

Field and Petrographic Insights of Ultramafic-Mafic Rocks of the Naga Hills Ophiolite Exposed in Choklangan Village, Noklak District, Nagaland, India

Sujang Khamniungan^{1*}, Kakoli Gogoi¹ and Kevilhoutuo Theunuo²

¹Geology Discipline, School of Sciences, Indira Gandhi National Open University, New Delhi-110068, India

²Geological Survey of India, Western Region, Jaipur-302004, Rajasthan, India

(*Corresponding Author, E-mail: sujangkhamniungan@gmail.com)

The Naga Hills Ophiolite (NHO) occurs as a series of fragmented tectonic slices located within the accretionary wedge at a convergent boundary where the Indian plate subducted eastward beneath the Myanmar plate (Ghosh, 1986; Bhattacharjee, 1991; Dey *et al.*, 2018). The ophiolite in the eastern region of India is part of the Indo-Myanmar Range (IMR) and stretches from the Naga Hills in the north, through Manipur, to the Andaman in the south (Ghose and Agarwal, 1989; Acharyya *et al.*, 1990; Bhattacharjee, 1991; Ghosh and Ray, 2003; Ghose *et al.*, 2014; Htay *et al.*, 2017; Singh *et al.*, 2024).

The NHO in Nagaland represents the northernmost extension of the ophiolite belt trending NNE-SSW, measuring approximately 90 km in length with a notable 30 km segment located within the Noklak district (Chattopadhyay *et al.*, 1983; Mitra *et al.*, 1986; Acharyya *et al.*, 1989; Ghose *et al.*, 2014; Singh *et al.*, 2016; Ghosh *et al.*, 2017; Khamniungan and Gogoi, 2024). The dismembered ophiolite sequence comprises a basal serpentinitised mantle peridotite, gabbroic cumulate, sheeted dyke, mafic volcanic, often topped by deep-sea pelagic sediments (Mitra *et al.*, 1986; Acharyya *et al.*, 1989; Ningthoujam *et al.*, 2012; Ghose *et al.*, 2014). Highly serpentinitised ultramafic rocks are present as serpentinites. Most rock outcrops have undergone extensive alteration due to deformation and thrusting, and are often covered with thick soil and vegetation.

Previous research on NHO, comprising 27 papers, is based on data from the Web of Science Core Collection, including only online publications (Khamniungan and Gogoi, 2024). This database has been accessible since 2011, with data collected up to June 2023. Research on the geochemical and petrological characteristics of the NHO reveals a complex origin from different tectonic settings. Studies of mafic rocks such as basalts and gabbros indicate both normal mid-ocean ridge basalt (N-MORB) and enriched mid-ocean ridge basalt (E-MORB) signatures, suggesting origins at both mid-ocean ridges and arc settings (Dey *et al.*, 2018; Imchen *et al.*, 2015). Similarly, studies on ultramafic rocks show a

mixed origin. Mantle peridotites from NHO are identified as abyssal peridotites that originated at a mid-ocean ridge (MOR) but were later modified by melt-rock interaction in a supra-subduction zone (SSZ) environment (Ghosh *et al.*, 2018; Singh *et al.*, 2022). This evolution from MOR to SSZ setting is further supported by studies identifying multiple high-temperature stages in the peridotite evolution within a Neo-Tethyan subduction channel (Ao *et al.*, 2020; Ao and Satyanarayanan, 2021). Other papers suggest a mixed origin for the entire ophiolite, with some rocks showing mid-ocean ridge/ocean island basalt signatures and others showing forearc-depleted basalt signatures (Khogekumar *et al.*, 2020; Imtisunep *et al.*, 2021). Specific rock types, like dunites, are identified as residual mantle from extensive partial melting in a subduction zone (Singh *et al.*, 2021), while tectonite peridotites and cumulate pyroxenites are believed to have formed at MOR before being thrust onto the Indian Plate (Singh *et al.*, 2016). Further research indicates that while gabbro and gabbro-norite are cogenetic, crystallised from a common parental melt at different depths (Saikia *et al.*, 2022). Ultramafic rocks from the NHO in Manipur were also found to be abyssal peridotites from a MOR that were serpentinitised at a slow-spreading ridge before emplacement (Ningthoujam *et al.*, 2012).

Studies on the metamorphic history of the Nagaland Ophiolite Complex (NOC) are characterised by high-pressure, low-temperature conditions indicative of a cold, mature subduction zone. Studies of blueschists reveal a low thermal gradient, suggesting they are a tectonic slice from different subducted slab depths (Ao and Bhowmik, 2014). The presence of aegirine-bearing metabasic rocks in the Nagaland Accretionary Prism suggests their formation at high pressure and low temperature in a nascent forearc setting (Ghose *et al.*, 2021). Analysis of eclogite samples shows a clockwise pressure-temperature (P-T) path from an Early Jurassic burial-exhumation cycle, providing the oldest evidence for Neo-Tethyan subduction (Rajkakati *et al.*, 2019). Geochronological data from carbonate veins indicate that peak blueschist metamorphism occurred to 95 Ma and retrograde metamorphism to 90 Ma, with an estimated exhumation rate of about 1 cm/year (Maibam *et al.*, 2023). A review of high-pressure metamorphic rocks revealed a complex history of burial and exhumation with two distinct

subduction systems (Bhowmik *et al.*, 2021), while another study identified two cycles with counterclockwise P-T paths, offering new insights into the subduction initiation and evolution of the Neo-Tethys subduction channel (Bhowmik and Ao, 2016).

Research on the tectonic evolution and geological setting reveals that the NHO is part of a complex tectonic setting at the eastern margin of the Indian plate. The Naga Metamorphics are of Early Ordovician age, while the NHO itself is a younger, Early Cretaceous intra-oceanic island arc that was emplaced onto the Indian margin in the Paleocene/Eocene (Aitchison *et al.*, 2019). The Nagaland-Manipur Ophiolitic Mélange is classified as a "subduction channel mélange" that formed from the obduction and exhumation of tectonic slices during the collision of the India and Burma plates (Fareeduddin and Dilek, 2015). The sediments of the Upper Disang Formation, which include turbidites from both distant and local sources, were deposited during the Late Eocene in a westward-migrating accretionary prism complex (Imchen *et al.*, 2014).

The discovery of well-preserved Upper Jurassic radiolarians provides the first robust age for deep-marine sedimentation in the region and links the Naga Hills and Yarlung Tsangpo ophiolites (Baxter *et al.*, 2011). The presence of titanium-bearing garnets suggests a regional calcium-metasomatism event from hydrothermal alteration of chromitite protoliths (Ghosh *et al.*, 2017). The discovery of native gold and a gold-silver alloy in olivine gabbro suggests a primary source of precious metals in the NHO (Ghose, 2014). The presence of manganilmenite, a diamond indicator mineral, suggests a potential for microdiamond exploration in the Indo-Myanmar ranges (Nayak and Meyer, 2017). Finally, ultramafic peridotite rocks were found to have equilibrated in the upper mantle at high temperatures and pressures, with the primary sulfide mineral being pentlandite (Khwhairakpam *et al.*, 2017).

Based on bibliometric analysis, the keywords associated with research on the NHO reveal the central themes of the literature (Khamniungan and Gogoi, 2024). The most frequently occurring keyword, "Geochemistry" (count of 9), highlights that the majority of studies focus on the bulk chemical composition and magmatic origin of the rocks. This focus is reinforced by keywords related to primary mineralogy and tectonic affinity, such as "Chromian Spinel" and "Midocean Ridge" (each with 7 counts). Furthermore, "Myanmar Orogenic Belt" (8 counts) places the research within its broader tectonic context (Fig. 1). While these trends clearly indicate a strong existing focus on the petrogenesis and tectonic affinity of the NHO through geochemistry, there is a lack of data regarding the microstructural features, modal mineralogy, and metamorphic textures, which is crucial for establishing a complete tectono-metamorphic model for the NHO.

This paper aims to correlate the existing knowledge regarding the petrology, field relationships, and tectonic history of the NHO Belt. While the Noklak district hosts a significant portion of the NHO, detailed geological data from the Choklangan village area are very limited in the public domain. The Choklangan area provides exceptional exposures of the basal ultramafic and volcanic mafic lithounits of NHO, making it an ideal location to study their direct relationships and tectonic contacts. The purpose of this research is to provide a local context for the broader regional geology. In this paper, we present a detailed study of the geological field relationships and petrography of the ultramafic-mafic rocks observed at a regional scale in and around Choklangan village. This

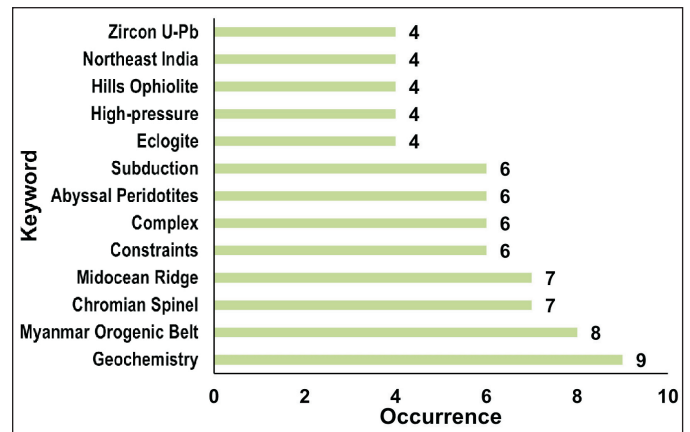


Fig. 1. Graph of keywords derived from Web of Science data and biblioshiny analysis

approach highlights the detailed, local-scale investigation in this underexplored region.

Geological Setting

Geologically, Nagaland is divided into four tectono-stratigraphic divisions, from east to west: Naga Metamorphics, Ophiolite, Disang Formation and Barail Group. The ophiolite in the study area is a NNE-SSW trending, highly tectonised and dismembered linear belt that covers approximately an area of 150 sq.km (Fig. 2a-c). Located in the northernmost part of the NHO, the study area extends from N 26°03'47.8" to N 26°04'27.0" latitude and E 95°05'20.6" to E 95°07'55.6" longitude (Fig. 2d). The NHO is tectonically sandwiched between Naga Metamorphics and Disang sediments. It is overthrust by the Naga Metamorphics on the eastern side and overlies by the younger Disang Formation on the western side (Ghose and Agarwal, 1989; Ghosh and Ray, 2003; Ghose *et al.*, 2014; Rajkakati *et al.*, 2019; Singh *et al.*, 2024). The ophiolite comprises dismembered and overlapping sheets of mantle derived serpentinised peridotite tectonite, ultramafic-mafic cumulates, volcanics dominated by basalt and spilite and radiolarian red chert (Ghose and Agrawal, 1989; Ao and Satyanarayanan, 2021). The basalts are altered, metamorphosed to greenschist or amphibolite and occasionally deformed.

Methodology

The study area was investigated through a combination of fieldwork and petrographic studies. An initial field survey was carried out using Survey of India toposheet No. 83 N/4 at a 1:50,000 scale to identify major geological features, including rock types, lithology, and their relationships in the field. This fieldwork was essential for understanding rock characteristics and geological processes.

Field Relationship

The NHO in the study area is highly tectonised and dismembered, with individual lithological units appearing as thrust slices that are difficult to correlate over short distances. Field observations indicate that the primary lithology of the NHO is composed of partially serpentinised ultramafic rocks. Due to the

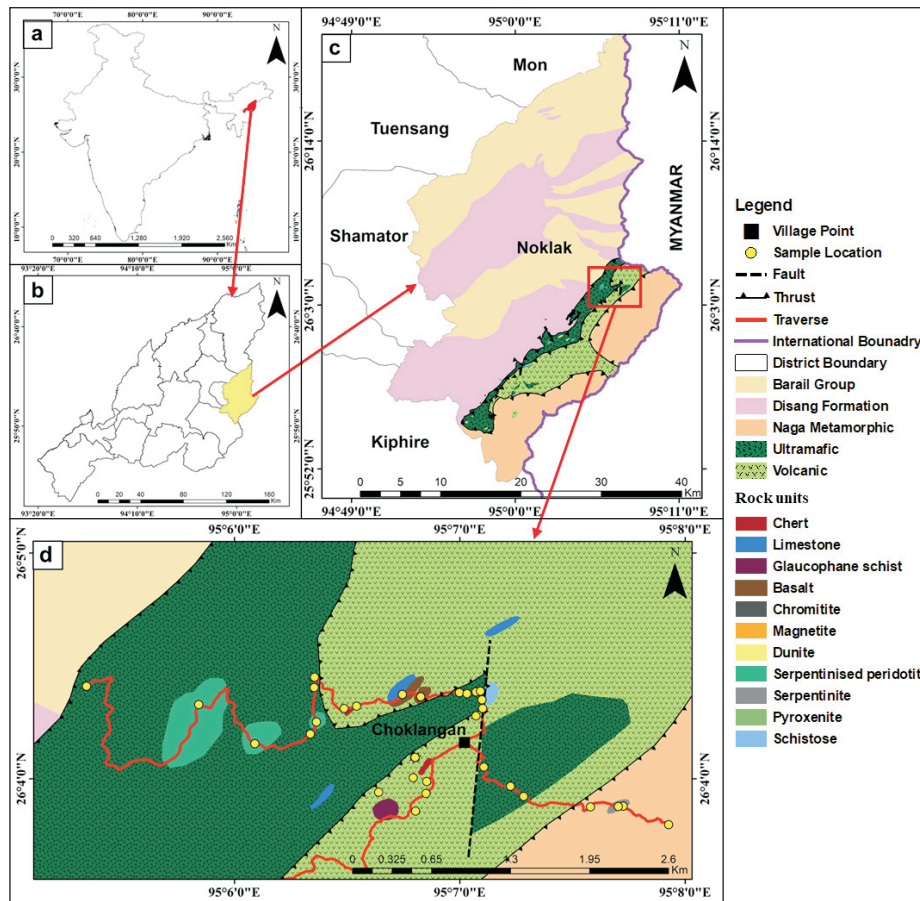


Fig. 2. Geological map of the study area. Different lithounits of Noklak district, where the ophiolite is marked by shades of green and the study area is marked in a red box.

complex deformation history of the area, distinguishing among different ultramafic lithologies in the field proved difficult.

The ophiolite sequence is composed of serpentinised peridotite, serpentinite, basalt, schistose rock and chromitite, representing ultramafic-mafic lithounits. During an east-west traverse, numerous thrust slices at the eastern and western edges were observed. A diverse assemblage of lithologies including serpentinised peridotites, volcanics, and schistose rocks are exposed in a single area. Although these lithologies likely formed in different parts of an ophiolite sequence, they appear to have been tectonically juxtaposed (Fig. 3a). Further to the east, bouldery serpentinite rocks are also exposed (Fig. 3b). A sheared schistose rock with high schistosity is visible near the contact between the ultramafic and volcanic lithounits (Fig. 3c). The schistose rock outcrop trends E-W with a dip of 7° (Fig. 3d), with a steeper dip of 49° in another location (Fig. 3e). Further west, the trend shifts to NE-SW with a steep dip of 85° (Fig. 3f).

West of Choklangan village, a massive basalt outcrop is observed. The partially serpentinised basalt appears as a bouldery outcrop (Fig. 3g). Further west, the massive basalt outcrop is in contact with marble, although this contact is partially obscured by soil and vegetation (Fig. 3h).

Near the contact between the ultramafic and volcanic lithounits, the serpentinised peridotite outcrop shows evidence of shearing (Fig. 3i). A bouldery serpentinised peridotite rock located further east shows less fracturing (Fig. 3j). It contains thin, pale green to white serpentinite layers with a smooth texture, trending NNE-SSW at 58° dip (Fig. 3k) and the trend shifts to NW-SE at 78°

dip (Fig. 3l). Away from the contact, massive serpentinised peridotite outcrops are observed for approximately 1 km along the road cutting (Fig. 3m). The contact between Barail sediments and ophiolite is often covered by thick soil. Brecciation of the serpentinised peridotite is evident near the contact zone (Fig. 3n).

Chromitite bodies are exposed southwest of Choklangan village as small outcrops on a sloped, vegetated terrain (Fig. 3o). It extends approximately 12m in length and is 6m wide (Fig. 3p). Chromitite often forms massive layers or lenses where densely packed chromite grains are separated by narrow interstices filled with silicate minerals. Both podiform chromite (Fig. 3q) and disseminated chromite (Fig. 3r) are observed in the study area, with serpentine and chlorite appearing as alteration products of the silicate minerals. The presence of chert to the east of the chromitite location (Prasad and Sharma, 1981; Vidyadharan and Joshi, 1983) suggests that these two rock types are juxtaposed due to tectonic thrusting, which has transported the layered ultramafic (chromitite) into contact with the pelagic sediments (chert), a deviation from the typical ophiolite sequence.

Results

Petrographic Studies

This study involved the petrographic analysis of thin sections using a Nikon Eclipse E-200 microscope. Petrographic analyses and modal assessment led to the classification of the ultramafic-mafic rocks as lherzolite, serpentinite, basalt, schistose rock and

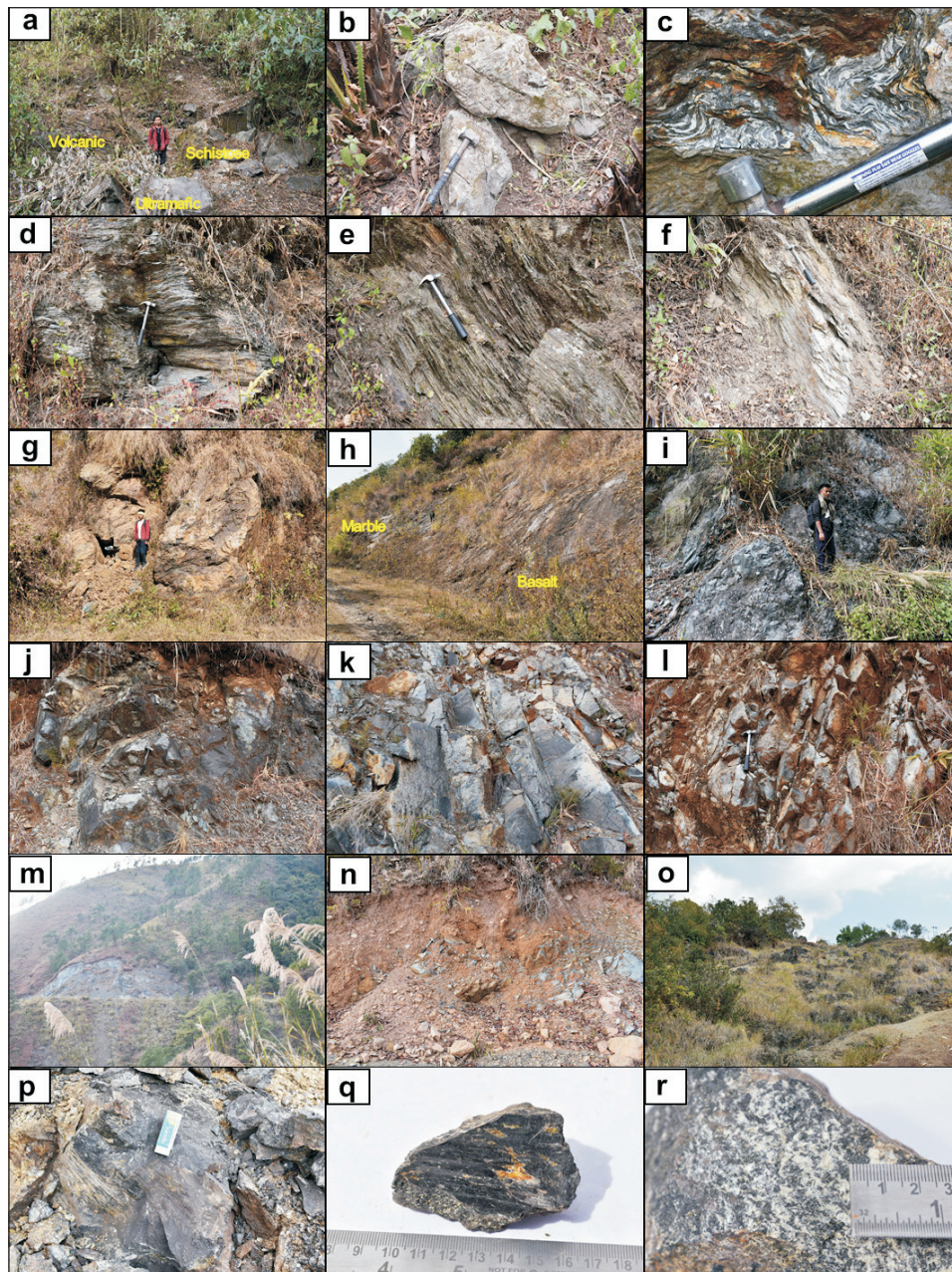


Fig. 3. (a) Serpentinised peridotite, volcanic and schistose rock, (b) Serpentinite rock outcrop located east of Choklangan village, (c) Sheared schistose rock exhibiting high schistosity, (d) E-W strike orientation of the schistose rock, (e) NE-SW strike of the schistose rock. (f) NE-SW strike of the schistose rock, (g) Partially serpentinised basalt bouldery exposure with observable fractures, (h) Contact zone showing marble on the west and basalt on the east, (i) Sheared serpentinised peridotite, (j) Bloudery exposure of serpentinised peridotite, (k) NNE-SSW strike of partially serpentinised peridotite, (l) NW-SE strike of partially serpentinised peridotite, (m) Panoramic view of serpentinised peridotite body extending approximately 1.2km, (n) Brecciated serpentinised peridotite showing the contact between Disang sediments and Ultramafic lithounits, (o) Chromite bodies, (p) Green serpentine mineral present as thin veins within the chromitite, (q) Podiform chromite and (r) Disseminated chromite with associated serpentine minerals

chromitite. The rock samples were analysed to identify minerals based on their optical properties and document their textural relationships. Detailed petrographic descriptions of the ophiolite rocks are provided below.

Lherzolite

Lherzolite is comprised of olivine, orthopyroxene, clinopyroxene, chrome spinel and magnetite. The rock is highly serpentinised, with large olivine crystals altered to serpentine, forming a mesh texture. This process releases fine magnetite

minerals, which are visible within the serpentine veins (Fig. 4a). Smaller, less altered neoblastic olivine crystals occur along corroded grain boundaries of orthopyroxene, which appear as anhedral grains with predominantly corroded boundaries, indicating melt-rock interaction (Fig. 4b). Orthopyroxene porphyroclasts show exsolution lamellae of clinopyroxene (Fig. 4c). Clinopyroxene is relatively well-preserved and unaltered compared to the olivine and orthopyroxene, appearing as anhedral grains between 500 μm to 1 mm in size, with high birefringence, high relief and inclined extinction (Fig. 4d). Chrome spinel is present as anhedral grains from 100 and 400 μm (Fig. 4e).

Serpentinite

In the serpentinites, olivine and pyroxene grains have been completely replaced by serpentine minerals. This complete alteration indicates extensive hydrothermal alteration or serpentinisation of an ultramafic protolith. The rock is dominant

by shades of blue, white and grey and exhibits a classic pseudomorphic texture, where the original shapes of pyroxene and olivine crystals are replaced by aggregates of serpentine minerals (Fig. 4f). Finely dispersed magnetite minerals are distributed throughout the serpentine matrix, particularly along the boundaries of the original grain. Chromite grains appear as anhedral crystals

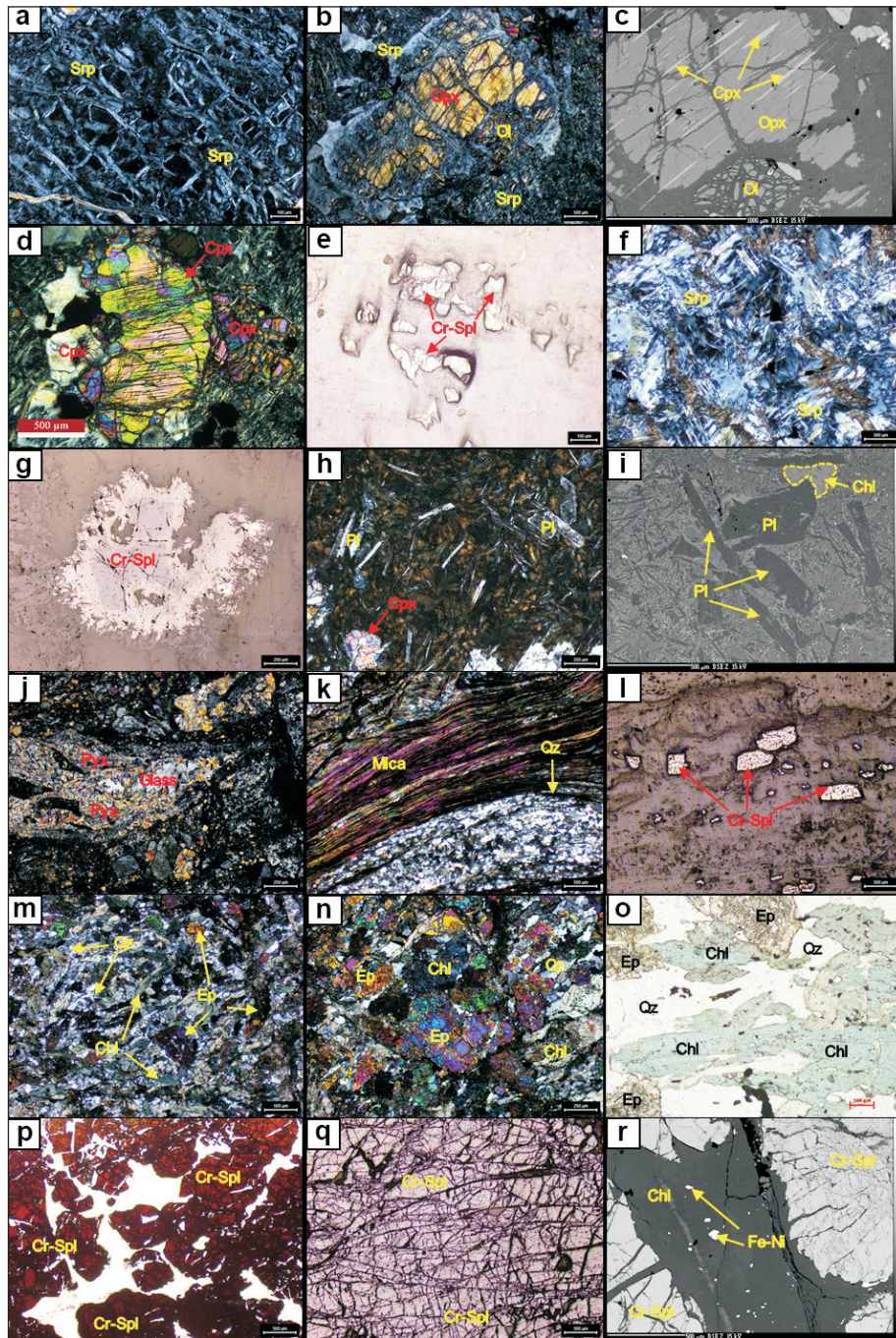


Fig. 4. (a) Serpentine exhibiting mesh texture with opaque magnetite minerals in Iherzolite (cross-polarised light, XPL), (b) Orthopyroxene grains showing a corroded boundary with fresh olivine neoblasts observed along the boundary in Iherzolite (XPL), (c) Backscattered electron image (BSE) of orthopyroxene porphyroclasts displaying exsolution lamellae of clinopyroxene in Iherzolite, (d) Subhedral clinopyroxene grains associated with serpentine minerals in Iherzolite (XPL), (e) Anhedral chromite grain observed in reflected light (RL) in Iherzolite, (f) Serpentine minerals observed in serpentinite (XPL), (g) Anhedral chromite grains within serpentinite (RL), (h) Laths of plagioclase and subhedral pyroxene minerals in basalt (XPL), (i) BSE image of basalt showing laths of plagioclase and subhedral pyroxene minerals, (j) Volcanic glass filling the interstitial space between the plagioclase microlites in basalt (XPL), (k) Layers of mica and quartz in quartz-mica schist (XPL), (l) Euhedral chromite grains showing sharp contact with a layer of mica minerals in quartz-mica schist (XPL), (m) Recrystallised quartz grains, which are generally equant, along with epidote and chlorite grains in quartz-mica schist (XPL), (n) Epidote grains occurring as randomly distributed, small grains in quartz-mica schist (XPL), (o) Pale green chlorite grains (PPL) in quartz-mica schist, (p) Chromite grains observed in disseminated chromitite rock (RL), (q) Chromite grains observed in podiform chromitite rock (RL), (r) Chlorite inclusion observed within the interstitial spaces between the chromite grains (BSE)

within the serpentine matrix (Fig. 4g), with sizes from 50 µm to 500 µm.

Basalt

The basalts consist of pyroxenes crystals (predominantly clinopyroxene) and crystallised phases of plagioclase. Both minerals occur as phenocrysts and elongated laths (Fig. 4h, i). The lath-shaped plagioclase, ranging in size from 10-50 µm, is the most abundant mineral phase and shows no evidence of zoning. The subophitic texture observed (Fig. 4h) is characterised by plagioclase laths partially enclosed by clinopyroxene crystals. Plagioclase also forms slender grains or microlites within the groundmass. The clinopyroxene are mainly subhedral and mostly occur as groundmass, ranging in sizes from 50-250 µm. Plagioclase also forms as microlites about 5 µm long, with intervening spaces filled by intersertal volcanic glass (Fig. 4j).

Schistose Rock

The Quartz-mica-schist exhibits a lepidoblastic texture with alternating bands of quartz and mica, where quartz is the primary mineral (Fig. 4k). In the field, folding of the layered minerals can be observed (Fig. 3c). Euhedral chrome spinels are also observed, showing sharp contact with mica (Fig. 4l). The Quartz-epidote-chlorite schist displays a similar foliated texture, with abundant epidote and chlorite, suggesting a mafic protolith. Quartz occurs as recrystallised grains that are generally equant with polygonal outlines, although some stretching has been observed (Fig. 4m). Epidote is present as randomly distributed small grains (Fig. 4n). While chlorite appears as scaly aggregates (Fig. 4o). These schistose rocks are found at the major contact zones between the ultramafic and mafic units, representing a zone of intense shearing and metamorphism.

Chromitite

The chromitite mineralogy is predominantly chromite, with accessory minerals such as serpentine, chlorite, and Fe-Ni alloy. Chromite occurs as euhedral to subhedral grains, ranging from cubic to subrounded forms, often showing evidence of alteration along fractures and grain boundaries. Grain sized range from 250 µm and 3 mm. The textures vary from discrete euhedral grains with angular edges (Fig. 4p) to intricate fracture networks in subhedral grains (Fig. 4q). The extensive fracturing in the chromite grains is likely due to tectonic deformation and serpentinisation, with fractures acting as pathways for alteration fluids. Chlorite appears as small inclusions within the interstitial spaces between chromite grains (Fig. 4r). The presence of chlorite indicates that the chromitite has undergone hydrothermal alteration, which is often associated with serpentinisation and can lead to the formation of a more iron- and chromium-rich variety of chromite, known as ferrochromite, in the altered grain rims.

Discussion

Unlike an idealized ophiolite sequence, which represents an intact section of oceanic lithosphere, the NHO does not exhibit an ordered succession from mantle to sediments. The exposure of serpentinised peridotites, volcanics, and schistose rocks within a

single outcrop (Fig. 3a) confirms a history of intense tectonic activity that has brought together lithologies originally formed in different parts of an oceanic crust-mantle sequence. This fragmentation is a key characteristic of the NHO and is a direct result of its emplacement history.

The presence of a *mélange*-like zone of schistose rocks at the contact between the ultramafic and mafic units reinforces this interpretation. The quartz-mica-schist, with its lepidoblastic texture and significant folding (Fig. 4k), and the quartz-epidote-chlorite schist, indicative of greenschist facies metamorphism, represent a high-strain zone. These features suggest that the schistose rocks acted as a tectonic medium during the obduction process, facilitating the thrusting of the ophiolite units. This observation is consistent with the model of a "subduction channel *mélange*" as proposed by Fareeduddin and Dilek (2015).

Petrographic analysis further supports the field observations, highlighting the pervasive alteration of the ophiolite units. The extensive serpentinisation of lherzolite, characterised by the development of a mesh texture (Fig. 4a), and the complete replacement of primary minerals in serpentinite (Fig. 4f) indicate a significant history of hydrothermal alteration affecting the mantle section.

The presence of corroded orthopyroxene with fresh olivine neoblasts (Fig. 4b) and the exsolution lamellae of clinopyroxene (Fig. 4c) in lherzolite provides evidence of a complex mantle history, including high-temperature melt-rock interaction before serpentinisation. The chromitite bodies, found as both podiform and disseminated types, are crucial indicators of the tectonic setting. Their extensive fracturing (Fig. 4q) is a direct result of tectonic deformation.

The findings of this study on the northernmost section of the NHO align with the understanding of its overall fragmented structure. The brecciated serpentinised peridotite observed at the contact with the Disang sediments and the obscured basalt-marble contact is consistent with the extensive deformation and thrusting observed in the area. The combined evidence from field relationships and petrography reinforces that the tectonic processes have completely disrupted the original stratigraphy. This local-scale data is crucial for a more comprehensive understanding of the NHO's evolution and highlights the need for further geochemical and geochronological studies.

Conclusions

This study provides a detailed account of the field relationships and petrographic characteristics of the Naga Hills Ophiolite (NHO) in and around Choklangan village. The NHO in the study area does not conform to an idealised ophiolite sequence but rather exists as a series of tectonic slices. Field observations confirm that lithologies such as serpentinised peridotite, basalt, and schistose rocks are tectonically juxtaposed, indicating a history of intense thrusting and emplacement onto the continental margin. Petrographic analysis of the ultramafic-mafic rocks reveals that lherzolite, the primary protolith, shows extensive serpentinisation with characteristic mesh textures and evidence of prior melt-rock interaction. The presence of podiform and disseminated chromitite is indicative of a mantle section origin, likely formed in a supra-subduction zone (SSZ) environment. The schistose rocks represent a high-strain, *mélange*-like zone, facilitating the emplacement of the ophiolite units. This detailed, local-scale investigation in the

Choklangan area validates broader regional geological models of the Naga Hills Ophiolite.

Author's Contributions

SK: Conceptualization, Investigation, Writing-Original Draft. **KG:** Conceptualization, Visualization, Supervision, Reviewing, Editing. **KT:** Supervision, Reviewing and Editing.

Conflict of Interest

The authors declare no conflict of interest.

Acknowledgments

We would like to thank the Geological Survey of India, Jaipur, Petrology Division, for permitting us to study the thin section and to take photomicrographs. We are also grateful to Indira Gandhi National Open University (IGNOU) for its facilities and to the faculty of the Geology discipline for their encouragement and support. We also gratefully acknowledge the National Fellowship and Scholarship for Higher Education of Scheduled Tribe (ST) Students, offered by India's Ministry of Tribal Affairs, for providing the fellowship, which helped with funding throughout this research.

References

- Acharyya, S.K., Ray, K.K. and Sengupta, S. (1990). Tectonics of the Ophiolite belt from Naga Hills and Andaman Islands, India. *Earth Plan. Sci.*, v. 99(2), pp. 188-199.
- Acharyya, S.K., Ray, K.K., and Roy, D.K. (1989). Tectono-stratigraphy and emplacement history of the ophiolite assemblage from the Naga Hills and Andaman Island-arc, India. *Jour. Geol. Soc. India*, v. 33, pp. 4-18.
- Aitchison, J.C., Ao, A., Bhowmik, S.K., Clarke, G.L., Ireland, T.R., Kachovich, S., Lokho, K., Stojanovic, D., Rorder, T., Truscott, N., Zhen, Y. and Zhou, R. (2019). Tectonic Evolution of the Western Margin of the Burma Microplate Based on New Fossil and Radiometric Age Constraints. *Tectonics*, v. 38, pp. 1718-1741.
- Ao, A. and Bhowmik, S.K. (2014). Cold subduction of the Neotethys: the metamorphic record from finely banded lawsonite and epidote blueschists and associated metabasalts of the Nagaland Ophiolite Complex, India. *Jour. Metamorph. Geol.*, v.32(8), pp. 829-860.
- Ao, A. and Satyanarayanan, M. (2021). Petrogenesis of mantle peridotite and cumulate peridotite rocks from the Nagaland Ophiolite Complex, NE India. *Geol. Jour.*, pp. 1-19.
- Ao, A., Bhowmik, S.K. and Upadhyay, D. (2020). P-T-melt/fluid evolution of abyssal mantle peridotites from the Nagaland Ophiolite Complex, NE India: Geodynamic significance. *Lithos*, v. 354-355, pp.105344.
- Baxter, A.R., Aitchison, J.C., Zybrev, S.V. and Ali, J.R. (2011). Upper Jurassic radiolarians from the Naga Ophiolite, Nagaland, northeast India. *Gond. Res.*, v. 20 (2-3), pp. 638-644.
- Bhattacharjee, C.C. (1991). The ophiolites of northeast India—a subduction zone ophiolite complex of the Indo-Burman orogenic belt. *Tectonophysics*, v. 191, pp. 213-222.
- Bhowmik, S.K. and Ao, A. (2016). Subduction initiation in the Neo-Tethys: constraints from counterclockwise P-T paths in amphibolite rocks of the Nagaland Ophiolite Complex, India. *Jour. Metamorph. Geol.*, v. 34 (17-44), pp. 17-44.
- Bhowmik, S.K., Ao, A. and Rajkakati, M. (2021). Tectonic framework of the high-pressure metamorphic rocks of the Nagaland Ophiolite Complex, North-east India, and its geodynamic significance: A review. *Geol. Jour.*, pp. 1-22.
- Chattopadhyay, B., Venkataramana, P., Roy, D.K., Bhattacharyya, S. and Ghosh, S. (1983). Geology of Naga Hills ophiolites. *Rec. Geol. Surv. India*, v. 112(2), pp. 59-115.
- Dey, A., Hussain, M.F. and Barman, M.N. (2018). Geochemical characteristics of mafic and ultramafic rocks from the Naga Hills Ophiolite, India: Implications for petrogenesis. *Geosci. Front.*, v. 9, pp. 517-529.
- Fareeduddin and Dilek, Y. (2015). Structure and petrology of the Nagaland-Manipur Hill Ophiolitic Mélange zone, NE India: A Fossil Tethyan Subduction Channel at the India - Burma Plate Boundary. *Episodes*, v. 38(4), pp. 298-314.
- Ghose, N.C. (2014). Occurrence of native gold and gold-silver alloy in the olivine gabbro of layered cumulate sequence of Naga Hills Ophiolite, India. *Curr. Sci.*, v. 106(8), pp. 1125-1130.
- Ghose, N.C. and Agrawal, O.P. (1989). Geological framework of the central part of Naga Hills ophiolite, Nagaland. *In: Ghose, N.C. (Ed.), Phanerozoic Ophiolites of India*. Sumna Publishers, Patna, pp. 165-188.
- Ghose, N.C., Chatterjee, N. and Fareeduddin. (2014). Geology of the Naga Hills Ophiolite. *A Petrographic Atlas of Ophiolite*, pp. 25-46.
- Ghose, N.C., Singh, A.K., Dutt, A. and Imtisonup, S. (2021). Significance of aegirine-bearing metabasic rocks in the metamorphic evolution of the Nagaland Accretionary Prism, northeast India. *Geol. Jour.*, v. 52(12), pp. 5207-5221.
- Ghosh, B. and Ray, J. (2003). Petrology of the Ophiolitic Assemblage around Mayodia, Dibang Valley District, Arunachal Pradesh, North-Eastern India. *Ind. Miner.*, v. 57(1 and 2), pp. 39-52.
- Ghosh, B., Morishita, T., Ray, J., Tamura, A., Mizukami, T., Soda, Y. and Ovung, T.N. (2017). A new occurrence of titanian (hydro)andradite from the Nagaland ophiolite, India: Implications for element mobility in hydrothermal environments. *Chem. Geol.*, v. 457, pp. 47-60.
- Ghosh, B., Mukhopadhyay, S., Morishita, T., Tamura, A., Arai, S., Bandyopadhyay, D., Chattopadhyaya, S. and Ovung, T.N. (2018). Diversity and evolution of suboceanic mantle: Constraints from Neotethyan ophiolites at the eastern margin of the Indian plate. *Jour. Asian Earth Sci.*, v. 160, pp. 67-77.
- Ghosh, D.B. (1986). Geology of Nagaland Ophiolite. *Geol. Surv. India Mem.*, v.119, pp. 80-93.
- Htay, H., Zaw, K. and Oo, T.T. (2017). The mafic-ultramafic (ophiolitic) rocks of Myanmar. *In: A.J. Barber, Z. Khin, and M.J. Crow (Eds.), Myanmar: geology, resources and tectonics*. Geological Society of London: *Geol. Soc. Mem.*, v. 48, pp. 117-141.
- Imchen, W., Patil, S.K., Rino, V., Thong, G.T., Pongen, T. and Rao, B.V. (2015). Geochemistry, petrography and rock magnetism of the basalts of Phek district, Nagaland. *Curr. Sci.*, v. 108(12), pp. 2240-2249.
- Imchen, W., Thong, G.T. and Pongen, T. (2014). Provenance, tectonic setting and age of the sediments of the Upper Disang Formation in the Phek District, Nagaland. *Jour. Asian Earth Sci.*, v. 88, pp. 11-27.
- Imtisonup, S., Singh, A.K., Bikramaditya, R., Khogenkumar, S., Chaubey, M. and Kumar, N. (2021). Evidence of intraplate magmatism and subduction magmatism during the formation of Nagaland-Manipur Ophiolites, Indo-Myanmar Orogenic Belt, north-east India. *Geol. Jour.*, v. 57(2), pp. 782-800.
- Khiamniungan, S. and Goigoi, K. (2024). Mapping Ophiolite Research with an Emphasis on Naga Hills Ophiolite: Biblioshiny Analysis. *Asian Jour. Geol. Res.*, v. 7(3), pp. 370-387.
- Khogenkumar, S., Singh, A.K., Kumar, S., Lakhan, N., Chaubey, M., Imtisonup, S., Dutt, A. and Oinam, G. (2020) Subduction versus non-subduction origin of the Nagaland-Manipur Ophiolites along the Indo-Myanmar Orogenic Belt, northeast India: Fact and fallacy. *Geol. Jour.*, v. 56(4), pp. 1773-1794.
- Khwarakpam, N., Bidyandana, M. and Singh, S.S. (2017). Silicate and sulphide mineralogy, and conditions of equilibration of ultramafic

- rocks of the Indo-Myanmar ophiolite belt between Tusom, Manipur and Shomra village, Myanmar. *Curr. Sci.*, v. 112(2), pp. 406-410.
- Maibam, B., Palin, R.M., Gerdes, A., White, R.W. and Foley, S. (2023). Dating blueschist-facies metamorphism within the Naga ophiolite, Northeast India, using sheared carbonate veins. *Int. Geol. Rev.*, v. 65(3), pp. 378-395.
- Mitra, N.D., Acharyya, S.K., Datta, A.K., Ghosh, S., Nandy, D.R., Roy, D.K., Vidyadharan, K.T., Venkataramana, P., Srivastava, R.K., Bhattacharyya, S., Joshi, A., Jena, S.K. and Goswami, H.K., (1986). Geology of Nagaland ophiolite. *Rec. Geol. Sur. India*, pp. 119.
- Nayak, B. and Meyer, F.M. (2017). Manganilmenite in the magnetite ore body from Pokphur area of Nagaland, North East India and the possibility of microdiamonds in the ophiolites of Indo-Myanmar ranges. *Curr. Sci.*, v. 112(1), pp. 155-160.
- Ningthoujam, P.S., Dubey, C.S., Guillot, S., Fagio, A.S., and Shukla, D.P. (2012). Origin and serpentinization of ultramafic rocks of Manipur Ophiolite Complex in the Indo-Myanmar subduction zone, Northeast India. *Jour. Asian Earth Sci.*, v. 50, pp. 128-140.
- Prasad, K.R.K. and Sharma, H. (1981) Systematic Geological mapping of Shamatore Panso-Noklak Area, Tuensang District, Nagaland. Geological Survey of India. Progress Report for Field Session 1980-81. (unpublished)
- Rajkakati, M., Bhowmik, S.K., Ao, A., Ireland, T.R., Avila, J., Clarke, G.L., Bhandari, A., and Aitchison, J.C. (2019). Thermal history of Early Jurassic eclogite facies metamorphism in the Nagaland Ophiolite Complex, NE India: New insights into pre-Cretaceous subduction channel tectonics within the Neo-Tethys. *Lithos*, pp. 346-347.
- Saikia, A., Kiso, E., Naeraa, T., Akhtar, S. and Negi, P. (2022). Trace element constraints on the parental melt of gabbroic cumulates from the Naga Ophiolite Complex, North-East India. *Int. Jour. Earth Sci.*, v. 111, pp. 1009-1032.
- Singh, A.K., Chung, S.L. and Somerville, I.D. (2022). Petrogenesis of mantle peridotites in Neo-Tethyan ophiolites from the Eastern Himalaya and Indo-Myanmar Orogenic Belt in the geo-tectonic framework of Southeast Asia. *Geol. Jour.*, v. 57(12), pp. 4886-4919.
- Singh, A.K., Khogenkumar, S., Kumar, S., Singh, L.R. and Thakur, S.S. (2021). Insights into the petrogenesis of depleted mantle dunite from the central part of the Nagaland-Manipur Ophiolites, North East India. *Curr. Sci.*, v. 120(8), pp. 1381-1388.
- Singh, A.K., Khogenkumar, S., Singh, L.R., Bikramaditya, R.K., Khuman, C.M. and Thakur, S.S. (2016). Evidence of Mid-ocean ridge and shallow subduction forearc magmatism in the Nagaland-Manipur ophiolites, Northeast India: constraints from mineralogy and geochemistry of gabbros and associated mafic dykes. *Chem. Erde*, v. 76, pp. 605-620.
- Singh, A.K., Nayak, R., Khogenkumar, S., Subramanyam, K.S.V., Thakur, S.S., Singh, R.K.B. and Satyanarayanan, M. (2016). Genesis and tectonic implications of cumulate pyroxenites and tectonite peridotites from the Nagaland-Manipur ophiolites, Northeast India: constraints from mineralogical and geochemical characteristics. *Geol. Jour.*, v. 52(3), pp. 415-436.
- Singh, T.G., Soibam, I, Theunuo, K., Pal, T., Singh, C.D., Singh, M.P. and Ajit, K. (2024). High Grade Garnet Clinopyroxene Bearing Metamorphic Sole from South-Eastern Manipur Ophiolite Belt. *Jour. Geosci. Res.*, v. 9(2), pp. 82-94.
- Singh, Y.R., Devi, K.B., Singh, W.A., Devi, K.R., Chanu, T.N., Singh, S.P. and Kilong, L. (2024). Biostratigraphy and Depositional Environment of the Upper Disang Formation, Indo-Myanmar Ranges, Northeast India. *Jour. Geosci. Res.*, v. 9(1), pp. 41-48.
- Vidyadharan, K.T. and Joshi, A. (1983) Systematic Geological mapping in the northeasternmost part of Naga hills ophiolite belt around Chokla-Wui-Kenjong-Chipur-Pang areas, Tuensang district, Nagaland. Geological Survey of India Progress Report for Field Session 1982-83. (unpublished)