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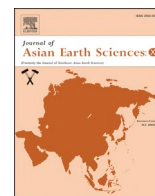
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Active deformation of the Central Myanmar Forearc Basin: Insight from post-Pleistocene inversion of the Pyay Fault

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ABSTRACT

Pyay sub-basin is located in the southern part of the Central Myanmar Forearc Basin, an elongate belt of en-echelon folds and thrust faults formed as a result of the hyper-oblique convergence of the India and Asia plates. Limited neotectonic studies suggest that the Pyay Fault is a major Pliocene inverted structure that trapped the hydrocarbons in Pyay sub-basin, where only sparse field-based observations are available to address the nature of very recent neotectonic processes. This study focuses on structural deformation related to active inversion of the Pyay Fault using field-based geological observations and interpretations of industrial seismic data. We map the ~105 km long Pyay Fault, an east-dipping high-angle reverse fault with a significant dextral strike-slip component. The fault underlies the western limb of the major NNW-SSE-striking anticlinal ridge that forms the western margin of Pyay sub-basin. Growth strata within the Pliocene-Pleistocene Irrawaddy Formation, imaged in the shallow part (<1 km) of 2D seismic profiles, reflects the deposition of Pliocene-Pleistocene sediments synchronously with the inversion of the underlying Pyay Fault. In addition, uplifted fluvial terraces of the Ayeyarwady River on the hanging wall of Pyay Fault reflect the post-Pleistocene inversion of the Pyay sub-basin. This study suggests that the Pyay Fault is a prime example of active deformation of the Central Myanmar Forearc Basin which plays an important role in the basin evolution and an earthquake source potential of the Myanmar territory.

1. Introduction

Forearc basins (FABs) are significant features of active subduction boundaries. Most subaerially exposed FABs in the world, such as the Great Valley of California (e.g., Dickinson and Seely, 1979) and the Tumaco basin of Columbia (e.g., López, 2009) are inactive, while most active FABs, such as Sunda (e.g., Hamilton, 1979; Karig et al., 1980), Nankai (e.g., Moore et al., 2015), Aleutians (von Huene et al., 1986; Moore et al., 1991), and Peru (Krabbenhöft et al., 2004) are submerged, limiting studies of neotectonic processes to widely-spaced seismic reflection profiles supplemented by a few sediment cores for dating. Neotectonic studies of active, subaerial FABs therefore have the potential for providing globally significant insights into FAB evolution.

The on-going development of the Central Myanmar Belt (CMB;

Fig. 1) results from the Cenozoic oblique convergence between India and Asia (e.g., LeDain et al., 1984; Hutchison, 1989; Ni et al., 1989). Because the CMB is the most important on-shore petroleum (oil and gas) province in Myanmar (e.g., Ridd and Racey, 2015; Than, 2017), extensive seismic studies have been carried out, along with drilling of exploration and production wells. These data provide valuable information for understanding the regional-scale tectonic setting and general structural patterns along the CMB (e.g., Pivnik et al., 1998; GIAC, 1999). Recent seismological studies show that small- and moderate-sized strike-slip earthquakes ($M_w > 5$ – < 7) occur in the shallow crust of the backarc basin (BAB) of the CMB, indicating on-going crustal deformation (e.g., Soe et al., 2003; Wang et al., 2018; Chit et al., 2020; Fig. 1). There is, however, no recent shallow seismicity within the FAB, even though the epicenters of deeper intra-slab earthquakes occur beneath the central

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part of this region (e.g., Lin et al., 2019). Furthermore, the extent to which shallow crustal structures in the FAB are active is unknown.

Despite the importance of its history, the central Myanmar FAB has been the subject of relatively few field-based neotectonic studies, but those studies have shown that the Pyay Fault, a prominent structure within the Pyay sub-basin, plays an important role in the present-day deformation of the FAB (Wang et al., 2014; Lin Thu Aung, 2014; Sloan et al., 2017). Industrial sub-surface exploration data indicate that the Pyay Fault is a positive inverted structure comparable to the Wheeler Ridge Thrust Fault in southern San Joaquin valley, California (Keller et al., 1998). However, the link between Pyay Fault-related surface and

subsurface structures has not been studied in detail, so the kinematics associated with its ongoing structural evolution remains unclear.

The purpose of this study is to document ongoing deformation within the FAB of central Myanmar and to identify recently active structures and geomorphic features related to inversion of the Pyay Fault. We determine the geometry of subsurface structures along the Pyay Fault and their relationship to recent deformation of the fluvial sediments from field-based observations and industrial subsurface data interpretation. Defining the neotectonics of this region allows us to better understand the continuing regional tectonic processes that have inverted the CMB, which is one of the best-exposed active forearc basins around

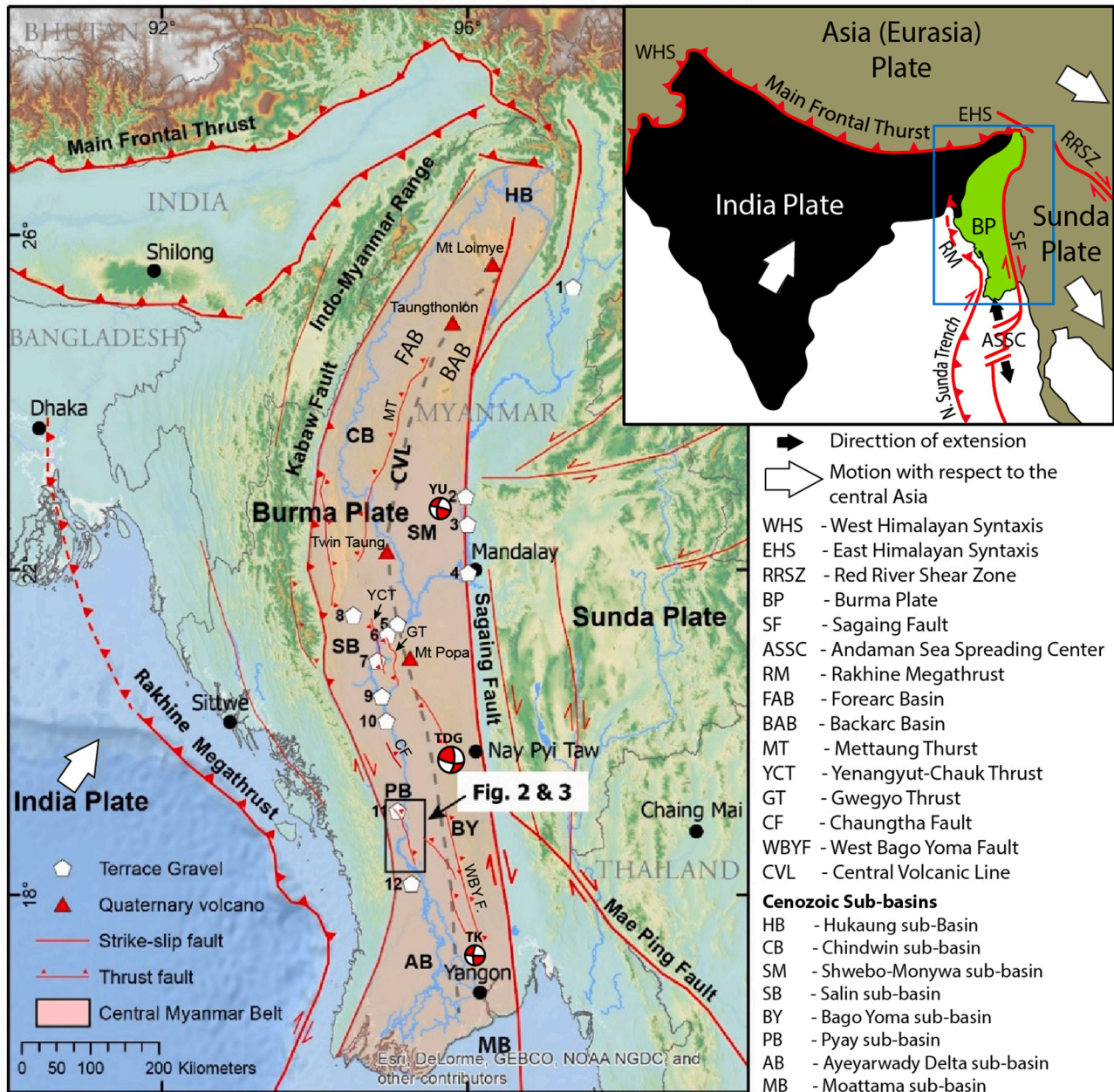


Fig. 1. Tectonic map of Myanmar and surrounding regions shows the tectonics of the India-Asia convergent zone from west to east: the Rakhine Megathrust (northern extension of the Sunda subduction zone); structural elements of the Burma Plate with the distribution of Pleistocene fluvial terrace gravels; and the Sunda Plate (modified after de Terra, 1943; Curran et al., 1979; Soe, 2007). Pleistocene terrace gravels: 1. Myitkyina, 2. Thabeikkyin, 3. Singu, 4. Sagaing, 5. Pakkoku, 6. Bagan, 7. Chauk, 8. Pauk, 9. Yenangyaung, 10. Magwe, 11. Pyay, and 12. Kyangin. Focal mechanisms of TDG- Mw 6.6 Taungdwingyi earthquake 2003; YU- Mw 5.5 Ye-U earthquake from USGS and TK- Mw 5.1 Taikyi earthquake from Wang et al., 2018. Thick red lines indicate the plate boundary structures, and thin lines indicate the internal structure within the tectonic domain.

the world.

2. Geological background

2.1. Regional tectonic framework

The Tertiary tectonic evolution of Myanmar has been strongly controlled by the interaction between the India and Asia plates (Curry et al., 1979; GIAC, 1999). The Burma Plate has been described as a sliver plate located at the margin of the India-Asia convergent zone (Curry et al., 1979; Hutchison, 1989). It is bounded by oblique subduction of the India Plate along the Rakhine Megathrust¹ in the west and the N-S striking Sagaing strike-slip fault and Sunda Plate in the east, the northeast-striking Andaman Sea Spreading Center in the south, and the east-striking major compressional boundary of the India and Asia plates and East Himalayan Syntaxis (EHS) in the north (Curry et al., 1979; Holtet et al., 1991; Vigny et al., 2003; Maury et al., 2004; Nielsen et al., 2004; Curry, 2005; Rangin, 2017; Fig. 1).

The Burma Plate consists of the CMB in the east and Indo-Myanmar Ranges (IMR) (e.g., Brunnschweiler, 1966; 1974; Kyi et al., 2017) in the west. The IMR is interpreted as an accretionary prism (Tainsh, 1950; Curry et al., 1979; Bender, 1983; Nandy, 1986; Hutchison, 1989) and includes Cretaceous to Eocene pelagic strata and a thick section of Eocene flysch sequences, overlain by upper Miocene to Pleistocene molassic sediments that are mainly exposed along the western coastal region of the IMR (Brunnschweiler, 1966; 1974; 2011; Mitchell and McKerrow, 1975; Bannert et al., 1978; Mitchell, 1981; Curry et al., 1982; Rangin et al., 2013; Rangin, 2017). The development of the IMR began in the late Cretaceous, but the major phase of uplift occurred during the Oligocene to Miocene transition (Brunnschweiler, 1966; Mitchell and McKerrow, 1975; Najman et al., 2020). Sedimentary rocks of the IMR were deposited on the Asian continental margin, deformed during the middle Eocene eastward accretion of ophiolitic slices derived from the down-going Indian slab (Acharyya et al., 1990; Dasgupta and Nandy, 1995; Fareeduddin and Dilek, 2015; Hla et al., 2017; Moore et al., 2019), and emplaced along the Kabaw Fault zone (Hla, 1987; Mitchell, 1993). Although the Kabaw Fault, the major tectonic break between the IMR and the CMB, is considered a reverse fault, it has most likely accommodated a considerable amount of right-lateral strike-slip displacement, especially in the southern part of IMR (LeDain et al., 1984; Hla, 1987; Khin, 1989; Win and Win, 2008; Rangin, 2017).

The eastern boundary of the Burma Plate is the Sagaing Fault, a transcurrent plate boundary that extends ~1500 km from the Andaman Sea Spreading Center to the EHS and separates the Burma Plate from Sunda Plate (Curry et al., 1979; Win, 1981; LeDain et al., 1984; Woodcock, 1986; Fig. 1). This major right-lateral transform fault is estimated to have accumulated 360–550 km of total displacement since the middle Oligocene (Morley and Arboit, 2019) or late Miocene (Curry et al., 1979; Hla, 1987; Myint et al., 1991; Bertrand et al., 1998; Rangin et al., 2013; Soe and Watkinson, 2017).

The major structural elements of Myanmar and the SE Asia region have been controlled by the collision of India and the Sunda Plate starting in the late Cretaceous and continuing through the Cenozoic (Tapponnier et al., 1982; LeDain et al., 1984; Hutchison, 1989; GIAC, 1999; Morley et al., 2020). The effects of this oblique collision are especially prominent in the CMB.

2.2. The Central Myanmar Belt (Mesozoic-Cenozoic Forearc and Backarc Basins)

The CMB (Pascoe, 1964; Bender, 1983; Ridd and Racey, 2015; Sloan et al., 2017), is a N-S-striking, narrow and elongated subaerial fold and

thrust belt with flat, low-lying topography bounded by the IMR in the west and the Sagaing Fault in the east (Fig. 1) that extends for >1100 km from the EHS in the north to the Andaman Sea Spreading Center in the south (Bender, 1983; GIAC, 1999; Morley and Searle, 2017; Naing et al., 2017). The CMB is filled with thick sequences of Cretaceous to Neogene strata deposited under fluvial-deltaic conditions in the north that prograde to shallow marine environments in the south. Total sediment thickness of the CMB locally reaches ~13 km (Aung and Kyaw, 1969) and the section is intercalated with a series of calc-alkaline middle Miocene to Quaternary volcanic rocks (Stephenson and Marshall, 1984; Maury et al., 2004; Cumming et al., 2009; Lee et al., 2016; Belousov et al., 2018) that were erupted along the Central Volcanic Line (CVL), which divides the CMB into the backarc basin (BAB) in the east and forearc basin (FAB) in the west (Bender, 1983; Pivnik et al., 1998; Fig. 1). Aero-magnetic anomalies along the CMB show that the FAB is deeper than the BAB (Pivnik et al., 1998).

To the south of Mt. Popa, volcanic intrusions between the FAB and BAB are largely absent, although some doleritic sills and dykes have been reported along the western margin of the Bago Yoma sub-basin (Chhibber, 1934; Nyein, 2011; Nyein et al., 2011; 2013). The CMB is composed of a series of transtensional, pull-apart sub-basins formed in the early Eocene as the Burma Plate moved northward due to the oblique subduction of the India Plate relative to Sunda (Tankard et al., 1994; Rangin et al., 1999). From north to south, these sub-basins are the onshore Hukaung, Chindwin, Shwebo-Monywa, Salin, Pyay, Bago Yoma, Ayeyarwady Delta, and the offshore Moattama sub-basins (Fig. 1).

Along the western margin of the FAB, upper Cretaceous to Eocene sedimentary sequences, called the “Western Outcrop” by Ridd and Racey (2015), are exposed and cut by east-dipping thrust faults of the Kabaw Fault zone (Fig. 2) (Bender, 1983; Pivnik et al., 1998; Licht et al., 2015; Morley et al., 2020). These sequences were partially metamorphosed during the Cenozoic, probably related to the accretionary underplating of the IMR above the east dipping subduction zone (Hla, 1987; Khin, 1989; Kyi et al., 2017; Hla Htay et al., 2018). Detrital zircon U-Pb dating of the Western Outcrop strata suggests that FAB formation initiated at ~106 Ma, synchronous with the development of a structural high related to India Plate (Neo-Tethys) subduction along the western part of the Asian continental margin (Cai et al., 2019).

Pliocene to Pleistocene transpressional deformation, clock-wise fault block rotation (Westerweel et al., 2019), and continued northward migration of the Burma Plate along the Sagaing Fault resulted in FAB inversion, during which Miocene normal faults were reactivated as reverse faults (Pivnik et al., 1998; GIAC, 1999). Thus, this structurally complex region is characterized by multiple phases of deformation involving a variety of structures related to transtensional to transpressional deformation during the Neogene to the Quaternary (Pivnik et al., 1998; GIAC, 1999; Lin Thu Aung, 2014). Reverse faults and associated folds are the primary evidence for tectonic inversion that occurred simultaneously with dextral motion of the Sagaing Fault since the late Miocene.

Based on geodetic studies across Myanmar, deformation of the Burma Plate is partitioned between structures associated with the northward migration and subduction of India and dextral motion on the Sagaing Fault (Vigny et al., 2003; Socquet et al., 2006; Banerjee et al., 2008). Global positioning system measurements suggest that the Sagaing Fault absorbs ~20 mm/yr or ~60% of the overall 35 mm/yr India-Sunda oblique convergence. The remaining ~15 mm/yr or ~40% is accommodated by the Rakhine subduction zone and internal deformation of the Burma Plate associated with structures in the IMR and the CMB (Brunnschweiler, 1966; Acharyya, 1978; Bender, 1983; Nandy, 1986; Hla, 1987). Dextral strike-slip deformation of the CMB may account for as much as 10 mm/yr of the total (Nielsen et al., 2004), but the precise amount of basin shortening and deformation associated active inversion of the FAB are still unclear due to limited geodetic and field-based structural observations.

¹ See supplementary Table S1 for correspondence between current and previous usage of tectonic/geologic units.

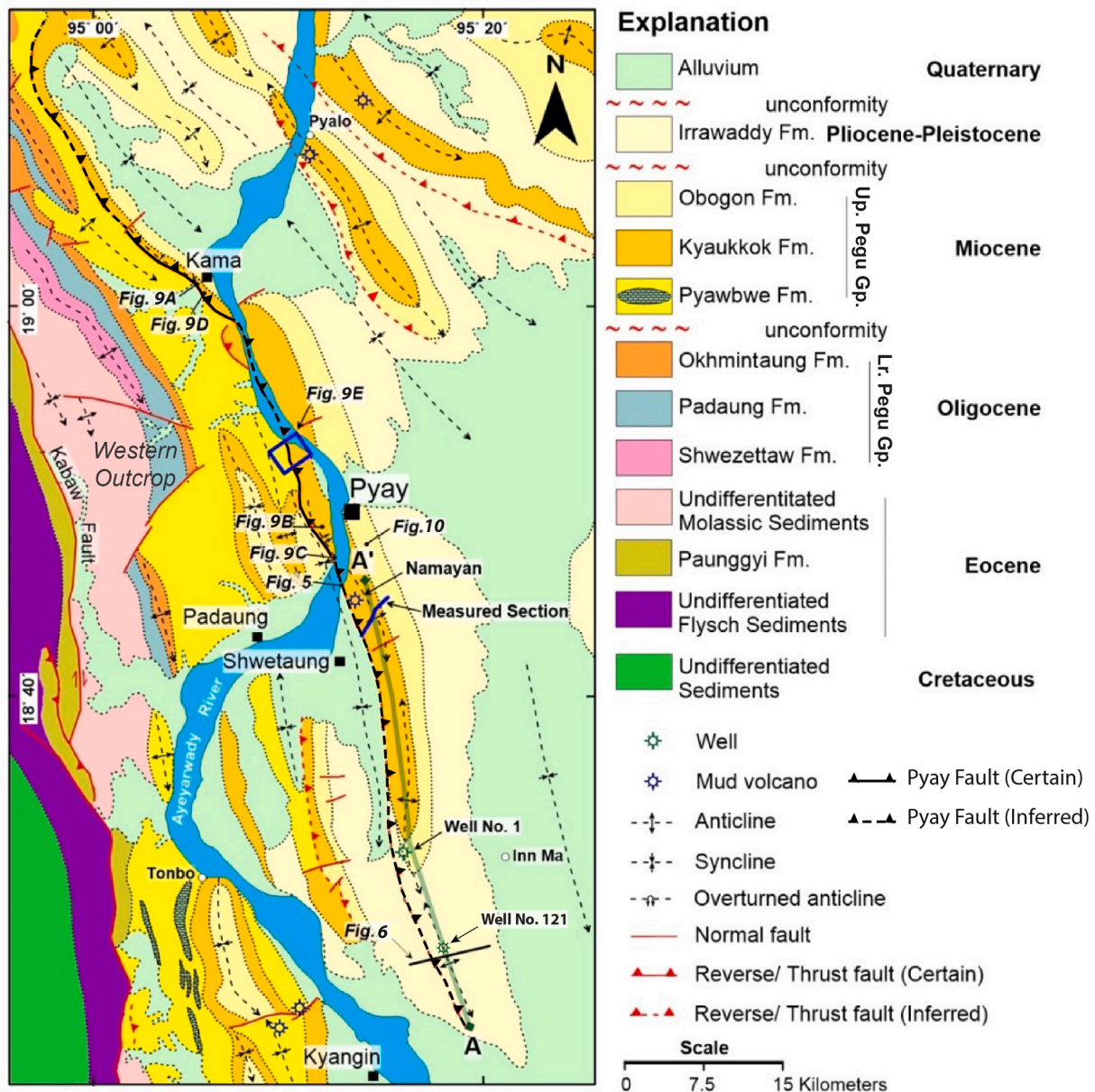


Fig. 2. Geological map of the Pyay region (modified after MOGE, 1977; Soe Thura Tun et al., 2014; Lin, 2014; Kyaw, 2015). The Pyay Fault is bounded by the western edge of the Kama-Pyay anticlinal ridge where Miocene to Pleistocene rocks are exposed. Thick green line (A-A') is the location of seismic line in Fig. 8.

2.3. Regional geology of the Pyay sub-basin

The Pyay sub-basin lies between 18° N and 20° N (Ridd and Racey, 2015) and is bounded by the Bago Yoma sub-basin in the east and the Kabaw Fault in the west (Fig. 1). The stratigraphy of Pyay sub-basin was first defined by Theobald (1871) and the geology and stratigraphic sequences along the FAB including Pyay sub-basin were also described by Pascoe (1962) and Aung and Kyaw (1969). However, information on the southern continuation of the Western Outcrop within the Pyay sub-basin is largely absent. Although localized stratigraphic names have been used by previous workers, here we adopt the classification scheme of Aung and Kyaw (1969). The stratigraphic sequences of the Pyay sub-basin (Table 1) range in age from Eocene to Pleistocene and may lie on top of the Mesozoic IMR accretionary prism basement (Pivnik et al., 1998).

The Eocene sections of undifferentiated molassic rock sequences are affected by low-grade metamorphism (mostly slates and occasionally phyllites) along the Kabaw Fault zone at the western margin of Pyay sub-basin (Fig. 2). To the east, the Oligocene Lower Pegu Group, deposited in

a marine to mixed fluvial environment, is exposed. Further east, in the Kama, Pyay, Shwetaung, and Kyangin areas, the Miocene Upper Pegu Group, deposited under shallow, warm marine to fluvial-deltaic conditions, is exposed. The lower and upper boundaries of these units are unconformities (Fig. 2).

The lower Miocene Pyawbwe Formation is exposed in the hanging wall of the Pyay Fault, but the exposures of Pyawbwe Formation are variable along the Pyay Taungdan Structure (Figs. 3 and 4C). The Kyaukkok and Obogon formations are exposed successively along the footwall of the Pyay Fault. The Irrawaddy Formation covers the eastern part of the Pyay sub-basin and caps the nose of the south-plunging Pyay Taungdan Structure named by Myanmar Oil and Gas Enterprise (MOGE). The angular unconformity between the Obogon Formation and at the base of the Irrawaddy Formation is exposed along the road cut section located on the west bank of the Ayeiawady River near Pyalo village, about 33 km to the north of Pyay.

The Irrawaddy Formation is composed of thick-bedded to massive, unconsolidated sandstones, gritty and gravelly sandstones deposited

Table 1

Stratigraphic correlation table of the lower part of the Central Myanmar Forearc Basin shows the general stratigraphic succession of the Salin (Aung and Kyaw, 1969), Pyay (Wandery, 2006), and Ayeyarwady Delta sub-basins (JNOC, 1985).

Epoch		Salin Sub-basin (A. Khin & K. Win, 1969)	Pyay Sub-basin (Wandery, 2006)	Ayeyarwady Delta Sub-basin (JNOC, 1985)
Holocene	Ma			
Pleistocene	0			
Pliocene	5	Up. Irrawaddy Fm.	Irrawaddy Fm.	Irrawaddy Fm.
Miocene	10	Lr. Irrawaddy Fm.	Obogon Fm.	Kathabaung Fm.
	15	Obogon Fm.	Kyaukkook Fm.	Kwingaung Fm.
	20	Kyaukkook Fm.	Pyawbwe Fm.	Tumyaung Fm.
	25	Pyawbwe Fm.	Pyawbwe Fm.	
	30	Okhmintaung Fm.	Okhmintaung Fm.	
Oligocene	35	Padaung Fm.	Padaung Fm.	
	40	Shwezettaw Fm.	Shwezettaw Fm.	
	45	Yaw Fm.	Yaw Fm.	Taunggale Fm.
Eocene	50	Pondaung Fm.	Pondaung Fm.	
	55	Tabyin Fm.	Tabyin Fm.	
	60	Tilin Fm.	Tilin Fm.	
	65	Laungshe Fm.	Laungshe Fm.	Kanbala Fm.
Paleocene	70	Paunggyi Fm.	Paunggyi Fm.	
Upper Cretaceous	75			
	80	Kabaw Fm.	Kabaw Fm.	
	85			
	90			
	95	Paung Chaung (Limestone) Fm.		
	100			

Legend

Alluvium

Deltic sand

Terrace deposit

Depositional break

Unconformity

under fluvial conditions that are extensively exposed through the CMB (including FAB and BAB), so the stratigraphic age and thickness are highly variable (Aung and Kyaw, 1969; Chavasseau et al., 2006; Wandery, 2006; Ridd and Racey, 2015; Than, 2017). Although its age is assigned as Pliocene by MOGE (1977), vertebrate paleontological studies have confirmed the age of the Irrawaddy Formation ranges from upper part of middle Miocene to Pleistocene, which correlates with the Siwalik Group of India (Chhibber, 1934; Colbert, 1938; Pascoe, 1962; Bender, 1983; Chavasseau et al., 2006; Zin-Maung-Maung-Thein et al.,

2008; Chit et al., 2009; Jaeger et al., 2011). Zircon fission track (ZFT) analyses of the Irrawaddy Formation also documented the middle Miocene to Pliocene age in the Pyay sub-basin (Najman et al., 2020). In our study area, located at the western margin of Pyay sub-basin, the age of the Irrawaddy Formation along the Pyay Fault is believed to be Pliocene-early Pleistocene, based on samples from wells in the Pyay oilfield (Soe and Aung, 1966; MOGE, 1966). Quaternary fluvial river terrace gravels deposited by the Ayeyarwady River unconformably overlie the Irrawaddy Formation.

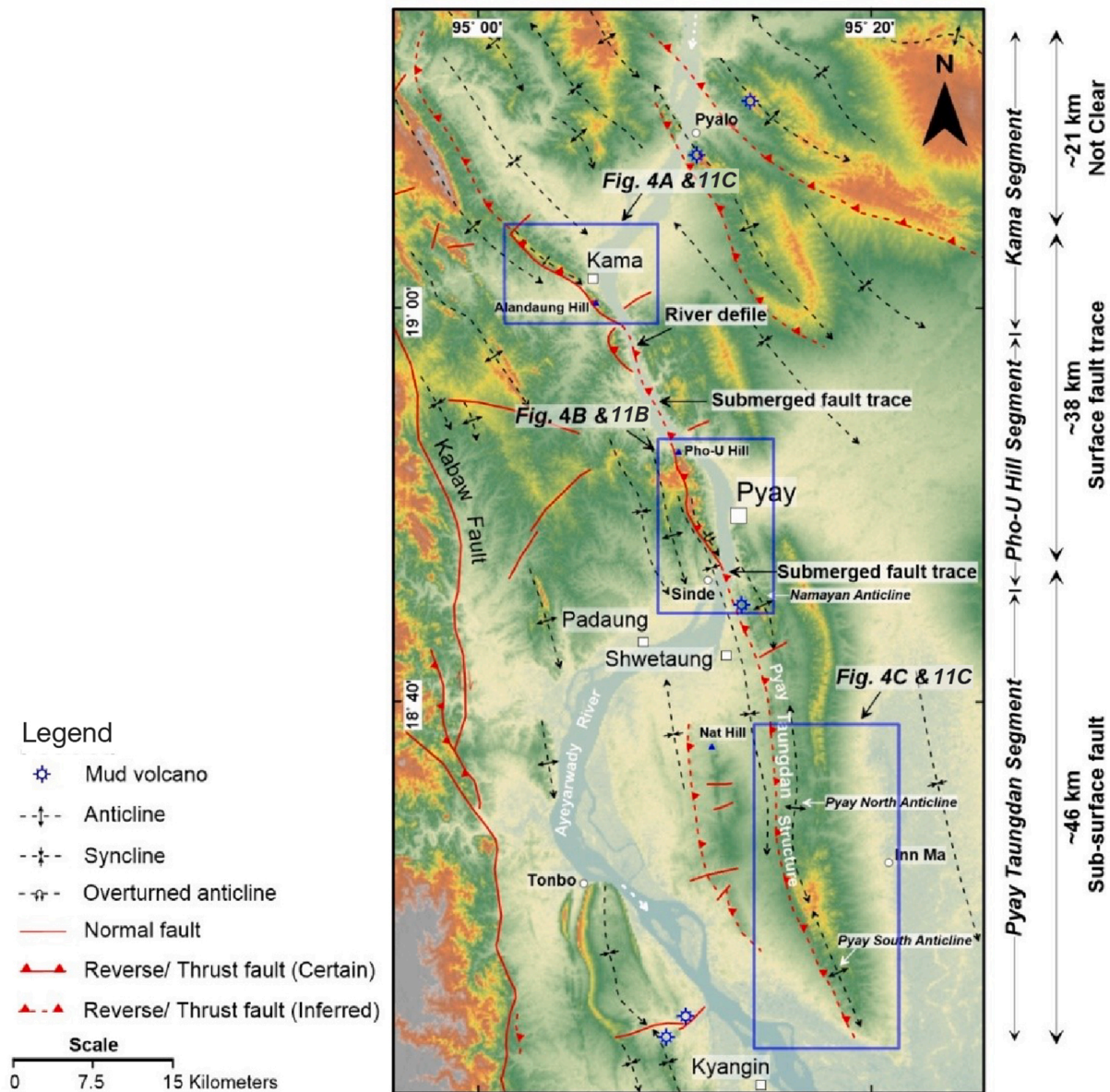


Fig. 3. Structural geological map of the Pyay city and its environs showing segmentation of the Pyay Fault. The Pyay Fault strikes NNW–SSE and numerous cross-fault and fractures oriented perpendicular to the main fault are present. Solid lines indicate clear surface fault traces and dashed lines indicate inferred/blind fault traces.

The measured stratigraphic section along Kyetpyudaung stream (located ~3 km NE of Shwetaung; Fig. 2) reported by MOGE (1966) shows that the total thickness of Miocene to Pliocene formations is 2365 m (Table 2). In the southern part of Pyay oilfield, the Irrawaddy Formation covers the anticlinal ridge of the Pyay Taungdan Structure where the middle Miocene Kyaukkok Formation is exposed along the axes of the Namayan and Pyay North anticlines as an inlier structure. In this area, well no. 1 (Fig. 2) of the Pyay oilfield shows the stratigraphic thickness of the Miocene units, as the well has penetrated the entire Miocene section. Successively from the bottom to top of the well, ~290 m of the Pyawbwe Formation and ~366 m of middle to upper Miocene Kyaukkok and Obogon formations were penetrated on the supra-thrust or the hanging-wall side and ~564 m of the Pyawbwe Formation and ~290 m of the Kyaukkok and Obogon formations were penetrated in the sub-thrust or foot-wall side of the Pyay Fault (Table 2).

3. Data and methods

We investigated the western part of Pyay sub-basin and compiled detailed structural and geological maps using Shuttle Radar Topography Mission (SRTM) data (30 m resolution), aerial photographs (1:25000), vintage geological maps (e.g., MOGE, 1977; Soe et al., 2014; Kyaw Zin Oo, 2015), field surveys, and seismic reflection data acquired by MOGE. We created a 3D photomosaic of the study area using the Photoscan software of Agisoft Ltd. to help delineate fault scarp morphology and geomorphic expression. We analyzed structural data collected in the field using lower hemisphere Schmidt net projection methods (Lise and Leyshon, 2004) and Orient software, version 3.11.1 (Vollmer, 2015). A comprehensive regional velocity model has not been constructed for time-depth conversion of the seismic data due to sparse and insufficient seismic and well-log information. So, we instead used a velocity function for time-depth conversion derived from a check-shot survey in well 121 of the Pyay oilfield (Fig. 2). The check-shot shows a non-linear time-depth function; P-wave velocity that decreases less at depth (Fig. S1).

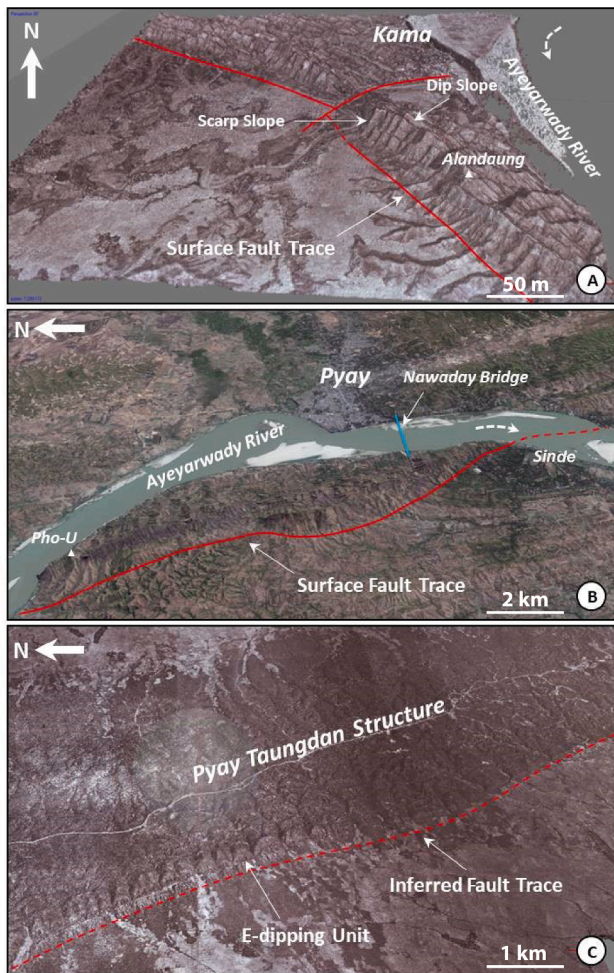


Fig. 4. 3D view of aerial photomosaic and Google Earth images illustrating the geomorphology of the Pyay Fault. (A) Aerial photomosaic (1:25000) of Kama Segment, (B) Google Earth image (vertical exaggeration- 3X) of Pho-U Hill Segment, W of Pyay, (C) Aerial photomosaic (1:25000) of Pyay South anticline. Locations of images are shown in Fig. 3.

We define the stratigraphic unit boundaries in the 2D seismic lines using the stratigraphic thickness of the well log units and measured section converted to depth with the check-shot velocity function. Vertical and horizontal fault slip and uplift rates are calculated using the approach of Hardynw and Poblet (2005).

4. Geology of the Pyay Fault

4.1. Fault segmentation

We mapped ~105 km of the Pyay Fault from the northern Kama area across Pho-U Hill ridge, Pyay, Sinde, Shewtaung, and the Pyay Taungdan Structure, extending to the Kyangin area in the south (Fig. 3). We divide the surface trace of the Pyay Fault into three segments: the Kama Segment in the north, the central Pho-U Hill Segment, and the Pyay Taungdan Segment in the south.

4.1.1. Kama Segment

The northern termination of Pyay Fault lies in the rugged foothills of the southern IMR or the Rakhine Yoma. Although the area is characterized by moderate topographic relief, a clear fault trace is not observed, and we suggest that this is due to a fault slip rate that is lower than the local erosion and sedimentation rates. Further south, the Pyay Fault abuts the western edge of Alandaung Ridge, a NW-SE-striking

anticlinal ridge located west of Kama on the west bank of the Ayeyarwady River (Figs. 3 and 4A). The Alandaung anticlinal ridge is composed of middle to upper Miocene sandstones of the Upper Pegu Group, the Kyaukkok and Obogon formations (Fig. 2), which dip to the NE. The Pyay Fault footwall is characterized by flat, low lying plains, i.e., the Made drainage basin. The total length of this fault segment is ~35 km.

4.1.2. Pho-U Hill Segment

Farther south, the trace of the Pyay Fault is located within the Ayeyarwady River, where a structurally-controlled river defile is present north of Pho-U Hill (Pho-U Taung) (Fig. 3). The strike of the fault trace in this central section, from north of Pho-U Hill to near Sinde village, is NNW-SSE. The middle part of the Pyay Fault cuts the western flank of Pho-U Hill ridge where the topographic relief is higher than to the north and south (Fig. 4B). The fault trace is bounded by a west-verging overturned anticline north of Sinde village. Steep slopes, V-shaped gullies, and short and straight drainage channels characterize this segment. The total length of the fault in the central segment is ~25 km.

4.1.3. Pyay Taungdan Segment

The structure and geomorphology of the southern segment is quite different from the north and central segments where the fault trace is not exposed on the surface (i.e., a blind fault segment). Vertical, cross-bedded sandstones of the middle Miocene Kyaukkok Formation are exposed along the west bank of Ayeyarwady River near Namayan village, north of the Shwetaung town (Figs. 3 and 5). East-dipping, gently inclined Miocene Kyaukkok and Obogon and Plio-Pleistocene Irrawaddy Formation rocks are exposed successively to the east. We suggest that the associated structure is a west-verging asymmetrical anticline cored by a high-angle reverse fault along the western edge of Pyay Taungdan Structure (Figs. 2, 3, 6 and 7C). The fault does not penetrate the surface, but rather is buried underneath the sandy loam deposits derived from the Plio-Pleistocene Irrawaddy Formation. To the south, thick-bedded to massive sandstone units of the Irrawaddy Formation cover both limbs of Pyay Taungdan Structure (Fig. 4C).

At the surface, the Pyay Taungdan Structure is characterized by moderate topographic relief and rolling hills that strike NNE-SSW with gentle slopes and long, sinuous distributaries. The structure is a petro-liferous anticlinal ridge marked at the surface by mud volcanoes on its faulted axis near Namayan village (Ridd and Racey, 2015; Figs. 2 and 3). 2D seismic lines across the structure image a west-verging anticline cut on its west flank by a high-angle, east-dipping reverse fault. A 2D seismic line parallel to the Pyay Taungdan Structure shows that the structure is subdivided into three different anticlines, which are the major hydrocarbon-bearing traps in the Pyay oilfield, namely the Namayan, Pyay North and Pyay South anticlines (Figs. 3 and 8).

The total length of this fault segment is ~45 km from the Namayan village to the east of Kyangin town at its southern termination. To the east of the anticline, a small anticlinal ridge called Nat Hill (Nat Taung) is 75 m in elevation and strikes nearly N-S, subparallel to the trend of the Ayeyarwady River to the west (Fig. 3). It is also bounded by the east-dipping thrust fault along the western limb. This structure is interpreted as an associated structure of the Pyay Fault and the underlying geometry of the Nat Taung Fault could be similar to Pyay Taungdan Segment.

4.2. Field structural data analysis and interpretation

4.2.1. Major structures along the Pyay Fault

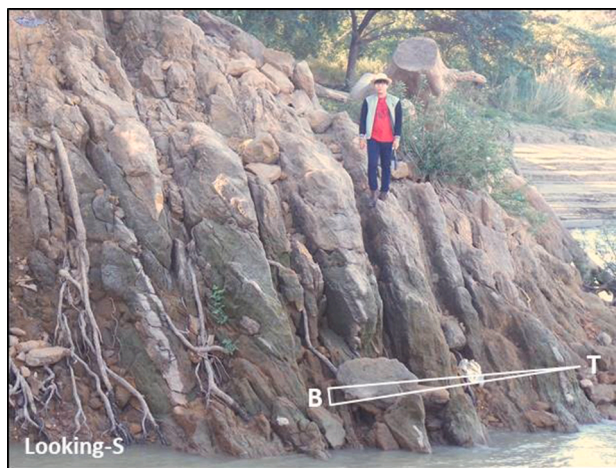
The mesoscopic structural deformation features observed along the Pyay Fault, i.e., brittle fractures and slip-planes, indicate upper crustal level deformation (Fig. 9; Tables S2 and S3). The bedding inclination of the overall anticlinal structure shows local variations: a symmetrical anticline (Alandaung ridge), an overturned anticline (Pho-U Hill) and an asymmetrical anticline (Pyay Taungdan Structure). Based on 175 bedding inclination measurements (Table S2), the western limb of the

Table 2

Stratigraphic thickness of the upper Pegu Group of Pyay oilfield based on Well No. 1 and a stratigraphic measured section along Kyetpyudaung stream section. Well location and measured section are shown in Fig. 2.

Age	Stratigraphic Unit	Stratigraphic Thickness		
		Well no. 1		Measured section
		Hanging Wall	Foot Wall	(Kyetpyudaung stream)
Holocene	Younger Alluvium	Sandy alluvium and loam		
Pleistocene	L ~~~~~	Fluvial terrace gravels of Ayeyarwady River		
	M ~~~~~			
	E ~~~~~			
Pliocene	Irrawaddy Fm.	~564 m	-	~156 m
Miocene	L ~~~~~	~366 m	~290 m	~1173 m
	M ~~~~~			~1163 m
	E ~~~~~	~290 m	~564 m	~107 m

~~~~~ ■ nonconformity      - - - Gradational contact



**Fig. 5.** Field photograph illustrating the vertical orientation of the cross-bedded sandstone unit of Kyaukkok Fm. exposed along west bank of Ayeyarwady River near Namayan village, N of Shwedaung. Orientation of the primary sedimentary structure (B-T indicates base-to-top direction), cross-bedding, indicates that the Namayan anticline is a west-verging asymmetrical anticline. Photo location is shown in Fig. 2.

anticline is steeper than the eastern limb. The lower hemisphere Schmidt net projection (pole contoured) shows that the mean bedding plane strikes NNW-SSE and dips to the west (Fig. 10A). This geometry describes west-verging anticlinal ridges along the Pyay Fault.

In the northern area, near Kama town, we are not able to identify major shear-planes because the main Pyay Fault plane is buried under Quaternary alluvium. However, dip-slip slickensides observed on bedding planes indicate flexural-slip (Table S3), possibly related to the folding of Alandaung anticline parallel to the main fault (Figs. 9A and 10B). The Pyay Structure exposed along the Pyay-Taungdok road cut, on west bank of the Ayeyarwady River near Nawaday Bridge (Fig. 4B), is the best place to recognize the major structure of anticlinal ridge. In this section, the middle Miocene Kyaukkok Formation is exposed across the central part of Pho-U ridge. The overturned sequence of medium- to thick-bedded sandstone suggests that this topographic ridge, south of

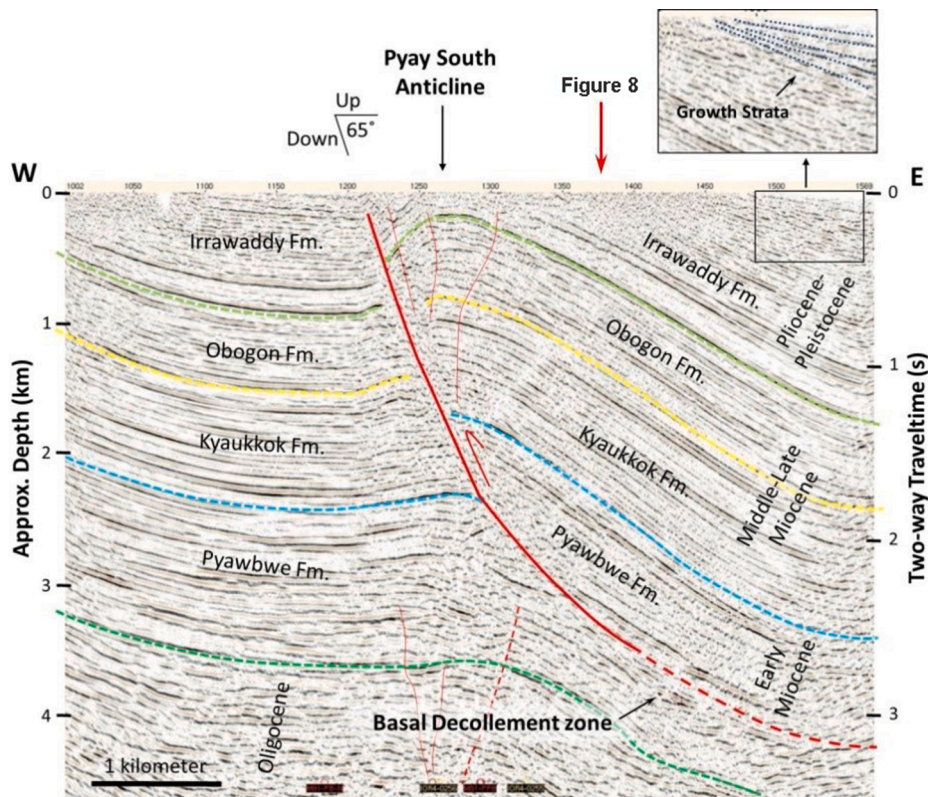
Pho-U Hill, is an overturned anticline (Figs. 3, 5 and 9B). To the south, near Sinde village, we observe a shear fabric in the thinly laminated siltstone and interbedded shale unit of the Kyaukkok Formation along with reverse displacement slicken-planes (Figs. 9C and 10B).

In general, small scale structures observed in some locations represent the orientation of the major structure of the whole region. This characteristic is observed in the northern part of Pyay Taungdan Structure, south of Pyay, where we observe a small-scale overturned fold bounded by a high angle reverse fault dipping to the east within the alternating thin-bedded sands and shales of the upper Miocene Obogon Formation. This is similar to the orientation of the major structure around the Pyay area (Fig. 10C). A lower hemisphere Schmidt net projection of the orientation of this small-scale structure indicate that the fold axis trends S33°E and plunges SSE. It is bounded by the SE-dipping thrust/reverse fault. Structural measurements suggest that the Pyay Fault in the Pho-U Hill Segment is an oblique-slip fault dominated by reverse faulting with a significant component of strike-slip displacement (Fig. 11B).

To the south, the main trace of Pyay Fault is submerged beneath the Ayeyarwady River from Sinde to Namayan villages (Fig. 3). At the western margin of the Namayan anticline, the fault trace is not exposed, but our field observations suggest that the buried fault plane bounds the western limb of Pyay Taungdan Structure (Figs. 3 and 5). Farther south, two parallel doubly-plunging anticlines, i.e., the Pyay North and Pyay South anticlines, with moderate topographic relief are bounded by the southern termination of Pyay Fault. The lower hemisphere Schmidt projection ( $\beta$ -diagram) of Pyay Taungdan oilfield shows that the general orientation of axial planes of these anticlines of the Pyay Taungdan Structure dips 3° to 175° (toward the south). These observations suggest that the Pyay Taungdan Structure plunges to the south, although it is composed of 3 different doubly-plunging anticlines, i.e., the Namayan, Pyay North and Pyay South anticlines (Fig. 11C).

#### 4.2.2. Cross-faults

We recognize two different sets of cross-faults in the study area; those with normal displacement that cut the Pyay Fault and those with oblique-slip displacement that are cut by the Pyay Fault. The northern section of the fault trace (the Kama Segment), observed along the railway section, is characterized by a series of normal faults that dip to the NW, parallel to the NW-SE orientation of the Pyay Fault (Fig. 9D). Most



**Fig. 6.** Interpretation of a 2D seismic reflection line across the Pyay South anticline acquired by Myanmar Oil and Gas Enterprise showing the subsurface geometry of the southern part of Pyay Fault. Approximate depths are extrapolated from near-by well data. East-verging folded Mio-Pliocene units are bounded by a high angle thrust fault which appears to be connected to the basal décollement zone below 4 km depth in the eastern part of the line. Onlapping of the growth strata onto the uppermost Irrawaddy Formation in the eastern part of the seismic line (hanging-wall of the Pyay Fault) suggests that the fault was still active during the deposition of the upper Irrawaddy (until the Pleistocene). The thick red line shows the location of the main fault, and thin lines indicate associated minor structures. Location of the seismic line shown in Fig. 2 and its intersection with the seismic line shown in Fig. 8 is indicated with a red arrow.

of the faults do not cross-cut the surface trace of the Pyay Fault, except for the major cross-fault near the Kama area that cuts the Pyay Fault along the Made stream. The stereographic projection of slicken planes along this cross-fault shows normal displacement (Figs. 10B and 11A). In the Pho-U Hill Segment, most obvious cross-faults are exposed near the Pho-U Hill where a dextral offset of ~140 m is observed between the Pho-U Hill (183 m) and Kyauk Saung Hill (196 m) (Fig. 9E). We interpret this structure as a significant dextral fault with a minor component of normal displacement based on the morphological and structural geological features. Farther south, one of the major cross-faults exposed on the Pyay-Taungdok motor road near the Nawaday Bridge (Fig. 4B), shows oblique (normal-dextral) displacement (Fig. 11B) similar in orientation to the cross-fault near Pho-U Hill.

These kinds of cross-faults also occur in the south, between Pho-U Hill and Sinda village, west of Pyay city (Figs. 4B and 11B). Along the Pyay Taungdan Segment, N-S-oriented, 2D seismic lines parallel to the Pyay Taungdan Structure show that most of the cross-faults do not cut the Irrawaddy Formation (Fig. 8). Fault offsets die out at the top of the Obogon Formation (at the base of Irrawaddy Formation). The surface geological map shows that these faults do not cut the major trace of Pyay Fault. NE-SW-striking cross-faults cut the Pyay North anticline in 2-D seismic lines (see next section) and some of the N-dipping normal faults penetrate the upper surface of the Irrawaddy Formation, indicating that these faults were still active until the deposition of the Irrawaddy Formation.

#### 4.3. Seismic reflection data interpretation

We also use 2D and 3D seismic data acquired by MOGE along the Pyay Taungdan Structure to define the geometry of the hidden or blind segments of the southern part of Pyay Fault. No seismic data are available to investigate the northern continuation of the fault. Our seismic interpretation in the upper 0.5 s of two-way time (TWT) (Fig. 6) allows us to identify *syn*-tectonic seismic stratigraphic features, i.e., growth strata, and also helps us determine the sediment deposition and

deformation rates associated with the Pyay Fault. The combination of the geometry and deformation features interpreted in the 2D seismic lines, along with the ages of sediment layers using the well data, we determine the timing of deformation and kinematics of underlying structures (e.g., Storti and Poblet, 1997; Shaw and Suppe, 1994; Shaw et al., 2004; Hubbard and Shaw, 2009; Hubbard et al., 2016).

The acquisition and processing (including post-stack migration) of these seismic sections emphasized the potential reservoir layers in the deeper part of basin, so that the upper parts of the seismic sections are poor in data quality for identification of near-surface deformation. We note that it is somewhat difficult to determine the exact fault geometry of the southern segment of Pyay Fault due to having only approximate depths because of the lack of sufficient regional velocity data. To constrain the stratigraphic boundaries, we used surface geology and stratigraphic data gathered from a measured section and well no. 1 (Table 2) to interpret the lithologic boundaries of seismic-stratigraphic units on both sides of the fault plane. In two of the seismic sections, i.e., N-S and E-W seismic lines of Pyay oilfield, we observe stratigraphic thickness variations that may be related to Miocene basin extension along the CMB and development of a series of sub-basins as a result of dextral strike-slip motion along the Sagaing Fault.

The 2D seismic line across the southern part of Pyay Fault shows a west-verging fault propagation fold cut by an east-dipping reverse fault (Fig. 6). Pyay South anticline is cored by Miocene sequences (i.e., Pyawbwe, Kyaukkok, and Obogon formations successively), and it is unconformably overlain by poorly cemented sandstones of the Irrawaddy Formation at the crest of anticline. Commercial accumulations of oil and gas are found in the Miocene units of Pyay Taungdan oilfield. The lower Miocene Pyawbwe Formation is the petroleum source rock (Lynn, 2015; Ridd and Racey, 2015; Than, 2017).

We observed vertical offsets of the fault plane within the Miocene units, ~750 m offset between the Pyawbwe and Kyaukkok formations, ~465 m offset between the Kyaukkok and Obogon formations, and ~375 m offset between the Obogon and Irrawaddy formations. In the shallow part of the eastern margin of the E-W seismic line, the thick

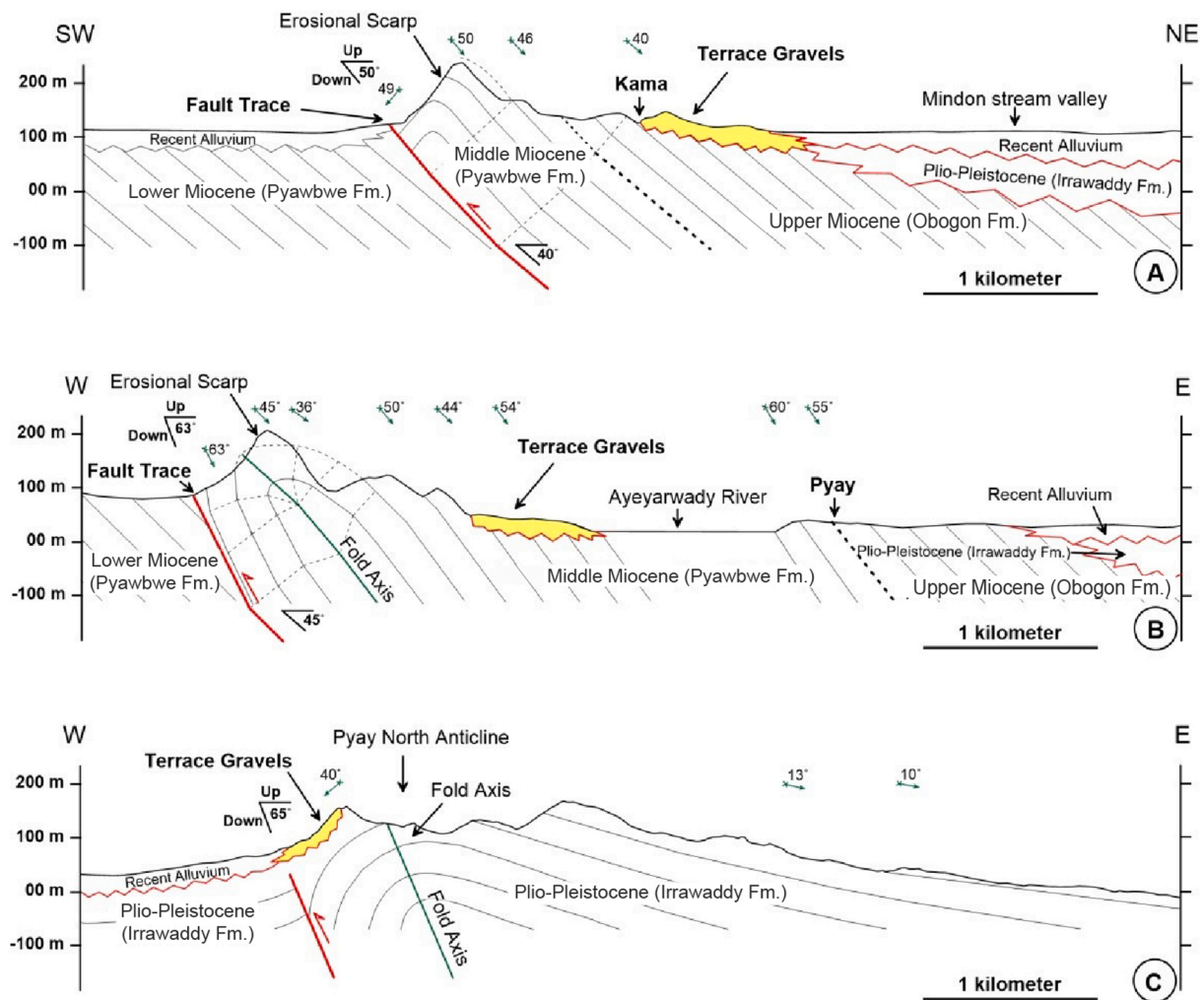


Fig. 7. Geological cross-sections illustrating the subsurface structural geometry and uplifted fluvial terrace gravels exposed on the hanging wall block of Pyay Fault. (A) NE-SW cross-section perpendicular to Pyay Fault in the Kama area, (B) E-W cross-section perpendicular to the Pyay Fault in the Pyay area, and (C) E-W cross section at the southern end of Pyay North anticline. Uplift of terrace gravels relative to the hanging wall kinematics of Pyay Fault occurred during Post-Pleistocene time. Green arrows represent the inclination of lithologic units and thick dotted lines represent lithological boundaries. The locations of the cross-sections are shown in Fig. 11.

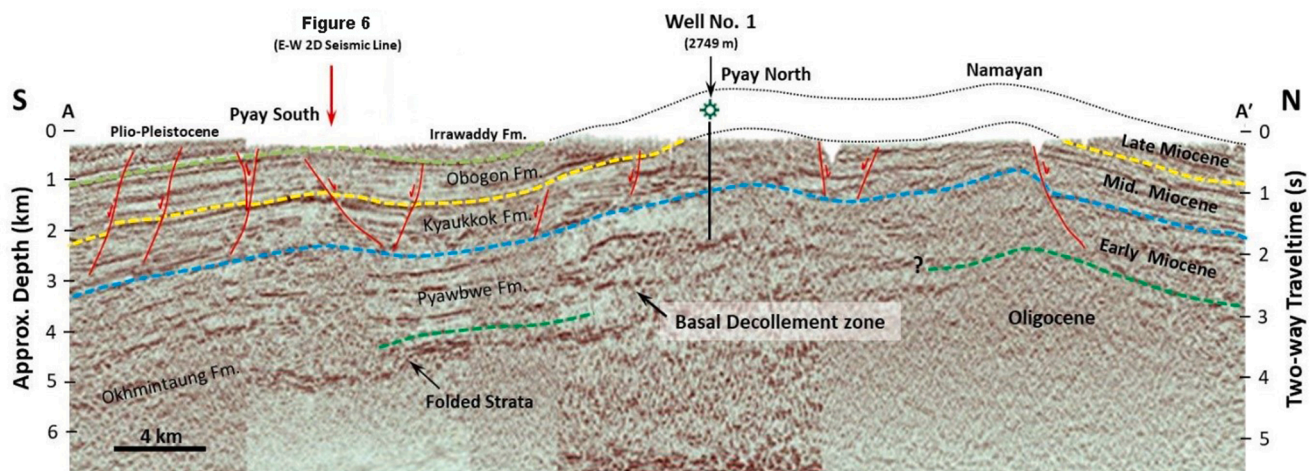
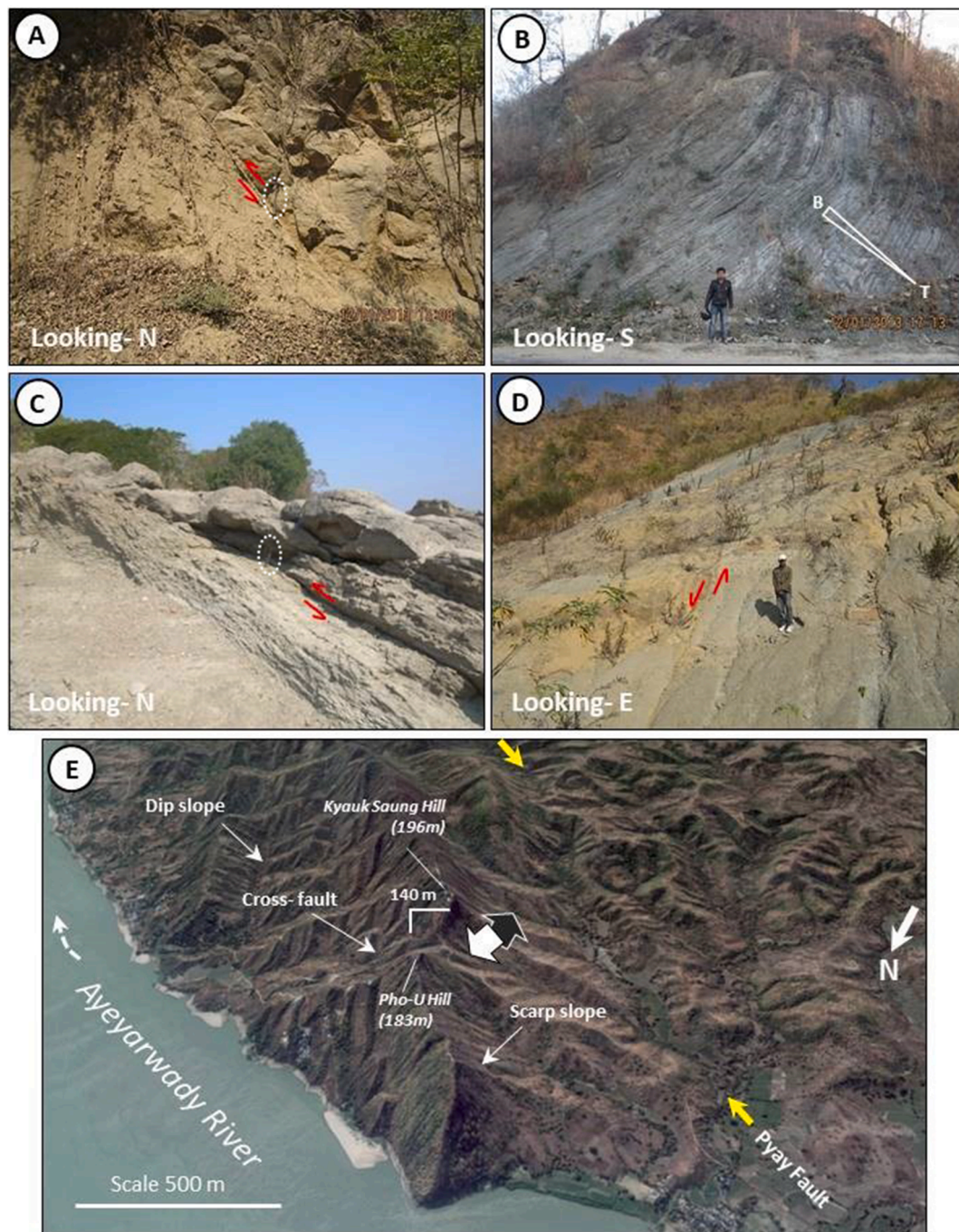


Fig. 8. A migrated 2D seismic reflection profile along the Pyay Taungdan Structure of the Myanma Oil and Gas Enterprise that images the S-dipping and N-dipping cross-faults that strike nearly E-W, perpendicular to the major structure. Pyay oilfield is divided by three structures, including the Namayan, Pyay North and Pyay South anticlines. Red lines indicate normal faults and colored dash-lines indicate approximate lithologic boundaries. Formation boundaries of the stratigraphic units are classified based on the biostratigraphic data integrated with the well log interpretations. The location of the seismic line is shown in Fig. 2 and its intersection with the seismic line shown in Fig. 6 is indicated by red arrow.

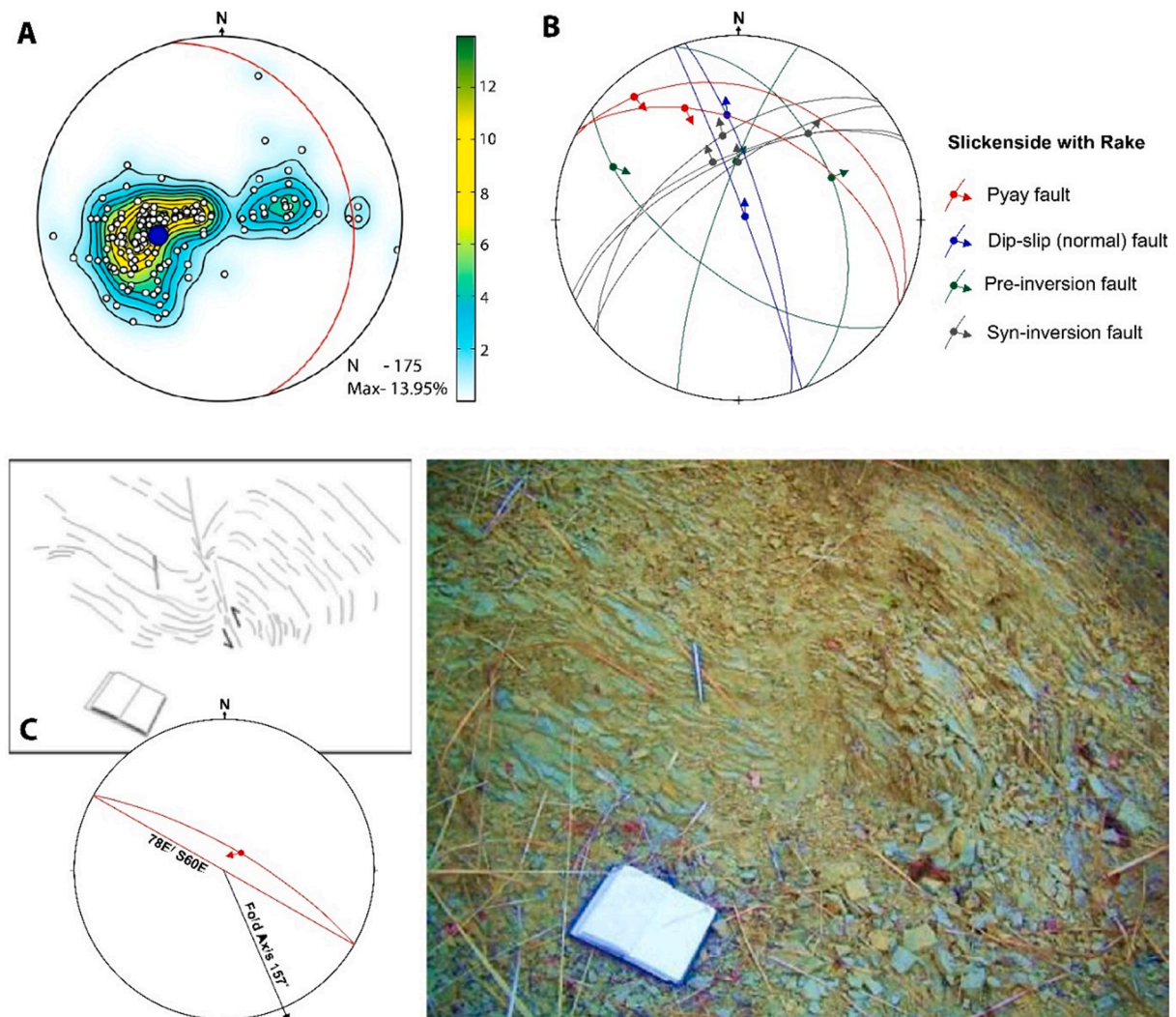


**Fig. 9.** Outcrop photographs illustrating the geometry of structures and stratigraphy along the Pyay Fault trace. (A) Slicken planes of Kyaukkok Fm., West of Kama; (B) Overturned sequence of Kyaukkok Fm. exposed along road cut W of Pyay, (C) Slicken planes of Kyaukkok Fm. exposed near Sinde village, (D) Normal fault plane of Kyaukkok Fm. exposed along a railway cutting, near Kama, and (E) Oblique view of a Google Earth image showing a cross-fault near Pho-U Hill. White dotted circles in A and C represent the geological hammer for the scale. The yellow arrows indicate the location of the Pyay Fault and red arrows in A, C and D indicate the fault displacement. Black and white arrows indicate the shear plane between the Pho-U Hill and Kyauk Saung Hill. Photo locations are shown in Fig. 2.

bedded unconsolidated sandstones unit of the upper part of the Irrawaddy Formation are overlapped by growth strata (Fig. 6). In the upper ~2 s TWT (~2–3 km), the fault plane dips ~65° to the east. The fault ramp dip decreases at a depth of ~3 km and terminates into a flat deformed zone within the Pyawbwe Formation. The Pyawbwe Formation is rich in clayey sediments and is thus likely to deform easier than the sandstone-dominated unit. We believe that this deformation feature observed within the Pyawbwe Formation is a basal décollement zone above the folded Oligocene sandstone unit (Okhmintaung Formation). The basal décollement zone can also be observed in both N-S and E-W

seismic sections (Figs. 6 and 8).

The N-S composite seismic section parallel to the fold axis of the Pyay Taungdan Structure (Fig. 8) shows the three distinct doubly plunging anticlinal structures discussed above and a series of cross-faults. Most of these cross-faults do not penetrate upward into the upper part of the Irrawaddy Formation, although some minor cross-faults on the surface were observed near Namayan anticline (Fig. 8). The evidence suggests that most of the cross-faults have not been active since the deposition of the upper-most Irrawaddy Formation (possibly since the end of Pliocene). Along the Namayan anticline, S-dipping and N-dipping normal



**Fig. 10.** Lower hemisphere Schmidt net projection of field structural data. (A) Pore contour diagram of bedding planes of rock units along the Alandaung-Pho-U-Pyay Taungdan anticlinal ridge (Table S2), (B) Displacements observed on the slickenside planes of major and minor faults along the Pyay Fault system (Table S3), (C) Mesoscopic character of the fault-bounded small-scale fold in sand/shale alternation unit of Obogon Fm. Two different pore contour anomalies indicate the Kama-Pyay west-verging anticlinal ridge and mean bedding plane represent NNE-SSE strike orientation. Field photographs of small-scale structure is similar to the regional nature of the Pyay Taungdan Structure. Color lines represent the slickenside planes and arrow heads indicate the sense of shear. Photo location is shown in Fig. 2.

faults that cut the Kyaukkok Formation die out with depth into the underlying Pyawbwe Formation. To the south, at Pyay North and Pyay South anticlines, the cross-faults are normal faults that die out in the lower part of the Kyaukkok Formation. The normal fault system at the southern termination of Pyay Fault penetrates into the base of Irrawaddy Formation and is perpendicular to the E-W compressional direction, suggesting that the generation of normal faults was synchronous with the uplift of the Pyay Taungdan Structure.

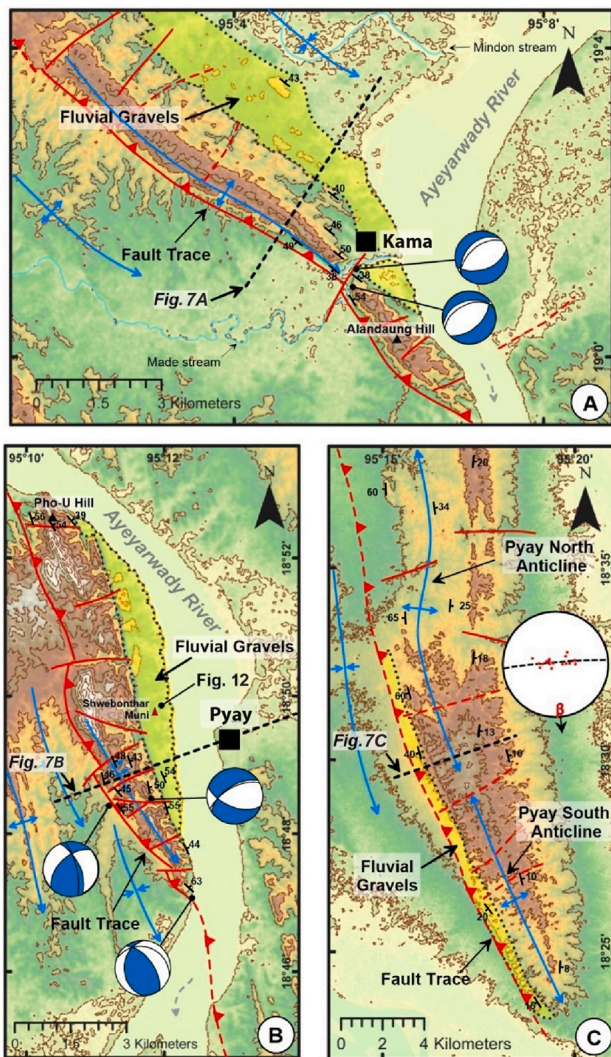
#### 4.4. Distribution and age of fluvial terrace deposits

The development of fluvial river terraces is controlled by the interaction of several factors including climatic conditions rates of river incision, and tectonic uplift (Blum and Price, 1998; Wang et al., 2009). Geochronology of the river terrace deposits reflects the timing of deformation and tectonic uplift of its underlying structures. Along the Ayeyarwady River banks in the CMB, the fluvial terrace deposits are exposed along Ayeyarwady River, extending from Myitkyina in the north (de Terra and Movius, 1943) to the Pyay and Kyangin area in the south (Fig. 1). In the Pyay basin, the terrace deposits unconformably overlie the Miocene Upper Pegu Group and/or the Plio-Pleistocene

Irrawaddy Formation. They are mainly composed of well-rounded, poorly- to moderately-sorted, reddish brown to buff-colored, polyolithic pebble and gravel deposits (Fig. 12). Most of the gravels and pebbles are quartz and feldspar with minor amounts of sandstone and silicified fossil wood. The fossil wood clasts are reworked from the underlying Upper Irrawaddy Formation (Theobald, 1869).

The Pyay Fault is a high-angle reverse fault with inclination steeper to the south. Geological cross-sections show that the fault dips are  $\sim 50^\circ$ ,  $\sim 63^\circ$ , and  $\sim 65^\circ$  sequentially from north to south (the Kama, Pho-U Hill, and Pyay Taungdan Segments respectively; Fig. 7). All the terrace deposits lie on the supra-thrust or hanging wall block (upthrown side) of the Pyay Fault. Along the fault trace, the terrace deposits occur along Mindon stream valley in the Kama Segment (Fig. 11A), on the west bank of the Ayeyarwady River near Shwebonthar Muni pagoda, one of the most famous Buddhist temples west of Pyay city (Fig. 11B) in the Pho-U Hill Segment, and along the western margin of the Pyay North and Pyay South anticlines in the Pyay Taungdan Segment (Fig. 11C). Our field investigations indicate that all river terrace deposits were uplifted to  $\sim 15$  to  $30$  m above the present-day water level of the Ayeyarwady River (Fig. 7A and B).

At the southern termination of Pyay Fault, the gravel deposits dip to



**Fig. 11.** Structural geological maps show our field structural data analysis (lower hemisphere Schmidt net projection) and distribution of fluvial terrace gravels along the Pyay Fault. (A) Northern part of fault trace near Kama area, (B) Middle part of fault trace, West of Pyay, (C) Southern termination of Pyay Fault. Stereographic projection of slickenside planes of the Pyay Fault (beach balls west of the Pyay Fault) show oblique sense of displacements and the cross-faults (beach balls east of the Pyay Fault) represent oblique normal (mostly dextral normal) and pure normal displacements (Table S2). Lower hemisphere  $\beta$ -diagram shows the mean orientation of plunge direction of southern Pyay Taungdan Structure where  $\beta$ -axis indicates the axial plane. Solid lines indicate the clear fault trace at the surface and dashed lines represent inferred/blind fault trace. Map index is shown in Fig. 3.

the west ( $\sim 15^{\circ}$ – $60^{\circ}$ ) due to folding associated with the Pyay Taungdan Structure (Figs. 7C and 11C) where the base of the anticline is cored by a blind or hidden east-dipping fault connected to the deformation zone within the Pyawbwe Formation at  $\sim 4$  km depth ( $\sim 3$ s TWT) (e.g., Fig. 6). Based on the distribution and stratigraphic relationships of the terrace gravel deposits, we believe that the deposits are of younger than lower Pleistocene, because they are overlying on the Irrawaddy Formation in general. Archeological studies of stone tools discovered along the Ayeyarwady River valley since the late 19th century help constrain the depositional age of these fluvial deposits. Although precise ages are not yet available, the archeological investigations of Paleolithic and Neolithic stone tools in the river terrace deposits from Myitkyina to Magwe suggest that the terrace gravel deposits are middle to late Pleistocene (Brown, 1931; Morris, 1937; de Terra and Movius, de Terra,



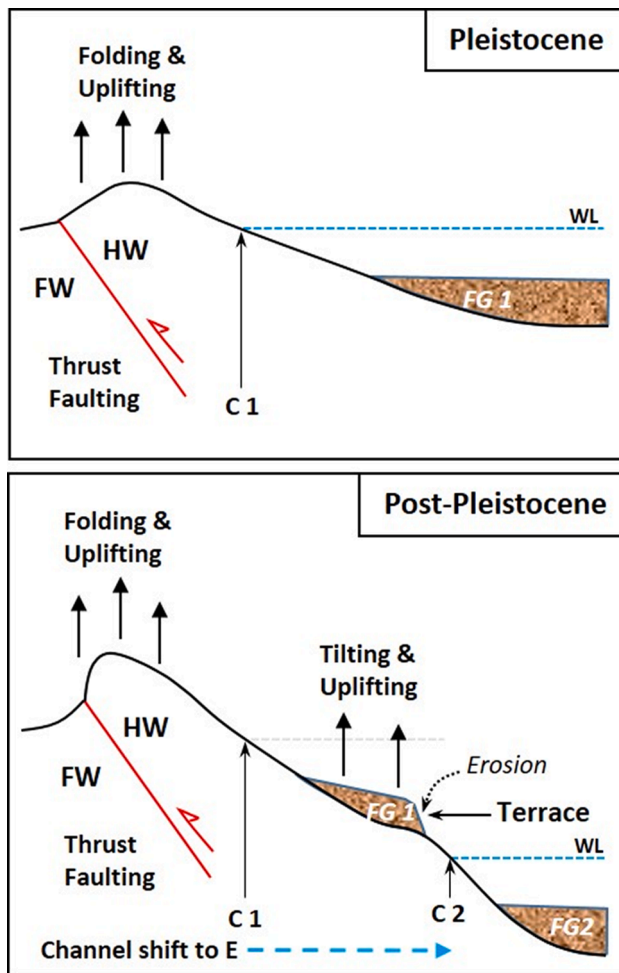
**Fig. 12.** Outcrop photographs of the fluvial terrace gravels exposed along the hanging wall of the Pyay Fault. (A) Gravel Hills and recent alluvium near Shwe Bon Thar Muni Pagoda, W of Pyay. (B) Angular unconformity between Middle Miocene laminated siltstone unit of the Obogon Formation and moderate to poorly sorted, well rounded channel deposits of fluvial gravels. Photo locations are shown in Fig. 11B.

1943; Aung Thwin, 2002; Fig. 1).

Additionally, the discovery of faunal habitation-migration evidence (Marwick, 2009) and mammalian fossils in the Ayeyarwady river terrace deposits also constrained the age of terrace gravels to be middle to late Pleistocene (Colbert, 1943; Bender, 1983; Chavasseau et al., 2006; Takai et al., 2006; Zin Maung Maung Thein et al., 2008). Our schematic geological cross-sections show the relationship between the present-day position of Ayeyarwady River terrace deposits and the underlying Pyay Fault (Fig. 7). We therefore propose that the tectonic uplift and tilting of these terrace gravels corresponds to post-Pleistocene activity along the underlying inverted structures of the FAB (Fig. 13).

#### 4.5. Vertical slip and horizontal shortening rates

The geomorphic expression at the northern termination of Pyay Fault (northwest of Kama) suggests that neotectonic activity has ceased and is being succeeded by erosion and denudation processes. In the same area, the fluvial terrace gravels exposed along the Mindon stream valley were uplifted, possibly during the post-Pleistocene, and highly eroded by weathering of the recent tropical monsoon in the lower regions of Myanmar. In the middle part of Pyay Fault (Pho-U Hill Segment), the surface fault trace and geomorphic features on the hanging wall side of the fault plane are sharp and more obvious under the same erosional conditions. The erosional features of uplifted gravel terraces of the up-thrown side of Pyay Fault exposed along the east bank of Ayeyarwady River are relatively lower than the same deposits exposed along Mindon stream valley. The inclinations of the uplifted terraces in both locations are gentle in the same eastward direction. The fluvial gravel deposits dip to the west where the east-dipping Pyay Fault (blind fault) is hidden along the western margin of the Pyay Taungdan Structure (Fig. 7C).



**Fig. 13.** Idealized cartoon of the neotectonic process of the Kama and Pho-U Hill segments of the Pyay Fault between the Pleistocene and post-Pleistocene. Deposition of fluvial gravels during the middle to late Pleistocene (Upper) and uplifting of fluvial gravels and formation of terraces due to the thrusting of underlying Pyay Fault in the post-Pleistocene or Holocene (Lower). This process causes the channel migration to the east and erosion of eastern bank of the Ayeyarwady River in northern Pyay city. HW- Hanging Wall, FW- Foot Wall, WL- Water Level, C1- Pleistocene Channel, C2- Post-Pleistocene Channel, FG1- Pleistocene Fluvial Gravel, FG2- Recent Fluvial Gravel. The present-day tectonic geomorphology and structural orientation of Pyay Fault are controlled by post-Pleistocene hanging wall kinematics of Pyay Fault.

The lithologic characteristics and presence of Neolithic stone implements (Smith, 1926) suggests the fluvial gravels on the hanging wall of Pyay Fault are terrace T3 or T4 of the composite succession of fluvial terraces of the Ayeyarwady river within the Salin sub-basin (de Terra and Movius, 1943; de Terra, 1943). Thus, we assume that the age of the fluvial gravels are middle late Pleistocene ( $\sim 0.1$ – $0.05$  Ma). Based on this geochronological inference and the maximum height of terrace gravels ( $\sim 30$  m) determined by field investigation, we calculate a vertical slip rate of  $\sim 0.3$  mm/yr for the underlying Pyay Fault.

The southern part of Pyay Fault is a blind structure that is buried along the western margin of the Pyay Taungdan Structure. The underlying geometry of the Pyay Taungdan Segment is a west-verging fault propagation fold as in the aforementioned sections. Hardynw and Poblet (2005) proposed a method to calculate the vertical and horizontal slip rate of both blind and exposed fault-related folds. Many successful studies have determined the flexural slip fold related faults of the many inverted basins of the world (e.g., Wesnousky et al., 1999; Kumar et al., 2001; Van der Woerd et al., 2001). The structural geometry of Pyay Fault is similar to the constant-thickness fault propagation fold for the

Kama Segment and the fixed axial surface fault propagation fold for the Pho-U Hill and Pyay Taungdan Segments (Hardynw and Poblet, 2005). We calculate an  $\sim 0.32$  mm/yr vertical slip rate and an  $\sim 1.01$  mm/yr horizontal shortening rate for the Pyay Taungdan Structure. This result is similar to the fault slip rate based on fluvial gravels exposed on the hanging wall of Pyay Fault in the north.

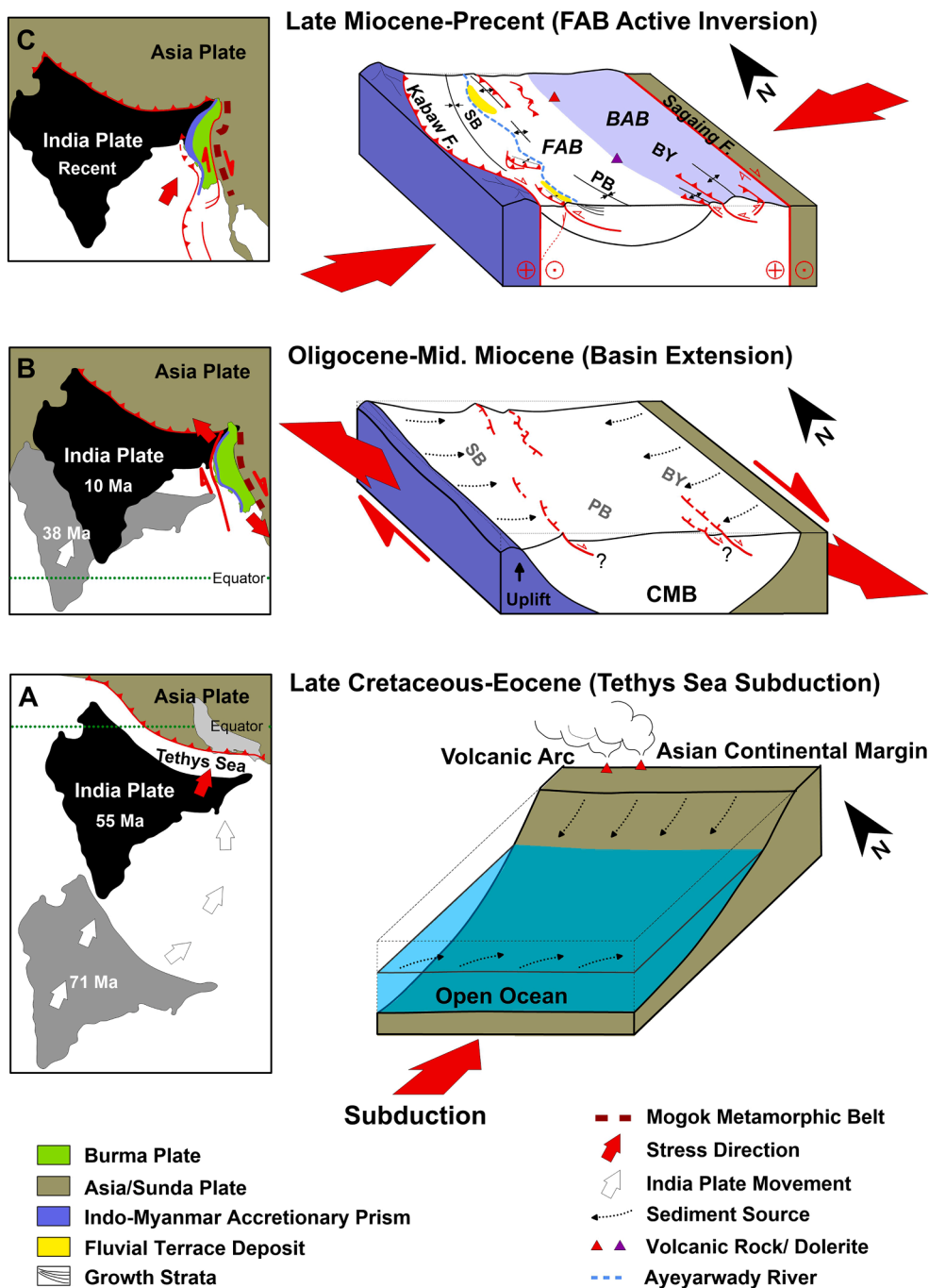
The result shows the vertical slip rate is approximately one third of the horizontal shortening rate of the Pyay sub-basin. Based on this estimation of the Pyay Taungdan Segment, the possible horizontal shortening rate of the Pho-U Hill Segment is  $\sim 1 \pm 0.05$  mm/yr. Our study thus suggests a vertical slip rate of  $0.32 \pm 0.01$  mm/yr along the Pyay Fault and  $\sim 1 \pm 0.05$  mm/yr of horizontal shortening rate of the Pyay sub-basin is  $\sim 10\%$  of the total strain partitioned within the Burma Plate as estimated by geodetic studies respect of the India-Asia collision. The remaining 90% of strain load (i.e.,  $\sim 9$  mm/yr) is absorbed by the other structures in the BAB in the east and the IMR in the west (Wang et al., 2014).

## 5. Discussion

### 5.1. Timing of FAB inversion and development of the Pyay Fault

Previous studies of Myanmar's regional tectonic framework generally agree that the Burma Plate was part of the continental margin of SE Asia before the India-Asia collision and was located to the southeast of its present position (e.g., Curray et al., 1979; Tapponnier et al., 1982; LeDain et al., 1984; Ni et al., 1989; Lee and Lawver, 1995). Low temperature thermochronological age analyses and provenance studies along the CMB and IMR suggest that sedimentation in the ancestral forearc basin was initiated as early as the late Cretaceous with deposition of the Kabaw Formation above ophiolite basement (Cai et al., 2019). Middle Eocene volcanoclastic sediments in both CMB and IMR were derived from the Andean-type, eastern Myanmar continental magmatic arc, suggesting an open connection to these areas (Kyaw et al., 2015; Licht et al., 2019; Najman et al., 2020). The IMR was accreted to the western edge of the Burma Plate over the east-ward subducting Indian slab (Tethys) at the end of the Eocene (Fig. 14A). The basin morphology of CMB was originally generated by uplift of the IMR as a barrier between the Asian continental margin and Tethys Sea in the late Oligocene, along with sediment transport from the east (Najman et al., 2020). India-Burma oblique continental convergence initiated in the Oligocene. This oblique collision resulted in transtensional deformation of the Burma Plate during the northward migration of India in the Oligocene to Miocene that is synchronous with diachronous cooling and exhumation along the Mogok Metamorphic Belt (MMB; Fig. 1) (Searle and Haq, 1964; Mitchell et al., 2007; Lee and Lawver, 1995; Pivnik et al., 1998; Bertrand and Rangin, 2003; Bertrand et al., 2001). At the same time, NNW-SSE crustal stretching and transtensional deformation occurred along the CMB, resulting in extensional normal faulting along the margins of the structural sub-basins. Therefore, the CMB was a NNW-SSE-striking extensional basin during the collision period that provided accommodation space for Miocene fluvial sediments (Fig. 14B). In the late Miocene, initiation of dextral motion along the Sagaing Fault caused the uplift of the BAB synchronous with the emplacement of Mt. Popa volcano and formation of the Bago Yoma anticlinorium (Bender, 1983; Stephenson and Marshall, 1984). The angular unconformity at the base of the Irrawaddy Formation and the absence of the Obogon Formation in the eastern part of Salin sub-basin indicates regional uplift of the BAB (Pivnik et al., 1998).

Intercalated layers of volcanoclastic material in the fluvial sediments of the upper Irrawaddy Formation that formed during the late stage of volcanism of Mt. Popa near Taung Kalat are dated as  $0.96$ – $0.8$  Ma (Cumming et al., 2009; Belousov et al., 2018), indicating that deposition of the Irrawaddy Formation continued until the early Pleistocene. In Salin sub-basin, tilting of the upper intra-formational unconformity between the lower Irrawaddy and upper Irrawaddy Formations is



**Fig. 14.** Tectonic model showing geodynamic of the India-Asia convergent zone (left) and evolution of the Central Myanmar Forearc Basin (right) within the Burma Plate. (A) Tethys sea subduction along the Asian continental Margin in the late Cretaceous to Eocene; (B) India-Burma plate collision, uplift of Indo-Myanmar Range and NNW-SSE extensional deformation (normal faulting) along the Central Myanmar Belt; (C) Strike-slip deformation along a Sagaing Fault, uplift of the Backarc Basin, reaction of Miocene normal fault and tectonic inversion of the Central Myanmar Forearc Basin in late Miocene to present. FAB- Forearc basin, BAB- Backarc basin, CMB- Central Myanmar Belt, SB- Salin sub-basin, PB- Pyay sub-basin, BY- Bago Yoma sub-basin. Folds in black colors represent the active inverted structures since (en-echelon folds and faults) of the Central Myanmar Belt. Red colors represent faults and arrows indicate the fault movements. The evolution of central Myanmar Forearc Basin is strongly controlled by the NNE India Plate migration, rotation of Burma Plate and transtensional-transpressional deformation along the Asian continental margin during the late Cretaceous to present. Grey color and plate boundaries are reference only. See also in Table 3.

observed in the seismic reflection profiles of Pivnik et al. (1998). Apatite fission-track data show that the folded unconformity at the base of the Irrawaddy Formation is 10 Ma and the horizontal intraformational unconformity is 5.33 Ma (Trevena and Varga, 1991), suggesting that structures at the eastern-margin of Salin sub-basin, i.e., Gwegyo Thrust, were active during the late Miocene (Pivnik et al., 1998; Kyaw et al., 2014; Fig. 1).

However, no deformation features younger than Pliocene are observed along the Gwegyo Thrust, indicating that it has been inactive since the Pliocene (Pivnik et al., 1998). To the west, deformation along the Yenangyut-Chauk Fault, i.e., overturned folding of Chauk anticline and tilting that generated intraformational unconformities within the upper Irrawaddy Formation in both hanging wall and foot wall, suggests that deformation is still active (Pivnik et al., 1998). Thickening of the

Miocene section in the hanging wall of the 20° N uplift (e.g., Chaungtha Fault (CF in Fig. 1)) in the Salin sub-basin suggests that the inversion of Miocene normal faults of the structural sub-basins within CMB occurred mainly in Plio-Pleistocene time, following the uplift of the Bago Yoma sub-basin and initial extrusion of Mt. Popa volcanics (Fig. 14 C). These en-echelon inverted structures along the CMB strike NNW-SSE.

The Pyay Fault has the same strike as structures observed in the Salin sub-basin. Along the northern part of Pyay Fault (near Kama and Pho-U Hill), the fault trace is clearly exposed at the surface but is buried under sandy alluvium along the Pyay Taungdan Structure in the south. Oblique-slip (dextral-reverse) motion indicated by slickensides on bedding planes of the middle Miocene Kyaukkok sandstones are the major evidence for motion on this surface fault trace (see Section 5.2). In the Pyay sub-basin, the Irrawaddy Formation thickens in the basin

depocenter and thins to the basin margin as observed in E-W integrated 2D/3D seismic surveys (Kyaw, 2015). Geological observations of previous workers suggest that the age of the Irrawaddy Formation is variable within the Pyay sub-basin, i.e., Plio-Pleistocene at the basin margin along the Pyay Fault (e.g., Soe and Aung, 1966) and late Miocene to Plio-Pleistocene in the depocenter (Wandery 2006).

We propose that structural inversion of the Pyay Fault was synchronous with the 20° N uplift in the southwestern part of Salin sub-basin where the Miocene extensional normal faults were reactivated as reverse faults since Pliocene time (Pivnik et al., 1998; Lin et al., 2015). However, definitive evidence related to Miocene extensional normal faulting of the Pyay Fault is not observed in seismic sections across the Pyay sub-basin. Our study suggests that inversion of the Pyay sub-basin is most likely due to folding of the Pyay Taungdan Structure that was previously believed to be a Miocene normal fault reactivated as a reverse fault in the Pliocene, synchronous with the inversion of Salin sub-basin to the north. This further suggests that the anticlinorium along the strike of Pyay Fault and development of growth strata within the Plio-Pleistocene Irrawaddy Formation represents inversion of Pyay sub-basin initiated during deposition of the Irrawaddy Formation (Fig. 6). Previous workers, however, have not reported evidence related to the active tectonics of inverted structures in the CMB.

The tectonic history of the central Myanmar FAB can be summarized as Oligocene to Miocene transtensional deformation followed by Pliocene to recent transpressive deformation, all resulting from India-Asia convergence since the Cretaceous. The overall tectonic development of the India-Sunda convergent margin and the relative deformation phases of the CMB are summarized in Table 3.

### 5.2. Fault geometry and post-Pleistocene uplift

The relationship between the stratigraphic features and underlying geometry of the Pyay Taungdan Structure documents the timing of development of Pyay Fault. The schematic geological cross-sections perpendicular to the strike of Pyay Fault in the Kama (Figs. 7A and 11A), Pho-U Hill (Figs. 7B and 11B), and Pyay Taungdan segments (Figs. 7C and 11C) show different underlying structural geometries. In the northern Kama Segment, the underlying geometry is that of a break thrust fold (symmetrical anticline) with an ~50° fault ramp along the Alandaung Ridge in the Kama segment (Fig. 7A). The central Pho-U Hill Segment is characterized by a break thrust fold (overturned anticline) with an ~63° fault ramp along the Pho-U Hill ridge (Fig. 7B). Finally, the southern Pyay Taungdan Segment consists of a west-verging fault-propagation fold associated with an ~65° fault ramp (Fig. 7C).

**Table 3**

The major tectonic phases India-Sunda convergent zone and the neotectonic process of Pyay Fault by this study.

| Epoch           |     | Tectonic Events                                                              |                                                                     | Deformation History                               |                                                                                                    |                                                                   |
|-----------------|-----|------------------------------------------------------------------------------|---------------------------------------------------------------------|---------------------------------------------------|----------------------------------------------------------------------------------------------------|-------------------------------------------------------------------|
| Ma              |     | India-Sunda, Geochronology, Formation of CMB                                 |                                                                     | Myanmar                                           | Pyay sub-basin                                                                                     |                                                                   |
| Holocene        | 0   | Sagaing F.                                                                   | Mt. Popa (K/Ar) <sup>a</sup><br>0.96-0.8 Ma                         | Major Inversion                                   | - Reactivation of Miocene normal faults                                                            | - Pliocene to post-Pleistocene uplift                             |
| Pleistocene     | 0   |                                                                              | Mt. Popa (K/Ar) <sup>a</sup><br>4.30 ± 0.55 Ma                      |                                                   | - Eastern basin uplift                                                                             | - Development of growth strata within upper Irrawaddy Fm.         |
| Pliocene        | 5   | India-Sunda collision                                                        | IMR samples <sup>b</sup><br>(AFT, ZHe, ZFT)<br>~19 to 23 Ma         | Inversion                                         | - Opening of Andaman Sea Spreading Center                                                          | - Post-Pleistocene uplift and tilting of fluvial terrace deposits |
|                 | 10  |                                                                              |                                                                     |                                                   | Extensional Basins                                                                                 | - Development of the extensional basins and normal faulting       |
|                 | 15  |                                                                              |                                                                     |                                                   |                                                                                                    | Separation of CMB from IMR                                        |
|                 | 20  |                                                                              |                                                                     |                                                   |                                                                                                    |                                                                   |
| Miocene         | 25  | Tectonics along India-Asia convergent zone                                   | MMB/ Intrusive <sup>c</sup><br>rocks (40Ar/39Ar)<br>15.8 to 26.9 Ma | Metamorphism of the MMB                           | - Major uplift of Indo-Myanmar Range above sea level                                               |                                                                   |
|                 | 30  |                                                                              |                                                                     |                                                   | - Diachronous cooling and exhumation along Mogok Metamorphic Belt                                  |                                                                   |
|                 | 35  |                                                                              |                                                                     |                                                   | - Detachment and formation of Basin and range topography along Sunda block                         |                                                                   |
|                 | 40  |                                                                              |                                                                     |                                                   | - Deposition of volcanoclastic detritus sediments (Pondaung Fm.)                                   |                                                                   |
| Oligocene       | 45  | NE migration of the India Plate                                              | Flysch sequence samples (U-Pb)<br>62.39 to 65 Ma                    | Volcanism of Andean-type Continental Magmatic Arc | - Unroofing of upper Cretaceous-Eocene Andean-type continental magmatic arc                        |                                                                   |
|                 | 50  |                                                                              |                                                                     |                                                   | - Deposition of Cretaceous to Eocene sediments under shallow marine to fluvial-deltaic environment |                                                                   |
|                 | 55  |                                                                              |                                                                     |                                                   | - Formation of a series of continental pull-apart basins                                           |                                                                   |
|                 | 60  |                                                                              |                                                                     |                                                   | - Initiation of structural relief (proto- Indo-Myanmar Range)                                      |                                                                   |
| Eocene          | 65  | Tethys-sea subduction along the western part of the Asian continental margin | Western Outcrop samples (U-Pb)<br>~ 106 Ma                          |                                                   |                                                                                                    |                                                                   |
|                 | 100 |                                                                              |                                                                     |                                                   |                                                                                                    |                                                                   |
| Paleocene       |     |                                                                              |                                                                     |                                                   |                                                                                                    |                                                                   |
|                 |     |                                                                              |                                                                     |                                                   |                                                                                                    |                                                                   |
| Late Cretaceous |     |                                                                              |                                                                     |                                                   |                                                                                                    |                                                                   |
|                 |     |                                                                              |                                                                     |                                                   |                                                                                                    |                                                                   |

Note

CMB - Central Myanmar Belt  
IMR - Indo-Myanmar Range  
MMB - Mogok Metamorphic Belt  
AFT - Apatite fission track method  
ZHe - Zircon (U-Th)/He dating method  
ZFT - Zircon fission track analysis

a. Cumming et al., 2009

b. Najman et al., 2019

c. Bertrand et al., 2001

d. Cai et al., 2019

→ Main tectonic/ geomorphic episode

-- Gradual tectonic/ geomorphic episode

We classified two different types of cross-fault systems (Fig. 11): (1) nearly E-W to ENE-WSW and (2) NE-SW cross-faults, that are recognized along the surface trace of Pyay Fault based on their different structural styles and timing of deformation (Fig. 10B). The most prominent set (1) does not cut the Pyay Fault, is slightly oblique to the main trace of Pyay Fault and exhibits normal-dextral displacement. We propose that this cross-fault system is older than Pyay Fault and classify it as pre-inversion (Miocene age) (Fig. 10B). The other cross-fault system (2) exhibits mainly normal displacement and cross-cuts the Pyay Fault. The NE-SW strike of this system is perpendicular to the main trace of Pyay Fault, is probably related to Pyay Fault inversion, so we characterize it as a Plio-Pleistocene age, *syn*-inversion cross-fault system (Fig. 10B). The strikes of these cross-faults are parallel to the regional compressional stress field, the direction of India plate that has affected the Pyay sub-basin since the late Miocene (Figs. 11 and 14A).

Our field geological data show that the bedding of the Irrawaddy Formation exposed in the eastern limb of the Pyay Taungdan Structure is gently inclined ( $\sim 15^{\circ}$ – $20^{\circ}$ ) to the east (Fig. 11C). The Pyay Fault's geomorphic expression and underlying structural geometry indicate that uplift along the southern portion of the fault was active at least until the deposition of the upper Irrawaddy Formation (Plio-Pleistocene). Thrust faulting occurred simultaneously with Irrawaddy Formation deposition and, although the fault plane does not intersect the surface, shallow, *syn*-tectonic growth strata are imaged on the fault hanging wall overlying the Irrawaddy Formation (Fig. 6). Moreover, on the eastern limb of Pyay South anticline (the hanging wall block of the reverse fault), seismic reflection profiles across Pyay Taungdan oilfield document growth strata within the upper part of the Irrawaddy Formation. Thus, there is significant evidence for recent Pyay Fault motion preserved along the Pyay Taungdan Segment related to E-W shortening across the Pyay sub-basin in the southern FAB.

Our field observations show that the well-rounded, poorly-sorted, polyolithic gravels and pebbles of the fluvial terrace deposits are affected by tectonic tilting simultaneous with Pyay Fault uplift. The gravels were deposited on the hanging wall of Pyay Fault by fluvial river processes of the Ayeyarwady River. Thus, the Irrawaddy Formation might have been eroded by fluvial processes, producing an angular unconformity between the middle to upper Pleistocene terrace deposits (Fig. 12B). Tectonic tilting of the terrace deposits reflects the post-Pleistocene activity of the underlying structure. The most obvious tectonic tilting effect on the Pleistocene terrace gravel is the eastward inclination ( $20^{\circ}$ – $60^{\circ}$ ) of gravel deposits on the western limb of the southern Pyay Taungdan Segment exposed on the road cut through Pyay oilfield (Figs. 7C and 11C). The present-day geomorphology and orientation of these river terrace deposits are controlled by the underlying geometry and hanging wall kinematics of the Pyay Fault (Fig. 13). We therefore propose that the tectonic inversion of Pyay sub-basin began with folding of the Kama-Pyay anticlinal ridges followed by thrusting along the underlying Pyay Fault during Pliocene to post-Pleistocene time.

To the north of Pyay sub-basin, de Terra and Movius (1943) documented five successive stages in the development of fluvial terraces along the Ayeyarwady River from Pakokku to Magwe in the Salin sub-basin (Fig. 1). They suggested that terraces T2 and T3 developed during the third glacial and interglacial stages of the Himalayan sequence, respectively (de Terra, 1939; de Terra et al., 1943), and that terrace T4 formed in the fourth pluvial stage. Terrace T1 can be correlated with the Jade-bearing Uru Boulder Conglomerate (Chhibber, 1934) of the Myitkyina area (Fig. 1) and Terrace T5 is similar to the recent sediments of Ayeyarwady River. In contrast to the previous work, which did not utilize any subsurface geological data or neotectonic interpretation, we suggest that the present day orientation of fluvial terrace deposits and underlying fault geometry were formed as a result of river incision and the combination of the deposition of glacial-interglacial sediments and recent motion of the underlying inverted structures.

In the Chauk area of Salin sub-basin (Fig. 1), the Pleistocene terrace gravel deposits studied by de Terra and Movius (1943) lie on the

hanging wall of Yenangyut-Chauk Thrust (Pivnik et al., 1998; Lin Thu Aung, 2014), an inverted structure of late Neogene age that trapped the petroleum deposits in the Chauk, Lanywa and Yenangyut oilfields of the Salin sub-basin (Pivnik et al., 1998; Ridd and Racey, 2015). Seismic reflection lines across the Salin sub-basin supplemented by field observations indicate the presence of west-dipping reverse faults overlain by fluvial terraces on the hanging wall of Yenangyut-Chauk Thrust (YCT in Fig. 1), similar in orientation to our observations along the Pyay Fault.

Thus, our study suggests that the development of fluvial terraces of the Ayeyarwady River within the FAB occurred during multiple phases of river incision and sediment deposition related not only to climatic conditions but also to the structural inversion of underlying Yenangyut-Chauk and Pyay Faults, beginning in the Pliocene. Furthermore, deformation associated with the structural development of the Pyay sub-basin began in the Eocene and continued into the Quaternary.

### 5.3. Deformation related to strike-slip motion

The Burma Plate has experienced strike-slip deformation associated with the oblique dextral convergence of the India and Asia plates since the Cretaceous (Tapponnier et al., 1982; LeDain et al., 1984; Hutchison, 1989; GIAC, 1999; Morley et al., 2020). As a consequence, the Burma Plate has rotated clockwise via the formation of a series of pull-apart basins within the CMB (Fig. 14). All of the major tectonic elements in the CMB and the IMR including  $\sim$ N-S striking folds and faults exhibit dextral strike-slip motion. The NNW-SSE strike of the Kabaw Fault along the western margin of Salin sub-basin changes to N-S at the latitude of Pyay sub-basin. In the south, the strike of the Kabaw Fault changes to NNE-SSW along the western margin of the Ayeyarwady Delta sub-basins (e.g., LeDain et al., 1984; Fig. 1).

From north to south, structural and geomorphic features along the Pyay Fault change trend gradually from NE-SW to NNW-SSE: NW-SE trend north of Kama (e.g., Pyalo and Alandaung Ridges), NNW-SSE trend in the middle (e.g., Pho-U Hill ridge), and nearly N-S in the southern region (i.e., Pyay Taungdan Structure, Nat Hill, and Tonbo synclinal ridge) (Fig. 3). Similarly, the structural alignment changes from  $\sim 130^{\circ}$  in the north to  $\sim 165^{\circ}$  in the south resulting in a net  $\sim 35^{\circ}$  clockwise rotation of the structures. These major structural features also reveal a sigmoidal (S-shaped) bend due to the regional rotation within the Pyay-sub-basin as a strike-slip shear between the Sagaing Fault in the east and Kabaw Fault in the west (Figs. 1 and 3). All this information suggests that the Pyay Fault has experienced a significant amount of dextral strike-slip deformation in addition to thrusting.

In 2017, the  $M_w$  5.1 Taikkyi earthquake occurred at the southern continuation of the West Bago Yoma Fault system, located at the margin of the FAB and BAB, north of Yangon (Wang et al., 2018; Fig. 1). This is a major reverse fault system along the western margin of Bago Yoma uplift (an inverted sub-basin), which is oriented NNW-SSE parallel to the Pyay Fault in the west and Sagaing Fault in the east. The focal mechanism of this earthquake shows a significant dextral strike-slip component, although it is a reverse fault that originated as a normal fault during the Miocene. We suggest that the present-day tectonic inclination and uplift of terrace gravels in the southern segment of Pyay Fault are the result of dextral strike-slip deformation (as a strike-slip basin) within the FAB due to the hyper oblique convergence of the India plate in the west. Thus, the depocenter of the Pyay sub-basin is subsiding with continuous folding along the Alandaung- Pho-U Hill-Pyay Taungdan anticlinal ridges and thrusting of the underlying Pyay Fault at the western basin margin. This deformation is the result of strike-slip shearing along the southern Kabaw and Sagaing Faults, causing the development of flexural slip within the upper Miocene strata (e.g., Figs. 9A and 10B) and a décollement zone within the upper Miocene Pyawbwe Formation (Figs. 6 and 8).

Although no seismic events have recently been recorded along the Pyay Fault, we suggest that the associated neotectonics are similar to the West Bago Yoma Fault. Historical records of the 1858 earthquake

document that the Ayeyarwady River flowed backward (upstream) during the earthquake that caused serious damage in Pyay city and Thayetmyo, located about 30 km north of Kama (Chhibber, 1934). This behaviour is similar to the 1811–1812 New Madrid earthquakes of Missouri and Tennessee (central USA) that caused the Mississippi River to flow upstream due to the vertical uplift of the underlying Reelfoot Fault (e.g., Kelson et al., 1996; Mueller and Pujol, 2001). We suggest that the formation of the river defilement is controlled by present day activity of the Pyay Fault underneath the Ayeyarwady River (Fig. 3). Thus, we believe that possible hypocentre of the 1858 event is most likely at the inferred Pyay Fault between Kama and Pho-U Hills.

A positive flower structure is observed in the 2D seismic lines across the Pyay South anticline (Fig. 6), suggesting recent strike-slip deformation as opposed to the compressional folding and thrusting that caused tilting of fluvial gravels at the western margin of Pyay South and Pyay North anticlines. Again, the strike-slip deformation is due to rotation of the Burma Plate between the obliquely subducting India Plate and dextral shearing across the major Sagaing Fault.

## 6. Conclusions

The Pyay Fault is an ~105 km long, NNW-SSE-trending, high-angle reverse fault with a dextral strike-slip component located along the western flank of the Pyay sub-basin of the Central Myanmar FAB. The fault scarp geomorphic expression with moderate topographic relief along the fault trace demonstrates the significance of the Pyay Fault as an active inverted structure. Structural data suggest that the dextral reverse displacement along Pyay Thrust is superposed by two sets of cross-faults: a Plio-Pleistocene normal fault system that formed during inversion of the Pyay Fault and a Miocene set of faults that were reactivated due to strike-slip displacement during Pyay Fault inversion. Two-dimensional seismic lines across the Pyay oilfield show that the east-dipping Pyay Thrust plane soles out under the west-verging anticlinal ridge and connects to a basal décollement at a depth of ~4 km.

The folded Irrawaddy Formation and overlying, shallow growth strata indicate that the initial stages of Pyay Fault inversion probably started in the Pliocene, i.e., synchronous with deposition of the upper Irrawaddy Formation. Structural and geomorphological evidence, including the distribution of uplifted post-Pleistocene fluvial terrace gravels of the Ayeyarwady River on the hanging wall block of Pyay Fault in the Pyay sub-basin and Yenangyut-Chauk Fault in the Salin sub-basin, indicate that the tectonic inversion and crustal shortening that absorb ~10% of the strike-slip deformation is partitioned across the Burma Plate and continues to the present day. Although the slip rate of Pyay Fault is very slow, historical earthquake records and the young deformation features mapped along its strike characterized the fault as a significant active source of potential earthquake hazards in the southern central Myanmar region. Our study suggests that the Pyay Fault plays an important role in the present day deformation of the Central Myanmar FAB, even though the rate of neotectonics activity is very slow.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary material

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jaesx.2020.100037>.

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