INDO-BURMESE COLLISION OCCURRED AT EOCENE EVIDENCE FROM THE DETRITAL FISSION TRACK THERMOCHRONOLOGY OF NORTHEAST INDIA

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Abstract

Nagaland is part of the northern extension of the Indo Myanmar range(IMR).This area is representative of several orogenic upheavals in the Cretaceous-Tertiary that form a relativelyyoung and mobile land belt.Nagaland is the most recent crustal reaction to the collision of theIndian and Burmese Plate.Barail formation emerged at the active margin of the Indo-Burmeseplateconvergence.The majority of the available tectonic replica proposes that themalformation and uplift of the North-eastern. We aimed at the highlights of exhumation andsedimentation, and its other host processes like provenance characteristics of the Barail sandstones from Nagaland, India.Systematic geological mapping of approximately 50 square meters has been carried out in the study area.A geological map of the study area was made on a scale of 1:50,000 in the Indian Topsheet No.58M/4 survey in the Kohima district of Nagaland.The region was mapped according to need and accessibility by taking the traverses along the highways, footpaths and across the ranges.In this study,four quarry samples disseminated in various folds in the Barail Group yielded the ages ranging from 37.4±1.5Ma to 49.9±2.4Ma and younger than their predecessor sedimentary deposition ages(86.92-181.81Ma).The binomial distribution clearly stated that from 46.0to32.0Ma,the grain ages fitted peaks are usually dominated by the youngpeak.Combined with an interpretation of the origin,the detrital zircon of the young peak age and rocks indicated that most significant uplifting of the Barail Group occurred during EocenetotheOligocene,almost timed to coincide with the colliding of the Indo-Burmese plate more around ˜35-50Ma.Such findings have been consistent with the current geology of Naga Hills in theprovince of Nagaland.

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Abstract

Nagaland is part of the northern extension of the Indo-Myanmar range (IMR). This area is representative of several orogenic upheavals in the Cretaceous-Tertiary that form a relatively young and mobile land belt. Nagaland is the most recent crustal reaction to the collision of the Indian and Burmese Plate. Barail formation emerged at the active margin of the Indo-Burmese plate convergence. The majority of the available tectonic replica proposes that the malformation and uplift of the Northeastern. We aimed at the highlights of exhumation and sedimentation, and its other host processes like provenance characteristics of the Barail sandstones from Nagaland, India. Systematic geological mapping of approximately 50 square meters has been carried out in the study area. A geological map of the study area was made on a scale of 1:50,000 in the Indian Topsheet No.58M/4 survey in the Kohima district of Nagaland. The region was mapped according to need and accessibility by taking the traverses along the highways, footpaths and across the ranges. In this study, four quarry samples disseminated in various folds in the Barail Group yielded the ages ranging from 37.4 ± 1.5Ma to 49.9 ± 2.4Ma and younger than their predecessor sedimentary deposition ages (86.92-181.81 Ma). The binomial distribution clearly stated that from 46.0 to 32.0Ma, the grain ages fitted peaks are usually dominated by the young peak. Combined with an interpretation of the origin, the detrital zircon of the young peak age and rocks indicated that most significant uplifting of the Barail Group occurred during Eocene to the Oligocene, almost timed to coincide with the colliding of the Indo-Burmese plate more around ~35-50 Ma. Such findings have been consistent with the current geology of Naga Hills in the province of Nagaland.

Keywords: Detrital Fission Track, Indo-Burmese, Barail sandstones, Exhumation, Provenance, Northeast India

Introduction

The Indian plate had subducted eastward below the Burma microplate during the India-Eurasia collision, which is the start point for our understanding of the formation and evolution of Himalayas-Tibetan Plateau as well as the effects of environment and resources. Therefore, the onset time of the collision and subduction is one of the hotspots in Geoscience, however, are still seriously controversial, ranging from the Early Cretaceous to Paleogene (Evans, 1932; Gupta and Biswas, 2000; Acharyya, 2007, 2010), because the direct and confidence evidence is rare and poorly yielded. The Indo- Burmese collision have caused the uplift and exhumation of Nāga Hills, part of the complex mountain barrier on the collision border (Acharyya, 1986, 2007, 2015; Aitchison, 2019), with the syn-orogenic sedimentation of Nagaland Hills basin (Brunnschweiler, 1966; Acharyya, 2010; Aitchison et al., 2019) With the continue colliding of Indian-Burmese plates, This plate margin gives rise to all the tectonic lithological and relief features typical to the tectonic plate touch zones. For example, the mountain range chain reveals a variety of concurrent north-south orientation or subparallel ranges that have intervened by river valleys at present; meanwhile, with the uplifted of the western Indo-Burmese range, the Nagaland Hills basin was filled with sediments named Barail group sequences (Evans, 1932; Agrawal and Ghosh, 1986; Gupta and Biswas, 2000). Subsequently, these molassic sediments were North-East southwest folded and Elevated in and out of upstanding ridges, giving linearity to the belt with the defective regional activity and thrusting, representing the compression stress and crustal shortening The Barail group sequences mostly intercalated with sandstone with shale formations in the Naga Hills and the provenance analysis, are deeply studied and indicated that the source rocks (Srivastava, 2013, 2018; Ramamoorthy, 2015, 2016, Odyuo, 2018). However, their depositional ages are ambiguous, and the regional tectonic settings are poorly known, thus block the further. Interestingly, due to the basin complex tectonic history, lateral facies variations, scarcity of fossils, and partial reworking of the sedimentary material, differences still occur in published ages, and thus there is a lack of precise dating.

Naga Hills part of a complex mountain barricade at the Indo-Burmese boundary. A Northern extension of the Assam yoma system and it is reaching heights of 3,826 m on the India-Myanmar border at mount saramati. The Hills obtain heavy rainfall from monsoons and are naturally clothed with dense forest. Systematic geological mapping of approximately 50 square kilometers has been carried out in the Northeast, Nagaland. In the part of the India Topsheet No.58M/4 survey in Kohima district of Nagaland. The study area was mapped by taking traverses along the roads, footpath, and across the ranges according to necessity and accessibility. A comprehensive analysis of the Barail sediment group in Nagaland using a combination of origin and ZFT (Zircon fission track) is then presented. ZFT (Zircon fission track) is a proven method of investigating the lengthy-term background of diverging hillside belt exhumation (Spiegel., 2000; Bernet., 2001, 2004 a,b) typically used to calculate the oldest depository age using the youngest or peak age, allowing the reconstruction of the tectonic evolution of sediment origin (Aoki., 2012, 2014; Beranek & Mortensen, 2011). In comparison, earlier kinds of research on the ZFT dating of the Naga hill in these regions are not available. To date, the Naga hills geochronology of sandstones samples India Nagaland state was not yet explored in detail to define, provenance, and long term exhumation. From this research paper, we have been using fission-track grain age distribution for detrital zircon extracted from Naga hill sediments to solve bedrock cooling ages for orogenic origin. Detrital zircon samples were collected and dated from Barail sandstones in the Naga Hills, Northeast Nagaland (Figure 1), which document the early deformation of the region. From these regional perspectives, we suggest a period for the early Cenozoic uplift of the Indo-Burma collision and growth model, utilizing sedimentary measurements and the findings of the origin study from the Northeastern Naga Hills. These results can shed more light on the timing of cooling and exhumation events or periods and enhancing our understanding of the long-term evolution of Northeast.

Geological settings

Geographically, this study area is a central part of the Indo- Myanmar Range (IMR) and located in the inner Palaeogene fold belt of Manipur- Nagaland-Upper Assam and Arunachal

Pradesh. The most of the stretch of Disang Group with isolated covers with Barail Group distinguishes the geological setting of the area. Geological provinces are in north-eastern India mature even after time severance the land of Gondwana. In the collision of Indo-Burmese plates are during the middle part of the Cretaceous. Gradually, the evolution of Palaeogene Barail, Surma, Tipam formations are in the regions. Nagaland stratigraphic formation, altered after Mathur and Evans (1964), the Geology & Mining Directorate (1978), and Ghose et al.2010), is shown in table .1.

Nagaland rocks are present in the Kohima synclinorium and trending longitudinal belts of NE-SW. This research study is situated in the western part of the synclinorium. It covers an extensive area in the intermediate hill ranges of Nagaland. The highest ground of the Patkai Synclinorium comprises synclines with Barail rocks and the relatively open synclines are separated by faulted and overthrust Disang shale. Several folds with various types and their structure describe the area and suggest a variety of malformation events. In addition, faults are there negotiating from the study area. The study area (94 ° 05'45"N and 25 ° 39'34"E) which forms the synclinorium of Kohima and includes a group of rocks from Cretaceous to Eocene Disang (dominantly in clay), followed by the transition sequences from Disang-Barail (DBTS) (Pandey.N., 1998). It is light grey to grey (Barail sandstone) and has a fine to medium-grain consistency with occasional shale intercalation.

The Barail comprises thick sequences of sandstones intercalated with very thin papery shale. In these rocks, ages from the Upper Eocene to Oligocene, are scattered in patches in Nagaland (Evans, 1932; Srivastava.S.K, 1998; Gupta and Biswas, 2000). It is exposed in southern Kohima, the eastern parts of Nagaland, and all along the western margin of the state. The type area of Barail is limited to the northwest by the Haflong-Disang Thrust trending roughly NE-SW. It is overlying the Disang. They attain a thickness of about 4000 to 6000 m. The Barail is divided into three formations in the south and southwest of Nagaland (Evans, 1932) including the Laisong, Jenam, and Renji formations. The Laisong Formation consists of very hard, grey, thin to thick-bedded sandstones with ferruginous concretions. Occasional massive sandstones with intercalations of carbonaceous shale are not uncommon. Thin streaks of coal are also encountered. The thickness of this formation varies from 900 to 2000 m. The Jenam Formation with thicknesses varying from 900 to 2000 m exhibits a gradational contact with the underlying and overlying formations. The sandstones are dominantly grey to dark grey and thin to thick-bedded with carbonaceous shales. They are commonly interbedded with silts. The Renji Formation is the youngest member of the Barail Group. This formation extends into Assam and Manipur. The sandstones are massive, very thick-bedded, hard and ferruginous, and intercalated with minor shale. They form a thickly forested range with high peaks such as Japfü (3015 m) in the southwest of Kohima.

Methods and sampling

Zircon is a common type of rock resistant to weather attacks by physical and chemical. ZFT is ~240±30°C with annealing temperature and the standard orogenic cooling rate is 15°C/Myr (Hurford, 1986, Brandon, 1998). Hence Zircon is researching an excellent mineral for its thermochronology whose rocks are highly essential (Carter, 1999, Bernet, 2005). It has the superiority to retain knowledge on the current chronology of origin that makes the use of the ZFT study beneficial for connecting sediment deposits to the uplifting and Orogenic belts investigation past (Bernet, 2005). In comparison, research data on FT dating and Zircon length analysis are not yet adequate to enable simulation of the track range (Garver, 1999b).

Sediment samples have been collected from the Barail Group best exposure along the road. However, if marked differences in lithological and physical characters were encountered within a much shorter range, the sampling spacings were also reduced to collect the representative sample of the rocks. Four systematic sedimentary sandstone samples were collected from the Northeastern Himalayas in Nagaland. The samples were collected from the four quarry sections in the Naga Hills (Zubza, Khiruphema, Mezoma, and Jotsoma). Sample preparation was done by the mineral separation method (Patel RC, Singh P, Lal N (2015). The work on zircon mineral separation was carried out at the Department of Geophysics, Kurukshetra University. We followed international protocols for the use of specific analytical techniques. We used for separation instruments are disc mill, crusher, and Weiley water table. We separated a hundred zircon grains from all samples of good quality and equal-sized (Table 1) by standard, Crushing, Mounting Bromoform, and magnetic separation procedures of the FTD of Kurukshetra University, India. Zircon grains picked by hand and Grains are mounted (PFA® Teflon), polished, etched. For etching the Zircon's mineral surface at 240 °C 3h, KOH-NaOH chemicals have been used, and the Low Uranium Muscovite has been used as "external detector" to measure the caused track densities. The FRM-II, thermal column, Germany conducted sample thermal neutron irradiation. The neutron dosimeter was used for CN-2 uranium glass. External mediated track detectors (mica) were tested for 5 minutes at 48 percent HF at 35 ° C. Spontaneous track densities were examined on internal mineral surfaces using the Olympus BX-50 with 100 tons of dry lenses and a 1250x total magnification. Zircon crystals containing prismatic parts parallel to the crystallographic c-axis have been chosen to measure track densities. By standard zeta method (ζ) Hurford, A.J., Green, P.F. (1983), and Hurford, A. (1990) Ages with $\pm 1\sigma$ were determined. The Zeta factor is 127.61±4.31, which was obtained from the through multiple examinations of the age criteria for zircon grains. Such as Fish canyon Tuff, Bergell, and Tadree rhyolite.

Results

The present study obtained a limited amount of 50-68 grains from the surface samples and selected them for the determination of age. Nevertheless, defining the grainage components ensured definite results. For an example of the P (χ^2)>5%, age dispersion should be ~10% the cooling age, and the pool age will be the same (Snelling, 2005). We find that from the Barail group age of Eocene-Oligocene (53-33Ma) and ZFT ages were 37 to 49 Ma. In the Barail sandstones to the east of this depression, the ZFT ages are Cretaceous to Tertiary age (86-58 Ma) and do not appear in the regional pattern. All areas had shown trends of a very similar age. We had given the results of four quarry samples detailed and summarized in Table 2. It was shown very clearly from the study that the range and distribution of individual ZFT ages for each sample appeared within the Radial and Spectrum plots (Figs 2 a, b; Table 3) and binomial peaks for the measured surface samples shown in (Table 1 and Fig.2c).

Zubza section was identified as a pooled age is 37.4±1.5Ma with P(χ^2) 0.00%. It is derived from the 50 detrital zircon grains (Table 2; Fig 2c). However, the age dispersion was 0.00% and individual grains yielded evidence of single-grain ages from 55.67±10.7 Ma to 29.10 ± 6.1 Ma (Fig.2a). The histogram shows large spreads over the ages (Figs. 2a-c). The pooled and central ages are uniforms, 37.4±1.5 Ma. ZFT single grain age is derived from a sample of Jotsoma of Barail Group sediments ranged between 159.31 ± 49 Ma and 22.24 ± 5.6 Ma, with P(χ^2) = 0.00%. The pooled and central ages are 44.9 ±1.8 Ma and 44.5±1.8 Ma. Samples of Khiruphema yielded 46-grain ages, and the age dispersion is 0.00%. Khiruphema pooled age is 44.9±1.8 Ma as opposed to a central age of 44.5±1.8 Ma, with P (χ^2) = 0.00%. The Mezoma samples pooled age and central ages are 51.2±2.0 Ma and 49.9±2.4Ma respectively. However with the probability density plot shown the well-fitted peaks in Zubza as 34.5±0.8 Ma. The samples of Khiruphema location peaks value as 46.0±3.4 Ma, Mezoma location peak age is 41.8±1.6 Ma, and Jotsoma ages fit peaks shown as 32.0±2.6 Ma. The grain age range was usually dominated by young peaks, P1, which would have been subject to the study and ranged from 32.0 to 46.0Ma (Table 3; Fig.2c). There were older peaks present, 32% and 46.5% of the total distribution was present (Fig.2; Table 4).

Provenance and Long term exhumation

Many researchers published about provenance studies in sedimentary rocks over the years (Schlanke.S (1974), VonEynatten, H (1996, 1999), Schlunegger.F (1998), Garzanti.E, (2008) Jeffrey M.Amato and Greg H. Mack (2012) Xinchuan Lu (2018). The detrital ZFT can use the data of provenance analysis (Hurford, A.J (1984, 1991), and Carter. A., (1999), Wei Wang (2010). Each sample peak age is shown in Table 2, and they are associated with the times, it can be utilized to distinguish their potential sources of the Barail sediment group in northeastern Himalayan by comparing to the recent bedrock Fission Track ages (Fig.3). ZFT grain-age peak can be obtained from source areas where the recent bedrock detrital age of ZFT is younger or equal to the age of peak and these relationships allow the source area to contain candidates.

Generally, the peak ages between 32-46 Ma is importantly from the intensely exhumed sedimentary rocks of Barail, Nagaland. Detrital grains with freezing ages of around 32 Ma are insignificantly supplied from Late Eocene to Oligocene. In Figure 3, a contrast of euhedral, rounded zircons in four quarry parts is shown, which is deposited in the hinterland basin from 44 to 37 Ma. Because volcanic zircons have a common euhedral grain shape; if the volcanic input is significant, we expect to find only a strong shape-age relationship with the 32 Ma cooling age with euhedral grains. There were three hundred euhedral grains of the cooling age, younger and older euhedral grains, and rounded grains of the same age in each sample. The strong relationship between solid shape ages, which does not lead all 32Ma cooling ages to Oligocene Volcanism (Dunkl. I, 2001) have therefore not been confirmed. The maximum of 30-50 Ma will originate from the Nagaland that was eroded in the late Eocene-Oligocene from the locations, but it still occurs in parts of the North Eastern Himalaya.

The evolution of Peak ages in hinterland sediment deposits over time gives us an understanding of the long-term history of exhumation in Hinterland Naga Hills. Overall, P1 shows the most stable trend since late Eocene (44Ma) and Oligocene (37Ma) in the hinterland samples. In these result comes about can be point by point in two ways. The primary alternative is that at a certain time some source regions are expelled and give zircons with shorter times, but then the rapid exit is shifted to a different area, from which the short-lagged young zircons are supplied to the basins (Willett, S.D and Brandon, M.T, 2002). This thermochronology defined the condition as the time-invariant generation of the cooling age within a given spatial domain. Secondary alternative, zircon sources have been expelled at a constant rate. Such exhumation rates ought to be set up before reported by the primary event of detrital zircon with an 8 Myr lag time since none or partially recuperated cover-units must be removed first to see the young cooling age in the sediment record.

The crystal clear response is that the sample coverage in the hinterland basin is very complete, but it is also important that all samples are taken from the Barail group sequences, which have the benefit of being the best combination and can include all the different Fission track grain age components revealed at a regional scale in the source area. Samples taken near the source indicate a more local area, possibly a single surface area, not required by location in the FT ages of the whole orogenic system (Bernet, 2004a). Source areas can be located in Nagaland for 46Ma P1 zircon and do not directly affect the exhumation as a result of normal fault but only erosion. Old peak grains (180 Ma) can only be obtained from partially restored covered units, such as partially formed zircon P1 in each sample or re-established.

The fraction of grains with the Barail sediment cooling age (30 Ma) increases the overtime, which suggests that the surface area of zircon exposed bedrock with the Barail sediment, may have increased over time, at least for all the cooling ages, because the exhumation rates are very stable. With the accessible information, it is not evident how this relates to a possible alter within the measure of the mountain belt as proposed by researchers. For example, Schlunegger, F (1999) suggested the elevation mountains at the end of the Eocene to Oligocene based on the thermochronological details, dynamic modeling, and Cederbom C.E. (2004) assumed the narrowing of the orogenic system from uplifting and recycling of hinterland sediments to northeastern of the Himalaya since Eocene to Oligocene.

Exhumation history of Oligocene to Eocene ages

The cooling period provides a distinct relationship with the long-term exhumation and deposition of the sediment, whereas the cooling process is closely linked to the uplifting and exposure of sources' rock (Bernet 2005). Because the time to move erosion and sediments in comparison (Braun 2006, Brandon 1992) is quite short, the related data can provide the time delay. The period of delay is characterized as the difference between peak age and the age of deposition, Garver., (2006), Reiners. P.W (2005, 2007). In the absence of a thermal reset after burial, the quicker the law lapses the faster and measured the exhumation rate (Bernet, 2005). Erosion is largely responsible for the exhumation of the upper crustal (6-8 km deep) (Bernet, 2011). Thereafter, all ZFT ages in each sample were taken to represent the Exhumation rate of the rock source.

The interpretation of the time results and the changes in peak age by region can be based on the binomial fit within the main peaks to establish the historic exhumation status of the Barail Group. Within the permitted error spectrum, the peak age is about (Table 4) and the time decreases with the depository age and stays constant for the same strata. We tried to display peak age averages and measure the time given the effect of small grain counts on each sample. The Zircons have either placed such a peak;(1) It is extracted from a source rock which has undergone rapidity; But short-lived, cooling event and then gradually ejected;(2) recycling from a sediment source, whether the peak age is comparatively old and precedes oogenesis; or (3) the degradation of dense sections of non- reclaimed volcanic rocks(Bernet, 2011). Moreover in Patkai-Kohima numerous tectonic and sedimentary events occurred in sync, with plates from India and Burma colliding between about 35 and 50 Ma. The provenance details and cooling history obtained from sandstone may help to explain the creation of synchronous exhumation in Patkai-Kohima, where some samples have been dated so far. 5Ma shows the onset of the rapid evacuation of cooling paths from sandstones. Syntax regions full cooling histories have been collected for the first time and can be compared to the cooling and exhumation history of the other areas of the orogeny. This comparison highlights the similarities and distinctive variations illustrated by the intermediate Patkai-Kohima syntax between the east boundary of the Indo-Burmese plate and the western compression and subduction setting. According to our study, the zircon from the northeastern Barail Group sediments appears to come from Type A, which implies that the Barail Group has undergone a fast increase at 35-50 Ma and then has been exhumed gradually since then. If the exhumation rock is moderate induces long lead times and poor cooling (Garver. J, 1999b and Reiners P.W, 2006). The ZFT (240 ± 30 ° C), broadly dispersed ~40 Ma ZFT period, gradual exhumation and cooling rate of 4.1°C/myr after a fast, but short, cooling event at ~35-50 mare, were, by comparison, high closing temperatures. The initial Cenozoic uplift of the Barail Group took place at ~35-50Ma based on this analysis, based on ZFT results. On the basis of this ZFT study, a Cenozoic uplift of 35 to 50Ma occurred at the initial Barail group. In conjunction with the widely recognized Patkai-Kohima tectonic elevation occurrence align with the early advent of the Indian-Burmese collision by Cenozoic.

Conclusions

Detrital zircon FT results of each sample were used for the determination of sediment provenances and the long term exhumation rates in the Northeastern Nagaland. Sandstones from the Barail samples of the north-eastern Nagaland regions are conceptually identical, similar in age distributions, derived from recycled orogenic sources to their detrital zircon populations. A younger, Oligocene to Eocene, regardless of stratigraphy age, are the dominant population of the zircon within the sandstones. Four samples of Barail sandstone show a rather narrow span of central ZFT ages between 37.4±1.5Ma and 49.9±2.4Ma. Data from ZFT and sedimentary areas indicate that the Barail group has only rapid, regional uplift and cooling age at ~35–50 Ma when detritus material is delivered from northeastern Nagaland. It is uplifted from the Indian-Burmese collision. Since the Early Cenozoic Cooling age ~40 Ma, during the Early Cenozoic Cooling age, the Barail formations had a gradual exhumation and a cooling rate of 4.1°C/Myr. It is worth noting that in the Hinterland basin the long-term exhumation signals have been deposited over time. The ZFT data provided here provide no hint that the tectonic or climate structure in Naga Hills has experienced significant long-term exhumation since the continental crash and seems to be indifferent to 5 Myr. In Brief, ZFT data shows that the first Cenozoic uplift of the Barail Group occurred in ~35–50 Ma, in conjunction with a widespread tectonic uplift on the Patkai-Kohima synchronous with the onset of the Indo-Burmese collision during Early Cenozoic period. It concluded that since the Eocene-Oligocene period the Barail group exhumation pattern is driven by tectonic.

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Figure 1,2,3.

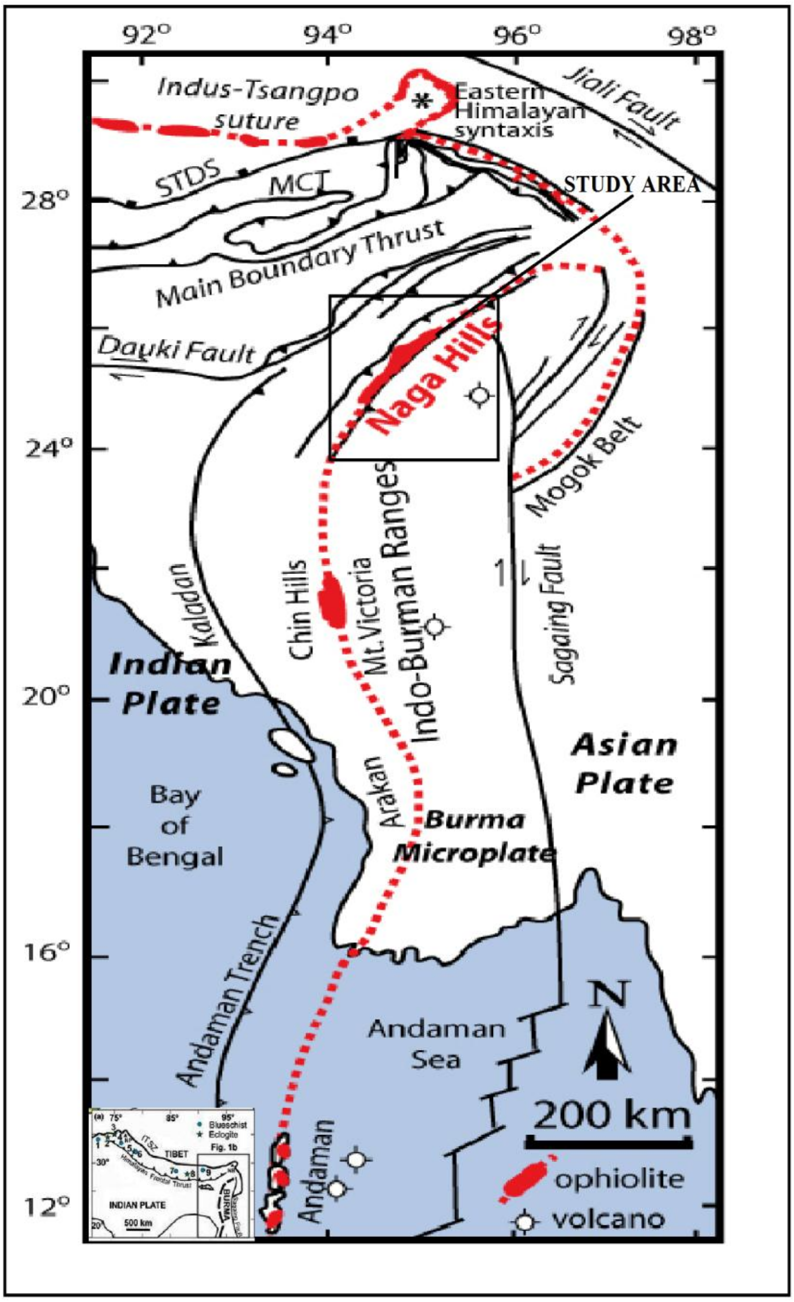
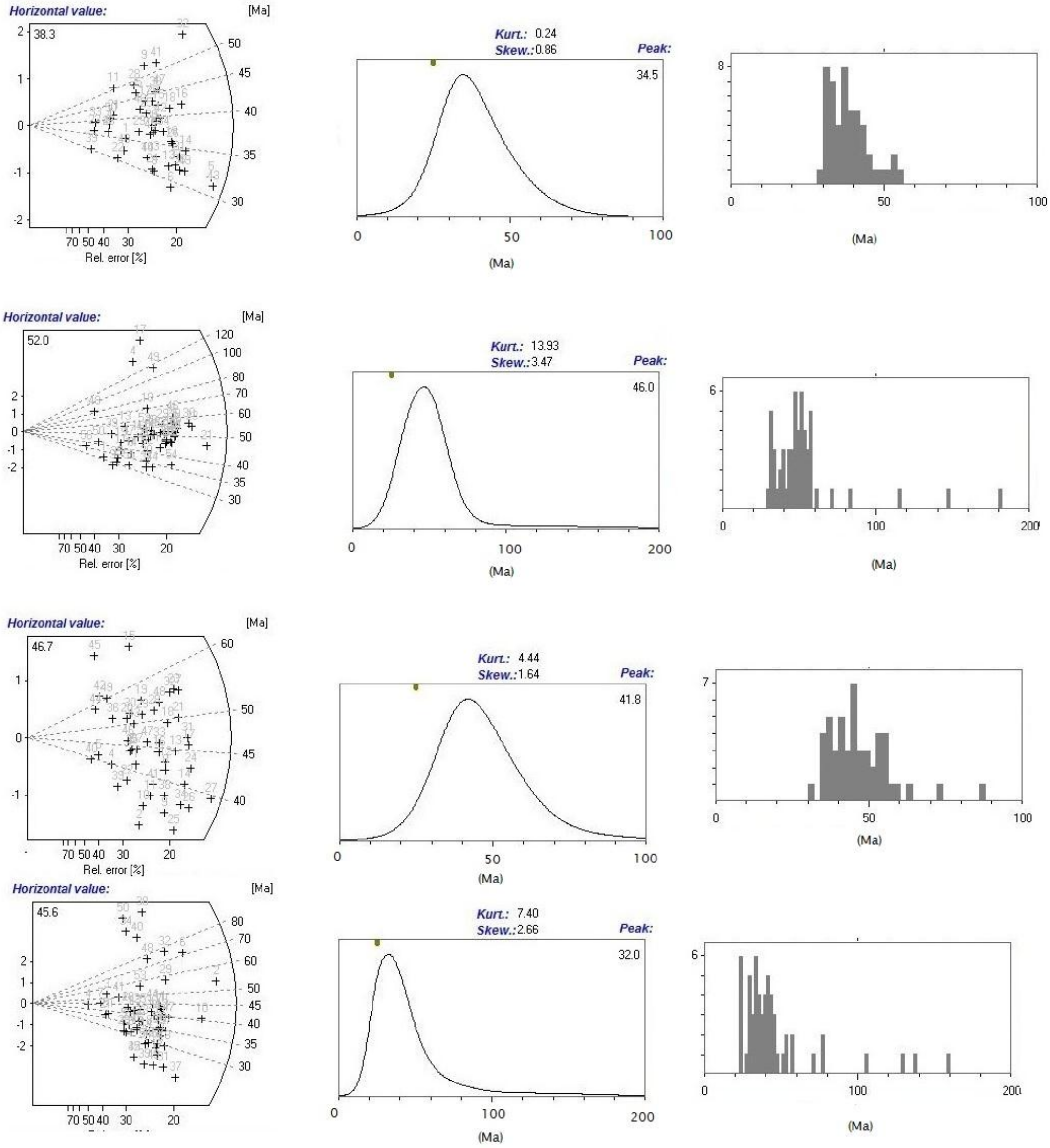


Fig.1. Simplified tectonic map of Nagaland and its surrounding areas (Modified by Nilan Chatterjee, 2014)



Figs. 2 a,b,c. Detrital zircon fission-track radial plots and single-grain age and decomposed age distributions for the northeastern Barail formation; the black crosses represent single-grain ages, gray dashed lines are the curves of observed grain age distributions, and bold lines are the curves of binomial best fit peaks; peak fitting follows Galbraith and Green (1990)and Brandon (1996) using BINOMFIT (Brandon, 1992).

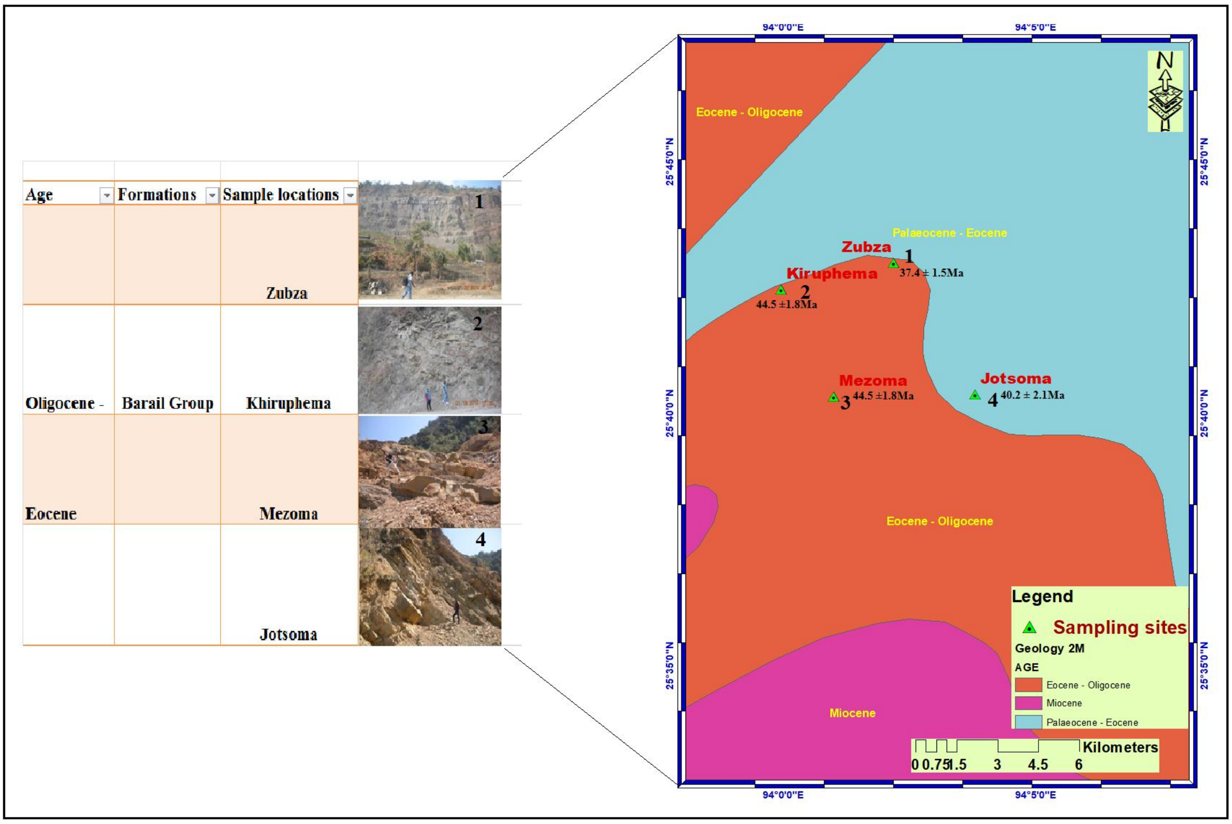


Fig. 3. Geological Map of the Nagaland showing evidence of rejuvenation or initiation of tectonic activity at ~35–50 Ma.

Table 1. Generalized stratigraphic succession of Nagaland, Eastern Himalaya (after Mathur and Evans, 1964; Agrawal and Ghosh, 1986; GSI, 1978; Gupta and Biswas, 2000, 2010)

Age	Group/Sub-Group	Formation and Thickness in metre	Lithology
Pleistocene to Holocene	Alluvium	Alluvium	Gravels, silts, and clays
Pleistocene	Dihing	Dihing (300-1600m)	Pebbles, Cobbles, and boulders of sandstone in a ferruginous coarse sandy matrix.
Pliocene to Pleistocene	Dupitila	Namsang (800m)	Sandstone, coarse occasionally pebbly gritty with mottled clay bands.
Miocene to Pliocene	Tipam	Girujan clay	Mottled clays, shales of varied colours with medium to fine-grained sandstone.
		1200 –2300	
		Tipam s.st	Massive sandstone, medium to coarse-grained with current bedded structures
Miocene	Surma	Bokabil (400m)	Alternations of shales with siltstone and sandstone.
		Upper Bhubhan (400m)	Alternations of sandstone and shale.
		Middle Bhubhan (450m)	Silty shale with sand lenticels, sandstone medium-grained soft with current ripples.
Late Eocene to Oligocene	Barail	Renji (900m)	Sandstone medium to thick-bedded, fine-grained, well sorted. Occasional carbonaceous shales.
		Jenam (850m)	Shales with subordinate sandstone; Sandstones occur as lenticular bodies and as thin bands.
		Laisong (1750m)	Sandstone with minor silty shale. Sandstone thin to thick-bedded.
Cretaceous to Eocene	Disang	Upper (1800-3000m)	Dark grey, splintery shale with non-calcareous siltstone and silty sandstone.
		Lower	metamorphosed sediments of slates, phyllites with lenticular limestone beds.Ophiolites

Table. 2. Detrital Zircon Fission Track Dating Results for the Barail Group

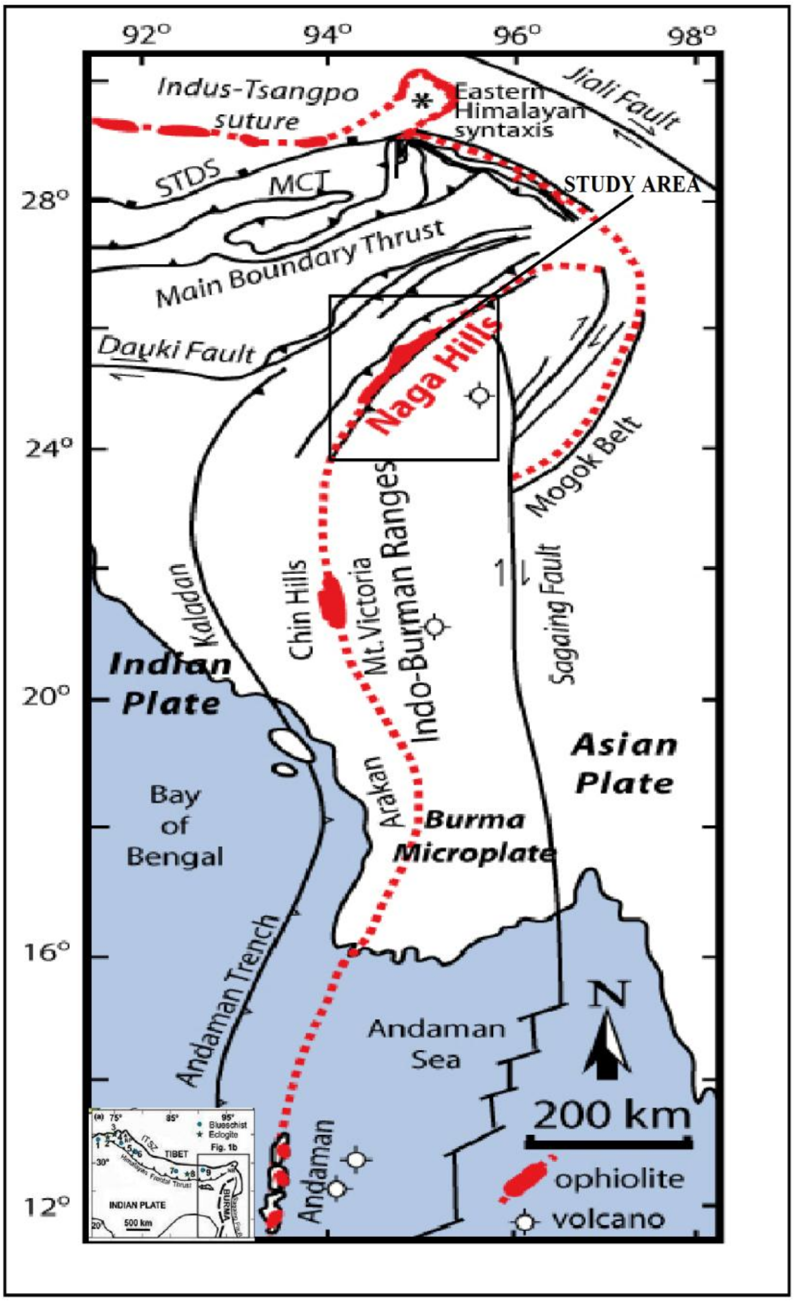
Sample name	Location	Elevation	Nc	ρs (105/cm)	ρi (105/cm)	ρd (105/cm)	P(χ2) (%)	Central age
				(Ns)	(Ni)	(Nd)		(Ma) (±1σ)
Zubza	25°44.235’	907	50	3.79E+06	2.42E+06	3.84E+05	0	37.4 ± 1.5
Khiruphema	25°43.855’	994	46	6.20E+06	3.33E+06	3.84E+05	0	44.5 ±1.8
Mezoma	25°40.520’	1443	56	7.27E+06	3.52E+06	3.84E+05	0	44.9 ± 2.4
Jotsoma	25°39.548’	1716	68	5.56E+06	3.22E+06	3.84E+05	0	40.2 ± 2.1

Nc = number of zircon crystals analyzed. P(χ2) = the probability of χ2 for ν degrees of freedom (where ν=Nc _1) [Galbraith, 1984. The age calibration standard used was Fish Canyon Tuff zircon (28Ma); the CN glasses prepared by J. Schreurs at Corning Inc., Corning (New York) was used as a dosimeter to measure the neutron fluencies during irradiation. All analyses were performed by Wanming Yuan, who employed a personal weighted mean zeta while using the above methods and standards.

Table. 3. Decomposed Results of Detrital Zircon Fission Track Grains and Peak ages

	Strata range (Ma)	**N**	**Young Peak age**	**Old Peak age**	**Age range (Ma)**	**Mean age, Width, and Size of best peaks**
Sample Locations						**Peak (ma)**
Zubza						34.5±0.8
	33-56	50	34.5	-	29.10-55.67	W=0.92
						Nf=46.5%
Khiruphema						46.0±3.4
	33-56	46	46	86.92	31.68-86.92	W=0.62
						Nf=32%
Mezoma						41.8±1.6
	33-56	56	41.8	181.81	28.52-181.81	W=0.87
						Nf=35%
Jotsoma						32.0±2.6
	33-56	68	32	159.31	26.25-159.31	W=0.4
						Nf=42%

N-the total number of grains counted; binomial peak fit age has given are a ±2σ error. The percentage of grains in a specific peak is also given.



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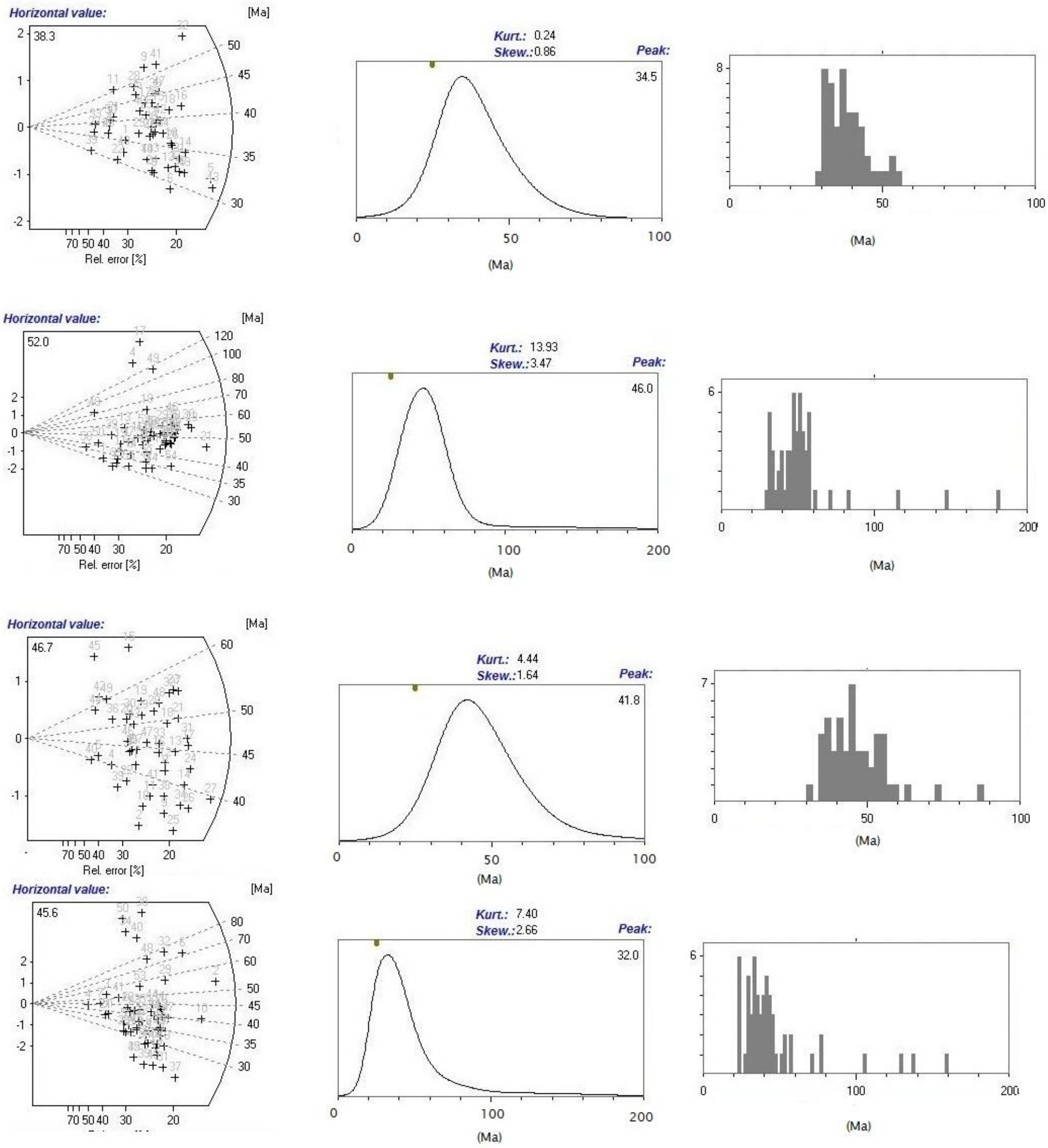

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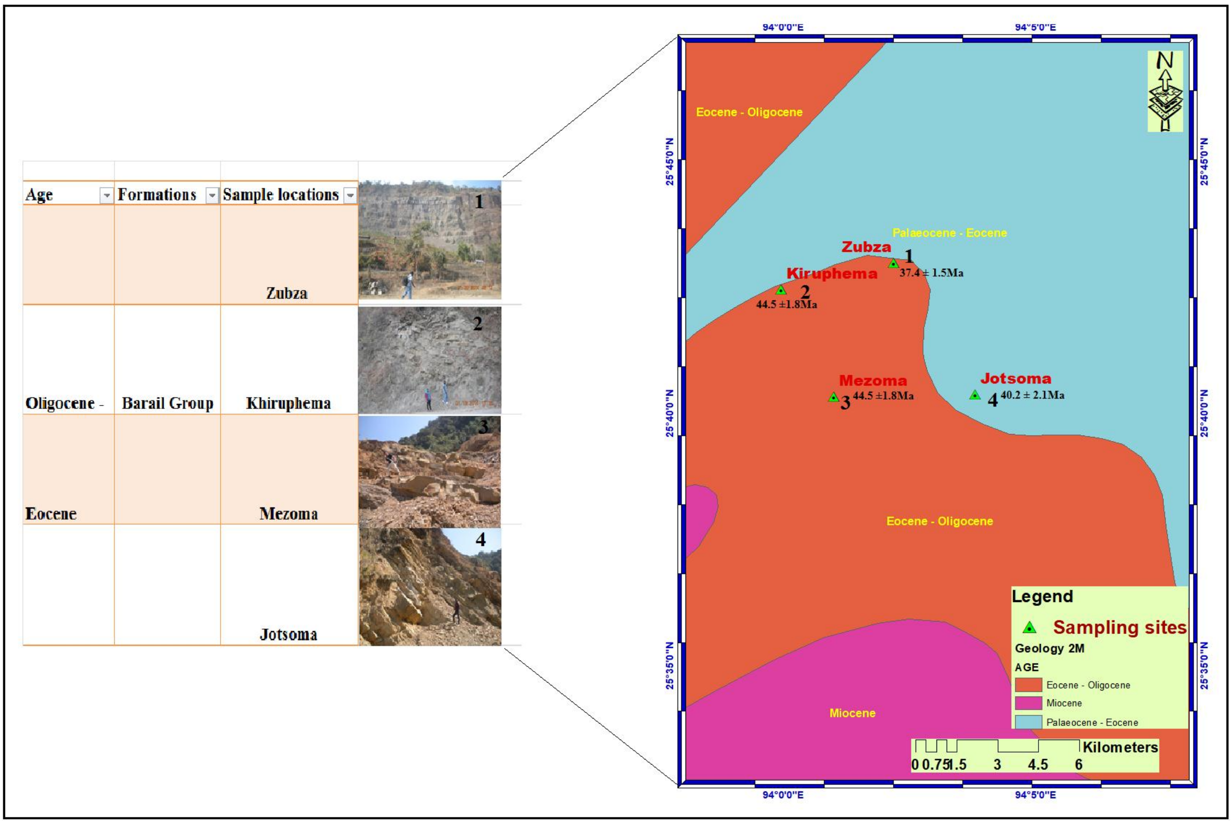

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