

Micropalaeontological and Geochemical Evidence of the Late Jurassic Radiolarians Cherts of Naga Ophiolite Hill, Nagaland, Northeast-India

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Abstract

We analyzed the radiolarian assemblages (pelagic sediments) and geochemical studies of 15 samples collected from Meluri district Nagaland, Naga Hills Ophiolite belt (NHO) and it consists of the Flysch Naga-Arakan-Yoma trough beyond the Indo-Myanmar border. It reflects one of the many components of the Himalayan Orogenic systems of Tethyan oceanic crust discovered in Nagaland at Meluri district of India and they have very well-preserved studies and can be identified to Upper Jurassic (Kimmeridgian-mid-Tithonian). As well as a continuous sequence of Kimmeridgian-mid-Tithonian, five radiolarian assemblages have been identified in this study. This is so far the first recovery of pelagic sediment assemblages (Radiolarians) from the Naga Hills Ophiolite complex. Samples of Naga Hills Ophiolite belts fell in the Sublitharenite, Litharenite, and Fe-shale Fe-sand area, and the A-CN-K diagram indicates that these sediments in the source region were exposed deep to moderate weathering conditions. In the discriminant plot, the Naga Hill-Ophiolite-Chert samples occupy the field of origin of the sediment quartzose, and the log (K₂O/Na₂O) versus SiO₂ samples fall into the active continental marginal

field, and only one sample falls into an island arch, suggesting that the tectonic framework of the Naga Hills-Chert samples was deposited in the active continental margin and the diagrams K_2O/Al_2O_3 and MgO/Al_2O_3 illustrated the tectonic setting of the marine environment from Naga Hill Ophiolite Chert. Such findings have been consistent with the current geology of Naga Hills in the province of Nagaland.

Keywords

Geochemistry, Late Jurassic, Radiolarians, Naga Hill Ophiloite, Northeast Nagaland India

1. Introduction

The NE-SW Naga Hills in the northeastern region of the Indo-Myanmar Ranges (IMR) at Manipur, Nagaland, regions of Arunachal Pradesh, and neighboring Western Myanmar states, Myanmar and central part of the mountainous region have been recognized as a small arcuate area for the formation of ophiolite [1]. Naga Ophiolite is a succession of strongly deformed and tectonized ophiolitic rocks that have formed in the Nagaland and Manipur northeastern provinces. The Naga-Andaman suture passes through West Burma at the northeastern end of such a large collection of authorities, which flows over more than 3000 kilometers from NE India to the Andaman Island in the Ocean [2] [3] [4]. The NHO consisted of serpentinized peridotite dismembered bodies, mafia-ultramafic deposits, volcanic mafic, pyroclastic, oceanic sediments, and high-pressure metamorphoses along with glaucophane bearing meta basics, and cherts [1]. The Naga Hills, in northeastern India, represents the northern segment of the N-S trend in the Indo-Burmese Range (IBR), which is generally recognized as an extension of the Andaman-Indonesian island arc. Further north, the Naga Hills have connected to the eastern end of the Himalayas [4] and a narrow path from the late Mesozoic to early Paleogene.

The ophiolitic rocks are situated at the northern edge of the Himalayas and the east side of the Indo-Burmese range, then proceed to a submarine sub arch of the Indonesian arch system, toward the south, towards the islands of Andaman-Nicobar-Mentawi. In Naga Hills and the Andaman Islands, ophiolitic rocks are in occurring as stacks of thrust. Even at close intervals, the 69 various parts of the dismembered suite are often difficult to correlate. Such parts are exposed and appear around a specific belt that holds a strong tectonic and a typical position in the centre of open Synformal Klippen. The ophiolite belts are approximately 200 kilometers long and relatively broad in its northern Nagaland. A number of deep-sea deposits, such as chert, carbonaceous mudstone, fine-grained sandstone, and the Naga Ophiolite itself, are driven westward by the formation of Disang and it is pressed out over to the super young Paleogene's to the west. Both higher growth areas have been assigned mostly to Upper Eocene [5]. In the appearance of *Nummulite* sp., the natural gas horizon was moved from Disang formations (Upper Eocene) and this biostratigraphic study was recently verified by Uddin [6]. According to the Disang Formation, other regions of Nagaland are divided into a range of sandy beds with Oligocene fragments for plants [7] [8] [9].

The previous study by [2] [8] [9] [10] [11] [12] results of the biostratigraphy of the Nagaland Ophiolite radiolarian location is summarized in Cretaceous foraminifera, calcareous Nano fossil, and six positions in Nagaland radiolarian assemblages. Unfortunately, photomicrographs are of poor quality and a large proportion of the dinosaur bones have been classified from genus-level inner chapters [10]. The ages allocated to these assemblages indicate that in this section of the Neotethyan Sea there are deep-sea requirements. In every tectonic study, it is necessary to better understand the life of the sea associated with the collapse of Gondwana and enabling the emergence of the Neotethyan Ocean.

The research paper provides an informative characteristic of the deep marine sediments of pelagic red Chert samples from the Naga Hills Ophiolite Belt, to determine their period (era) within the Neotethyan Ocean tectonic approach, based on radiolarian assemblages recorded from the study area. In comparison, earlier kinds of research on the geochemistry of the Naga hill in these regions are not available. To date, the Naga hills geochemistry of cherts samples India Nagaland state was not yet explored in detail to define its rock source characteristics, provenance, paleoclimate, and tectonic setting. The research article aims to present evidence of the oceanic pelagic sediments of NHO Red cherts, their tectonic settings, provenance, paleoclimate of the Naga ophiolite complex, Northeast India. We carried out the radiolarian species identification and geochemical analysis of radiolarian cherts to obtain an improved understanding of the biota and age determination from the Naga Ophiolite complex.

2. Material and Methods

2.1. Study Area

The Naga Ophiolite itself is thrust westwards over the Disang formation, a series of deep-marine deposits including cherts, carbonaceous mudstones, and fine-grained sandstones. The Disang Formation is thrust over younger Paleogene flysch to the west. It has been assigned to the Upper Eocene using foraminifers extracted from the upper portions of the formation. [5] assigned a shale horizon from the Disang Formation to the Upper Eocene, based on the presence of *Nummulites* sp. Recently, this biostratigraphic work was confirmed by [6]. The present study was performed at the Naga Hills Ophiolite, which is one of Nagaland, Northeast India's four distinct tectonostratigraphic units. Fifteen samples have been collected at Zipu and Mokie Village in the Meluri district, Nagaland (**Figure 1**). Various lithologies such as limestones, cherts, spillites, and many other volcanic rocks of ophiolite-derived sediments have been formed. All the samples collected from the Pelagic oceanic sediments of feebly metamorphosed red chert samples containing radiolarian were concentrated for the present study.



Figure 1. Location map of the study area.

2.2. Laboratory Procedures

Fifteen samples were taken from the Mokie and Zipu roadside areas and we followed the methods of [13] to perform radiolarian analyses. Red chert samples were collected and evaluated for various geochemical and Micropaleontological studies. A Chert sample fragment is etched with concentrated hydrofluoric acid (52% - 55%) for three to five minutes, removed from the acid and washed briefly but carefully with water and then with a stone mill or ground a steel mortar and pestle in fragments of 1 cm up to 5 cm. The crushed chert is placed in beakers with diluted HF acid (nine parts of water to one part of acid) for 24 hours. Radiolarian analyses were identified and extracted from the dried residues under a stereomicroscope and thereafter photograph with an SEM. The identified radiolarian species were later scanned and taken with SEM images from IIT, Chennai. For geochemistry, all the samples were selected from the cherts for preparation of laboratory works and analyzed using XRF instruments at the University of Madras, Chennai. Ten samples of the major and trace geochemical elements have been analyzed. Perhaps every sample collected has been salted into an agate mortar and heavy metal particles have been analyzed of the major elements of the PW 2404 Rhodium X-ray fluorescence spectrometer [13] [14]. Every sample has been analyzed three times and the results were compared. The LOI has been evaluated by a pre- and post-calcination weight of 1 h at 1000°C. The digested mixture of Hydro Fluoric acid, Sulphuric acid, and $HclO_4$ reagent is completely dissolved.

3. Results and Discussions

Radiolarians Identification, Accumulation, and Age Obligation

Radiolarians, the primary sediment-producing organisms, are abundant in all varieties of cherts exposed in this present study, but they are often affected or destroyed by diagenetic dissolution in the middle part of individual beds and are usually better preserved close to the bedding surfaces of chert layers. Their concentrations accentuate fine lamination, which is disrupted occasionally by bioturbation [2] [5]. We have been identified a total of five radiolarians taxa from the pelagic sediments of the study area and dominated the species of Zhamoidellum ovum dumitrica, Gongylothorax favosus dumitrica, Williriedellum crystallinum dumitrica, Hiscocapsa sp. Verbeeki and Holocryptocanium sp. dumitrica. The preservation of radiolarians was good excellent in all samples (Plates 1-3). It has been identified from the late Jurassic radiolarians of the NHO complex [15] [16]. The present research work on the radiolarian assemblages and their distribution in Naga Hills Ophiolite was carried out on the basis of morphological characteristic features and the previous work published literature carried out by [17] [18]. Radiolarians were often utilized key attributes of deep-sea sediment deposition in suture zones, which are also of crucial importance for limiting the time of major events. They are commonly used during Neotethyan Ocean researches and thus can be discovered in the sedimentary covering of the seafloor or interspersed with basalt pillows [17]. Some of the important constituents of the recorded radiolarian assemblage of the Naga Hills Ophiolites include Zhamoidellum ovum Dumitrica, gongylothorax favosus dumitrica, Williriedellum crystallinum dumitrica, Hiscocapsa sp. Verbeeki and Holocryptocanium sp. dumitrica as indicated in Plates 1, 2, 3. From the analysis of radiolarian assemblages, NHO determines their age from Jurassic to Cretaceous by [18], and it is determined using the standard proceedings and well-preserved taxa of five (5) radiolarians and found its dominance of age ranging from Kimmeridgian to mid-Tithonian. A biostratigraphic site of the Unitary Association (UA) with areas strongly connected to either the geological time of scale (2004) was evaluated using the very well-established Jurassic to Cretaceous Radiolarians Zoning [19]. Samples indicate that the Kimmeridgian to in the Mid-Tithonian period overlaps with large, well-preserved taxa (Table 1). In that same component including its Naga-Andaman suture zone, the development of the well-preserved



Plate 1. 1. *Hiscocapsa* sp. *Verbeeki*; 8. *Zhamoidellum ovum Dumitrica*; 10. *Gongylothorax favosus Dumitrica*; 12. *Gongylothorax favosus Dumitrica*.

 Table 1. Radiolarian zonation of late jurassic and stratigraphic ranges.

Age	Aelenian			Bajocian		Bathonian		Callovian	Oxfordian	Kimmeridgian		Tithonian
Taxa	1	2	3	4	5	6	7	8	9	10	11	12
Zones after Baumgartner												
Hiscocapsa sp. Verbeeki												
Zhamoidellum ovum Dumitrica										-		
Gongylothorax favosus												
Dumitrica												
Holocryptocanium sp.												
Dumitrica												
Williriedellum crystallinum												_
Dumitrica												



Plate 2. 1. *Hiscocapsa* sp. *Verbeeki*, 11. *Holocryptocanium* sp. *Dumitrica*, 12. *Holocryptocanium* sp. *Dumitrica*, 12. *Holocryptocanium* sp. *Dumitrica*, 13. *Holocryptocanium* sp. *Dumitrica*, 14. *Holocryptocanium* sp. *Dumitrica*, 15. *Holocryptocanium* sp. *Holocryptocanium*

Kimmeridgian to mid-Tithonian assemblages, derived from cherts NHO, will provide the robust age limitations on deep-sea sedimentation. It significantly increases the average age of this region's earth's oldest deep-sea sediments, from Cretaceous [3]—Late Jurassic.

4. Geochemistry

Geochemical data of the pelagic sediments of cherts are shown in **Figures 2-8**. The research was studied in sediment geochemistry that described a weathering of the source region [19] [20] and infer the source rocks [21] [22] [23] [24] and interpretation of the tectonic settings. The concentration of the major elements in the samples studied is quite variable. The analyzed samples show a large variability in the SiO₂ content. The SiO₂ concentration varies between 43.75% to



Plate 3. 13. Zhamoidellum ovum Dumitrica; 15. Zhamoidellum ovum Dumitrica; 16. Zhamoidellum ovum Dumitrica; 18. williriedellum crystallinum Dumitrica; 19. Gongylo-thorax favosus Dumitrica.

95.18% with an average of 81.29%. The Al_2O_3 content is observed with a maximum and minimum of (2.16% to 15.98% with a Mean of 5.92%) and percentages of CaO and MgO are low. Most of the samples show low content of Fe₂O₃ and range from 0.87% to 11.62% with an average of 3.57%. The concentration of Na₂O varies from 0.09% to 2.62% with an average of 0.91%. The K₂O ranges from 0.18% to 2.21% with an average of 0.93%. The TiO₂ varies from 0.05% to



Figure 2. Geochemical classifications of the chert samples of the naga hills ophiolite using Log (SiO_2/Al_2O_3) vs. Log (Fe_2O_3/K_2O) [25].



Figure 3. A-CN-K ($Al_2O_3 - CaO^* + Na_2O - K_2O$) plot for Naga Hill Ophiolite chert samples for the weathering trend [30].

1.53% with an average of 0.39%. MnO shows low values and it ranges 184 from 0.03% to 0.54% with an average of 0.25%. Most of the Chert samples contain a lower concentration of P_2O_5 ; it is ranging from 0.11% to 0.27% and a mean of 0.17%. Loss of ignition (LOI) values are ranging from 0.1% to 2% and an average of 0.90%.

Implications on Provenance, Paleoclimate, Tectonic Settings of the Pelagic Sediments

Our results demonstrate the radiolarian cherts samples from the NHO complex provide insight into provenance, paleoclimate, and tectonic settings. First, the provenance of classification in major elements of the analysis of this study is using a geochemical classification diagram and in Sublitharenite, two samples in litharenite, and one sample in the Fe-shale Fe-sand region (**Figure 3**) [25]. Naga hills Ophiolite belts CIA values vary from 65.91% to 80.85% with an average of 74.48%. The PIA values are calculated using the following equation:

 $PIA = CIA = (Al_2O_3 - K_2O) \times 100 / (Al_2O_3 + CaO + Na_2O - K_2O)$. In the present study the trace element concentrations of V, Cr, Ni, Cu, Zn, Rb, Sr, Y, Zr, Ba, and Pb have been analyzed. The trace metal concentrations of Nickel (Ni) ranges from 155.6 to 11.24 ppm with an average value of 57.5 ppm and copper (Cu) which ranges from 245.4 ppm to 34.67 ppm and an average value of 100 ppm. An association of radiolarian sediments with a considerable number of metallic elements such as Ni, Fe, Mn, and Cu, is suggested by the fact that the radiolarian mudstones and cherts from the abyssal seafloor contain more than 10 times as much Ni as the diagenetic flint nodules. Naga Hills Ophiolite has high SiO₂ concentrations, and Ni, Cu, and Zn were abundant with an average concentration of 201.7 ppm, minimum concentrations of 25.47 ppm, and a median concentration of 87.2 ppm. These geochemical properties may indicate sulfate-reducing deposits, and the sediments were silicified during the diagenesis and termed to deposit geochemically the elements are Molybdenum, Nickel, Copper, Zinc, and organic matter abundance, underneath suboxic-anoxic conditions [26]. The concentration of Naga Hills Radiolarian Chert of Ophiolite with a high level of Ni, Cu, and Zn may be illustrated in an incredibly badly airy, non-restricted region that is easily subtoxic, toxic, and oxidized. Several researchers have identified weathering history and used elementary ratios in various methods to investigate the weathering of rock sources [20]. The triangular A-CN-K plot [27] also describes the sediment weathering trend. The most important basic data provide useful information about the weather conditions during the deposit of sedimentary rocks [27]. The bivariate diagram $Al_2O_3 + K_2O + Na_2O$ differentiates the climatic conditions under which the sediments are deposited (Figure 4). The Naga hill sample shows a wide variation in SiO_2 content. The majority of the sample was shown in the humid climate and a few samples fell into the area of arid conditions, which shows an increase in chemical maturity (Figure 5). Roaldset [28] distinguished between the marine and non-marine by the interaction of K₂O/Al₂O₃ and MgO/Al₂O₃. The diagrams show the marine environment for the Naga Hill chert samples (Figure 6). Diagram A-CN-K demonstrates these sedimentary rocks were undergone deeply moderately weathering conditions in the source region. And only a few samples follow the A-CN-K trend and only one sample fall in the slightly weathered condition. This is also confirmed by the PIA values (plagioclase index of alteration) [29] [30].

Geochemical signatures of sediments have been used as a determination of the provenance [22] [31] [32] [33] [34] and SiO_2/Al_2O_3 ratio is responsive to the recycling process as well as weathering and has been generally used for the insight of sediment maturity. In unaltered igneous rocks, the typical SiO_2/Al_2O_3 ratio ranges between ~3.0 in basic and ~5.0 in acid, while in > 5.0 - 6.0 [22]. A variation



Figure 4. Discriminant function diagram for the provenance signatures of Naga Hill Ophiolite, chert suites using major elements [30].



Figure 5. SiO_2 vs. $Al_2O_3 + K_2O + Na_2O$ Binary plot [27].

of the SiO_2/Al_2O_3 ratio shows that almost all sediments are derived from sources of acidic and basic rock. The SiO_2/Al_2O_3 ratio indicates that most of the acidic and basic source rock was derived from sediments. In this discriminant diagram, most of the samples from Naga hill occupy the sediments' source field of the quartzose (**Figure 3**) and the major oxide data from its igneous rocks are from the sedimentary quartzose provenance. The tectonic settings were calculated utilizing discriminant function, element ratio, and bivariate diagram [20] [21] [22]



Figure 6. Log K_2O/Al_2O_3 vs. log MgO/Al_2O_3 plots Diagram depicting the depositional environment of the Naga Hills Ophiolite [28].



Figure 7. Geochemical data of cherts plot on Fe_2O_3/TiO_2 vs. $Al_2O_3/(Al_2O_3 + Fe_2O_3)$ discrimination diagram Samples from Naga Hills Ophiolite [38].

[35] [36] [37] [38]. They used CaO and LOI free basins and adjusted the data to 100% to demarcate various field boundaries [34] [38] [39]. Most Chert samples



Figure 8. Log (K₂O/Na₂O) vs. SiO₂ discrimination diagram of chert samples showing Active Continental Margin; field boundary coordinates derived from [31].

only fall on the active continental margin and another sample collapses in the field of the island arc (**Figure 6**), which implies the deposition of volcanic rocks measurements on the Naga hill chert in the Active continental settings. Another supporting diagram of geochemical data of the Cherts plot in the Fe₂O/TiO₂ vs. $Al_2O_3/(Al_2O_3 + Fe_2O)$ discrimination diagram (**Figure 7**) shows the most continental margin island arc and old upper continental crust [38]. [31] proposed a discriminating diagram using Log (K₂O/Na₂O) vs. SiO₂ to establish various tectonic settings of clastic rocks (**Figure 8**).

5. Conclusion

The present study using the pelagic sediments from red chert samples from Naga Hills ophiolite was carried out for geochemical and Micropaleontological studies. This shows that the iron-rich chert samples are rich in pelagic micro-organisms, i.e. Radiolarians. The chert comprises various radiolarian skeletons which are contained in a silica matrix in the form of cryptocrystalline quartz crystals. They are inserted into the silicate clay matrix with iron-rich minerals. The disappearance of pelagic calcite and the very low calcium content of the chert indicate that the chert is lower in the compensatory depth at which more calcite dissolves within the ocean. Five (5) radiolarians were identified and distributed in Naga hills Ophiolite namely Zhamoidellum ovum dumitrica, gongylothorax favosus dumitrica, Williriedellum kristallinum dumitrica, Hiscocapsa sp. Holocryptocanium sp. and Verbeeki sp. dumitrica has age supremacy ranging between Kimmeridgian and mid-Tithonian. Geochemical data of pelagic sediments in the NHO samples showed the provenance of the rocks are sublitharenite, Litharenite, Fe-shale, and Fe-sand field, and the A-CN-K, discrimination plots indicated the deep to moderate weather conditions and quartzose sedimentary provenance in the source region for these sediments. The tectonic settings of chert samples illustrated the

marine environment of NHO and the diagram of Log (K_2O/Na_2O) vs. SiO₂, for the determination of various tectonic-adjusting chert samples, only one sample drop in the field of the active margin falls inside this area of the island arc, implying that the tectonic setting of the Naga Hills has been deposited in the active continental margin.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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