

Geologic and Tectonic Evolution of the Yinkiong Group and Abor Volcanic Rocks in the Eastern Himalaya: An Overview of Geologic Data

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Abstract—The Siang valley in the eastern part of Arunachal Himalaya contains Paleocene–Eocene sediments of Yinkiong Group along with the Abor volcanic exposed in a wide lateral extent in the middle and lower Siang valleys. Based on available geologic data and detail geologic mapping present study proposes a new evolution model of the basin in the context of India–Asia collision tectonics. Integration of the field data on the disposition of different litho units from Pasighat (south) to Tuting (north) along the Siang valley and in the Mishmi block, helped us to constrain several major thrust fault and strike-slip faults in the area showing dextral and sinistral senses. Some of these faults are conjugate. It is postulated that during the early Paleocene, the Indian Plate collided with the Eurasian Plate and this collision resulted in the breakage of an edge of the Indian Plate along its northeastern extremity. This broken edge rotated towards the Burmese Plate and eventually formed a rift basin that led to the ingress of the Tethys Sea where sedimentation along with syn-sedimentary volcanism took place. The sedimentation in the basin continued throughout the Paleocene–Eocene time. The absence of rocks younger than Yinkiong Group indicates that this basin was closed at the end of the Eocene. The development of a highly folded sequence along the Siang valley in response to north south-directed compression can be constrained due to subsequent India–Asia collision. The broken edge of the Indian Plate and western part of the Burmese Plate amalgamated through Tuting–Tidding suture. This Indo-Burmese amalgamated part of the Mishmi block thrusted over the Paleocene–Eocene sequence from the east. The continued NNW ward movement of the Mishmi block resulted in the swinging of the MCT towards the northeastern direction. On the other hand, the overriding of the Himalayan metamorphic belt along the Tidding Thrust was intense, leaving only a narrow exposure of garnetiferous graphite-schist and garnetiferous amphibolites as slivers of the ophiolite package. The Lesser Himalayan sequences of the Mishmi block overrode the frontal molasses basin in many places and are in direct contact with the Brahmaputra alluvium in the southeastern part along the Lohit and Dibang valleys. The Lesser Himalayan sequence also overrode the Paleocene–Eocene sequence from the western direction showing significant occurrences in the Boleng and Bomdo area of the Siang valley.

Keywords: Eastern Himalaya, Siang valley, Paleocene–Eocene sequence, Yinkiong Group

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INTRODUCTION

One of the youngest mountain belts on the Earth, the Himalayan Orogen, is formed after the India–Asia collision and offers a superlative opportunity for understanding the development of mountain chains [57, 59]. The collision of Indian Plate with the Eurasian Plate during the Cenozoic period resulted in the formation of the Himalayan–Tibetan Orogeny [15, 31]. The 2400 km long, EW trending Himalayan orogenic belt terminates at the Nanga Parbat syntaxis in the west and the Namche Barwa syntaxis in the east [17]. The NE plunging, crustal-scale Namche Barwa antiform rep-

resents the Eastern Himalayan Syntaxis (EHS) [11]. In the eastern Arunachal Himalaya, Siang antiform is located in the SW part of the Namche Barwa Syntaxis. The NNW plunging Siang antiform is therefore also a crustal-scale structure and represents subsurface indenture of the buckled Indian basement below the Asian Plate [3]. Permian to younger Eocene lithostratigraphic units occupied at the core of the Siang antiform [46] and older Lesser Himalayan Sequence (LHS) and Higher Himalayan Sequence (HHS) lies on both the limbs of the antiform [11]. The generalized EW trend of the lithostratigraphic succession of the eastern Hima-

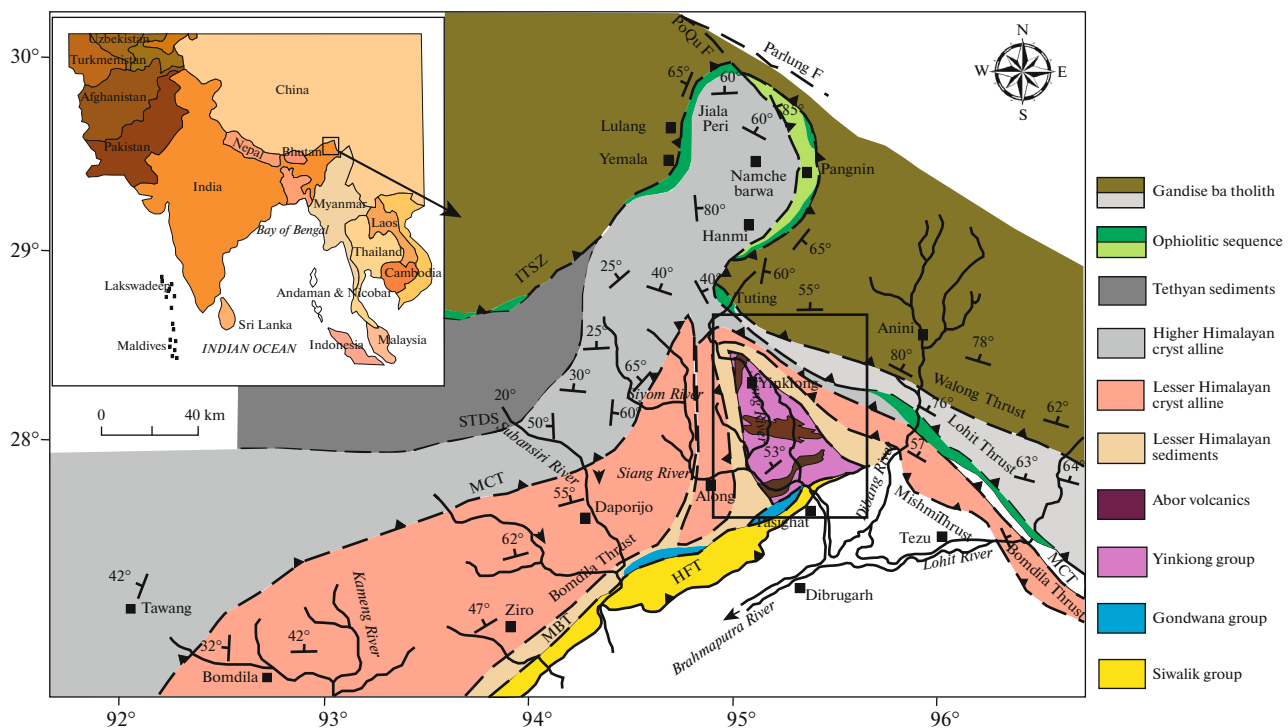


Fig. 1. Regional geological map of Eastern Himalaya (modified after [43]).

laya is traceable up to the Bame fault, in the western part of the Siang valley. However, the lithostratigraphic succession in the central and eastern Siang valley is quite dissimilar [26]. Regional geological map of the eastern Himalaya (Fig. 1) indicates that Gondwana and Lesser Himalayan rocks are thrust over the Siwalik Group in the western and central part of Arunachal Himalaya. But in Siang valley, Yinkiong Group of rock of Paleocene–Eocene age are thrust over the Siwalik Group.

Although the number of research conducted in this region on geology, structure and tectonostratigraphic setting of the Eastern Himalayan Syntaxis, however, the origin and evolution of the Paleocene–Eocene sequences, i.e., the Yinkiong Group of rocks along the Siang valley is still an enigma. The regional litho-succession of the Himalaya suggests the occurrence of LHS after the Siwalik and Gondwana Group, but in the Siang valley occurrence of Yinkiong Group and its vast N–S extent in place of LHS brings a mystery about the regional geology of the eastern Himalaya (Fig. 2B). The present work mainly focuses on the origin and subse-

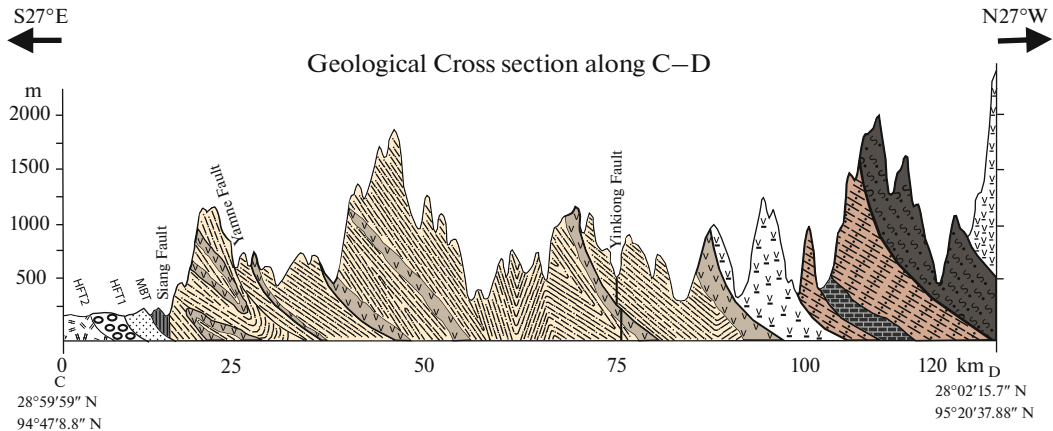
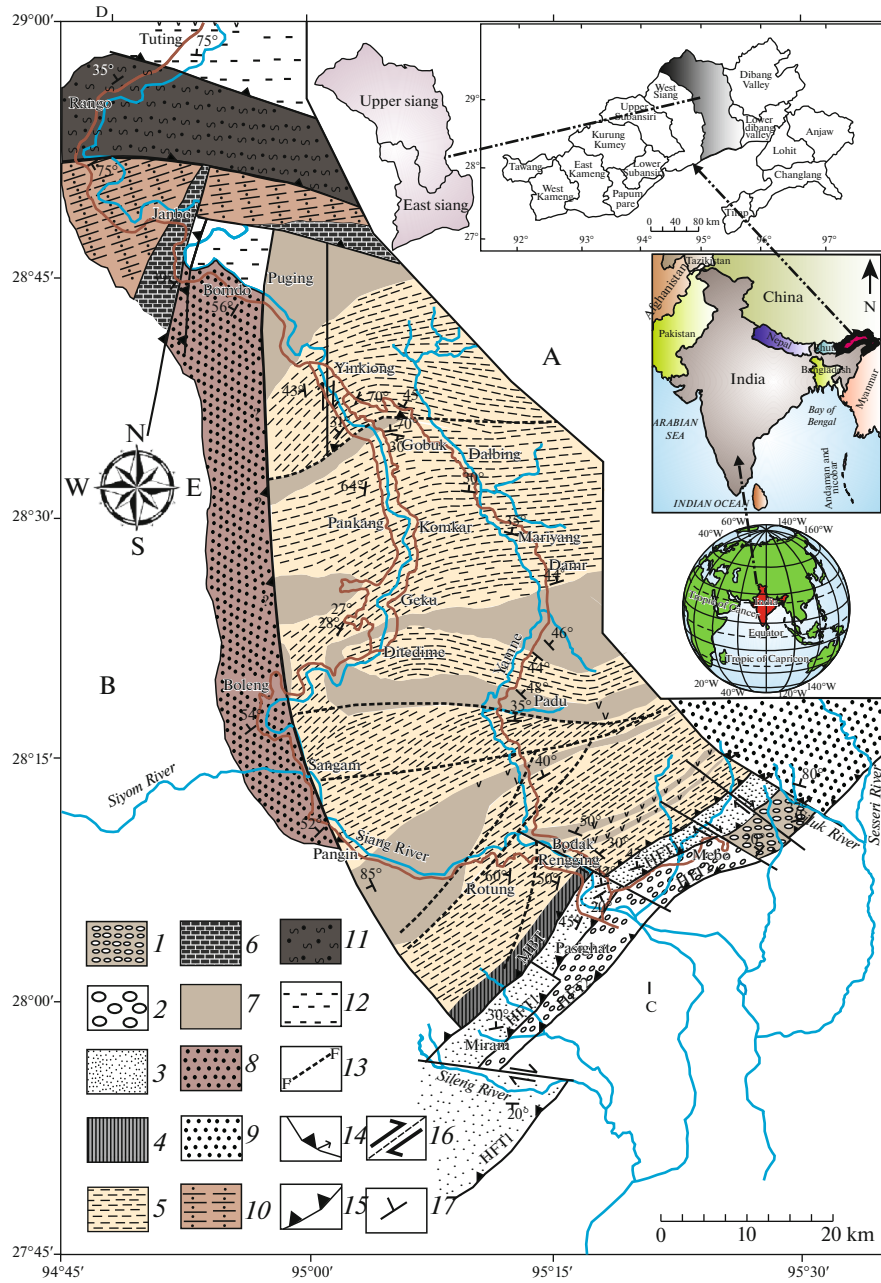
quent development of the Yinkiong Group of rocks, the presence of volcanic rocks namely Abor Volcanics, and its relation to the India–Asia collision. Although there is not any geochronological data, an attempt has been made to develop an evolutionary model based on published data and extensive field investigations along the Siang valley and Yamne valley. In this model, the development of the rift basin and deposition of the sediments with syn-sedimentary volcanism during Paleocene–Eocene time have been postulated. Subsequently, the basin was closed during late Eocene as the Indian Plate collides with Eurasian Plate in the north and Burmese Plate in the east. These collisions result in intense deformation of rocks of the Yinkiong Group due to N–S and E–W compression.

GEOLOGICAL SETTING

The Eastern Himalaya

The Eastern Himalaya (EH) mainly comprises of two parts, namely, Transhimalaya and Himalaya [46], which are separated by the Tuting-Tidding Suture [2]

Fig. 2. (A) Location map showing East and Upper Siang districts of Arunachal Pradesh of India. (B) Geological map showing different lithological and tectonic units along the eastern margin of Arunachal Himalaya: (1) Kimin Formation; (2) Terrace deposit; (3) Siwalik Group; (4) Gondwana Group; (5) Yinkiong Group; (6) Crystalline Limestone; (7) Abor volcanic; (8) Lesser Himalayan Quartzite; (9) Quartzite; (10) Lesser Himalayan Metasedimentaries (Schist and Gneiss); (11) Graphitic schist; (12) Metavolcanics; (13) Fault; (14) Oblique slip fault; (15) Thrust fault; (16) Strike slip fault; (17) The attitude of bed. (C) Geological Cross section along C–D (see Fig. 1) showing main lithological units and major structures of the area. This figure clearly shows the folding nature of the Paleocene–Eocene sequence in Siang window.



or Tuting-Tidding Belt [48]. In EH, the Transhimalayan part encompasses two main lithostratigraphic units; Tuting Granite in the north and Tuting Metavolcanics in the south, and each separated by the Yang Sang Chu Thrust [46]. The NW–SE trending Tuting Granites are confined to the northeast corner of the Eastern Syntaxial Bend (ESB) and extend up to the Dibang valley. The Tuting Granite and the Mishmi Diorite–Granodiorite complex, possibly represent large batholiths of Transhimalayan granitoid [48].

The Himalayan part of the EH, spread from the Himalayan Frontal Thrust (HFT) against the Brahmaputra plain in the south to the Tuting–Tidding Belt in the north, encompassing Proterozoic to Cenozoic rocks [46]. These units are named as Siang Group, Siyom Group, Rikor Group, Nikte Quartzite, Abor Volcanics, Yinkiong Group, Gondwana Group and Siwalik Group. The Siang Group comprises high-grade rocks and occurs as a linear belt between the Tuting Granite/Tuting Metavolcanics in the north and the low- to medium-grade metamorphic of Siyom Group in the south [26]. The Siyom Group consists of slate–limestone association, schistose quartzite, biotite–garnet schist, graphite schist, carbonaceous phyllite that tectonically overrides the Rikor Group in the Siang valley section [46]. The Rikor Group comprises quartzite–limestone–dolomite–phyllite and bounded between the Nelleng and Siyom thrusts against the Abor Volcanics and Yinkiong Group and the Siyom Group towards south and north directions respectively [46]. The Abor volcanic are extensively developed, massive, vesicular to amygdaloidal and porphyritic basic volcanic rocks present along the Siang and Yamne River sections [12]. These volcanic rocks are associated with the Paleocene–Eocene sedimentary sequence; Yinkiong Group. The southernmost ENE–WSW trending Siwalik Group (Upper Tertiary) rises abruptly above the Brahmaputra alluvium and thrust to the north by Gondwana Group [26].

Siang Valley

Siang River section

In the Lower Siang valley, from Pasighat to Siang-Yamne River confluence (SYC), there is an exposure of a wide variety of rock; Siwalik Group, Gondwana Group, Yinkiong Group and Abor volcanic. The Siwalik Group (sub-Himalayan) of rocks are overlain by para autochthonous marine Gondwana sequence along North Pasighat Thrust (NPT) [3]. The Siwalik Group exposed about 5 km along the Pasighat-Rengging road section, and further divided into Kimin, Subansiri and Dafla formations. The Kimin Formation is ~50–100 m thick and mainly characterized by a conglomeratic sequence consisting of alternating bands of conglomerate and sandstone (Fig. 3a). The Subansiri Formation is about 1500–2000 m thick and characterized by light grey, salt and pepper textured,

coarse- to medium-grained micaceous, thick-bedded massive sandstone (Figs. 3b, 3c). The Dafla Formation lies to the north of Subansiri Formation, which dominantly consists of grey to brown, fine- to medium-grained sandstone with tight folding (Fig. 3d).

It would be worth mentioning that the Gondwana and Dafla Formation are not exposed on the east bank of the Siang River, whereas, on the west bank, gentle north dipping fault plane exposes the Subansiri Formation which is overlain by rocks of the Dafla Formation in the north. The Gondwana rocks along this section are sandwiched between the Dafla Formation and Yinkiong Group. Beside the Siang valley, in other parts of Himalaya, the Lesser Himalayan Sequence in the hanging wall of the MBT comprises of Gondwana Group and Proterozoic low-grade metamorphic rocks. In the west bank of the Siang River, Siwalik Group has thrust contact with the Gondwana sequence, but Gondwana succession is overridden by Paleocene–Eocene Yinkiong Group in the east bank (Fig. 2B). The thin Gondwana belt consists of sandstone, quartzite, grey to black shale (Figs. 3e, 3f). In the hanging wall of the NPT/MBT, the shale–limestone–sandstone sequence of Yinkiong Group is exposed on the east bank of Siang River (Fig. 4a). The Yinkiong Group is differentiated into two units, late Paleocene to early Eocene Lower Yinkiong Formation (LYF) consisting variegated shale (grey, purple, pink) mixed with limestone and sandstone and mid-Eocene Upper Yinkiong Formation (UYF) consisting of shale, limestone, silty shale and fine-grained sandstone [16]. Additionally, basic volcanics occur in association with this shale–limestone sequence (Fig. 4b). Large massive dark green to black very fine volcanic rock exposed near Bodak village (Fig. 4c).

The volcanics showing the concordant relationship with the folded and thrustured Yinkiong Group of rocks further indicate a phenomenon of syn-sedimentary volcanism in the shale–limestone sequence (Fig. 4d). In various localities towards both north and south direction of Puding area, lower Siang valley, the mylonitic Abor volcanics have shown the thrust contacts [22] with late Paleocene to mid Eocene [7] Yinkiong Formation. Discordant relationship of the Abor Volcanics and the sedimentary sequence of Yinkiong Group are shown by the dykes cutting across the shale–limestone sequence near Rotung area (Fig. 4e). The intrusion of volcanic rocks in a folded sequence of Yinkiong Group is very prominent in the lower and middle Siang valley. These volcanics are considered Jurassic that is correlated with the Rajmahal Traps [12]. However, Gansser [20] correlated them with the Panjal Traps, and a study [26] reported them to be associated with Buxa-Miri Group and suggested a pre-Gondwana age. Nevertheless, after the discovery of Lower Tertiary rocks in the Siang valley by Geological Survey of India, a new line of thought had been developed [53, 54]. The association of these volcanic rocks with Yinkiong Group indicates the Paleocene–Eocene age of the

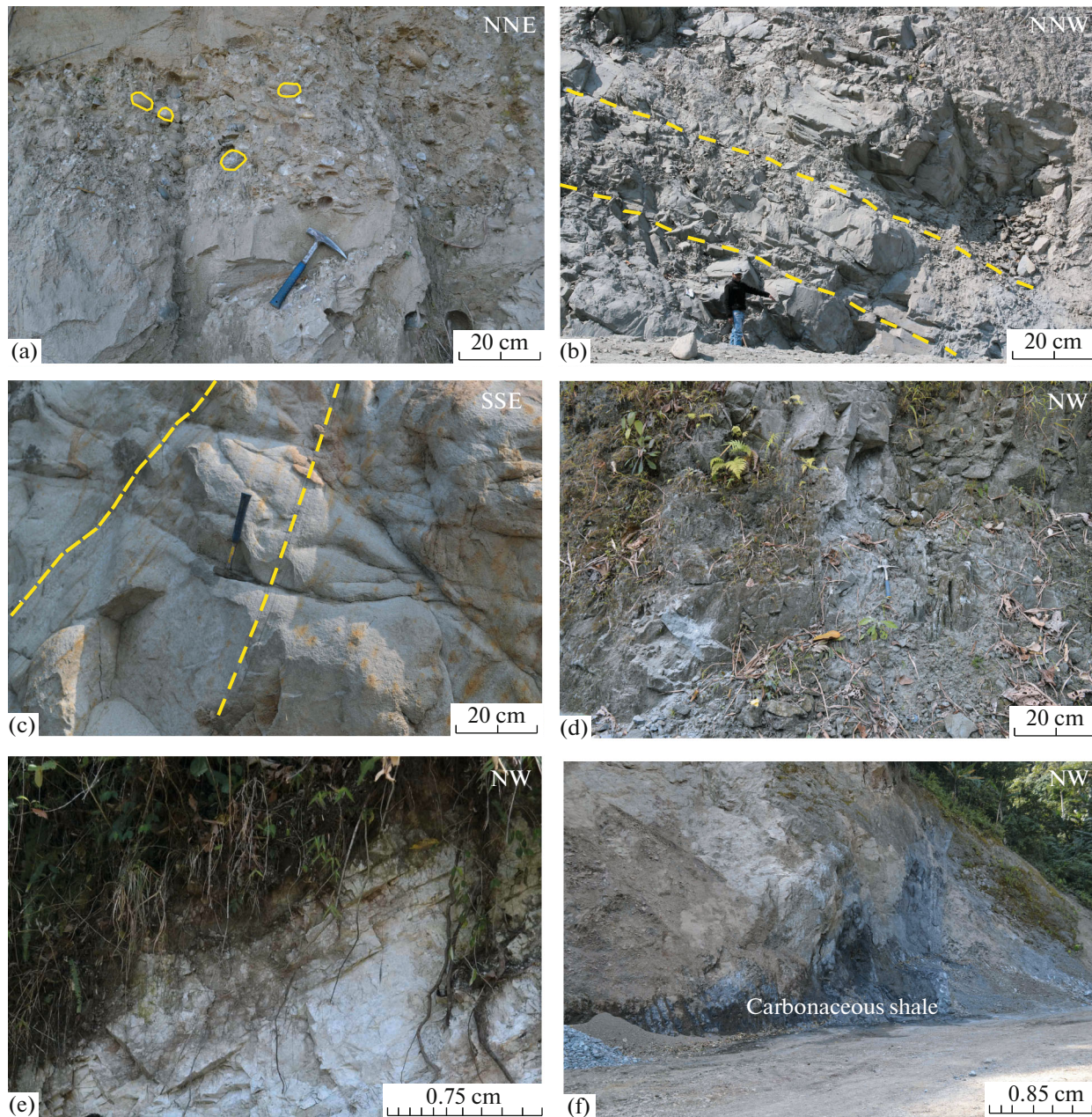


Fig. 3. (a) Kimin Formation consists of alternating bands of conglomerate with pebble and cobble and light grey friable sandstone exposed along the mountain front. (b) Hinterland dipping beds of Subansiri sandstone (light grey, medium to coarse grain) near Sirki Korong Nala on the west bank of Siang River. (c) Cross bedded sandstone of Subansiri Formation present 100 m downstream from Yeling Korong Nala on the east bank of Siang River. (d) Tight isoclinal fold in dark grey, fine to medium grain, massive sandstone of Dafla Formation. (e) Quartzite of Gondwana Group (white to light pink color) and (f) carbonaceous shale of Gondwana Group (dark grey color) on the west bank of Siang River.

volcanic. However, still it is a debate regarding the age of this volcanic, as some study proposed a wide range of ages ranging from Paleozoic to Eocene [4–6, 22, 29, 44]. The Lesser Himalayan Rikor Group is exposed from the Kebang–Pangin–Boleng road section having thrust contact with the Abor volcanic at the Pangin area. Earlier it has been clubbed with the

Abor volcanic and Yinkiong Formation to constitute the Miri Group [26]. The Rikor Group is divided into upper Pangin and lower Boleng Formation [46]. In Pangin it occurs as thin conglomerate lenses with quartzite bands and near Boleng massive white quartzite (Fig. 4f). In the present study, a detail field investigation has shown that LHS (Rikor Group) also appear

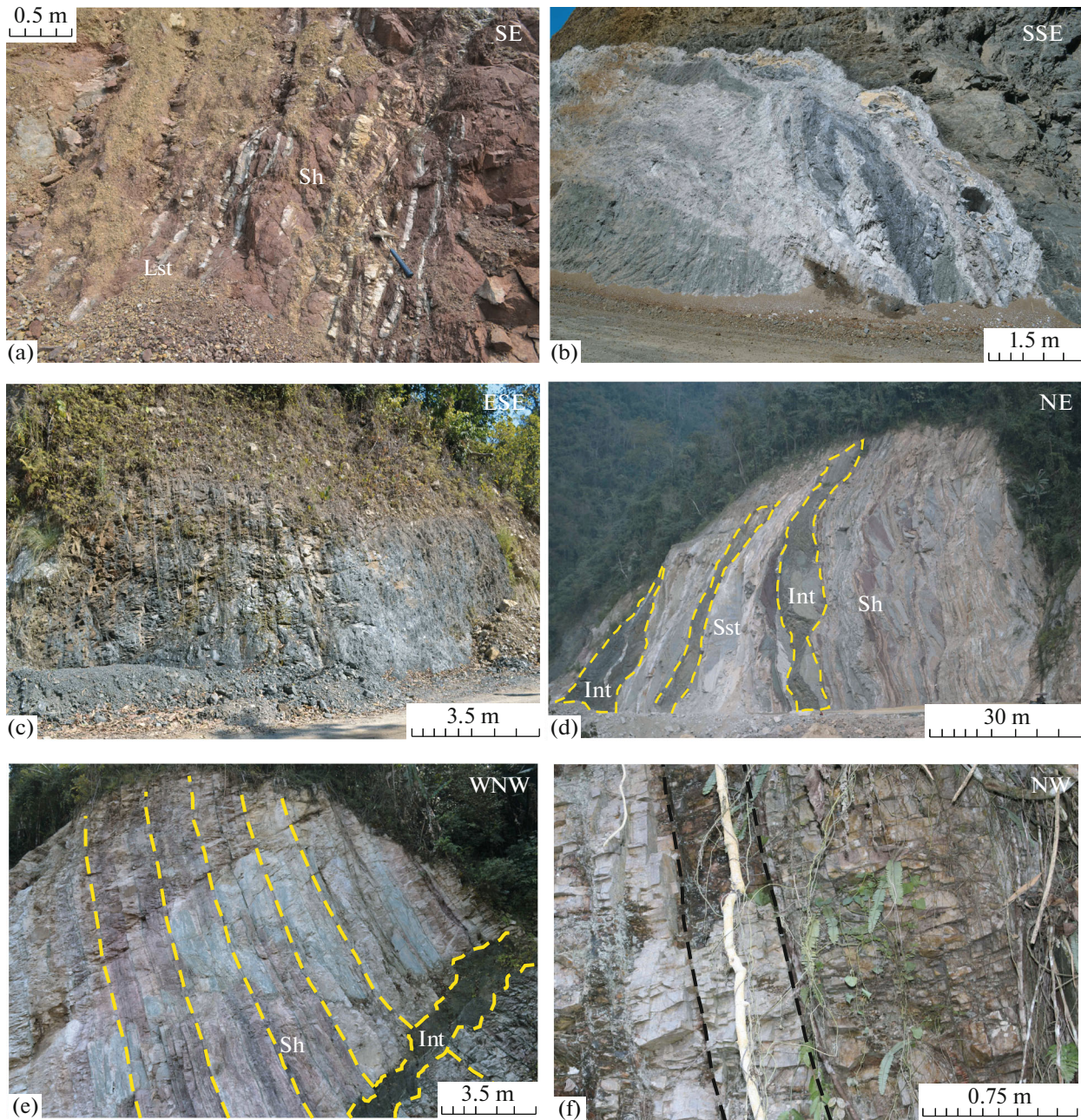


Fig. 4. (a) Shale-limestone sequence of Yinkiong Group of rocks near Modi Korong Nala on the east bank of Lower Siang valley. (b) Mixing of intrusive volcanic rocks and the Yinkiong Group 500 m upstream from Bodak. (c) Massive volcanic exposure (dark green to blackish grey) near Bodak village. (d) Concordant relationship of steeply dipping shale-limestone-sandstone sequence of the Yinkiong Group with the intrusive body near Siang–Yamne confluence. (e) Dyke basic intrusive rocks (dark green color) and shale-limestone (purple) sequence of the Yinkiong Group showing discordant relationship near Rotung. (f) Near vertical beds of Lesser Himalayan Quartzite near Boleng. Sh means shale; Sst, sandstone; Lst, limestone; Int, intrusive.

along the road section from Bomdo to Mosing, comprising of quartzite-crystalline limestone-phyllite with minor metavolcanics near Janbo (Fig. 5a).

A narrow band of LHS or Siyom Group [47] comprising of schistose and gneissic rocks, exposed along the road section from Mosing to Miging (Fig. 5b). Further to the north, the Siang Group of rocks is well exposed along the road section from Pango to Ningui-

ing that comprises of graphitic schist and dark grey slate (Fig. 5c). The most characteristic lithology of the Siang Group in the Upper Siang valley is graphitic nature (Fig. 5c) representing the Yang Sang Chu Formation [49]. Dark to light green metavolcanics are exposed in and around Tuting, representing the Transhimalayan part of the Siang valley. Along the Simang River, north of Boleng, Yinkiong Group of rocks reap-

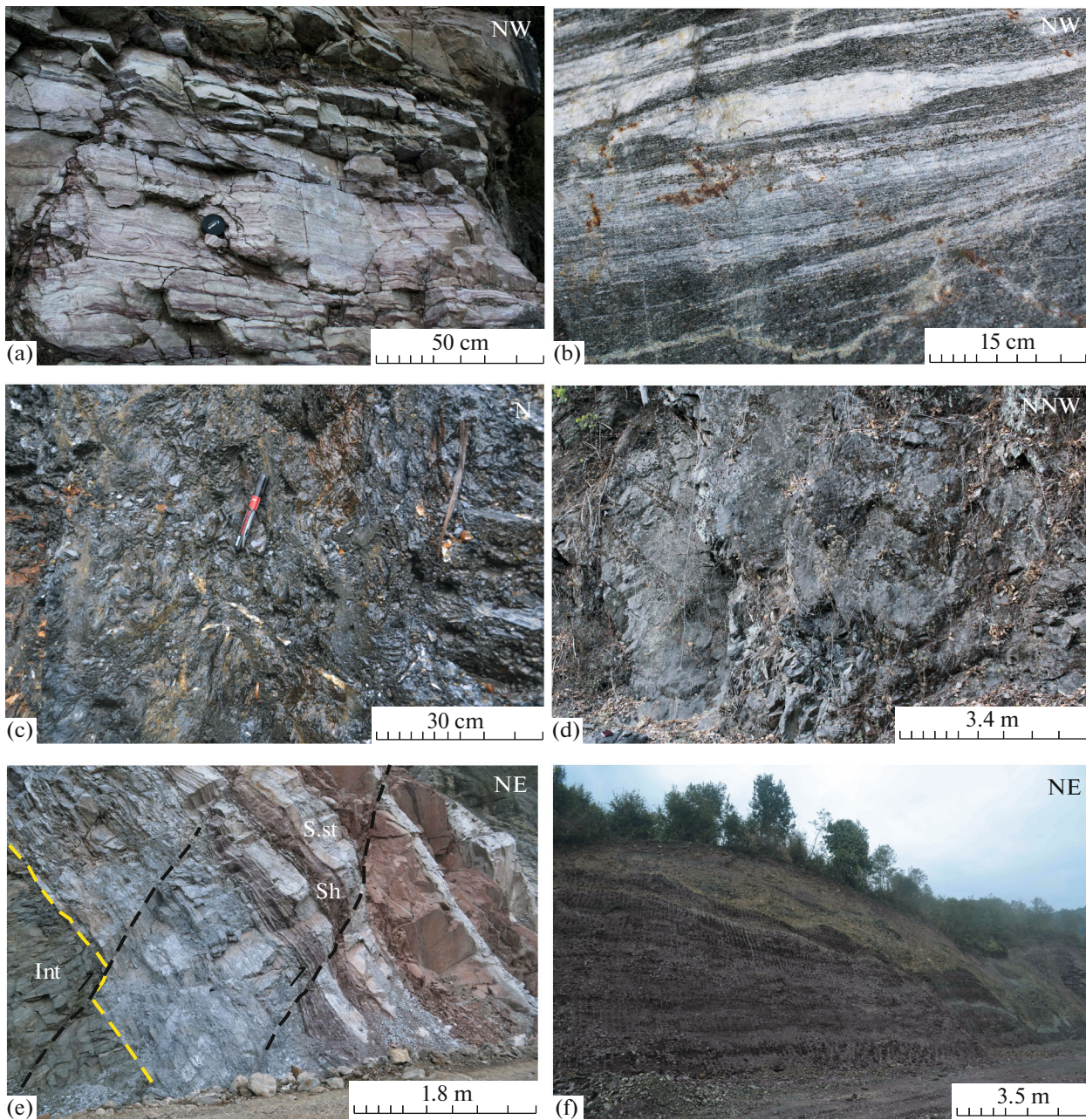


Fig. 5. (a) Off white Lesser Himalayan quartzite, beds dipping moderately to northwest direction, near Bomdo village. (b) Gneissic rock of Siyom Group exposed near Mosing village. (c) Graphitic schist of Siang Group exposed near Pango village. (d) Massive mafic volcanic rock (black to dark green) near Riga village. (e) Contact between (blackish green) volcanic rock with shale-sandstone of Yinkiong Group in the lower Yamne valley. Steeply dipping beds of purple shale and white sandstone are cut across by minor faults. (f) Purple color shale of Yinkiong Group near Mariang in the upper Yamne valley.

pears having contact between LHS and Abor Volcanics. The Yinkiong Group of rocks with Abor Volcanics has a wide lateral extent of about 30–40 km along the Siang River from Komkar (Middle Siang valley) to Ramsing (Upper Siang valley). The characteristic lithology of this section is purple and grey shale with limestone–sandstone–mudstone and black to dark green mafic volcanic (Fig. 5d). Massive, cross-bedded white to pale yellow arenitic sandstone is present near

Dite Dime intruded by some dykes of dark basaltic volcanic.

Yamne River section

The present study also deals with detail mapping of different litho units along the Yamne River (a major tributary of Siang River) flowing across the Siang dome on the eastern part. The Yinkiong Group has a

wide lateral extent from SYC up to Yinkiong town covering a lateral distance of about 50 km along the Yamne River. The white, massive arenitic sandstone and pink, hard shale showing contact with intrusive are present just north of the SYC (Fig. 5e). Highly jointed, white, massive current bedded arenitic sandstone occurs near Padu and Damro village. Purple shale of Yinkiong Group is the most dominant lithology along Yamne valley (Fig. 5f). Arenitic sandstone is much prominent in the Middle Siang and Lower Yamne valley. The Abor Volcanics is also prominent along this section showing some massive intrusive body within the Yinkiong Group. As compared to lower, the volcanic rocks are much more prominent in the middle and upper part of Yamne valley. Some massive, fractured, dark brown to black basaltic volcanic rocks are present along the area encompassing Padu to Damro as well as near Mariyang and Yinkiong. The Dalbuing Formation is exposed towards the southeast of Dumro, which is mostly purple to pale green and black shale, sandstone and dark grey limestone [40]. The presence of Nummulites, Assilina, Operculina, Spiroloculina Rotalia fossils in this fossiliferous horizon assigned to be an Lower to Middle Eocene [53]. Later on, a study [55] recorded some additional Orbitolites, Discocyclusina fossils and considered as Lower Eocene age. Therefore, the age constraints of the volcanic associated with Yinkiong Group is between Lower to Middle Eocene.

Structure of the Siang Dome

According to some of the past studies [1, 23, 40], the Siang window constitutes of antiformally folded and up-arched thrust sheets. The Himalayan thrust pile at the Siang dome has a marked orogen-transverse antiformal structure showing a trend of NW–NNW [3]. Regarding the major antiformal structure in the eastern Himalaya, the eastern and western limbs show NW–SE and N–S to NE–SW trends respectively having NNW–SSE axial trend and a moderate angle NNW plunges [46]. Most of the antiformal and synformal structures recognized along the Eastern Himalaya have an axial trend of N–S or NW–SE and plunging towards N, NW as well as S direction which might be the resultant of the N–S and NW–SE compression of the Indian, Eurasian, and Burmese plates.

The Himalayan Frontal Thrust (HFT) in this region is further divided into HFT-1 and HFT-2 that uplift Siwalik and Terrace deposits respectively above the Quaternary fluvial deposit. Steep scarps of 2–3 m height are observed along these faults (Fig. 6a). The Roing fault runs along the Siluk River, shows the tectonic contact between the Siwalik Group on the west and LHS on the east (Fig. 6b). The MBT is present along the Yeling Korong stream on the east bank and Sijor Korong stream on the west bank of the Siang River respectively. The hanging wall of MBT comprises the Yinkiong Group of rocks on the east bank of

Siang River while the Gondwana Group on the west bank, in addition, the Siwalik Group exposed on the footwall of MBT along both sides of the river. Similarly, on the west bank of Siang River, the MBT uplifts the Gondwana Group above the Siwalik Group, while on the east bank it uplifts the Yinkiong Group. This finding further postulate that the Gondwana unit may pinch out in this region or may be covered by the thrust sheet. A strike-slip fault extending from Pasighat and terminating against the Yamne fault is present along the Siang River having NW–SE trend, possibly makes the different deformation patterns of the rock sequence in both banks of Siang River. This fault is evidenced by the differential southeastward advancement of the mountain front in the area (Fig. 6c).

On the east bank, the folds are mostly recumbent and overturned verging towards SE direction (Fig. 6d), while on the west bank, folds are very tight and verging NW direction (Fig. 6e). The earliest ductile deformation in Yinkiong Group is represented by the shear related tight isoclinal F_{15} folds having axial plane dipping 30° to NNW and NW direction. These tight isoclinal F_{15} folds are associated with south vergent asymmetric F_2 folds. The F_1 s fold shapes resemble Class–II geometry [36] with thicker nose and thinner limbs. Overturned hinterland verging folds (F_3) with axial surface dipping $50^\circ \rightarrow 140^\circ$ (Avg) represents the next phase of deformation (Fig. 6e). The N–S trending major fault extending from Pangin on south up to Bomdo on the north, and it marked the contact between the LHS towards the west and Paleocene–Eocene sequence towards east. Major sheared [22] and the brecciated zone at Puding, Bomdo and Boleng are the evidence of the presence of this fault (Fig. 6f). This fault is considered as the western and northwestern margin of the Paleocene–Eocene basin. Many sympathetic intra formational faults have been encountered near Bomdo, which are present within the LHS. There is a major N–S trending strike-slip fault present across Yinkiong Town resulting into some large shear zones. The number of NE–SW intra formational faults has been marked around Siang–Yamne confluence, Padu village, Rotung and Gobuk. Major slide zones and distinct alignment of lineament are the evidence of these faults. The Lesser Himalayan schistose rocks near Migging area faulted over the graphitic schist and gneiss of the Yang Chang Chu Formation. This fault plays an important role in the evolution of the Eastern Himalaya as it brings a part of Mishmi block over the eastern Himalayan. A generalized NNW–SSE cross-section along the Siang River basin shows the main lithological units and major structural elements of the Siang dome (Fig. 1c).

EVOLUTIONARY MODEL OF THE EASTERN HIMALAYA

In our study, an evolutionary model of the easternmost part of Arunachal Himalaya is proposed to

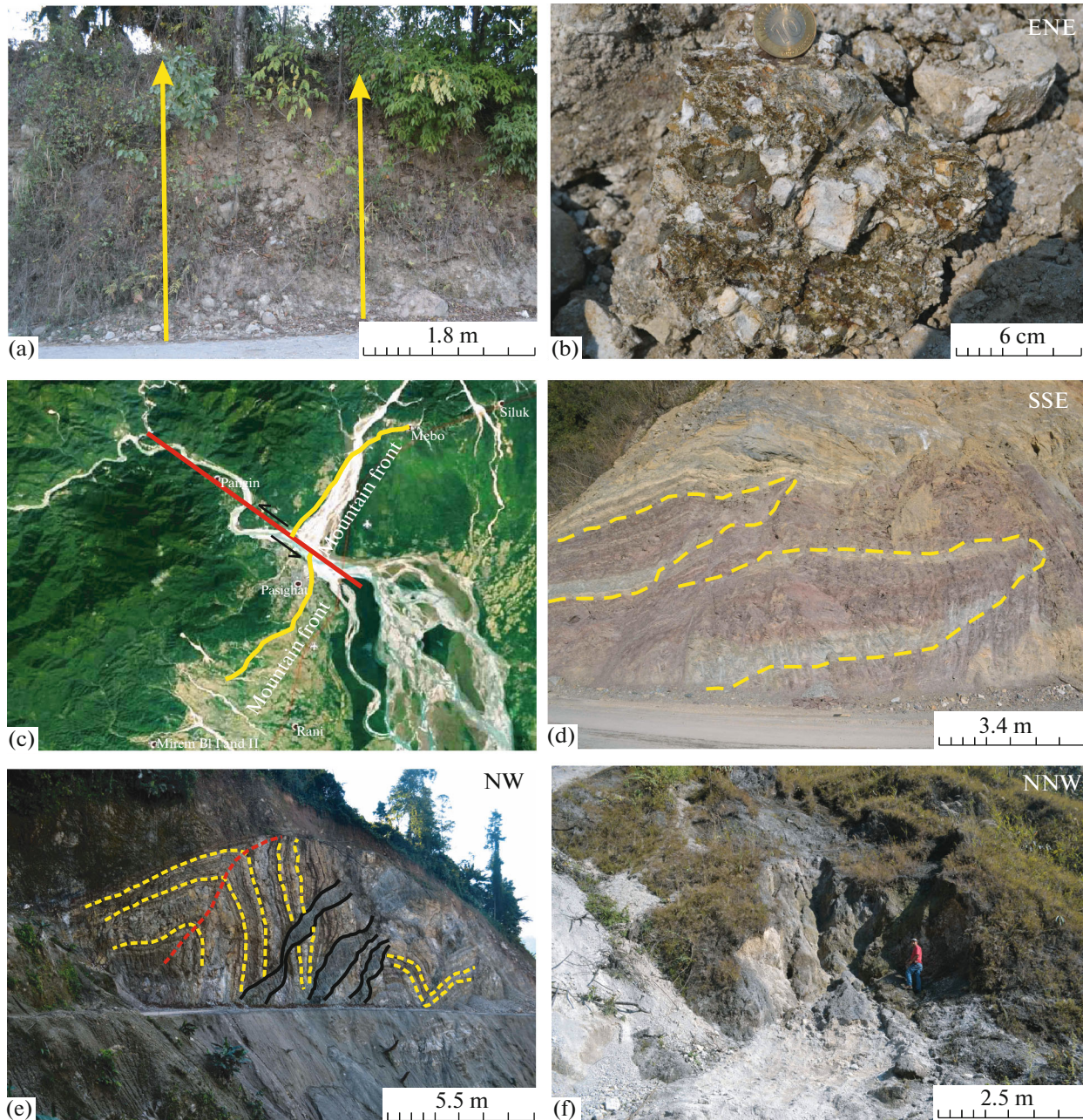


Fig. 6. (a) 15–20 m high uplifted terrace deposit near Sileng River, by the HFT-2. (b) Sheared material of the fault zone representing the eastern basin margin fault of Paleocene–Eocene basin near Siluk River. (c) Satellite imagery showing advancement of the mountain front on the southern part of the Siang River around Pasighat. (d) Recumbent fold verging southerly with axial planes trending ENE–WSW direction representing foreland propagating fold thrust belt of Yinkiong Group on the east bank of lower Siang valley. (e) Tight overturned folds verging towards northwest direction near Rotung on the west bank of Siang River, dykes of volcanic intrusive cut across the limbs. (f) Highly sheared and brecciated zone near Bomdo representing presence of the N–S western basin margin fault.

show different stages of movement of Indian Plate with respect to the Eurasian Plate and deposition of Paleocene–Eocene sequence with syn sedimentary volcanism.

Some important observations had been made by different authors along northwestern India and Central Nepal leading to the latest Cretaceous to the early

Eocene age of initial collision [19, 21, 37, 51]. The Collision in the Ladakh region is dated by marine sedimentation in the Indus Yarlung Suture Zone (ITSZ) at ~54 Ma [21]. The Indian Plate separated from the Australian Plate at ~125 Ma ago, started to move towards the north, and traveled ~7000 km in 30–20 Mys time span before colliding with the Asian Plate [33].

During Upper Cretaceous, widespread marine transgression took place covering some parts of the Shillong Plateau and Lesser Himalaya, in the Northwestern sector. The subduction of the northern tip of the Indian Plate began during the late Cretaceous as indicated by arc type granites in the Gangdese magmatic belt that yielded the age as 94 to 79 Ma. In the eastern part of the Himalaya, geochronological data from high-pressure Granulite in the Namche Barwa Group suggest that the India–Asia collision may have occurred between 70 and 65 Ma [16, 17] however, the recent study has shown some younger age ~55 Ma [7]. It is assumed that Indian continent has undergone numerous large extensional tectonic activities since Carboniferous to the present stage. The initial rifting of the Cimmerian terrane of Gondwana was started during Carboniferous–early-mid Permian [5, 6] and later on late Jurassic–early Cretaceous there was a breakup of eastern Gondwana forming the Kerguelen activity [29, 44]. The drifting of Indian Plate towards north was continuous and finally collided to the Asian Plate at mid-Eocene [1, 4, 7]. This mechanism of subduction of the Indian Plate beneath the Asian Plate and upper mantle heating [1, 58] could be the reason behind the Eocene volcanic activity in Siang valley, as well as clockwise rotation of the NE Plate fragment.

Numbers of paleomagnetic studies have been carried out in the Indian Ocean to constrain the India–Asia collision time [1, 27, 25, 35]. The detrital zircon U–Pb ages from Paleocene to mid-Eocene sandstone samples from north of ITSZ constrain the middle Eocene or older age for India–Asia collision in this region [11]. The relative velocity between the Indian and Eurasian plates decreased rapidly from ~15–20 to ~13–18 cm/yr at 50 Ma and even less, 4.5 cm/yr around 55 Ma [28]. Around 65–56 Ma, the presence of upper Cretaceous to Eocene marine sedimentary sequence on both south and north side of IYSZ in south-central Tibet is characterized by major changes in the depositional environment and sedimentary provenance [1].

Based on the mafic granulites, which represent a basal portion of the Gangdese continental arc that crystallized during magmatism at 160 and 65 Ma, Ding and the team [17] suggested that the collision between India and Asia at the eastern Himalaya initiated after 65 Ma. Thus, India–Asia initial collision was broadly contemporaneous during the Early Paleocene to Early Eocene. This collision resulted breakup of the NE edge of Indian Plate (Fig. 4a).

This separated portion of the Indian Plate has undergone a clockwise rotation due to the influence of the compressional forces and initiated for the development of a rift basin (Fig. 4b). The extensional tectonic environment in the Siang valley has been proposed based on geochemical characteristics of different mafic and felsic volcanic rocks [6, 10, 42, 43]. Several numerical models and laboratory experiments pro-

posed indentation of the rigid Indian Plate into the Asian Plate and predicted clockwise tectonic rotations in the eastern part of the Himalaya (e.g., see [8, 13, 24]). The paleomagnetic investigations of Cretaceous–Miocene rocks in the north and west region of the Namche Barwa Syntaxis is also identical with the clockwise rotation of the tear part of the Indian Plate (e.g., see [15, 25, 34, 38, 39, 56]). For the present aseismic surface movements around the Namche Barwa Syntaxis the clockwise rotational pattern is clearly shown by velocity vectors obtained from global positioning system [30, 41, 50, 59, 60].

This is supported by the Cenozoic magnetic anomalies in the Indian Ocean show that the relative velocity between the Indian and Eurasian plates decreased rapidly from 15–20 to 13–18 cm/yr at 50 Ma [38]. In the next phase during Upper Paleocene and Lower Eocene, sedimentation took place in the rift basin, which is also associated with volcanism (Fig. 4c). The impact of orogenic movement and sedimentation is evident in Siang valley that led to the change of sedimentary facies from continental during upper Paleocene; Geku Formation, to marine during Lower Eocene; Dalbuing Formation. This change in sedimentation and provenance of the Eocene sediments along the Siang valley indicate the presence of a paleosea. The rift basin formed a new sea or the Tethys Sea might had entered along the rift due to which the marine facies is prominent along the basin. This Upper Paleocene to Lower Eocene rocks around Yinkiong preserves good evidence of continental and marine sedimentation along the Siang valley. The lower part of this formation comprises of volcanoclastic rocks-ignimbrite and tuffs with mafic volcanic while the upper part constitutes purple and green shale yielding dicot plant fossils like *Apocynophyllum* sp., *Canavalia* sp., *Hicora* sp., *Grewiopsis* sp. and *Sophera* sp. [52] assigning to Upper Paleocene to Lower Eocene age. The Dalbuing Formation is exposed along the Yamne River section and the presence of abundant marine fossils, indicate a marine environment at the Eocene time [45]. In late Paleocene to early Eocene Lower Yinkiong Formation (LYF), detrital zircon U–Pb ages cluster between Cambrian and Archaean, which resembles cratonic and early Himalayan Thrust belt affinity; whereas in early to mid-Eocene Upper Yinkiong Formation (UYF), Cenozoic grains are present with Asian and Himalayan Thrust Belt affinity [7]. Baral and the team [7] also proposed that after the early Eocene Period, a terrestrial environment of deposition changed to the marine environment and started to accommodate detritus from the Asian Plate. So, the change in depositional environment and shift in provenance could be caused due to the collisional effect of India-Asia and formation of the rift valley.

As a result of India–Asia collision, north-south directed compressional forces were generated during middle Eocene and mark the initiation of the Hima-

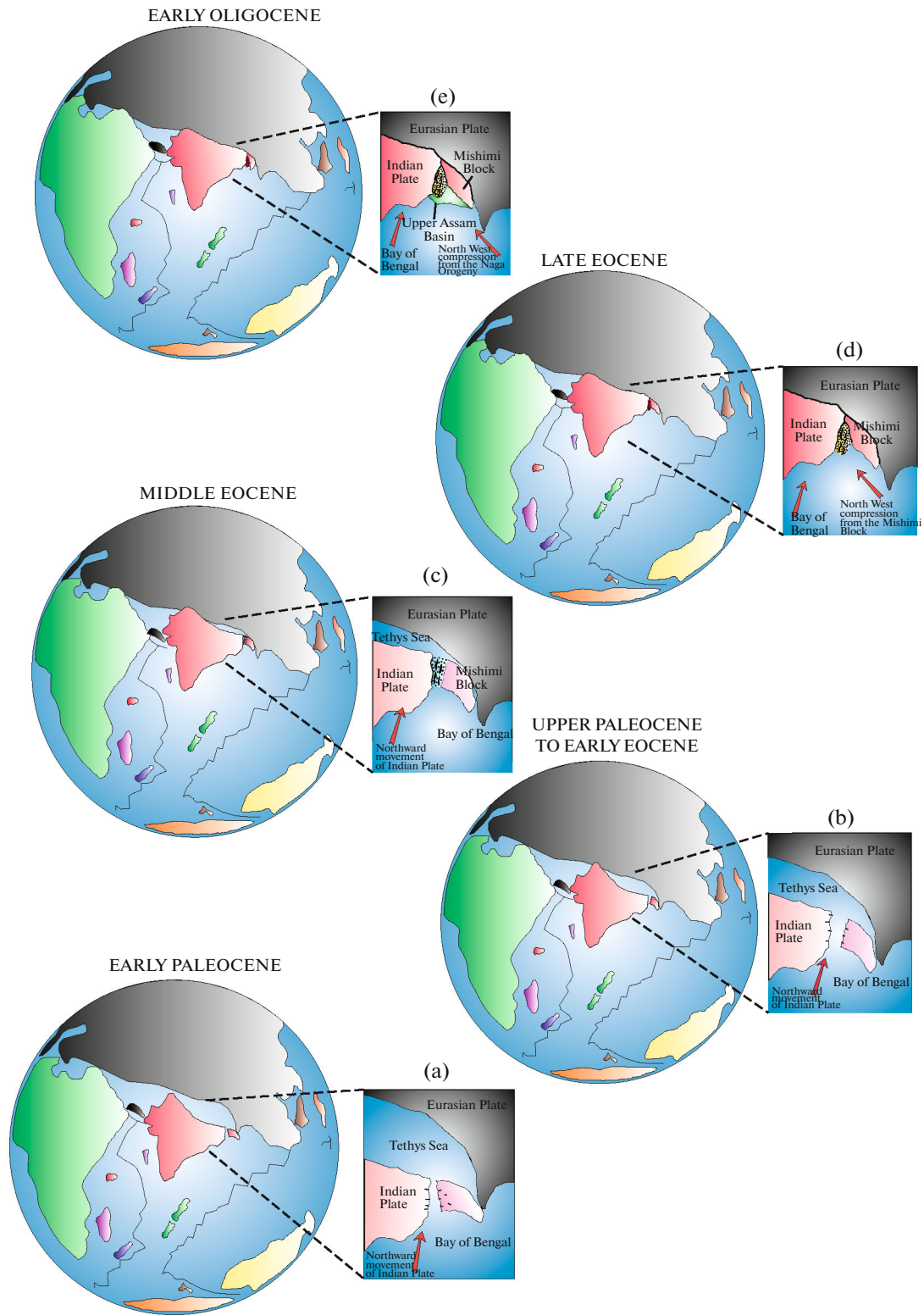


Fig. 7. Schematic paleotectonic diagrams showing the movement of the Indian Plate at different geologic times (a) Early Paleocene, collision of northeastern tip of the Asian Plate with the Eurasian Plate, (b) Upper Paleocene to Early Eocene, formation of rift basin (c) Middle Eocene, sedimentation continue in the rift basin (d) Late Eocene, closing of rift basin and (e) Early Oligocene, deformation of sequence in rift basin.

layan orogenic movement. Further convergence of Burmese Plate develops WNW–ESE compressional force which deformed the sediments of the rift basin. It resulted in the development of overturned isoclinal folds, which were refolded because of two compressional fields acting in the area (Fig. 4d). At this stage of evolution, the eastern part of the Indian Plate experiences compressional forces from both N–S and WNW–ESE developing a large number of cross faults and tight to open folding along the Siang valley.

Because of two compressional fields developed due to collision of India with Eurasian Plate and Burmese Plate which results in the thrusting of a broken part of Indian Plate and Burmese Plate over Paleocene–Eocene sediments from east. This is evident from the thrusting of quartzite of Lesser Himalaya over the Yinkiong Group along Roing fault in the east. Fault contact of Yinkiong Group with proterozoic Lesser Himalaya near Boleng and Janbo indicates the presence of rift basin margin fault. In the later phase of evolution in the area after the closing of the rift basin N–S compression dominates over WNW–ESE compression. This is evident from the deformational pattern observed in the Yinkiong Group and Siwalik Group of rocks which is shown in the geological map. The contact between Boleng Quartzite and Paleocene–Eocene sequence is well established near Boleng and similar contact was observed near Bamdo, indicating the presence of a basin margin fault from the north of Janbo extending upto the MBT. From both east and west, the Proterozoic quartzite has been uplifted over the Paleocene–Eocene sequence and Abor Volcanics. This event ultimately closed the basin and facilitated the formation of the foredeep basin in front of Himalayan Mountain and deposition of Neogene sediments (Fig. 4e).

RESULTS AND DISCUSSION

In the study area, the eastern extension of Siwalik rocks extends to Siluk River where there is a thrust contact with Paleozoic quartzite. The Paleocene–Eocene Yinkiong Group also has the thrust contact with quartzite of Paleozoic age. In the west, the Yinkiong Group of rocks has a faulted contact with Proterozoic rocks of Lesser Himalaya and towards the north, it has thrust contact with Rikor Group of Proterozoic age. The nature of thrust contact of Yinkiong Group of rocks in all the sides further indicates that the detritus was deposited in a basin that evolves during the collision of Indian Plate with Eurasian and Burmese plates (Figs. 7a, 7b). Due to WNW–ESE compression of Burmese Orogeny, Mishmi block overrides the Paleocene–Eocene basin, and finally makes the closure of the basin (Fig. 7b). The early collision of the northeastern extremity of the Indian Plate is also supported by the paleomagnetic data [60], which indicates a sudden decrease in velocity of the Indian Plate around 55 Ma, which coincides, with the age of Yinki-

ong Group of rocks. It is postulated that after rifting of the extreme northeastern part of the Indian Plate and clockwise rotation of that fragmented block resulted in the development of the Paleocene–Eocene rift basin in which Yinkiong Group of rocks were deposited (Fig. 7c). Continued movement causes convergence of welded fragmented Indian Plate and the Burmese Plate resulted in the closure of the rift basin and deformation of Yinkiong Group of rocks. This fact is supported by the overriding of the Yinkiong Group of rocks by the Mishmi block. Furthermore, change in the trend of MCT from E–W to NE–SW in the Siang valley is mainly due to the combined effect of N–S compression of Himalayan Orogeny and WNW–ESE compression of Burmese Orogeny (Fig. 7d). The structural evolution of the Siang valley is the result of the complex deformation of two compressional regimes from the Himalaya and Burmese orogeny. This fact is further supported by the presence of Paleocene–Eocene Yinkiong Group of rocks sandwiched between LHS towards west and Mishmi block towards east. Moreover, the model proposed from the present study has been postulated to explain the presence of rock similar to Lesser Himalaya both in the eastern part of Siang valley and Mishmi block, however, the absence of HHS in Mishmi block needs further explanation. The presence of the Indus–Tsangpo suture in the eastern Himalaya and Tidding suture in the Mishmi block and the presence of Lohit complex towards the NE of Tidding Suture [32] and its affinity towards the Burmese Plate is also a good evidence of welding of the part of the fragmented Indian Plate with the Burmese Plate (Fig. 7e).

CONCLUSIONS

It concluded that the Paleocene–Eocene basin of Siang valley is the resultant of rifting due to the fragmentation of the northeastern extremity of the Indian Plate and its clockwise rotation. The complex compressional forces experienced from both Himalayan and Mishmi block results in the development of complex folding, oblique-slip fault and thrust. These folds and thrusts/faults have different disposition than other parts of the eastern Himalaya.

Moreover, in most of the published regional maps of the Siang valley, the trend of MBT is NE–SW towards the eastern part of Siang valley but towards Mishmi hills, it changes to NW–SE. The trend of MBT in the eastern part and western part is almost right-angled in published maps, that need to be reviewed because instead of bending of the same thrust; two thrusts might be developed in a compressional setting which is almost perpendicular to one another. The present work indicates that the basin margin fault of the Paleocene–Eocene sedimentary basin is marked as the same thrust instead of two basin margin fault. However, it would be proper to separate both thrusts and named differently as two basin margin faults, instead of bending MBT. Moreover, whether this Siang valley should be

considered as the bending of orogeny, i.e., syntaxis, or simply it is the margin of two orogenic elements, need further research in this area.

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