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Petrography and heavy mineral assemblage of the Oligocene Barail sandstones exposed in and around Khonoma village, Kohima district Nagaland, India

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Abstract
Barail sandstones exposed in and around Khonoma village, south- west of Kohima town, Nagaland, India have been studied for provenance interpretation using petrography and heavy minerals. Moderate to well-sorted Barail sandstones is mainly composed of both undulatory and non-undulatory monocrystalline quartz. However, polycrystalline quartz was also observed. Most common feldspar in these sediments is the plagioclase feldspar. Rock fragments are represented by chert, siltstones and schist. Constituent wise they are second in abundance. Euhedral, subrounded and rounded zircon, tourmaline, rutile, staurolite, sillimanite, and kyanite constitute the heavy mineral assemblage of the studied Barail sandstones. Rounded iron oxides represent opaques. Petrography studies and heavy minerals point towards a mixed provenance dominated by a sedimentary source. Petrography and heavy mineral studies also suggests that owing to changing plate interaction contributions might have come from the Karbi-Anglong massif and Naga metamorphics. In addition to that sediments formed under earlier tectonic regimes might have also supplied the sediments.

Introduction
Naga Hill sector provides an ideal setting for examination of the evolution of the Assam-Arakan orogenic belt during Mesozoic-Cenozoic periods. Geological evolution of the Naga Hills and related features of the north-eastern Indian geology has been attributed to the interactions of the Indian plate with the Myanmar plate. Evolution of the north-east south-west trending foreland basin has been attributed to the the changing plate interactions through time resulting in transformation of the passive margin setting into an active margin (Kumar and Naik, 2006). An oblique collision and tectonic wedge model has been suggested by Naik (1994) for the region. Geology of the Naga-Lushai-Patkai hill ranges was first discussed by Mallet (1876). Later, significant information were added by many including Evans (1932), Mathur and Evans (1964), Brunnschweiler (1966), Desikachar (1974), Rangarao (1983), Ganju and Khar (1985), Chakravarti and Banerjee (1988), Nandi (2000), Acharrya (2007). Depositional environments, ichnology, stratigraphy provenance and tectonics of Naga Hills have been discussed by the Geological survey of India, (1975), Directorate of Geology and Mining, Government of Nagaland (1978), Srivastava (2002), Srivastava *et al.*, (2004), Srivastava and Pandey (2005), Srivastava and Pandey (2011), Srivastava (2013), Imchen *et al.* (2014), Srivastava *et al.*, (2015) Lily and Pandey (2016), Ramaswami *et al.*,(2016), Kichu and Srivastava (2018), Kichu *et al.*, (2018),Srivastava *et al.*, (2017), Khalo and Pandey (2018) Srivastava and Kikon (2021) and Mekro and Pandey (2021), Srivastava and Kichu (2021), Aienla *et al.*,(2022). In the present work, an attempt has been made to interpret the source rock using framework

grains and heavy mineral assemblage. As not much information is available on these sediments, present work would provide important information on these sediments.

Study area

There are three NE-SW trending linear zones within the Assam-Arakan basin designated as; from west to east the Schuppen Belt, the Inner Fold Belt (IFB) and the Ophiolite Belt (Mathur and Evans (1964). Present study area is a part of the IFB which is occupied by two synclinoria: the Patkai Synclinoriumin the north and the, and, Kohima Synclinorium in the south. Present study area lies within Kohima Synclinorium. Tertiary sediments within the Kohima Synclinorium is represented by argillaceous Disang sediments, mixed sand-shale lithologies of Disang-Barail Transition (Srivastava *et al.*, 2004) and the arenaceous Barail Group. The well-developed Oligocene Barail sediments (Figure 1), south-west of Kohima town, have been examined for their petrographic compositions and heavy mineral contents for source rock interpretations. Barail sandstones of the study area are represented by thickly bedded multi-story sandstones (Figure-2). The study area is a part of the topographic sheet no. 83 K/2 and is bounded between latitudes 25^{0}36ˈ00ˮ N and 25^{0}41ˈ00ˮ N and longitudes 94^{0}00ˈ00ˮ E and 94^{0}05ˈ00ˮ E. In 1876 Mallet first studied the rocks of this Group. However, the term Barail was coined by Evans in 1932 that accorded these sediments the status of a 'series'.

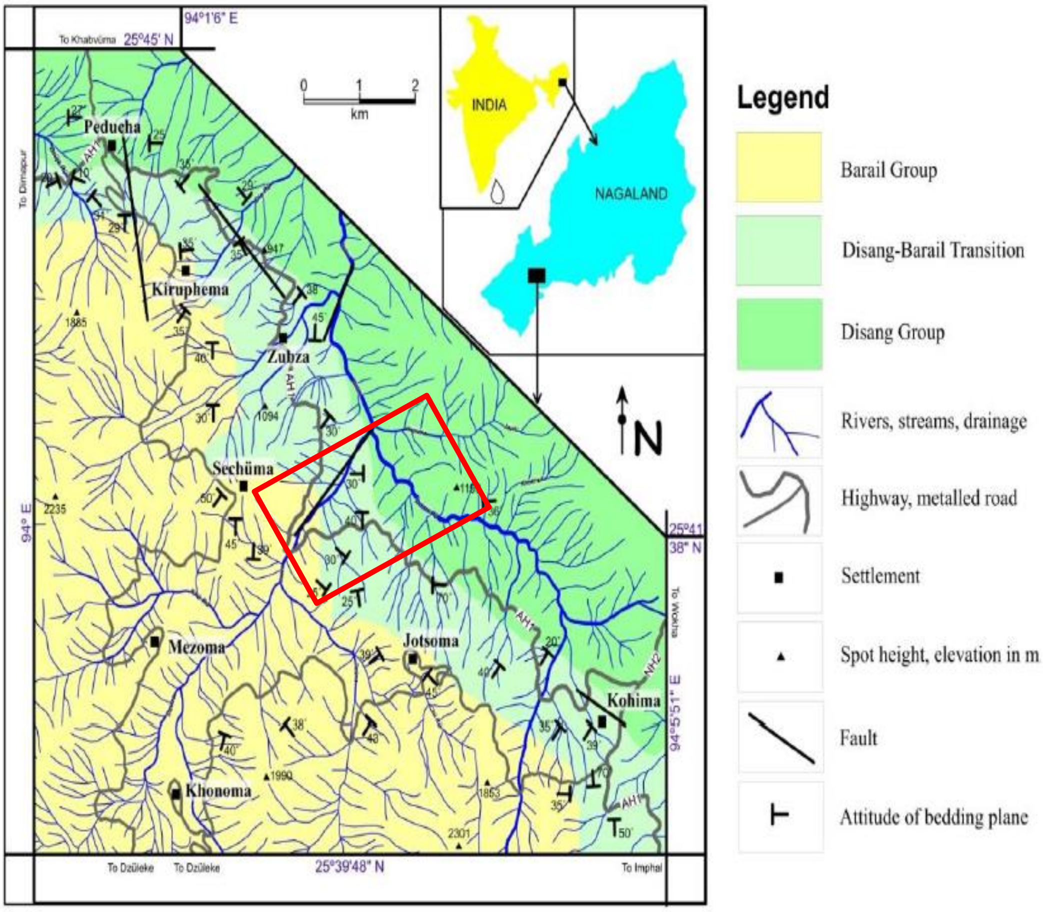

Figure 1: Geological map of the study area (Srivastava, 2004)

Figure-2: Field photographs showing (A) intercalated beds of sandstone and shale (B) Multistoried sandstones

Materials and method

Sandstone samples from the Oligocene Barail exposures of the study area were collected both in time and space. Petrographic studies on representative sandstone samples were performed at the Department of Geology, Nagaland University, Kohima Campus, Meriema. For heavy mineral separation, ten representative sandstone samples were also processed using technique suggested by Folk (1980). For removal of iron and clay coatings, gently crushed samples were treated with H_2O_2, $SnCl_2$ and dilute HCl. Separated heavy fractions were separated using heavy liquid Bromoform (Sp. Gr. 2.89). Separated grains were then mounted on glass slides and identified under the Leica petrological microscope (TL/RL) DM 2700P in the Department of Geology, Nagaland University, Kohima Campus, Meriema.

Petrography

a. Framework grains

Quartz is the dominant framework grain in Barail sandstones. Quartz is represented by both undulatory and non-undulatory variety. Undulatory quartz has been identified by wavy extinction. Polycrystalline quartz as well as quartz with inclusions has also been noticed. Most of the quartz grains belong to sub-angular to sub-rounded in variety. However, a few well-rounded grains were also seen (Figure 3a). In addition to that, a few recycled quartz grains with abraded overgrowths have also been noticed (Figure 3b). Among the feldspars, plagioclase feldspar showing characteristic albite twinning (Figures 3e, 4a, 3f & 4c) dominates over K-feldspar. Albitized feldspar has also been observed. Rock fragments, identified by their compositional and textural criteria (Dickinson, 1970), constitutes a significant portion and is next to quartz and are. Rock fragments are dominated by sedimentary fraction and are represented by siltstones and chert. Schist and phyllites characterize the metamorphic fragments. Flaky minerals such as biotite, muscovite and chlorite have been encountered, occurring as shreds and flakes, many of which have been bent and warped around quartz grains.

b. Cement and Matrix

Cements are the authigenic material filling the interstitial spaces. Many minerals act as cements however, clay minerals, carbonates, silica and iron cement are particularly common cements in sandstones. Both silica and iron cements were observed in the present study. Yellowish/red colored iron oxides occurring around the grains or as over-coating form the other cement. Matrix is finer-grained material that fills inter-particle openings among framework grains. Identification of type of matrix under microscope is very difficult owing to its fine size. Enmeshed Quartz, mica and feldspar in clay have also been considered as matrix by many. Both matrix rich and matrix poor sandstones were seen and places, grain boundaries have been digested by the matrix.

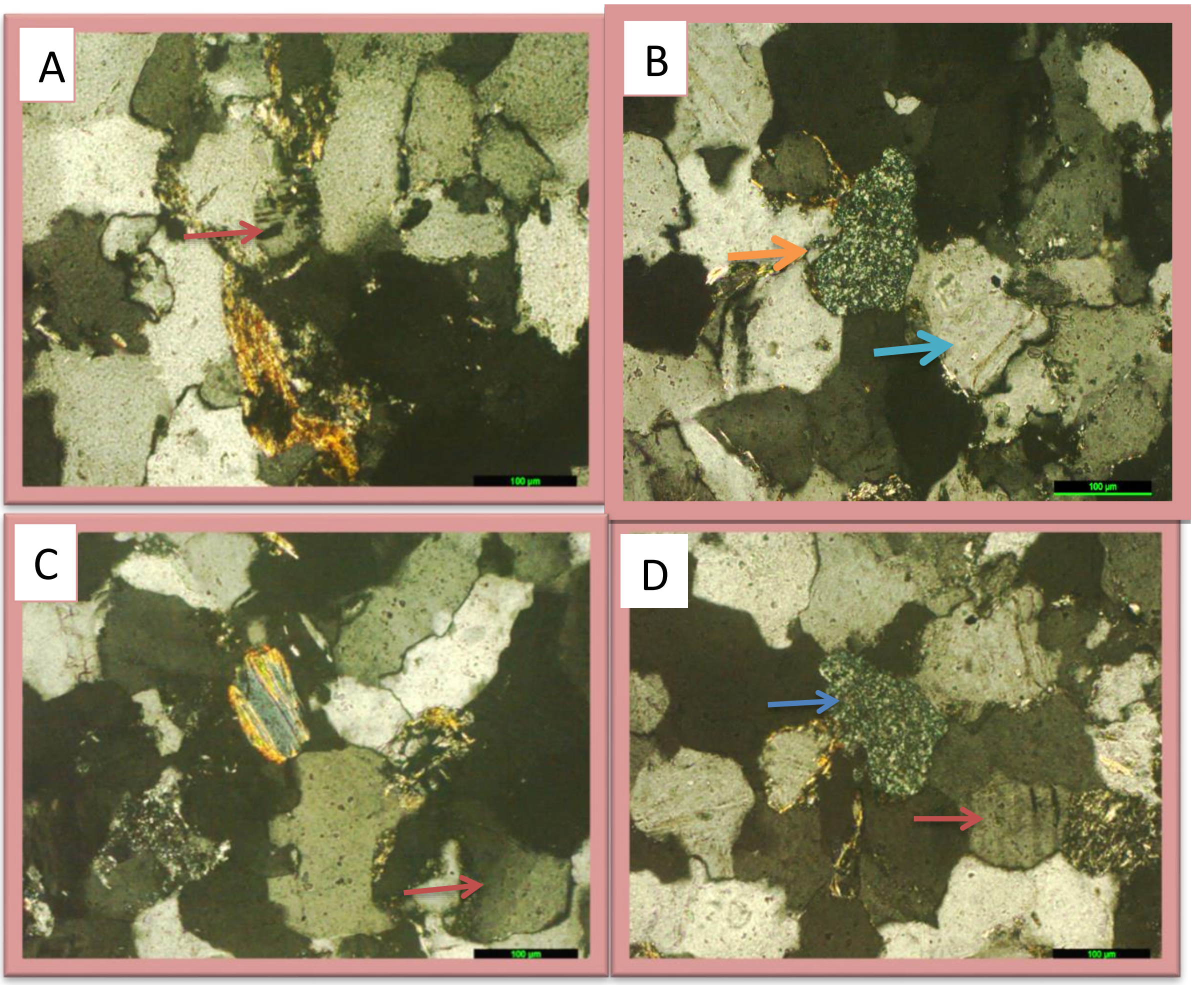

Figure-3. Photomicrographs:A-Plagioclase feldspar (arrow) and polycrystalline quartz, B-Chert (orange arrow) and K-feldspar (blue arrow), C-Unulatory quartz(red arrow) and mica., D-Chert(blue arrow) and plagioclase feldspar(red arrow).

C. Heavy minerals

Non opaque heavy minerals observed in the studied sandstones include zircon, tourmaline, rutile, kyanite, staurolite and sillimanite. Opaque varieties are mostly iron oxide.

Zircon

Zircon grains are sub-rounded to sub angular and have been identified by their straight extinctions, high refractive index, and high order polarization colours.A few well rounded grains were also seen. Zoned zircons as well as zircons with inclusions and dark boundaries have also been noticed. Etched and pitted marks on the surface of the grains are common (Figure 6).

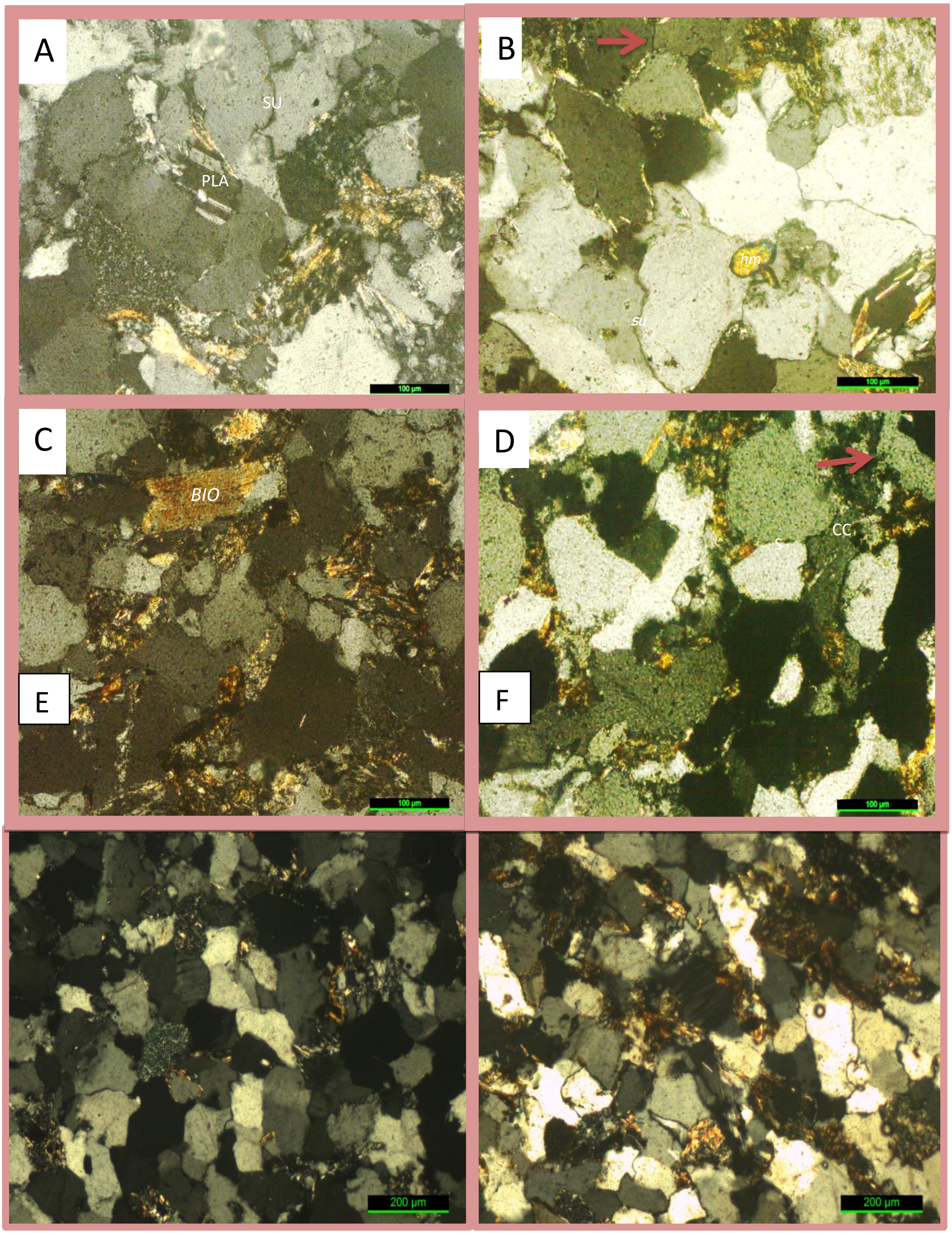

Figure-4. Photomicrographs: A.Plagioclase feldspar (PLA), chert and matrix, B.Well rounded zircon and undulatory quartz (red arrow) C. Biotite(bio) and schist RF. D .Poor sorting and polycrystalline quartz(red arrow) E.Chert, plagioclase and RF F.Undulatory quartz silica overgrowth and matrix.

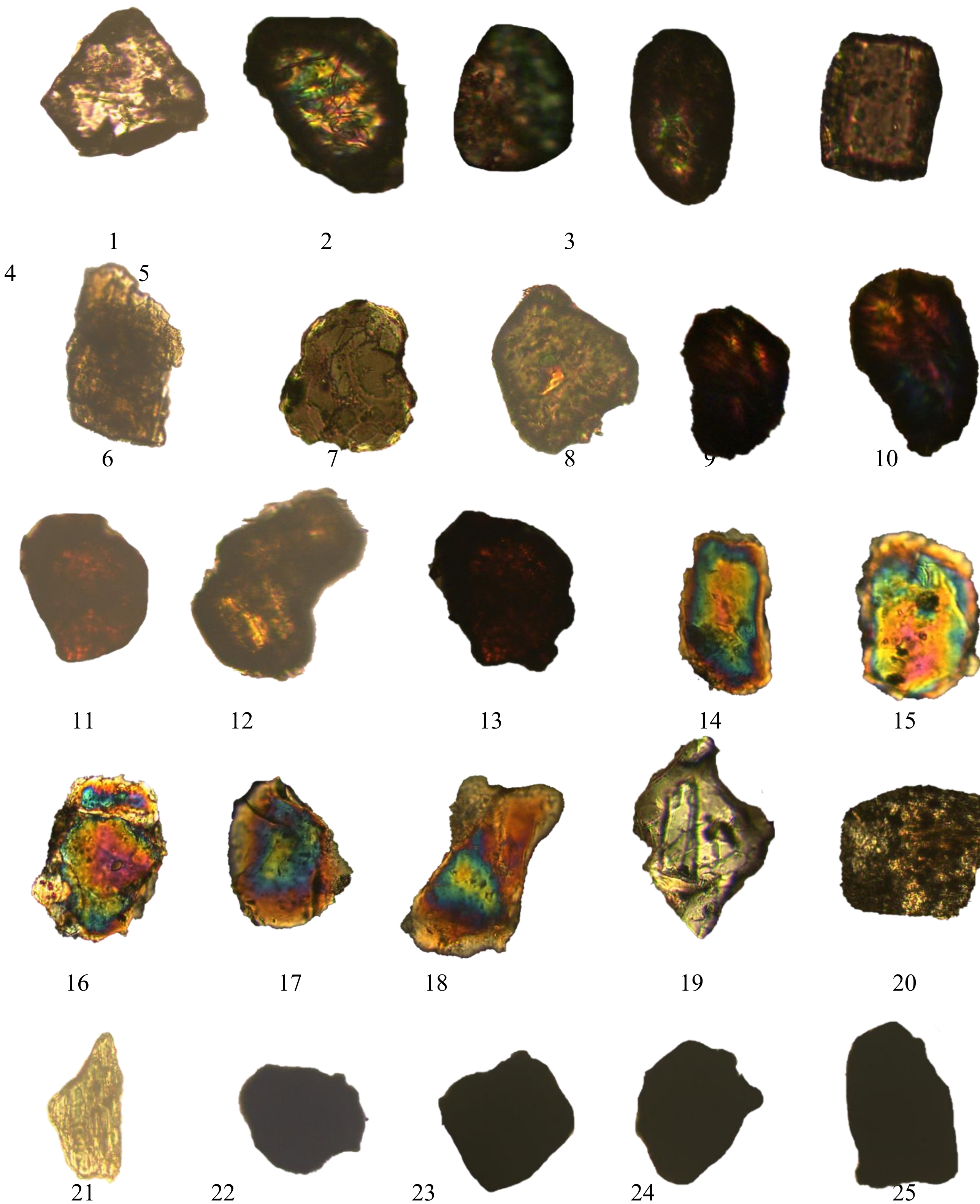

Figure.5 Heavy minerals in Barail sandstones of the study area Zircon (1-4), Tourmaline (5-8), Rutile (9-13) Kyanite (14-18), Staurolite (19-20), Sillimanite (21), Opaques (22-25)

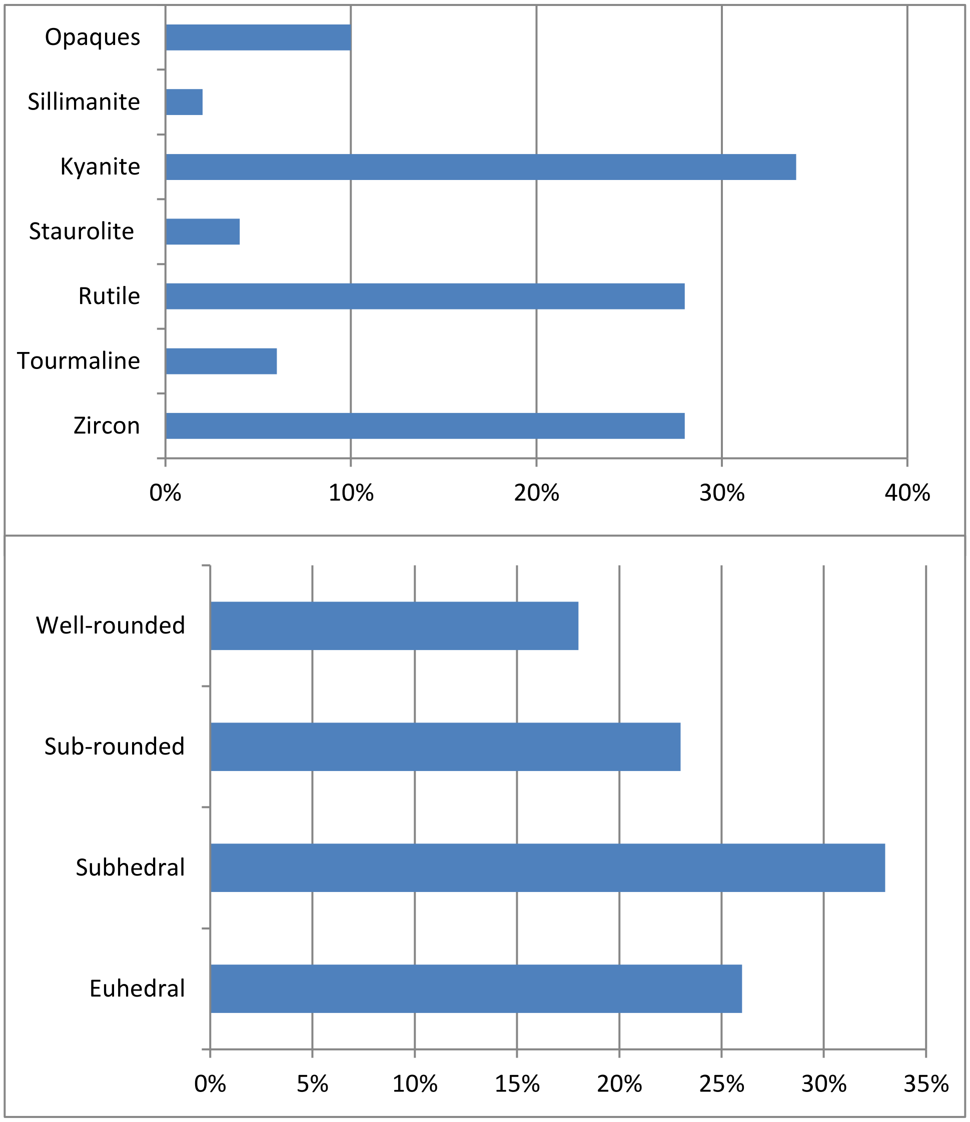

Figure-6: Bar diagrams showing A & B. abundance and roundness of the various heavy minerals.

Tourmaline -The tourmaline grains are mostly sub-rounded to sub-angular. A few well rounded grains were also observed. It exhibits a broad spectrum of colours like greenish yellow or pale yellow, brown, pale brown and green. Grains with and without inclusions and have also been noticed (Figures 7 & 8).

Rutile - Most of the rutile encountered in the present study is euhedral in shape; however, some angular grains were also seen. They are identified by their deep- red colour, weak pleochroism, very high refractive index and dark boundaries. Yellow colored rutile with striations was also seen. They (Figure 8).

Kyanite, sillimanite, and staurolite- Kyanite is usually colourless and exhibits euhedral shape and does not show any inclusion. Sillimanite, is identified by its green colour and fibrous nature. Staurolite grains are irregular in shape and show conchoidal fracture with sieve structure and exhibits high refractive index and moderate to low birefringence (Figure 9).

Opaque minerals- Opaque minerals were common in all the examined samples. They are mostly composed of iron oxides. Euhedral to sub-rounded as well as rounded grains were seen (Figure 10). Relative abundance of heavy minerals according to type and shape are represented by Pie diagrams (Figure 11).

Discussion

Framework composition and heavy minerals of sandstones has been applied by many workers for interpreting source rock and tectonic settings (Dickinson and Rich, 1972; Dickinson and Suczek, 1979; Dickinson and Valloni,1980; Mack,1984; Miall, 1990; Uddin and Lundberg,1998a, 1998b; Singh *et al.*,2004; Srivastava *et al*,2004; Mishra and Tiwari 2005;Srivastava and Pandey,2011,Imchen *et al*,2014; Devi *et al*.,2016; Sen *et al*.,2016; Srivastava *et al.*,2018; Mahanta *et al*.,2019; Sangeeta *et al*.,2019; Chutia and Sarma,2021; and Srivastava and Kichu,2021) as appearance of a particular petrographic character can be correlated with tectonic events (Prothero and Schwab, 2004). However, the composition of the source rock is not the only controlling factor, many other factors also control the final composition (Suttner, 1974; Davis and Ethridge, 1975; Basu, 1976; Suttner *et al*., 1981; McBride, 1985; and Uddin and Lundberg, 1998a). Recycling, long transport and palaeoclimate generally determine the final composition where quartz content can be increased at the cost of other grains. Processes related to sediment transportation, deposition and burial all are linked, which ultimately control the final composition (Johnson (1993). Particular heavy mineral assemblage has been used for correlation with the source rock composition (Blatt et al., 1980) and tectonic settings (Nechaev and Isohording, 1993; Singh *et al*., 2004; Srivastava and Pandey, 2011 and Sangeeta *et al*., 2019; Srivastava and Kichu, 2021). In the present study, framework grains and heavy mineral suite point towards a mixed provenance, for the investigated sandstone. Presence of types of K-feldspars as well as plagioclases feldspars, undulatory/non-undulatotry/polycrystalline quartz and rock fragments (chert/siltstone; schist; volcanics) also suggest the same. Presence of non-undulatory and undulatory/polycrystalline quartz points towards igneous and metamorphic sources, respectively (Boggs Jr., (2009). Presence of a few first generation heavy minerals viz. staurolite, sillimanite, kyanite, rutile, zircon and tourmaline can be correlated with the un-roofing of metamorphic and igneous rocks (Boggs Jr. 2009). A recycled orogen as source has been suggested by the well rounded to sub-rounded ultra-stable heavy minerals (zircon, tourmaline and rutile; Mishra and Tiwari, 2005; Srivastava and Pandey, 2011; Sangeeta *et al*, 2019; Naidu *et al*., 2020, Srivastava and Kichu, 2021). Most probably they have been supplied by the KarbiAnglong massif lying west of the area. Angular to sub angular heavy mineral suite (rutile, sillimanite, kyanite, staurolite) and schist rock fragments suggest contributions from a regionally metamorphosed source (Srivastava and Pandey, 2011; Naidu *et al.*, 2020, Srivastava and Kichu, 2021). Presence of both angular and well-rounded varieties of heavy minerals suggests different sources (Srivastava and Pandey, 2011). In addition to that it also suggests a sedimentary source (Mishra and Tiwari, 2005; Srivastava and Pandey, 2011; Srivastava and Kesen, 2018; Kichu, 2019). Based on the above discussion, it can be envisaged that the Oligocene Barail sandstones had received the sediments from a mixed provenance where major contributions coming from a sedimentary source.

Conclusions

Petrographic study on the Barail sandstones of the study area reveals the presence of moderately sorted subangular to sub rounded monocrystalline non-undulatory quartz and sedimentary and metamorphic rock fragments. Heavy mineral assemblage of the Barail sandstones comprise of well-rounded to euhedral zircon, tourmaline, rutile, staurolite, sillimanite, and kyanite with some iron oxides. Framework constituents of the Barail sandstone and contained heavy minerals suggest a mixed provenance; where major contribution came from a sedimentary source. In addition to that study also suggests contributions from igneous and metamorphic sources also probably from Karbi-Anglong massif and the Naga metamorphics.

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