Fluvial Architecture of Reverse Directional Channels in the Irrawaddy Sandstone, Salin Basin, Central Myanmar*

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Abstract

An outcrop of the Irrawaddy Formation (Pontian to Pliocene) in the Salin Basin, Natmauk area of central Myanmar, northern tip of Bago Yoma was studied in order to provide a better understanding of the architecture associated with braided-fluvial deposits. The main section of outcrop, which is exposed over 1200 m, is interpreted to have been deposited in a proximal, sandy braided river at the eastern edge of the Salin Basin. Eleven lithofacies were identified, based on petrology and sedimentary structures. These lithofacies were grouped into five architectural elements, including channel fill, transverse bar, longitudinal bar, abandoned channel fill and overbank fines.

Two different major current directions can be considered as a lower channel showing SSW direction and stacked by reverse directional channels from the evidence of petrology and sedimentary structures related with inversion of pull-apart central Myanmar basins. It appears that the majority of sedimentary materials of the lowest channels were shed from a site NNE of the present area, while the sediments of reverse directional upper stacked channels were shed from a SSE source. For all provenance aspects of Irrawaddy sediments, paleocurrents, lithic grain parameters and P/F values suggest that particles comprising the Irrawaddy Formation were shed from an uplifted basement (Shan Taninthayi Block/Shan Plateau) and/or a rifted continental margin/transform fracture zone (the western margin of Shan Taninthayi Block/Shan Plateau) (Figure 1).

These sediments were deposited in three stages: active, abandonment, and reactivation. These reflect channel switching, waxing and waning of the fluvial system and it is further considered that the sediments were carried by a river that was less sinuous and braided in nature and with shallow bathymetry.

Location and Geologic Setting

The tectonic framework and location of the study area is shown in Figure 1 and Figure 2. It is in the Kyaukpadaung and Natmauk Townships, Mandalay Division, Myanmar, between North Latitudes 20° 32' to 20° 43' and East Longitudes 95° 18' to 95° 23' of fairly rugged terrain. It occupies a part of the Western Trough of the Cenozoic Belt of Myanmar and situated just east of the Central Volcanic Line that runs north-south. The Eastern and Western Troughs both exist in the Central Basin that was separated by the Central Volcanic Line (see in Figure 1) and contains a sequence of deformed shallow marine and fluviatile sediments up to 8000 m thick. The sediments reflect a gradual filling of the basins during the Tertiary Period (Aung Khin and Kyaw Win, 1969).

The sedimentary sequences consist of the Kyaukkok Formation (518 m), Obogone Formation (425 m), Diamictite unit and Irrawaddy Formation (276 m) which are overlain by Quaternary deposits. The intermittent volcanism that occurred during the Pliocene resulted in interfingering of shallow marine Pegu and Irrawaddy fluvialtile sediments with pyroclastic rocks.

In the present area, this unit is well developed in the outer part of the major anticline. They occur mostly in lowland areas and cultivated fields, and in turn are capped by recent alluvium, plateau gravels and red earth. In places badland topography is mostly developed. Fossil wood fragments, vertebrate bones and shark teeth are commonly found in it. The stratigraphic contact between the underlying Obogon Formation and Irrawaddy Formation is arbitrarily placed and generally concealed by the Quaternary deposits and recent alluvium (Figure 1). A regional stratigraphic column for the Salin Basin is shown in Figure 2.

Mode of Occurrences

According to McBride's classification scheme (1963), the Irrawaddy sandstones fall in the field of lithic arkose (Than, 1993).The average modal composition of the Irrawaddy Sandstones contain 73 to 76% detrial grains and 24 to 27% chemical cement. The maximum diameter of detrital grains ranges from 0.3 to 0.7 mm and the minimum diameter ranges from 0.13 to 0.23 mm. The ratio of the largest to smallest grains is about 5.38. It occurs moderately to poorly sorted and sub-rounded to sub-angular with some elongated quartz grains in many samples.

The framework of these sandstones is mostly normal to para-conglomeratic, but some show poikilotopic type. The nature of grain contacts are long and point contact among the grain-to-grain boundaries.

It is loosely cemented and consisting of quartz, feldspar, mica and rock fragments. The mechanical analysis of sand for the Irrawaddy Formation shows that the size distribution of the sands are unimodal with five numbers of mode with the modal class being medium sand size 0.5-0.25 mm. The Irrawaddy sands have 1.8-49.85% coarse admixtures and 0.2-40.0% fine admixtures.

The mean values range from 0.16 to 0.34 that generally increase stratigraphically upward. Most of the sands are poorly to moderately sorted. The skewness values of sediments are positive and vary from 0.69 to 7.18, while kurtosis values plotted in the platykurtic to very leptokurtic distribution. It appears that the Irrawaddy sediments were deposited under mainly fluvial conditions (Fuchtabaure and Muller, 1970; Reineck and Singh, 1980).

Reverse Directional Channel in Studied Outcrops

The discontinuous exposures above 1200 m exhibit several cycles of lithologic sequences along a stream section of the Kularmyaw Chaung (Stream) just east of the Sinthegan village (Figure 2). The studied outcrops are exposed along the western section in terms of Stations One, Two and Three that can be laterally correlated (Figure 9). Station Two-A is exposed at the eastern section as present as opposite site of Station Two.

At Station One, two different major current directions can be considered as a lower channel that consists of a transverse bar with channel fills in a SSW direction, with a flat to concave base and erosional surface on top showing discontinuous discharge and stacked by reverse directional channel. Overlying channel consists of imbricated, crudely bedded, channel lag gravels (Gm) that show the northward reverse current direction (Figure 4) related with inversion of pull-apart Salin basins in central Myanmar.

At Station Two the longitudinal bar exposure (LB 1) consists of lenticular or wedge-shape with a flat or an erosional base and a convex top showing northward current flow. An abandoned channel (ACH) can be found in the eastern section, opposite the site of outcrop Two and named as Two-A that also indicates the upper channel flows northward with westward channel migration.

A good cliff section is exposed at station three about 300 m away from Station Two and 12 m in height. At Station Three, channel lag, channel fills, fine sediments of over bank by westward migrated, stacked channels (i.e. CH 1, OF, CH 2, CH 3, CH 4) (Figure 6) in turn capped by northward longitudinal bar (LB 2) with horizontal fine sediments laminations.

Lithofacies and Architectural Elements of the Irrawaddy Formation

Miall (1978) stated that an individual lithofacies is a rock defined on the basis of its distinctive features, including composition, grain size, bedding characteristics and sedimentary features. Each lithofacies represents an individual depositional environment. A paleogeography of an area is made on the basis of lithofacies analysis.

Architectural Element

Various lithofacies can be grouped as "architectural elements", which are characterized by a distinctive facies assemblage, internal geometry, external form, and vertical profile (Miall, 1985, 1988). The recognition of architectural elements, their characteristics and their relationships allow an interpretation of local and regional processes of fluvial evolution in the basin (Miall, 1978a, 1978b, 1985; Allen, 1983; Yu et al., 1992) (Figure 3).

Based on Miall's general lithofacies classification scheme (Miall, 1978a, 1978b, 1988), the eleven lithofacies identified in the Irrawaddy Formation are grouped into five architectural elements: channel fill (CH), longitudinal bar (LB), transverse bar (TB), abandoned channel fill (ACH), and overbank fines (OF) (Figure 4, Figure 5, Figure 9).

Descriptions of Lithofacies and Interpretations

Transverse Bar (TB). Sp-ghb, St-sn

In the Irrawaddy Formation outcrops, transverse bars are composed mainly of planar-tabular cross bedded sandstones (Sp-ghb) and trough cross bedded sandstones (St) (Figure 4, Station One). In the lower part of the transverse bar, there are fine to coarse sandstones with small trough cross beds (St-sn) which pass upward into planar-tabular cross beds (Sp-ghb) (Figure 4). Tabular beds are 0.5 to 1.3 meter thick and typically extend several tens of meters laterally.

Transverse bars have a concave-up base and erosional surface at top (Figure 4), and measured paleo current indicates the southward direction that has been reported as a common element in braided streams dominated by vertical accretion (e.g. Smith, 1971; Cant and Walker, 1978; Miall, 1978a; Crowley, 1983; Ramos et al., 1986; Bristow, 1993; Sánchez-Moya,1996) (Yu. et el, 2002).

Longitudinal Bar (LB) : Gm, Sp-glc, Sp-shc, Sh

Locally, fine to coarse sandstones with imbricated crudely bedded gravel (Gm) overlain on Transverse bar of channel one with northward current direction (Figure 3, Station One). Longitudinal bars are characterized by fine to coarse sandstones with planar-tabular bedding (Sp) (Figure 6), with horizontal lamination (Sh).

From base to top, bars contain planar-tabular cross-bedded sandstone with low-angle (<10°) convergent laminations (Sp-glc), overlain by sandstones with planar-tabular cross bedding and high-angle (>10°) convergent laminations (Sp-shc). These are capped by fine to coarse sandstones with horizontal laminations (Sh). In cross-section, longitudinal bars are lenticular or wedge-shaped with a flat or an erosional base and a convex top (Figure 5, Station Two-A), and are interpreted as downstream accretion bedforms (Miall, 1988).

Channel Fill (CH): Gm_ St-le or St-lc_ Sm-v, M-cm

Channel fill consists mainly of medium to very coarse sandstones with trough cross bedding (including St-le, St-lc and St-sn), with minor massive sandstones (Sm-v), and massive or crudely bedded gravel (Gm) at the bases (Figure 4, Figure 5, Figure 6). These strata show a thinning-upward or fining-upward trend. Channel bases are conglomeratic (Gm) and interpreted to have been deposited by high-gradient, braided streams with great fluctuations in discharge.

The lower part of the channel-fill succession contains large-scale trough cross bedding (St-le and St-lc) and massive bedding (Sm-v). These sandstone bodies were deposited during the early stage of channel development when the cross-section of river channel was narrow and water level and sediment load high. Higher in the succession, sandstones with parallel or flat bedding were deposited during late stages of channel development in wide shallow channels.

Mudstones (M-cm) at the top of the fill succession formed during the last stages of channel abandonment and infill. In cross-section, channel fill sandstone bodies are lenticular or wedge-shaped with an erosional, concave base. The deposition of channel-fill sandstones occurred mainly during high-discharge events and by lateral and vertical accretion, along with channel cutting and abandonment (Sánchez-Moya et al., 1996).

Channel fills are common architectural elements in the Irrawaddy Formation. There were four channel-fill units identified (CH in CH1 to CH4 in Figure 5, Figure 6, Figure 9). Channel-fill sequences are 3 to 5 m thick and occur mostly in the western section of Station Three and the upper part of Stations One and Two (Figure 8).

Abandoned Channels (ACH) Sm, Fm, M-dh

One abandoned channel was recognized at the eastern part of Station Two-A that is located at the opposite site of longitudinal bar of Station Two (Figure 7, Figure 8, Figure 9). Abandoned channel is characterized by multiple, massive sandstone (Sm), wedge-shaped, thin sandstone bodies interbedded with thick mudstones. Single sandstone layers are 0.3 to 1.5 m thick. They may also locally contain massive siltstone (Fm) and dark mudstone with horizontal laminations (M-dh) and desiccation cracks. The reactivation surfaces, small scale diapirism and scour and filled with northward paleocurrent, suggesting that deposition took place as episodic, discontinuous stream discharge.

Overbank Fines (OF): Sm, Sh, Sr, Fm, M

Overbank fines consist of mudstones (M) and silty mudstones (Fm) with thin sandstone lenses (Sm, Sh, or Sr). Individual sandstone beds are 1.5 to 3.0 m thick and 20 to 50 m in length. These sandstones are lenticular in shape and have a concave base and a flat or convex top. Some of these sandstone lenses display a crude, coarsening-upward trend. The lateral extension of overbank fines is over 160 m.

At Stations Two and Three, overbank fines occur mostly in the middle part of the section and top most part. Horizontal lamination (Sh) occurs at the top of longitudinal bars. In cross-section, overbank fines have a flat or concave-up base and a gentle-convex top (Figure 5, Figure 6).

Channel Outline and Central Basin Inversion

The available exposed stations and channel outline is drawn in mosaic Figure 9 where an abandoned channel is present at Station Two-A on the eastern side. The correlated mosaic Figure 8 along the western section exhibits the lateral continuity of reverse channels, multi-stacked with westward migration to the northward direction. From the evidence of petrology and sedimentary structures, two different major current directions can be recorded: (1) Lower channel showing SSW orientation, and (2) stacked up by reverse directional channels followed with multi-stacked channels show the northward current direction with westward migration. They are likely to be related with inversion of pull-apart basins of central Myanmar (Pivnik et al., 1998).

A schematic inversion of the Chaungtha Fault (E 19° 45’, N 95° 05’) during the Pliocene, creating a structure typical of inverted normal faults that occurs at the southwest vicinity of the present area (Figure 10). This model may be applied to the Yedwet Uplift (E 20°30’, N 95°

15') (Figure 11), which also has thickened and uplifted Miocene section in the hanging wall of the reverse fault that underlies it (Pivnik et al., 1998).

Depositional History

Sandstone bodies occur as linear bands extending from north to south. In cross-section, these sandstone bodies are lenticular with a concave base and flat top (Figure 4 and Figure 8). Frequent channel switching resulted in channel stacking. Within the sandstone complex, there are some muddy intercalations, but they are very thin and of limited lateral extent. Overbank floodplain fines bound channel complexes. The sandy, braided river developed in three stages: from active, to abandoned, and then to reactivated. These stages reflect channel switching of a fluvial system with variable discharge.

Early Active Stage

During an early active stage, sandstone bodies of a channel complex (e.g. TB-1) were deposited (Figure 4) and flowed from north to south. The active stage took place at the lower part of Station One. The exposed part of TB-1 is followed by the reverse directional channels with northward currents as resultant of Salin Basin inversion. The southern continuation of upper channels exhibits at station two and three (Figure 5, Figure 6, Figure 8)

Abandonment Stage

The sandy, braided river was abandoned after deposition of LB-1, probably due to upstream channel avulsion with westward migration that deposition took place as episodic, discontinuous stream discharge (ACH at Station Two-A of eastern section) (Figure 7, Figure 9). During this period, overbank fines were deposited, mainly in the station two and three of western section (OF) (Figure 5, Figure 6, Figure 8, Figure 9). Although the main channel was abandoned during this period, some small channels probably still existed, as indicated by sandstone lenses interbedded with overbank fines (Station Two).

Reactivation Stage

This stage is divided into 3 phases: channel incision, channel filling, and channel waning. During the early phase, strong incision is indicated by a concave, erosional surface. At Stations Two and Three, the incision steps are interpreted. During early filling, the water depth and sediment load were high, because the channel was relatively narrow. The depositional process during this phase was dominated by downstream and vertical accretion, resulting in large-scale trough cross bedding. Later, the channel became wider (e.g. CH-2, CH-3, CH-4 in Figure 5, Figure 6, Figure 8) and water depth shallower as the channel began to bifurcate.

The depositional processes changed to vertical and lateral accretion, forming longitudinal bars with large-scale planar or tubular cross bedding. In the final phase of the channel infill, sandstone bodies were formed by small- to medium-scale bedforms (e.g. CH-4 in Figure 6). During the channel waning phase, fine sediments were deposited.

It appears that the majority of sedimentary materials of the lowest channels were shed from the NNE site of the present area; the sediments of reverse directional, upper stacked channels were shed from a SSE source. For all provenance aspects of Irrawaddy sediments, paleocurrents, lithic grain parameters and P/F values suggest that particles comprising the Irrawaddy Formation was shed from an uplifted basement (Shan Taninthayi Block/Shan Plateau) and/or a rifted continental margin/transformed fracture zone (the western margin of the Shan Plateau) (Figure 1).

The Irrawaddy River is generally influenced by low-sinuous, shallow bathymetry, sandy braided river studied by Central Myanmar Basin (Naing Maw Than,1993) which could be the combined systems of meandering and braided channels response to sea level changes and tectonic controls (Naing Maw Than, 2011) formed as current scenario.

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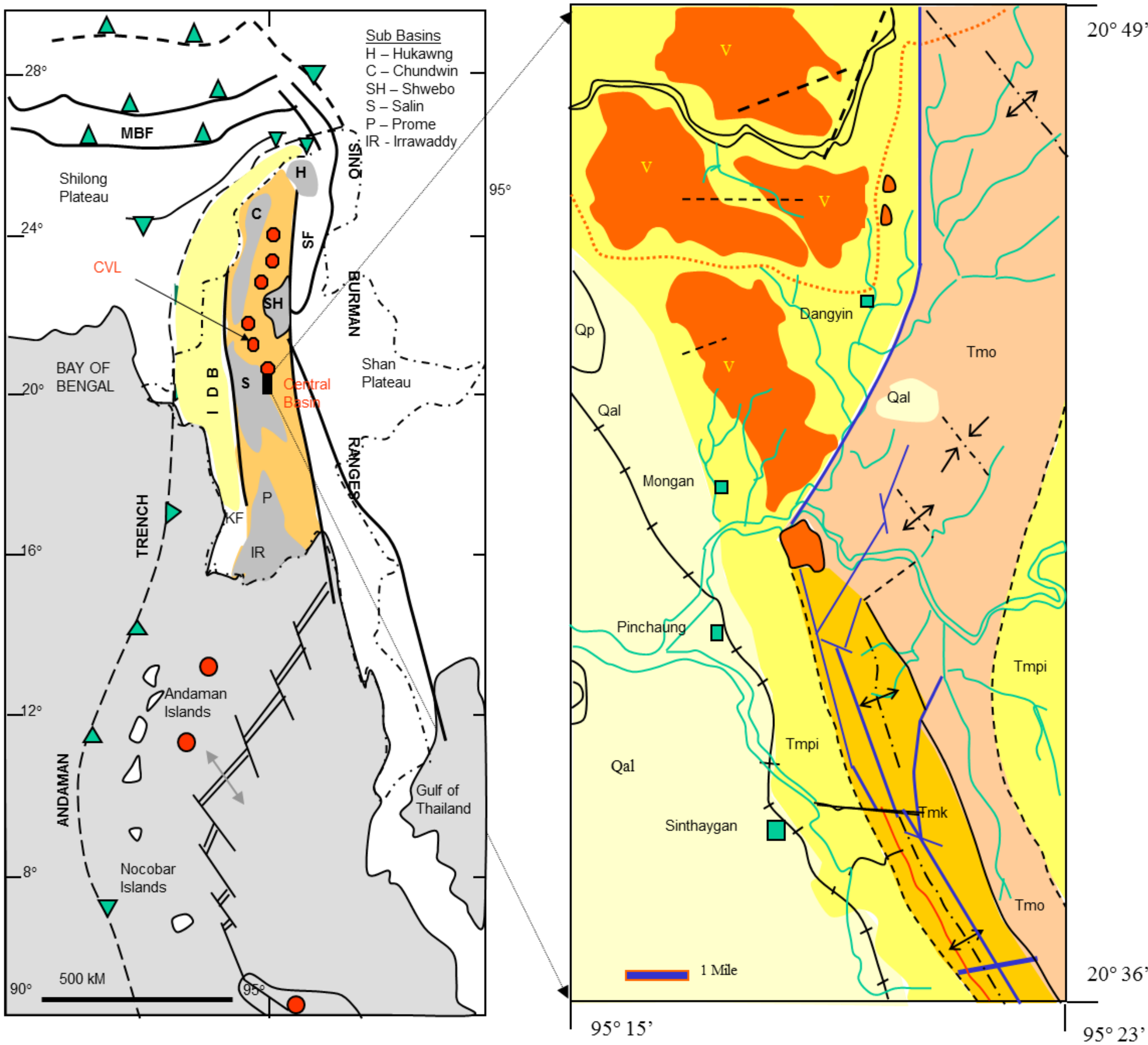

Figure 1. (Left) Tectonic framework and subbasins of the Central Myanmar Basin (after Pivnik et al., 1998). (Right) General outcrops, lithology, structural pattern, study area (in rectangular box) of the Taungni-Pingadaw area (modified from Naing Maw Than, 1993).

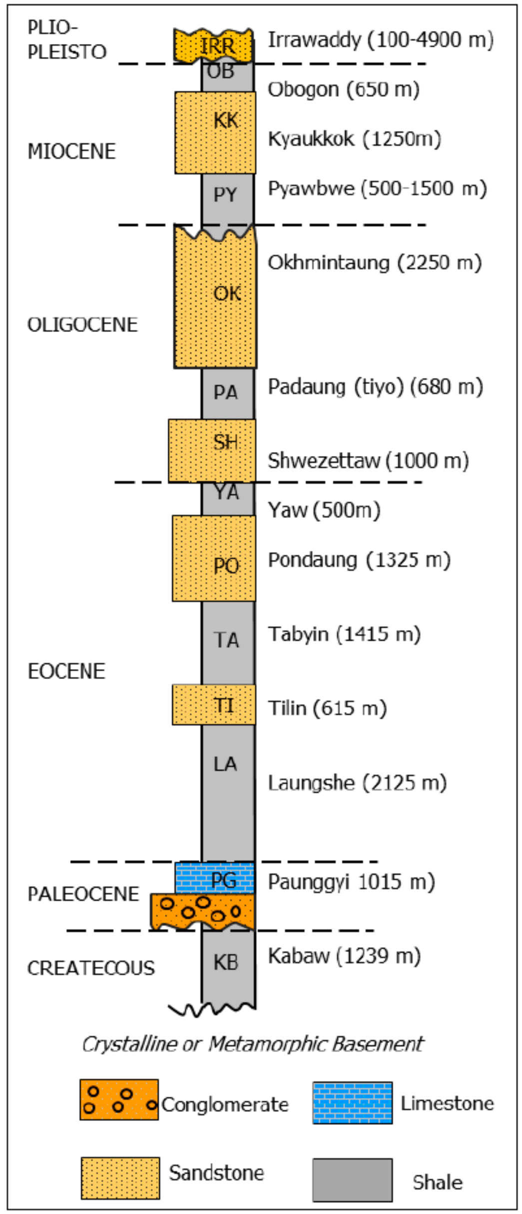

Figure 2. General stratigraphic column of Salin Basin (Pivnik et al., 1998).

Code		Depiction	Grain Size	Sedimentary Structure Description	Interpretation
Gm			massive or crudely bedded gravel	horizontal bedding, imbrication	longitudinal bars, lag deposits, sieve deposits
Sp	Sp-glc		sand, fine to medium coarse may be pebbly	grouped planar-tabular crossbeds with low-angle (<10°) convergence laminations	diagonal bar
	Sp-ghb		sand, medium to very coarse may be pebbly	grouped planar-tabular crossbeds	transverse bar
	Sp-shc		sand, medium to very coarse may be pebbly	solitary planar crossbeds	longitudinal bar
St	St-le		sand, medium to very coarse may be pebbly	Solitary or grouped large bed sets (thickness >50cm) trough crossbeds with eccentric laminations	channel fills
	St-lc		sand, medium to very coarse may be pebbly	solitary or grouped large bed sets (thickness >50cm) trough crossbeds with concentric laminations	channel fills
	St-sn		sand, very fine to coarse	solitary or grouped small bed sets (thickness <50cm) trough crossbeds	small dunes
Sm	Sm-u		sand, very fine to coarse	massive with uniform grain size	abandoned channel fills
	Sm-v		sand, medium to very coarse may be pebbly	massive with various grain size	channel fills, lag deposits
Sr			sand, very fine to coarse	ripple crosslamination	current ripples
Sh			sand, very fine to coarse	horizontal lamination parting or streaming lineation	planar bed flow
Fh			silt, mud	horizontal lamination	overbank or waning flood
Fr			silt, mud	small ripple crosslamination	levee,current ripples
Fm			silt, mud	massive, desiccation cracks	overbank or drape deposits
M	M-cms		mud, silt to sand, motley	massive, desiccation cracks	overbank or backswamp deposits
	M-dh		mud, dark	horizontal lamination, shale	backswamp pond deposits
	M-cm		mud, motley (colour)	massive, desiccation cracks	overbank or drape deposits

Figure 3. Summary of lithofacies after Miall (1978b, 1988) and Yu et al. (2002).

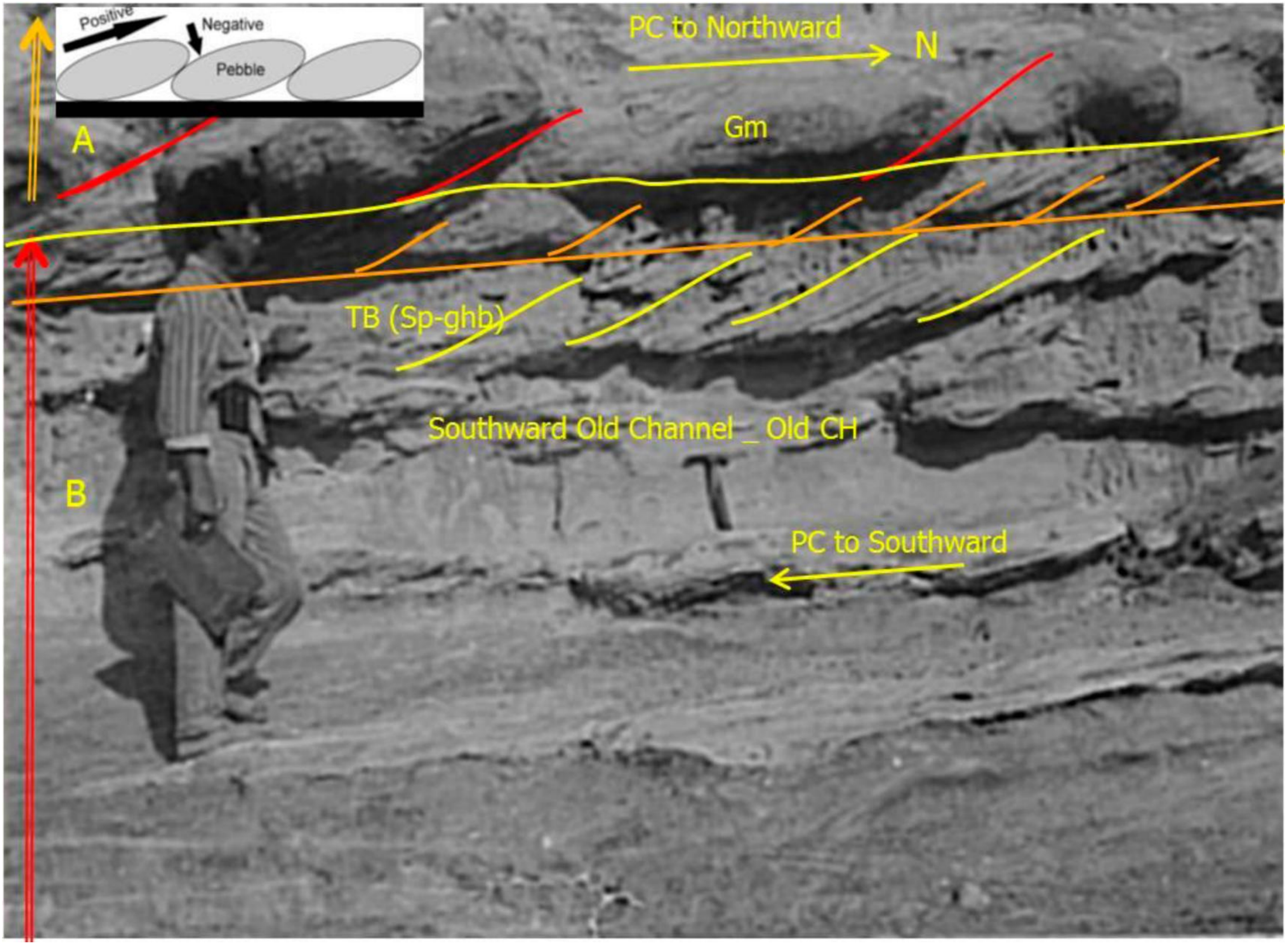

Figure 4. Reverse channels at outcrop Station One at western section. (A) Upper reverse channel, channel fill and lag deposits Gm, massive or crudely bedded, horizontal, imbrication, PC to northward; (B) Lower channel transverse bar (TB), sand, medium to very coarse, group planar X-bed sets (Sp-ghb), PC to southward flat/concave base, erosional top.

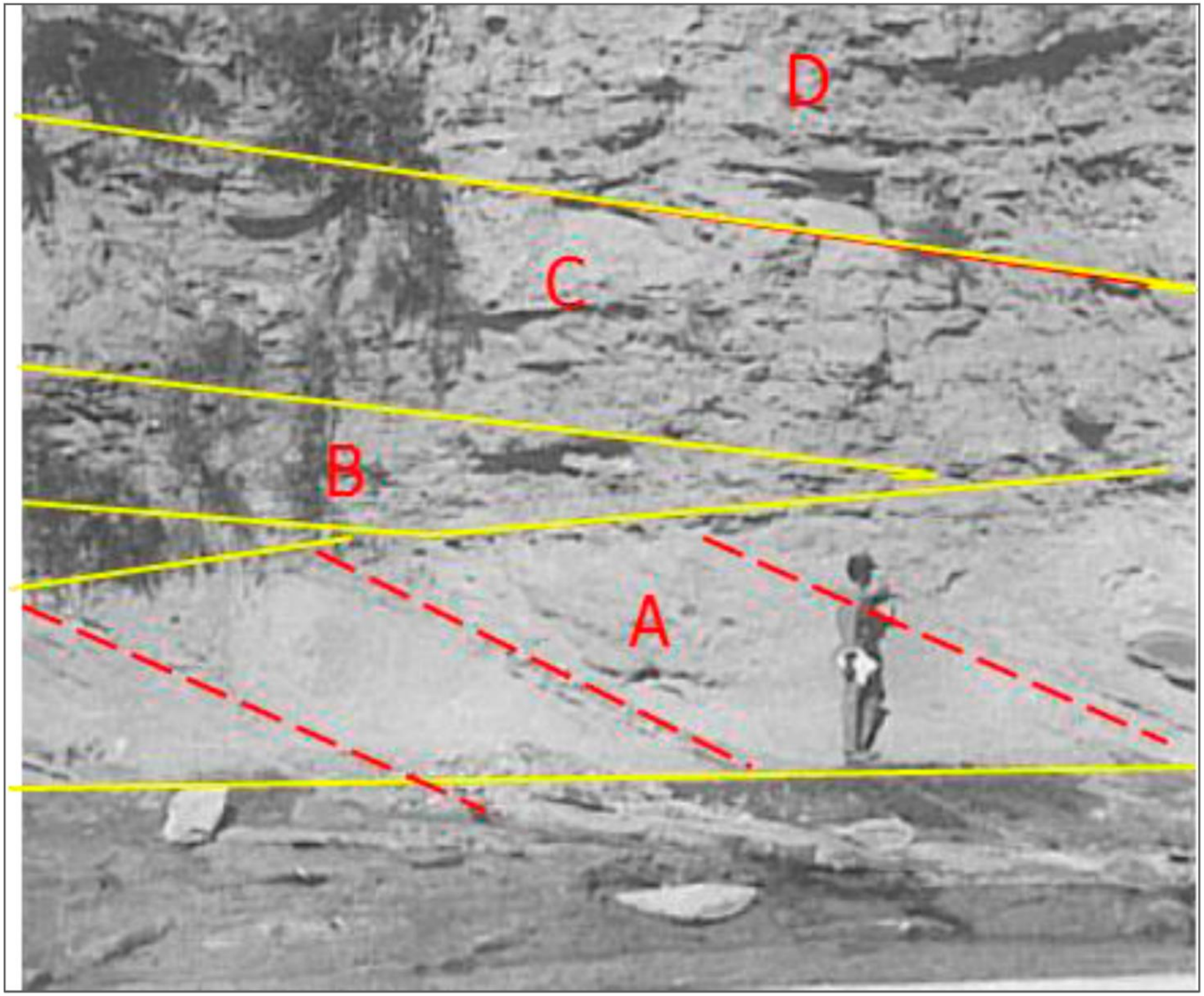

Figure 5. Station Two, longitudinal bar (LB 1) at the middle part of the western stream section. (A) (LB 1) Sand, solitary planar high angle > 10 deg, X-bedded sandstone Sp, horizontal lamination Sh, Lenticular/Wedge shape, erosional/flat base, convex top, downstream accretion; (B) Overbank fines; (C, D) Channel fills (CH 3, CH 4), sand (Sm V), medium to very coarse, pebbly, massive, trough X-bed, (St-le), eccentric lamination, group large bed sets > 50 cm with fining upward succession.

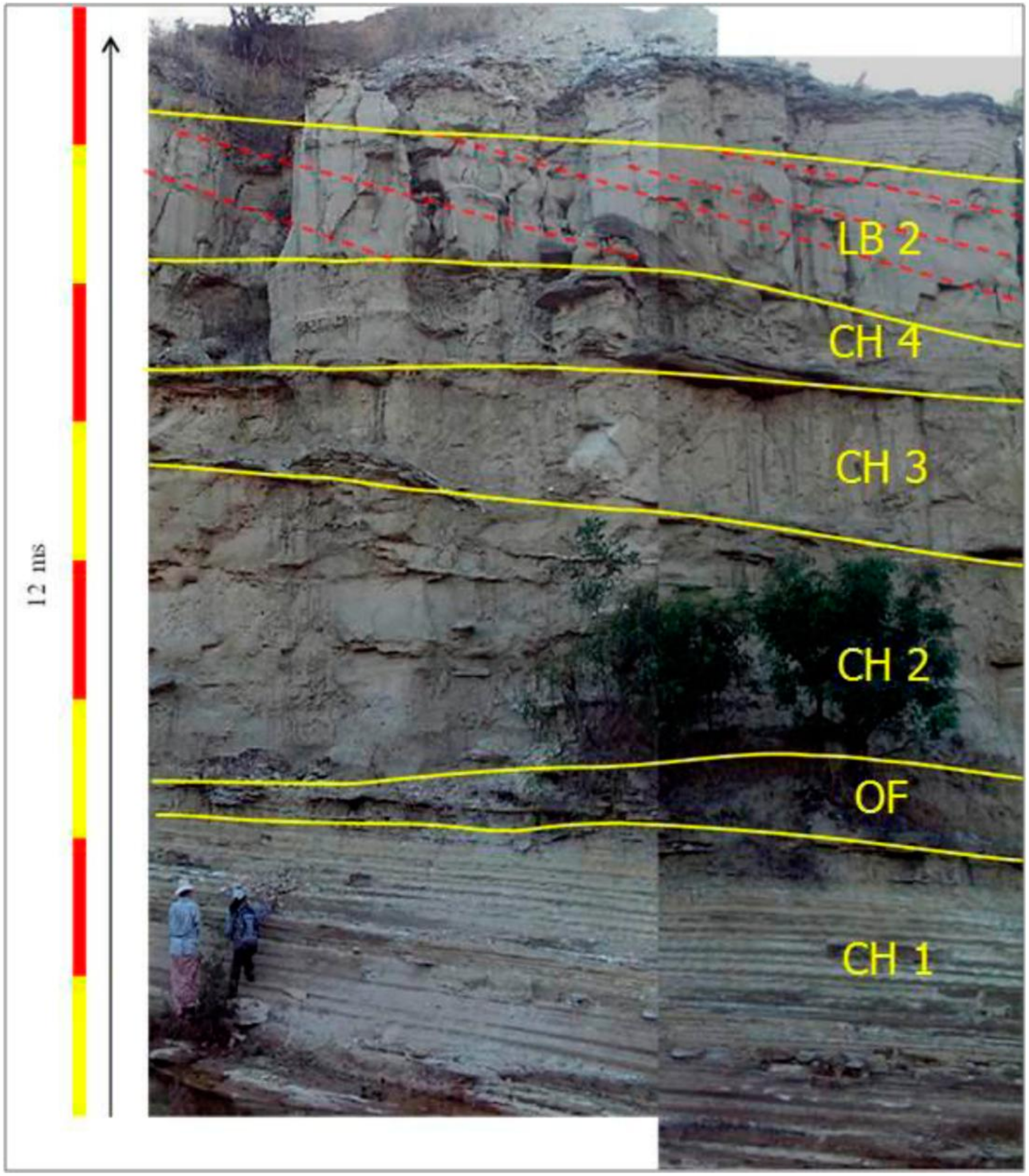

Figure 6. Station Three at western cliff section occurs channel fills (CH 1, CH 2, CH 3, CH 4), over bank fine (OF) and longitudinal bar (LB 2) as multi-stacked channels with westward avulsion.

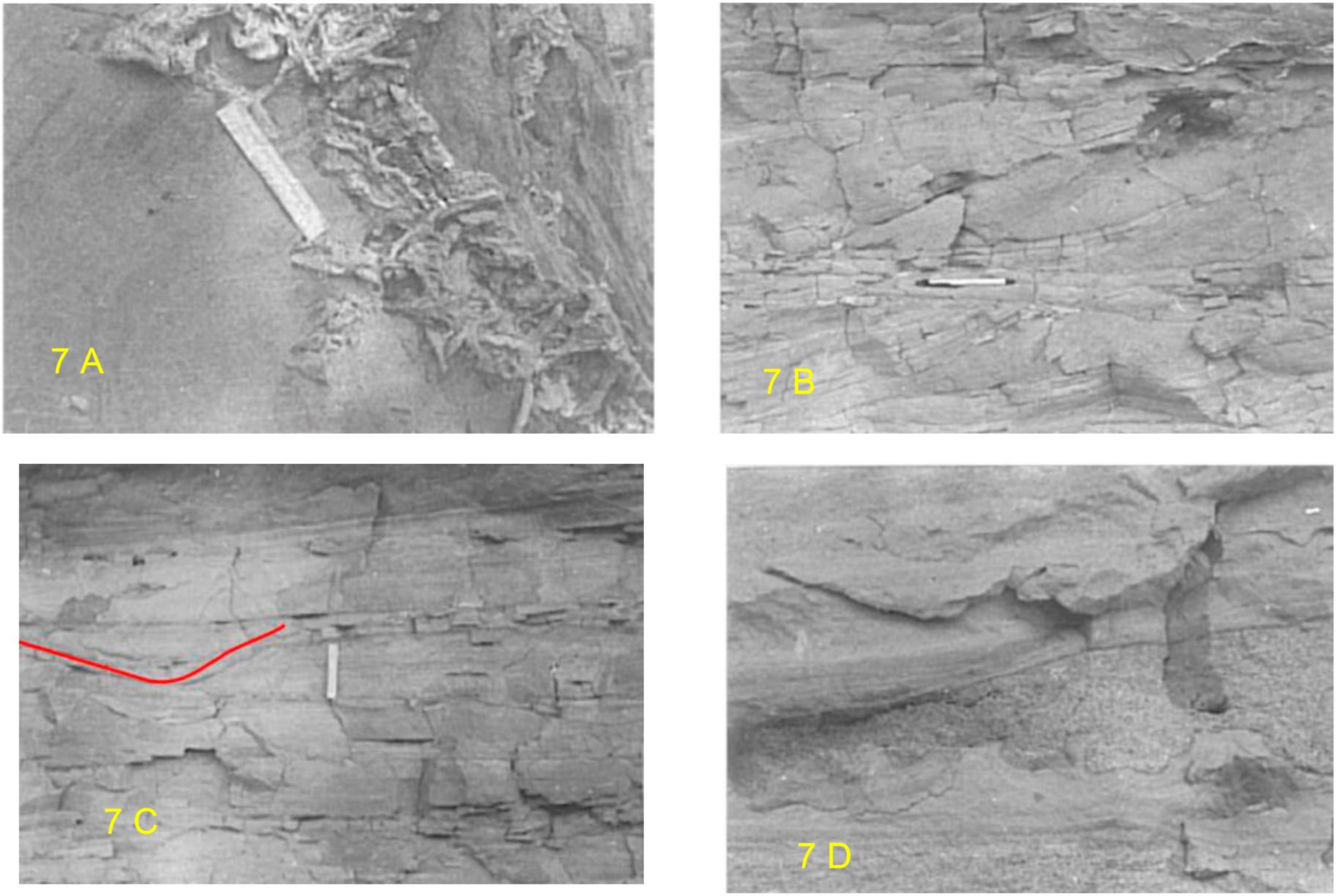

Figure 7. Shows abandoned channel (ACH) at eastern side, Station Two A with northward current direction. (A) (SmU), sand, massive with uniform grain size and anastomosing tubular concretions; (B) Multiple, wedge-shaped, thin sandstone bodies interbedded with med-thick mudstones; (C) Desiccation cracks in mudstone and scour and fill shows PC to northward current direction; (D) Diaprism or upward flame of mudstone into overlying sandstone

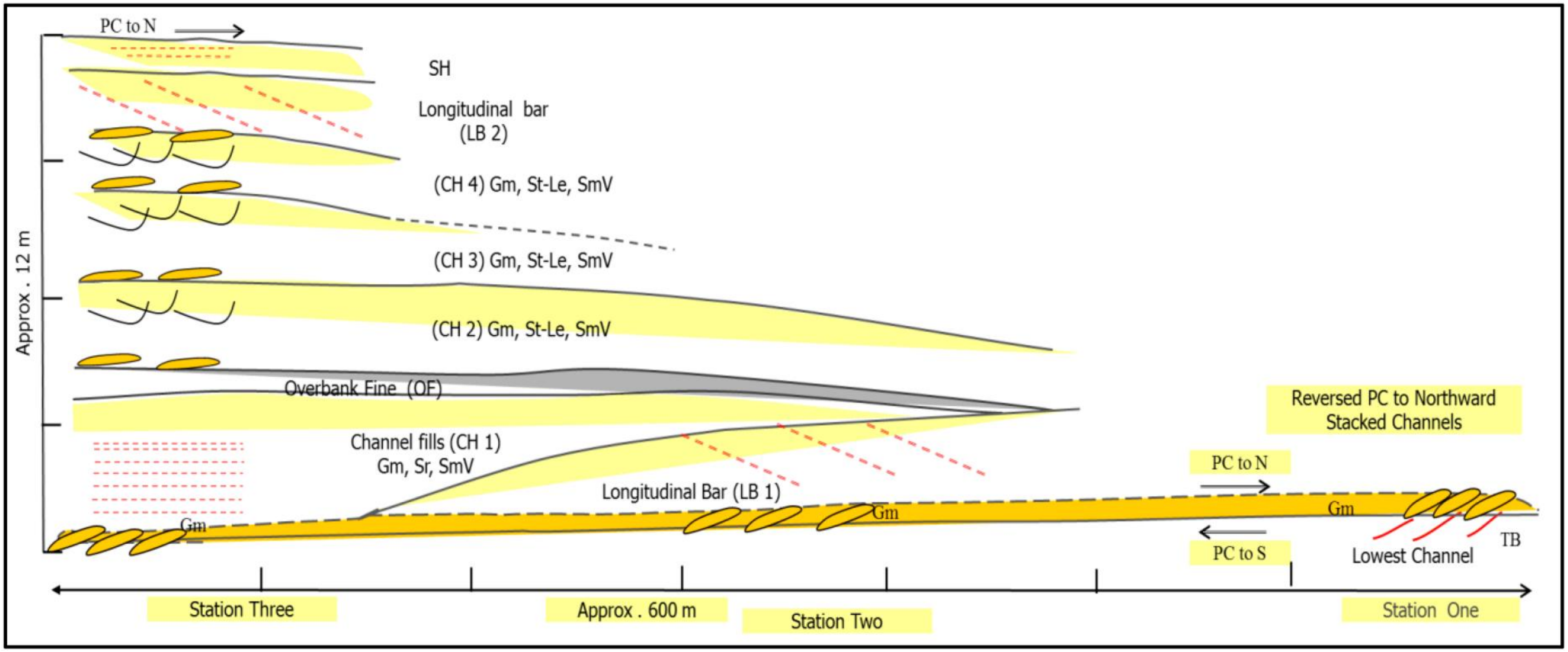

Figure 8. The mosaic layout of outcrops Stations One, Two, Two A and Three with channel outline, red line configures the present stream and blue line is paleochannel outline.

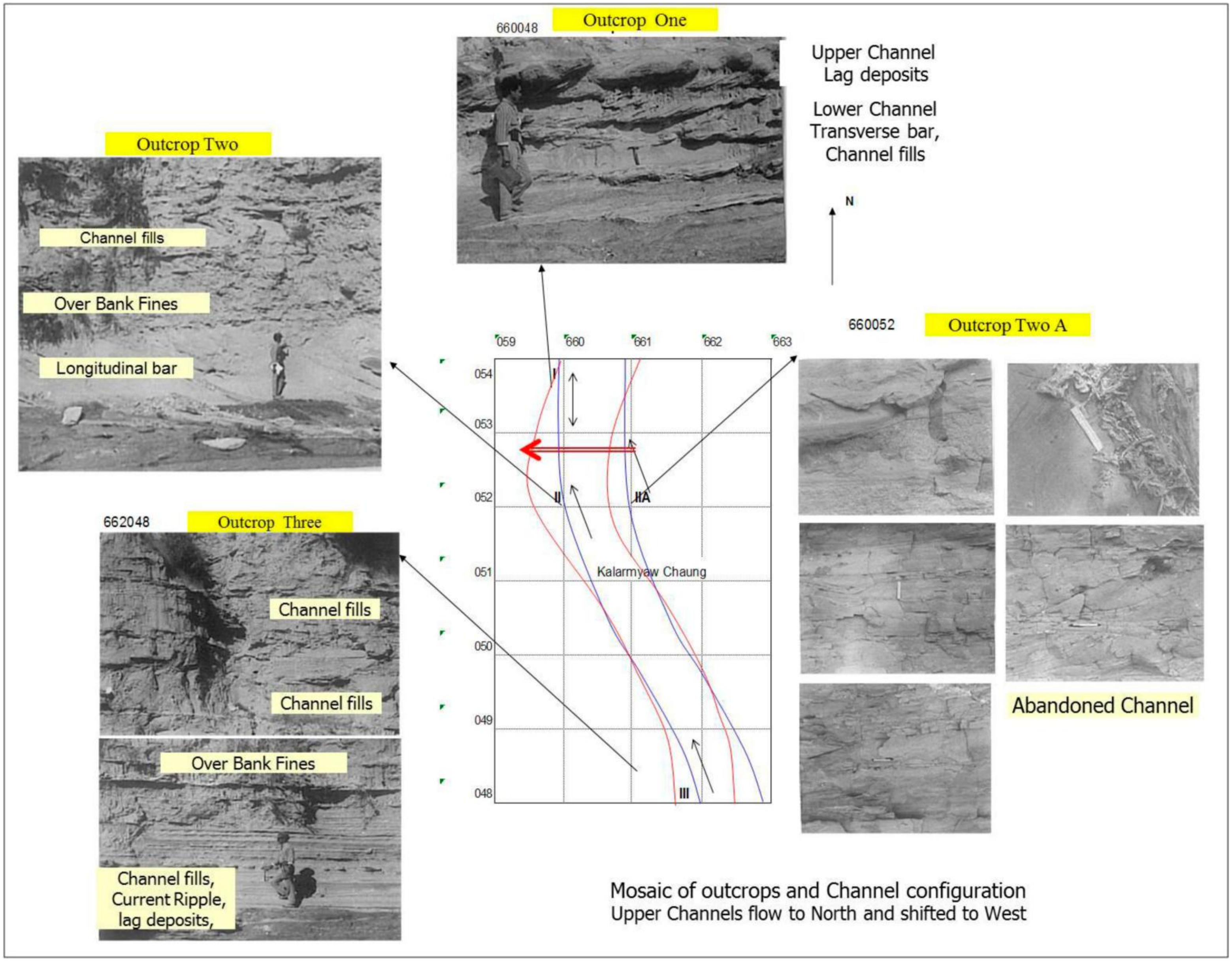

Figure 9. The lateral continuity of fluvial architectures of braided channels along the western section correlating Stations One, Two and Three with facies associates (scale approximate).

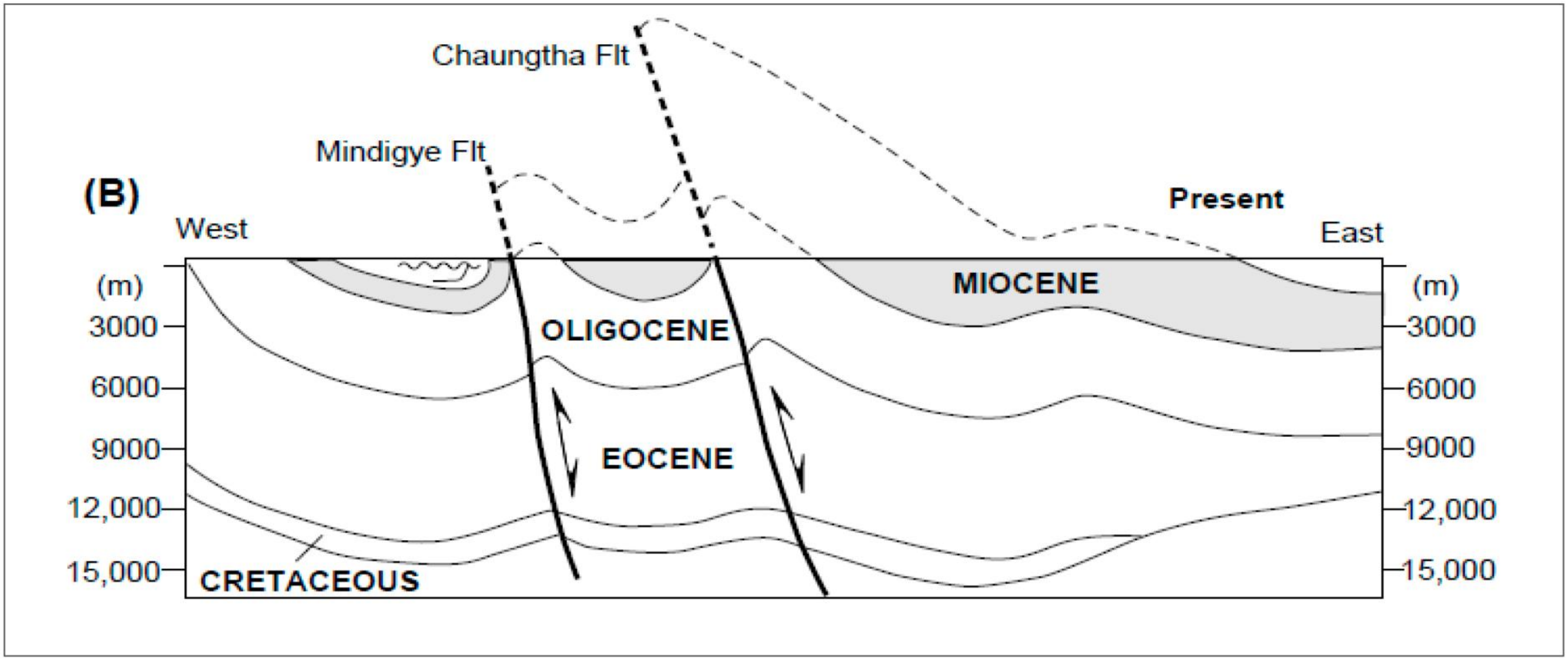

Figure 10. A schematic inversion of Chaungtha Fault present in northwest part of study area during the Pliocene, creating a structure typical of inverted normal faults (Pivnik et al., 1998).

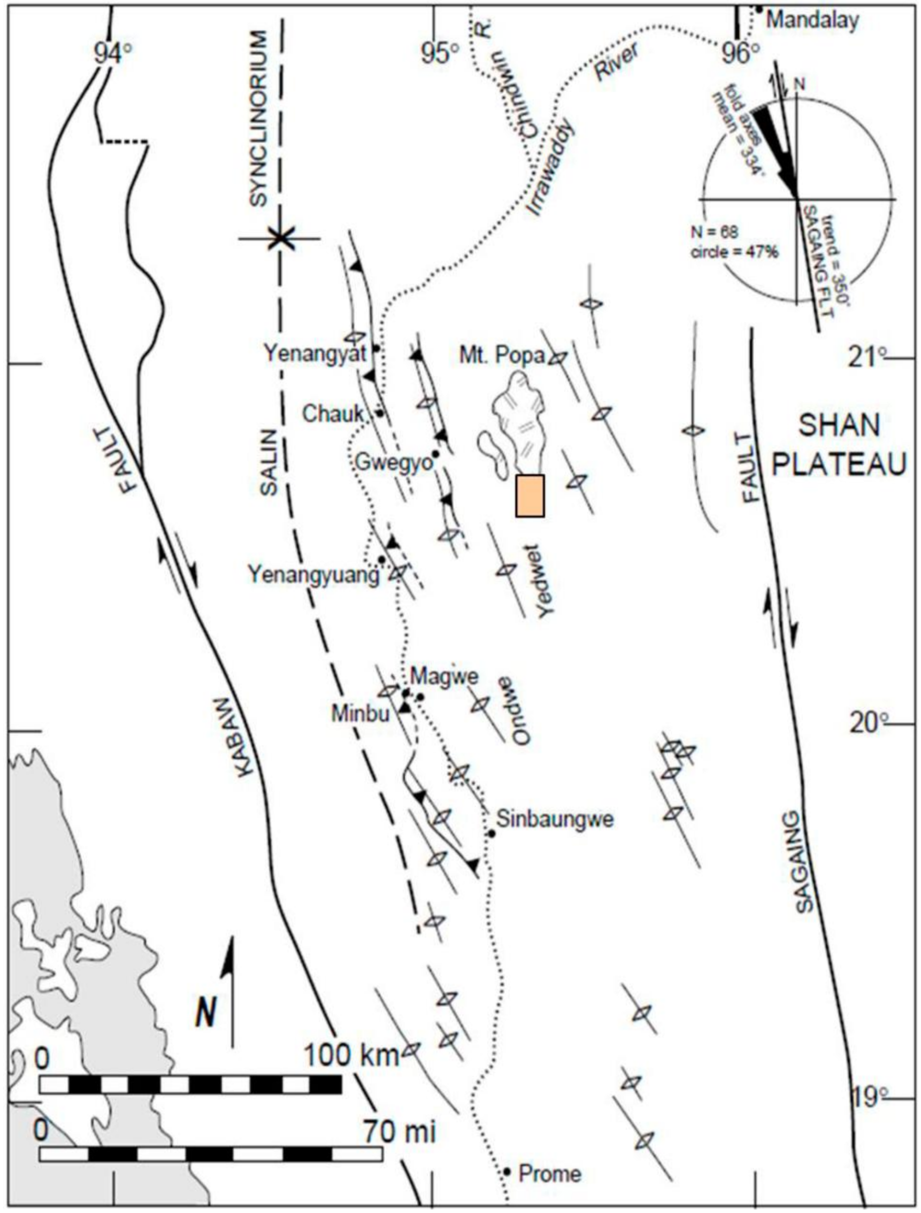

Figure 11. A location map and structural patterns in the Salin Basin and Yedwet Uplift adjacent to the study area in shaded box (Pivnik et al., 1998).