has taken place. Quartz-II occurs as recrystallized undeformed grains with sharp extinction. Muscovite is an unstable mineral in the gneisses and its boundaries with quartz and plagioclase are invariably corroded.

The important mineral assemblages in the gneisses are (1) muscovite-biotite-garnet-tourmaline-amphibole-quartz-sillimanite-K-feldspar, (2) muscovite-biotite-garnet-sillimanite-quartz-plagioclase-K-feldspar (3) muscovite-biotite-garnet-kyanite-sillimanite-quartz-plagioclase-K-feldspar. Muscovite in the gneisses is unstable and invariably reacts with muscovite and plagioclase by the following reactions

Muscovite + quartz = K-feldspar + sillimanite +melt (Storre, 1972)

Muscovite + albite + quartz = K-feldspar + sillimanite (Thompson and Tracy, 1979)

Sillimanite occurs as fine needles within the K-feldspar (Figure.3 Right). Sillimanite observed in the area is generally present as needles and very small grains in small quantities within the K-feldspar porphyroblasts.

On the basis of mineral assemblages and the characteristic discontinuous mineral reactions, the area can be divided into three metamorphic zones. The reaction isograds separating these zones have been distinguished on the basis of the mineral reactions.

Zone-I: Garnet-biotite zone

..........................kyanite-biotite isograd......................

Mg-chlorite + muscovite = phlogopite + kyanite + H₂O

Zone II: Kyanite-biotite zone

..........Sillimanite-K-Feldspar isograd ......................

Muscovite + albite + quartz = K-Feldspar + Sillimanite + melt

Zone III: Sillimanite-K-feldspar Zone

The pelitic assemblages in Zone I include chlorite-biotite-muscovite-garnet-quartz; chlorite-biotite-muscovite-garnet-plagioclase-quartz; biotite-muscovite-garnet-quartz; biotite-muscovite-quartz; biotite-muscovite-
plagioclase-quartz; garnet-biotite-muscovite-plagioclase-quartz. The assemblages in Zone II are garnet-kyanite-biotite-muscovite-plagioclase; garnet-kyanite-biotite-muscovite-plagioclase-quartz ± K-feldspar; garnet-kyanite-biotite-muscovite-quartz ± zoisite; kyanite-biotite-muscovite-plagioclase-quartz. Pelitic assemblages in the Zone III are sillimanite-garnet-biotite-K-Feldspar-quartz ± muscovite ± plagioclase and sillimanite-kyanite-garnet-biotite-K-Feldspar-quartz ± muscovite ± plagioclase. The quartzofeldspathic assemblage is K-Feldspar-quartz ± muscovite ± albite. The minerals magnetite, ilmenite and tourmaline are present additionally in the pelitic assemblages of all zones from zone-I to zone-III.

The observed mineral assemblages of minerals from each metamorphic zone are quite similar to the adjacent area and the electron microprobe analysis of minerals shows a range of Al₂O₃ and Xₘ₉ in each metamorphic zone are plotted from the adjacent area (Tiwari, 2004). These are plotted in Thompson’s AFM projections (Figure.5 and 6).

The reaction isograd map prepared by us is shown in Figure. 7 on the basis of reactions identified in the thin sections as detailed above. The garnet-biotite Zone, biotite-kyanite Zone
and K-feldspar-sillimanite Zone are shown on the map. Note the repetition of both the biotite-kyanite Zone and the K-feldspar-sillimanite Zone thrice in the area due to tight to isoclinal F$_2$ regional folding with the fold axis oriented WNW-ESE to NW-SE in the area. A later open F$_3$ fold with the fold axis roughly oriented E-W has further affected the area in the southern part.

Figure 7. Reaction isograd map prepared for the area 1, 2 and 3 in index respectively represent garnet-biotite Zone, biotite-kyanite Zone and K-feldspar-sillimanite Zone. Note the repetition of biotite-kyanite Zone and the K-feldspar-sillimanite Zone thrice in the area due to tight to isoclinal F$_2$ regional folding in the area.
The P-T results of different existing geothermobarometries applicable to the rock types of the studied area are discussed here. The temperatures were calculated at 6 kbar and the pressures were calculated at actually calculated temperatures.

The pressure-temperature conditions of garnet-biotite zone samples were estimated by “Window TWQ 2.02” (Berman, 1991). The selected phases are garnet, biotite, plagioclase and muscovite. The properties of garnet-biotite-plagioclase-muscovite are calculated by CMP programme. The reactions are produced by plotting the graph in the Software.

The temperature estimated for the rocks of garnet-biotite zone by TWQ programme is 504°C and pressure is estimated to be 4.69 kbar. The temperature estimated for the rocks of kyanite-biotite zone is 573°C and pressure estimated to be 5.2 kbar. The temperature estimated for the rocks of Sillimanite-K-feldspar Zone is 611°C and pressure estimated to be 7.0kbar (Tiwari, 2004).

CONCLUSIONS
The area has been subjected to multiple deformation and polymetamorphism. The schists and gneisses of the Saryu Formation of the Almora Group exposed in the central parts of the nappe do not show any field or petrographic evidence of mylonitization. The earliest foliation (S1) is developed parallel to the axial plane of F1 folds and appears to be genetically related to the later. The F2 folds are co-axial with the F1 folds. The F1 and F2 folds have almost similar geometries but for marginal difference in their interlimb angles. The F1 folds are geometrically isoclinal while F2 folds are tight to isoclinal. The bedding (S0) is folded by F1 folds while F2 folds affects the oldest foliation (S1) and axial plane of F1 folds. Regionally the area has been subjected to three metamorphic events, viz. the regional metamorphism, the contact metamorphism and the dynamic metamorphism. The regional metamorphism has affected the metapelites and metapsammites or the Almora Group from green schist (garnet-biotite zone) to upper amphibolite (Sillimanite-K-feldspar zone) facies of metamorphism. Zone-I (garnet-biotite Zone), Zone-II (kyanite-biotite Zone), Zone-III (sillimanite-K-feldspar Zone) are present in the area studied.

The occurrence of Sillimanite-K-feldspar Zone was recorded for the first time by Joshi and Tiwari (2004, 2007, and 2009) from the Almora Nappe. On the basis of occurrence of sillimanite-K-feldspar in the rocks of the area it can be concluded that the metamorphism in the area reached upper amphibolites facies conditions contrary to the belief held by earlier workerst hat the metamorphism did not proceed beyond the garnet zone of green schist facies and the Almora Group comprised low grade rocks (Valdiya, 1980).

The geological map prepared for the area clearly brings out alternate banding of metapelitic and metapsammitic rocks in a folded sequence. A carefully prepared reaction isograd map of area clearly brings out the repetition of biotite-kyanite Zone and the K-feldspar-sillimanite Zone three times in the area due to tight to isoclinal F2 regional folding in the area. This field evidence clearly demonstrates that the hypothesis of Inverted Metamorphic Sequences, so characteristic of the Higher Himalaya and almost invariably reported from many other Lesser Himalayan Crystalline Nappes of the Lesser Himalaya, does not hold for the northern flank of the Almora Nappe for its northeastern parts.

Almost all the workers believed in the existence of IMS in the Lesser Himalayan nappes and their root zone viz. the Higher Himalayan Metamorphic belt. However, Joshi and Tiwari (2004, 2007, 2009) demonstrated for a transect
across the central part of the Almora Nappe that the metamorphic sequence of the Almora nappe is not inverted but normal and the isograds are folded. Consequentially the different metamorphic zones show repetition. The present findings of folded reaction isograds in the northeastern flank of the Almora Nappe substantiate the work of Joshi and Tiwari (2004, 2007, and 2009) who have documented Precambrian metamorphic and structural signatures from the upper most structural levels of the Almora Nappe.

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REFERENCES

[5]. Burrard, S.G., and Hayden, H.H., 1933, A sketch of the Geology and Geography of Himalayan mountain and Tibet, Revised by Sir Sydney Burrardand A.M. Heron, Parts I-IV, Delhi, 369p.
[15]. Middlemiss, C.S., 1887, Crystalline and metamorphic rocks of the lower
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Himalaya, Garhwal and Kumaun section


[19]. Storre, B., 1972, Dry melting of muscovite + quartz in the range P s = 7 GPa to P s = 20 GPa, Contrib. Mineral. Petrol., 3, 7, pp. 87-89


