Sedimentological aspects of the Temburong and Belait Formations, Labuan (offshore west Sabah, Malaysia)

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Abstract: The sedimentological features of lower to middle Miocene sedimentary rocks in the northern part of Labuan Island, offshore west Sabah, are described. The Temburong Formation (or "older Setap Shale") forms the core of the Labuan Anticline. Excellent exposures of the Temburong Formation occur along the coast near Tg. Layang-Layangan, where the formation consists of an overall regressive (shallowing) sequence of heterolithic facies deposited in environments ranging from relatively deep water and unstable slopes to shallow nearshore settings.

The Belait Formation crops out in the northern part of Labuan as a prominent strike ridge that extends from Tg. Kubong to Tg. Layang-Layangan and in the eastern part of the island from Tg. Kubong to Tg. Batu, essentially forming the two limbs of the northeastward-plunging Labuan Anticline. The sedimentology of the Belait Formation is described based on field work in the Tg. Kubong area, which included detailed logging of a major road-cut at the Chimney. Here, the basal Belait is a sequence of conglomerate and sandstone laid down by fluvial systems that were eroding into the uplifted Temburong Formation. A transition from high-relief low-sinuosity to low-relief high-sinuosity fluvial system is indicated by the upward-decreasing grain size and pebble content in the channel fill deposits, and by the occurrence of coal in the overlying alluvial plain deposits, which are exposed on Bukit Kubong. The fluvial succession passes upwards into a transgressive (deepening) sequence of nearshore and offshore shallow marine sandstone and mudstone dominated by hummocky cross-stratified sandstone intercalated with shale. Syndepositional deformational structures are a common feature of the shallow marine deposits in both the Temburong and the Belait Formations which resulted from sedimentation on the once actively-deforming continental margin of NW Sabah.

INTRODUCTION

The island of Labuan is located within the Inboard Belt structural zone of the NW Sabah continental margin, which is characterised by spectacular shale-cored anticlinal ridges separated by broader synclinal depocentres (Hazebroek and Tan, 1993). These structures are thought to have formed by deep-seated wrench fault movements (Bol and van Hoorn, 1980; Levell, 1983; James, 1984). The island of Labuan is the emergent part of a northeastward-plunging anticline which can be traced southwestwards into Brunei as the Labuan-Muara Ridge (Fig. 1). The stratigraphy of Labuan represents two main phases of sedimentation under contrasting tectonic regimes: a more argillaceous succession (Setap Shale and Temburong Formation) forming the core of the island represents deepwater deposition associated with an active subduction margin, and the overlying Belait Formation representing fluvial to shallow water sedimentation after subduction had ceased. The rocks of Labuan provide a unique opportunity to study the products of sedimentation on this once actively-deforming continental margin. Furthermore, these deposits are the lateral equivalents of some of the hydrocarbon reservoirs in the offshore areas of NW Sabah. The aim of this paper is to describe and interpret the sedimentological features in the Temburong Formation (or "older Setap Shale") and Belait Formation exposed in the northern part of Labuan (Fig. 2).

STRATIGRAPHY AND TECTONIC SETTING

The continental margin off northwestern Sabah is underlain by a great thickness of Tertiary sediments that represents a complex history of sedimentation in an actively-deforming continental margin. During the Oligocene-early Miocene, deep water sedimentation was contemporaneous with southeastward subduction of an ocean basin beneath the NW Sabah-Palawan margin (Taylor and Hayes,

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1980), which resulted in the formation of the Rajang-Crocker accretionary prism (James, 1984). Subduction ended with the collision of Reed Bank-Dangerous Grounds continental fragment with NW Borneo, causing surface uplift and exhumation, which resulted in a regional unconformity, known as the "late T_{e5} unconformity" in onshore NW Borneo or the "Deep Regional Unconformity" (DRU) in offshore Sabah (Levell, 1987). During the middle Miocene the NW Sabah margin became the southern margin of the South China Sea marginal basin. Clastic sediment progradation was accompanied by compressional deformation of the NW Sabah margin.

The stratigraphy of Labuan is a continuation of the stratigraphy of onshore western Sabah, Brunei, and northern Sarawak (Liechti *et al.*, 1960; Wilson, 1964; Potter *et al.*, 1984; Koopman and Schreurs, 1996). The rocks were assigned to three lithostratigraphic units: Temburong Formation, Setap Shale Formation, and Belait Formation (Wilson, 1964). There is a major unconformity at the base of the Belait Formation which is correlated with the Deep Regional Unconformity in offshore NW Sabah, marking the end of subduction along the NW Sabah margin in early Miocene times (Levell, 1987; Tan and Lamy, 1990; Hazebroek and Tan, 1993). The same unconformity has long been recognised from onshore areas and was dated T_{e5} (early Miocene) (Liechti *et al.*, 1960). Structural styles above and below the unconformity are different; highly deformed marine sequences (Setap Shale and Temburong Formations) beneath the unconformity and gently-tilting fluvial to marine deposits (Belait Formation) above.

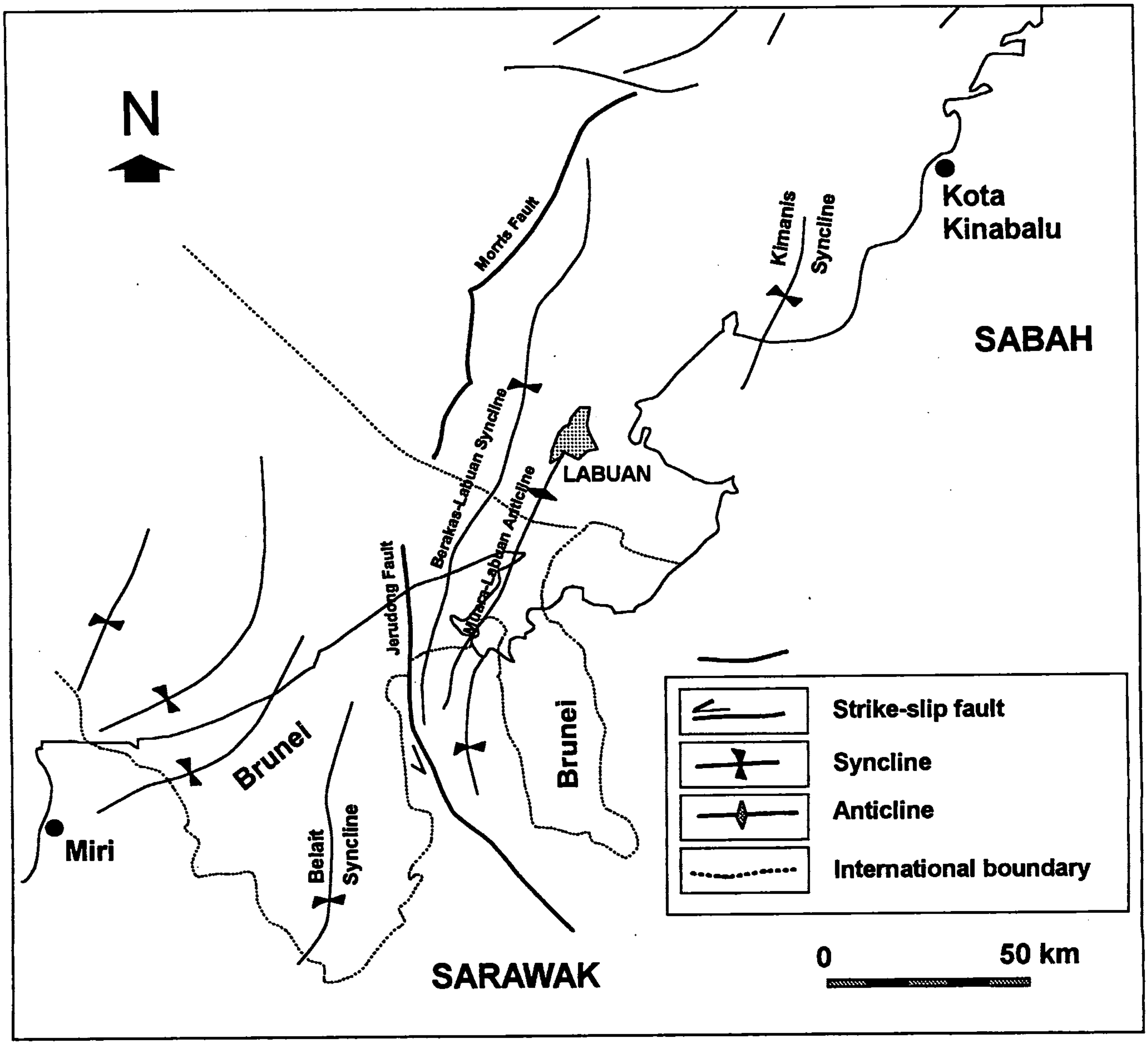


Figure 1. Map showing the location of Labuan and major structural elements of the surrounding area.

TEMBURONG FORMATION

The marine deposits below the Deep Regional Unconformity belong to the "older Setap Shale", or according to Brondijk's (1962) terminology the "Temburong Formation". Mazlan Madon (1994) has discussed the problem with the existing stratigraphic terminology in this area, and assigned these rocks to the Temburong Formation. Outcrops of deformed argillaceous strata of the Temburong occur south of Tg. Layang-Layangan and along Jln. OKK Daud (Loc. B, D, E; Fig. 2). The beds dip steeply (50–70°) to the north or northwest and, in some places, are tightly folded and even overturned. Various scales of faulting were observed, from large-scale faults with displacements of several meters down to small-scale syndepositional faults with a few centimetres of displacement (Fig. 3). Most of the large-scale faults appear to be high-angle normal faults that have been tectonically rotated. Faults that are now horizontal were rotated about a horizontal axis. Small-scale faults often show curved surfaces and associated rollover folds. These are soft-sediment growth fault attributed to gravitational slumping of unconsolidated sediment.

In the coastal exposure at Tg. Layang-Layangan (Mazlan Madon, 1994) the succession consists of very steeply dipping (62° to the NW) mudstone and thin sandstone beds passing upward into thicker bedded sandstones and interbedded muddy facies. The sand content increases up the section (northwards), indicating gradual shallowing of a

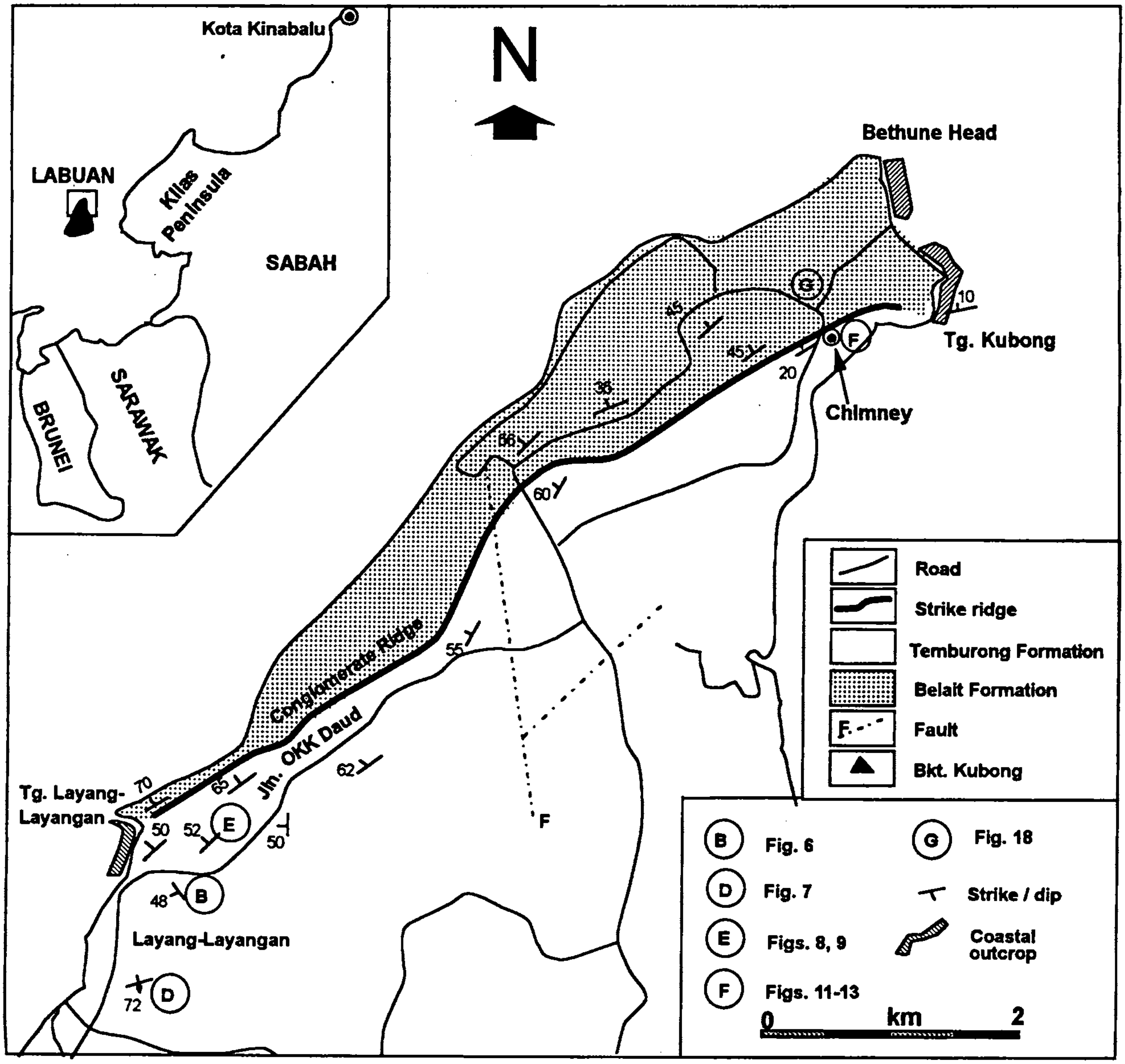


Figure 2. Simplified geological map of Labuan showing the location of place names and location of the outcrops described in this paper.

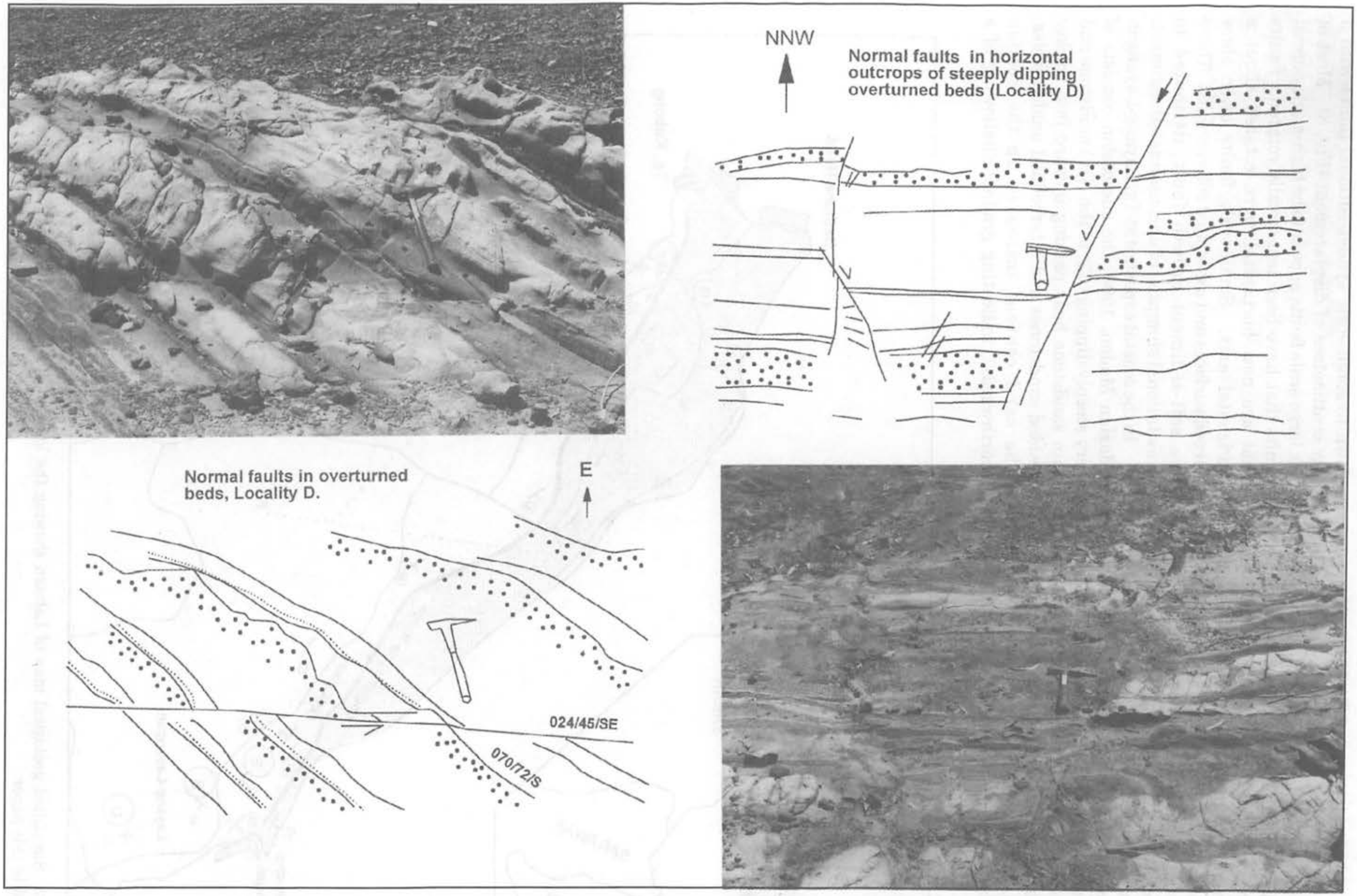


Figure 3. Structures in the argillaceous beds of the Temburong Formation near Taman Layang-Layangan (Loc. B). Sedimentological log in Fig. 6. The outcrops are steeply dipping and overturned (see Mazlan Madon, 1994). Pictures are plan view of horizontal exposures. Left picture shows normal faults in sandy heterolithic facies. Right picture shows conjugate normal faults producing minor graben structure.

delta-front environment (Lee, 1977; Mazlan Madon, 1994). The sequence consists of two units: a lower unit and an upper unit. The lower unit is characterised by lenticular or tabular-shaped sandstone bodies with large-scale (wavelength > 70 m) hummocky cross-stratification (HCS) intercalated with mudstone (Fig. 4). Angle-of-repose cross stratification is limited to thin beds of climbing ripple cross-lamination within the HCS sandstones. A thick sandstone body at the base of the measured sequence shows large-scale trough cross-stratification and contains reworked coal fragments. The mudstones show abundant soft-sediment deformation features such as load casts and pseudo-nodules, centimetre-scale growth faults, and chaotic beds containing rotated blocks of laminated sandstones. Burrowing is rare and generally restricted to thin sandstone beds within shaly intervals.

The argillaceous nature of these sediments suggests deposition in relatively deep water. Features that are indicative of deposition below storm wave-base on an unstable shelf to slope are: (1) The lack of burrows, unlike in the shallow water deposits in the overlying Belait Formation. (2) Abundant large-scale hummocky cross-stratified beds alternating with shaly intervals suggesting deposition by punctuated high-energy events (i.e. the sandstone beds are tempestites). (3) Abundant soft-sediment features, indicative of rapid sedimentation by gravity-driven mass-flows and slumps on an unstable slope, probably a delta front. (4) Graded bedding associated with the HCS, indicative of sedimentation by suspension fall-out.

The lower unit of HCS sandstones and mudstones passes upward into more sandstone-rich upper unit composed of alternating thinly to medium-bedded sheet sandstones and thinly-bedded mudstone-sandstone intercalations. HCS is rare, and is replaced by trough and tabular cross-stratification. The intervening heterolithic mudstones contain rippled sandstone layers and exhibit lenticular, wavy, and flaser bedding. Load casts occur on the underside of some sandstone beds. Straight to slightly sinuous-crested wave ripple marks on bedding surfaces indicate that palaeocurrents flowed roughly to the north and northwest. The contact with the overlying Belait Formation is not exposed, but is inferred to be at the base of the trough cross-bedded conglomerates which form the steep NW-sloping promontory of Tg. Layang-Layangan.

The upper part of the Tg. Layang-Layangan coastal exposure represents shallower water and/or closer to the sediment source compared to the lower unit. The predominantly trough/tabular cross-stratification indicates deposition mainly by unidirectional traction currents. The sheet-like geometry of the sandstones, with sharp base and tops, indicate discrete episodic events of sediment supply. Wave-current ripples in the intervening heterolithic facies suggests relatively shallow water but below storm wave base, probably under the influence of strong tidal currents.

Two other outcrops of Temburong Formation near Tg. Layang-Layangan (Fig. 2) show a variety of sedimentary features that suggest shallow to deep marine environments, with strong indications of unstable slope deposition and storm/wave-dominated regime. An outcrop at Loc. D (Fig. 2) consists of overturned beds that may be part of a tight fold limb (see Mazlan Madon, 1994; his Fig. 8). The succession (Fig. 6) consists of mainly heterolithic sandstone-mudstone facies with abundant cm-scale ripple cross-laminated sand layers. Three main packages of trough cross-bedded sandstone occur; two are intercalated with heterolithic facies that have high-relief scour bases and, in places, with ripped-up coal clasts on bedding foresets. *Ophiomorpha* burrows are common. Sandstone bed thickness ranges between 0.5 and 2.0 m.

The top 3.5 m is a sandstone with large-scale cross-stratification and minor intervening mudstone layers, and is cut by large *Ophiomorpha*. Cross-bed sets indicate palaeocurrents flowed to the northeast. Sandy heterolithic facies that is transitional between the muddy heterolithic facies underneath and the cross-stratified sandstone above show decimetre-scale graded bedding alternating with carbonaceous mudstone/siltstone layers. Abundant wave-ripples, large-scale cross-stratification, and *Ophiomorpha* suggest deposition in relatively shallow water (offshore), probably dominated by wave and storm sedimentation. Sandstone beds with scour bases were probably deposited during high-flood stages and/or storm events.

At Loc. B (Fig. 2) the rocks are spectacularly folded into an asymmetrical anticline that apparently verges to the east (Mazlan Madon,1994, Fig. 6). The succession consists of medium to fine-grained sandstone with trough cross-stratification, intercalated with heterolithic sand-mud facies with small-scale ripple cross-lamination. The trough cross-stratification indicates that palaeocurrent directions gradually changed from westwards to northwards (Fig. 7). There is abundant evidence for soft-sediment deformation, including slump features and load casts. Burrows are relatively rare. The high sand percentage, the abundant trough cross-stratification, and only minor wave ripple-lamination in the heterolithic facies suggest deposition in relatively shallow water. Rapid

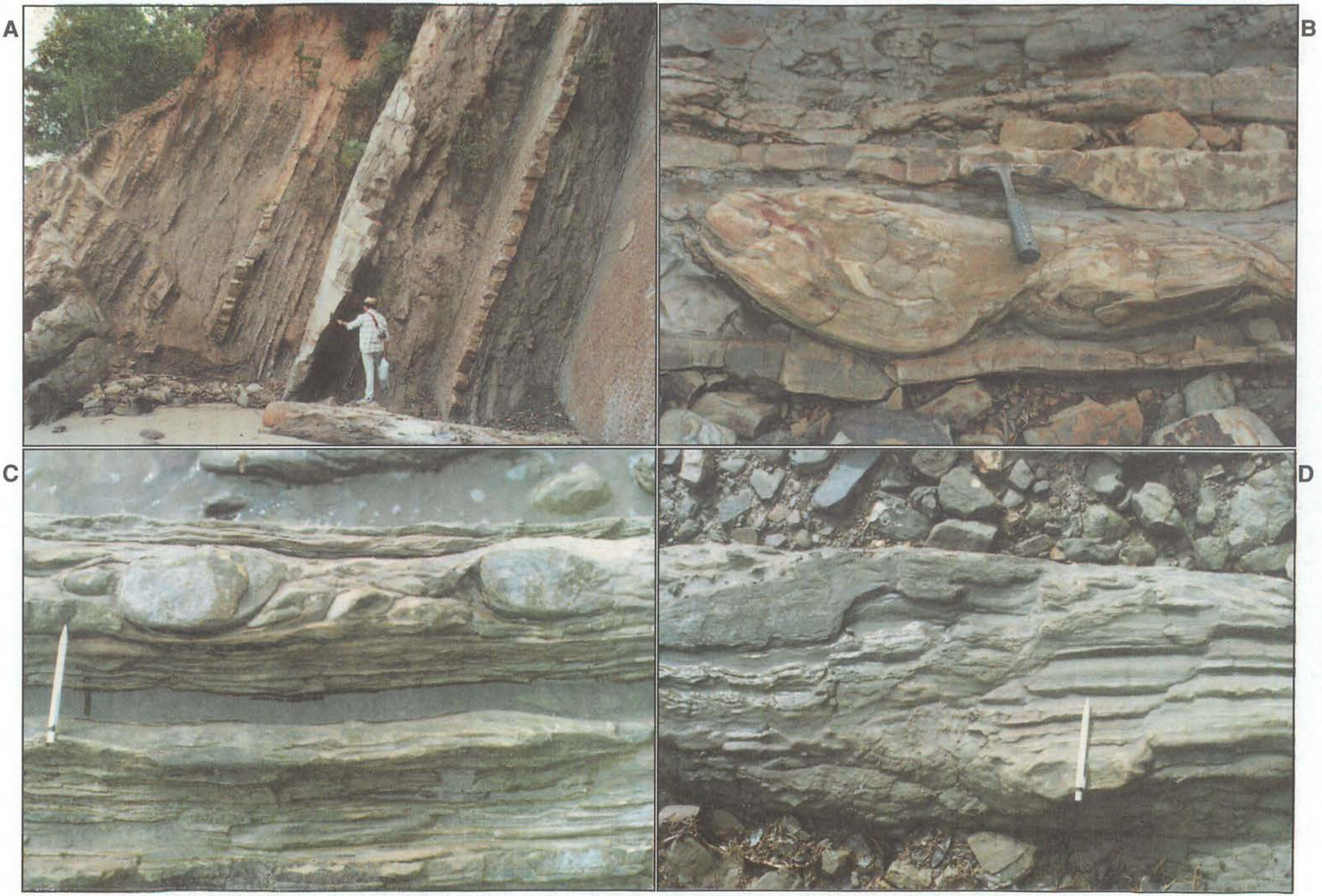


Figure 4. Sedimentary structures in the Temburong Formation, Tg. Layang-Layangan coastal outcrops, indicative of storm deposition and unstable depositional environments. (A) Argillaceous sequence with centimetre-scale sandstone beds. The lenticular sandstone bed at centre is characterised by hummocky cross-stratification (cf. Mazlan Madon, 1994, Fig. 10). (B) Load casts in sandstone bed between mudstone. (C) Well-rounded sandstone load balls in sandstone-mudstone intercalation. (D) Soft-sediment microfaults in HCS beds. For scale: hammer is 33 cm, pencil is 15 cm long.

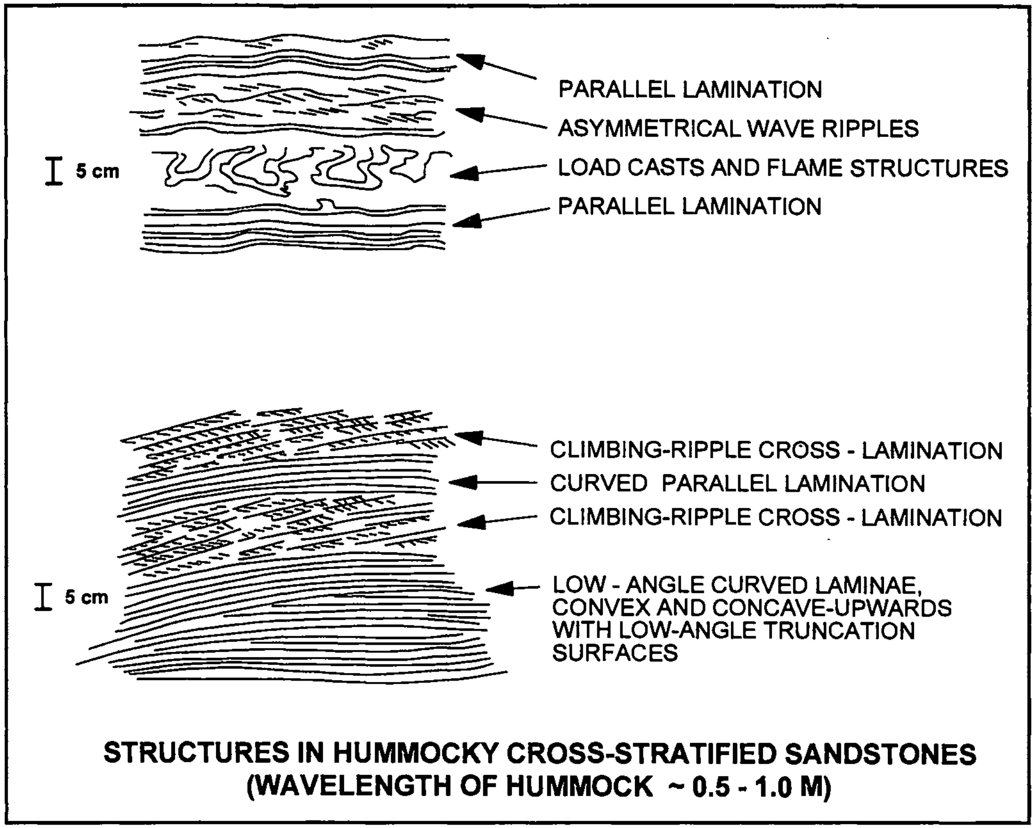


Figure 5. Sketch of internal stratification and sedimentary features within hummocky cross-stratified sandstones, Temburong Formation, Tg. Layang-Layangan.

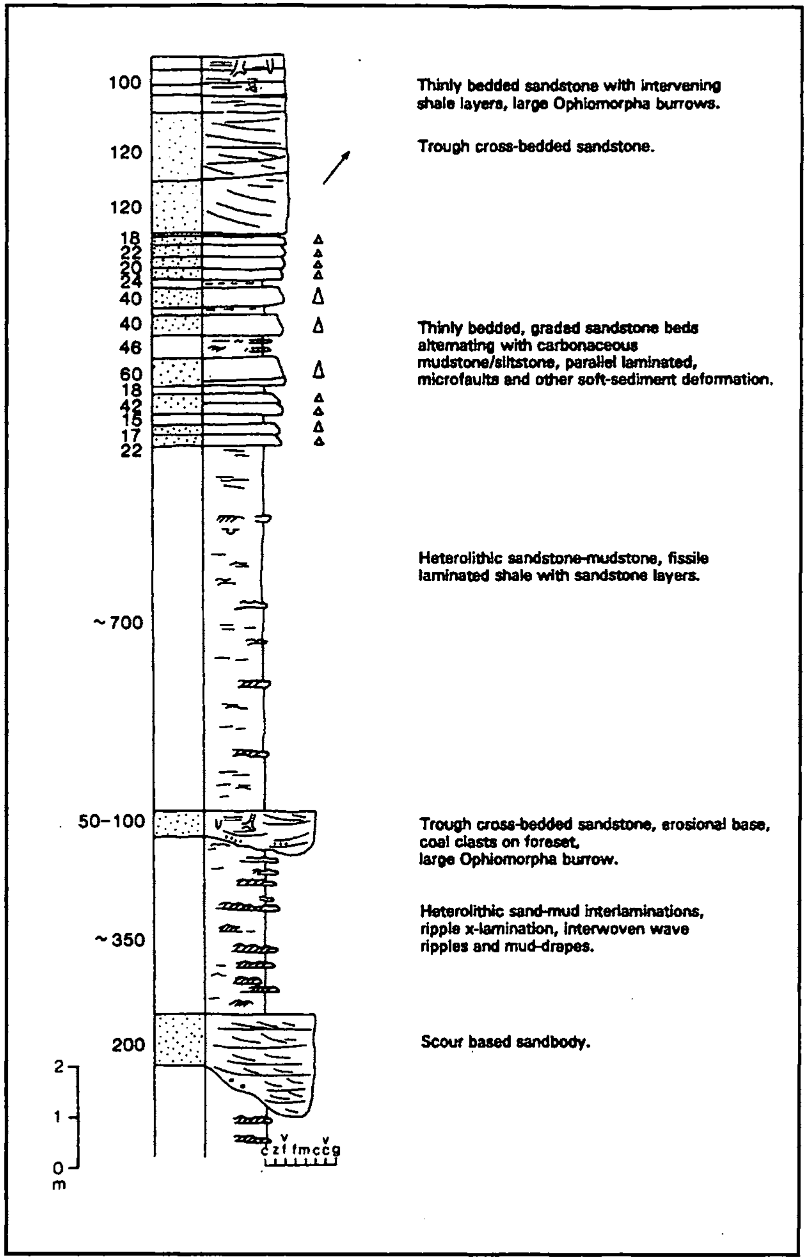


Figure 6. Sedimentological log of outcrop at Loc. D, near Taman Layang-Layangan. Numbers on the left are bed thickness in centimetres. Fining-upward sandstone beds are indicated by triangles. Arrow represents palaeocurrent azimuth. Lithological symbols in Fig. 20.

sediment influx may have resulted in load structures in relatively unconsolidated muddy substrate. Slumping on downstream banks may have resulted in deposition of the sandstone blocks.

The Temburong is also well-exposed in an abandoned quarry at Loc. E (Fig. 2) where it consists of more than 30 m of steeply bedded (52° to the NW) sandstone-mudstone interbeds (Figs. 7, 8). A variety of soft-sediment deformation structures are observed through the succession, which comprises two main coarsening-upward parasequences capped by 2 to 3.5 m-thick cross-stratified sandstone. The lower parasequence consists of dark grey shale with very thin interbeds of ripple-laminated sandstone. The parasequence is topped by a 2 m-thick fining-upward sandstone characterised by large-scale trough cross-stratification and pebbles at the base. The upper parasequence consists of heterolithic sandstone-mudstone facies with abundant carbonaceous laminae. Within it are lenticular sandbodies that show graded bedding and numerous scour-and-fill features. Abundant soft-sediment deformation structures occur, including faults, slump folds and sand-filled Neptunian dykes (Fig. 9). The parasequence is topped by a 3.5 m-thick fine-grained sandstone with low-angle inclined stratification and sharp upper and lower bounding surfaces.

The sequence at Loc. E was deposited in relatively deeper water compared to those at Loc. B and D. The lack of burrowing suggests inhospitable environments probably in a high-energy unstable slope where punctuated sediment input occurs via submarine slumps and channels. The scour-and-fill features are products of turbidity currents transporting sediments from off the shelf during high-energy events such as those during submarine slides or river-floods. The Neptunian dykes may have been produced by dewatering of unconsolidated sediment, probably triggered by faulting or earthquakes and indicates high pore pressures in the sediment as a result of rapid sedimentation and burial rates. The blocky sandstone bodies at the top of the parasequences are probably submarine channel deposits.

BELAIT FORMATION

The Belait Formation is exposed along the northeastern corner of Labuan between Kubong Bluff and Bethune Head (Fig. 1). The sequence here has been described in general by Wilson (1964) but relatively new exposures along Jln. Tg. Kubong and Jln. Lubok Temiang, as well as on Bukit Kubong, have not been described. The sequence consists of conglomerates and pebbly sandstones at the base, passing upward into alternating sandstone, shale, and coal. The conglomerates are resistant to weathering and form a prominent topographic ridge across the northern part of Labuan between Kubong Bluff and Tg. Layang-Layangan (Fig. 2). The erosional base of the Belait Formation represents a major erosional unconformity, separating gently tilting Belait strata from the underlying more deformed sequence of the Temburong Formation (Mazlan Madon, 1994). Wilson (1964, p. 75) reported the occurrence of *Globigerinoides* of T_f1 age (basal middle Miocene) from Kubong Bluff. The underlying shales, supposedly of the Setap Shale Formation (Wilson, 1964; Levell, 1983) is nowhere exposed, but have been reported to contain a pelagic fauna and grade upwards into very sandy strata with brackish water foraminifers (Brondijk, 1963). I sampled indurated dark shales below the Belait conglomerates south of the Chimney outcrop for foraminiferal analysis, but no foraminifers were found.

Fluvial deposits

Approximately 85 m of the fluvial sequence is exposed between Kubong Bluff and Kg. Lubok Piasau (Figs. 10, 11). A transitional facies comprising brackish water siltstone and shale is observed in small exposures near Kg. Lubok Piasau. About 80% of the basal Belait at Kubong Bluff is medium to very coarse-grained pebbly sandstones and conglomerates. The sediments are thickly bedded, and show large-scale trough cross bedding, commonly with pebbles on the foresets and toesets of the cross-laminae. Interbedded with these conglomeratic rocks are generally pebble-free medium to fine-grained sandstones and minor mudstones. Some erosive-based sandstone bodies contain large coalified drift-wood and well-rounded coal fragments. The cross-bedding indicates that palaeocurrents flowed to the north.

A road-cut exposure at the Chimney, along the bend of Jalan Tg. Kubong, provides an excellent pseudo-3D view of the fluvial deposits of the basal Belait (Figs. 10, 11). The succession comprises four depositional units (I to IV, Fig. 11) separated by major bounding surfaces, some of which are erosional. These bounding surfaces probably correspond to the fifth order surfaces of Miall (1988). Erosion surface A is planar and characterised by NW-striking straight-crested ripple marks and is therefore assumed to represent the palaeo-horizontal.

Unit I: Braided channel complex

This basal unit is a fining-upward facies association, comprising cross-bedded conglomerates and pebbly sandstones interbedded with very coarse-grained sandstones (Figs. 12 and 13). This

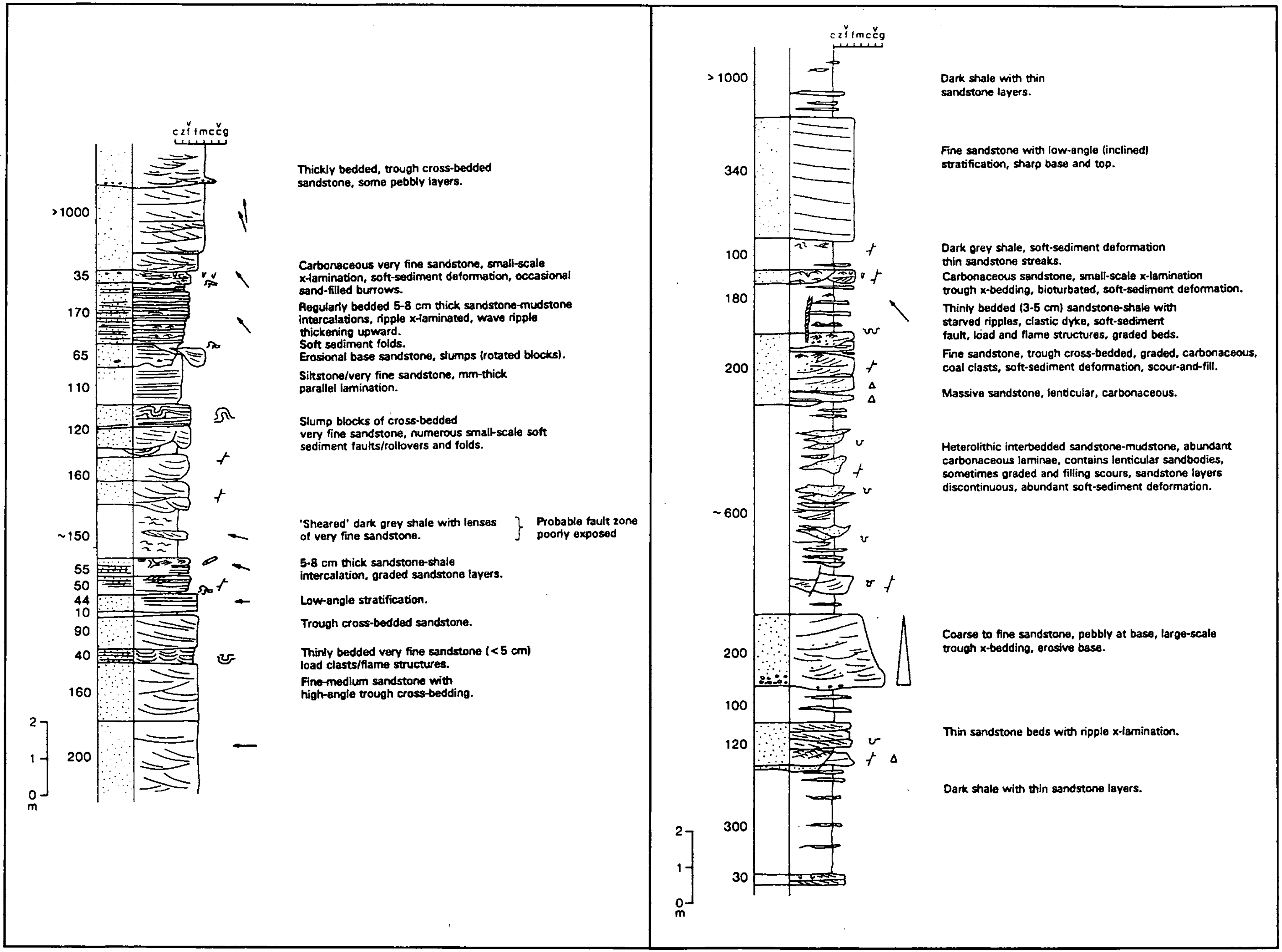


Figure 7. Sedimentological logs of Temburong Formation. Left: outcrop at Loc. B, where the Temburong Formation is asymmetrically folded (see also Fig. 6 of Mazlan Madon, 1994). Right: outcrop at Loc. E, showing major sedimentary features (Photographs from Loc. E are shown in Fig. 8.). Numbers on the left are bed thickness in centimetres. Arrows represent palaeocurrent azimuth. Fining-upward sandstone indicated by triangle. Lithological symbols in Fig. 20.

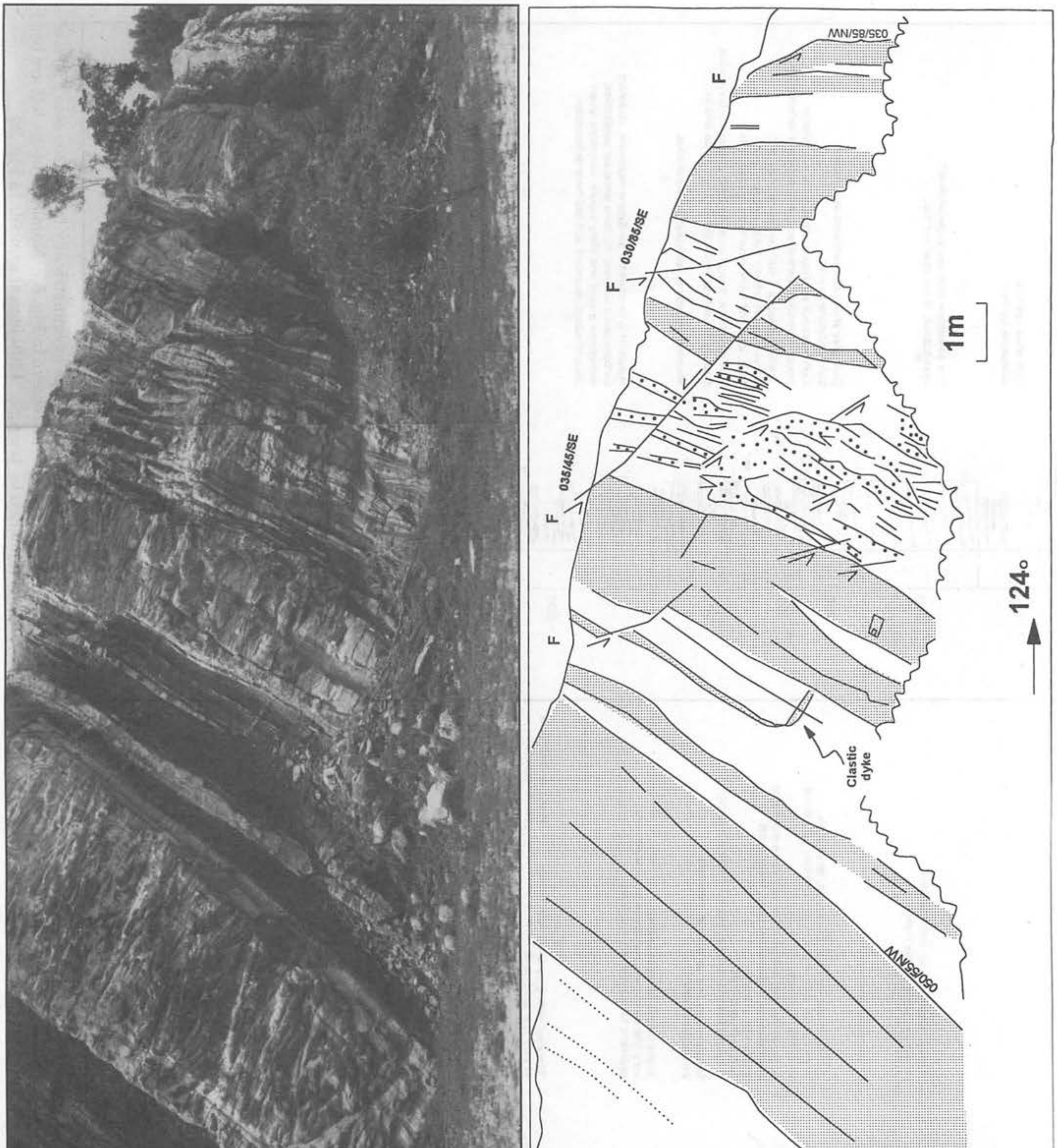
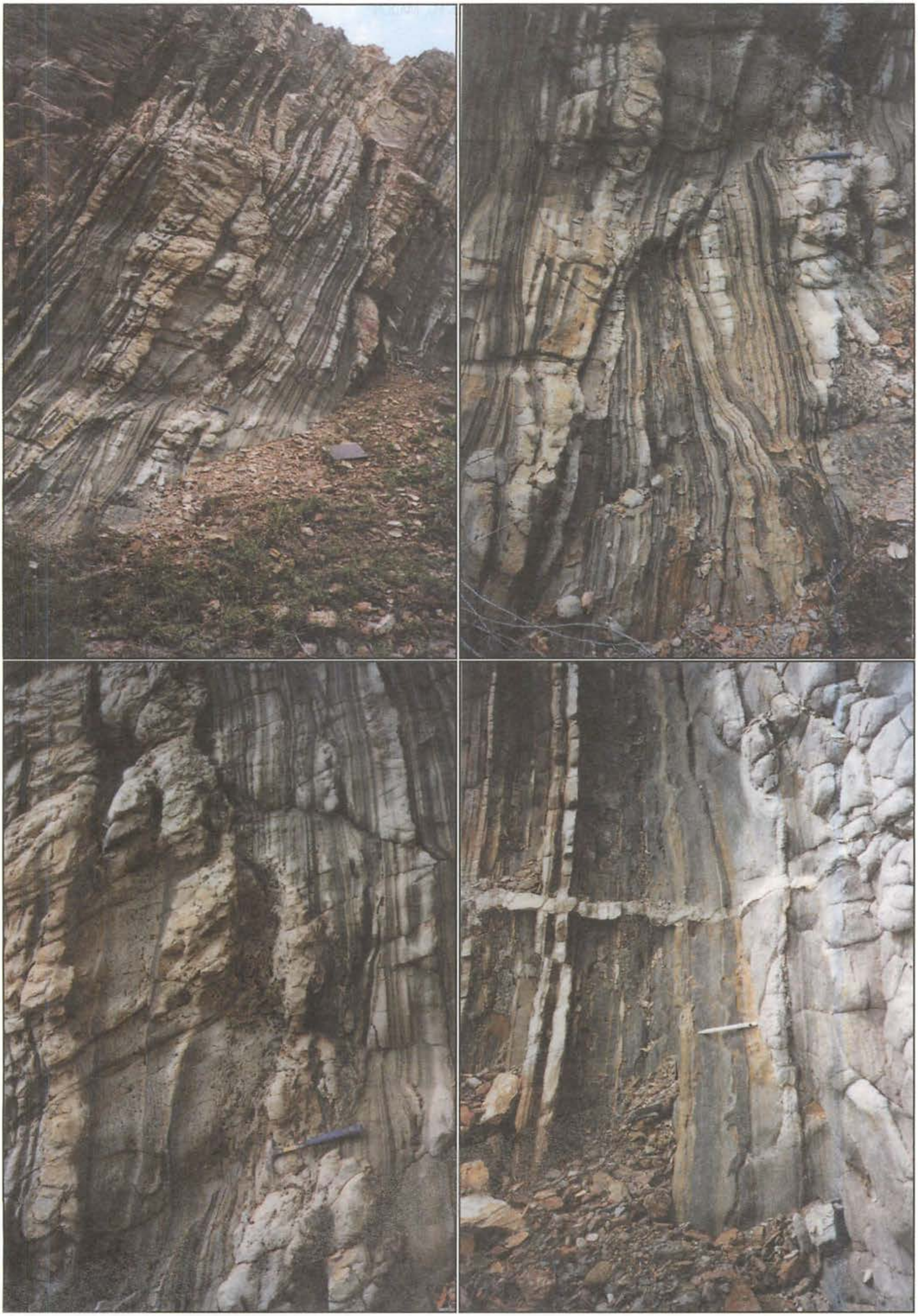


Figure 8. Field photo (top) of Temburong Formation exposed in an abandoned quarry off Jalan OKK Daud, near Kg. Kassim (Loc. E), showing two major coarsening-upward parasequences. Line drawing (bottom) emphasises the heterolithic nature of the sediments and the main structural features.

Figure 9. Sedimentological features of the Temburong Formation show in Fig. 8. (A) Heterolithic facies in the middle part of the sequence, characterised by thin lenticular sandstone stringers. (B) Close-up of heterolithic facies showing numerous cross-cutting relationship representing multiple episodes of sediment input via strong currents. (C) Close-up of heterolithic facies showing concave-up scour features filled with normally graded sandstone. (D) Subvertical sand-filled Neptunian dyke cutting across bedding in muddy heterolithic facies in the upper part of the section.


A
B
C
D

A

B

Figure 10. Sedimentary features in the Belait Formation. (A) Cross-bedded conglomeratic sandstone of Belait Formation at the top of Tg. Layang-Layangan succession. Note the well-rounded coal pebbles forming lag deposits. (B) Large-scale cross-bedding with asymptotic toesets in Belait Formation fluvial sandstones at Tg. Kubong (coastal exposure).

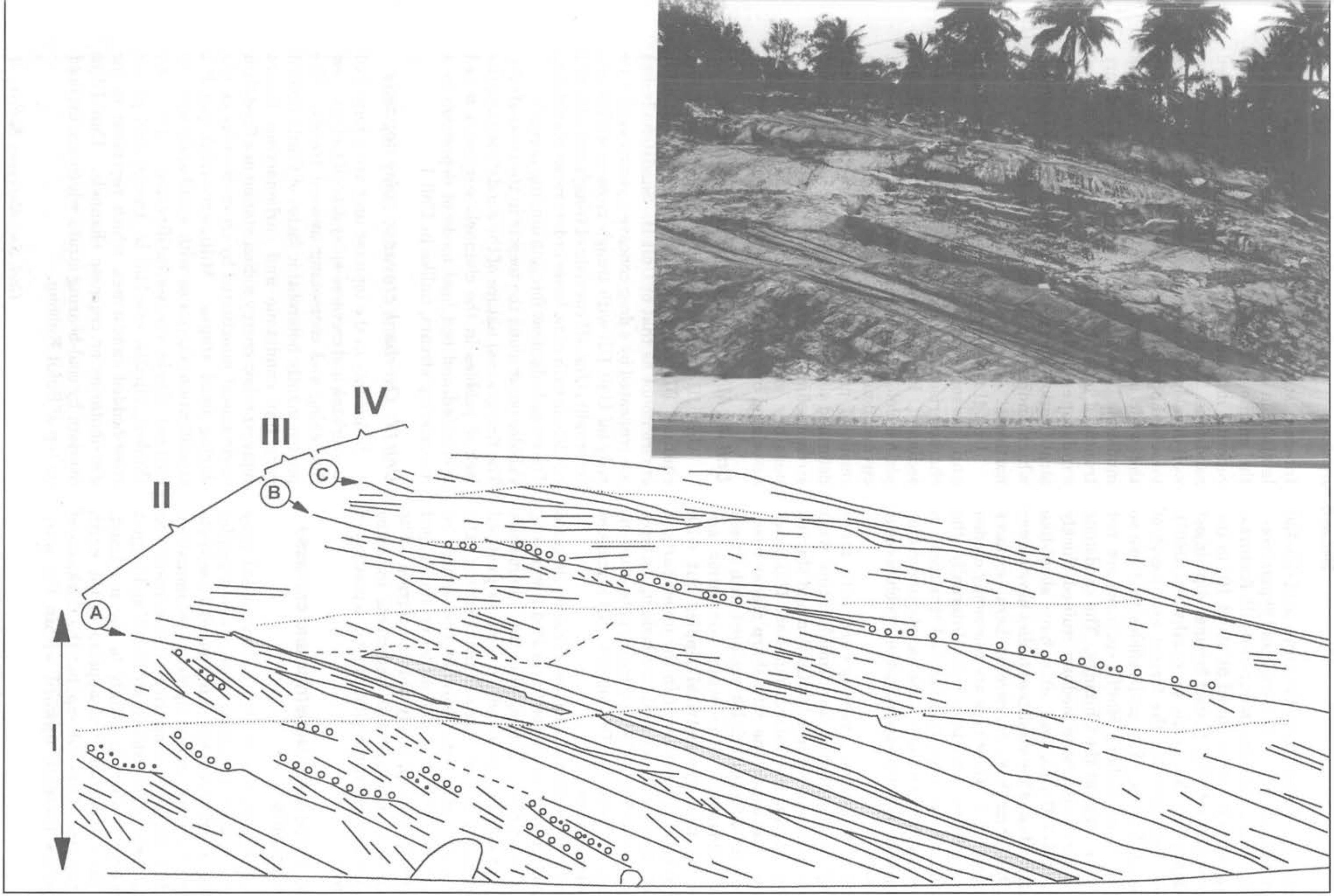


Figure 11. Belait Formation at the Chimney outcrop. (A) Photograph of road-cut along Jln. Tg. Kubong at the Chimney (Loc. A) showing excellent exposure of the basal part of the Belait Formation. Viewed roughly northwards. (B) Line drawing of A showing major bounding surfaces (A, B, and C) separating packages of depositional units (I and IV). The bounding surfaces are probably 5th order bounding surfaces (Miall, 1988) interpreted to be related to channel abandonment and switching. Vertical sedimentolgical log shown in Fig. 12.

conglomeratic facies is very thickly bedded (50–130 cm, thinning upward), with trough and planar cross-bedding and abundant scour-and-fill features. Bedding surfaces are inclined at about 10° to the palaeo-horizontal. The foreset laminae dip almost consistently to the north or northwest (080°). Pebbles often occur on the foreset and toeset of cross-stratification. The coal pebbles that are so common in the Kubong Bluff exposures are not seen in the rocks at the Chimney. The sandstone facies is mainly coarse to medium grained, thickly bedded (35–110 cm), and often have sheet-like geometry. Most of the sandstone bodies have planar bases, but some have concave-up basal surfaces with steep sides. Their tops are commonly eroded by the overlying sandstone bed. Internally, the sandstones have large-scale inclined stratification surfaces, high-angle asymptotic toesets, and minor high-angle trough cross-stratification. Pebbles occur in places.

The sandstones pass upward into more heterolithic laminated sand-mud facies with characteristic wave-ripple lamination and starved ripples producing lenticular lamination. This facies is of very fine sandstone with sharp planar bases and tops, 20–25 cm thick intercalated with linsen bedded mudstone. Some wavy lamination are formed by near-symmetrical ripples but with unidirectional foresets occur in the upper parts of the beds. Ripple marks on exposed bedding surfaces generally strike 310°–315°, indicating palaeocurrent direction to the north. The top of Unit I is marked by erosion surface A.

Unit I is interpreted as a low-sinuosity, braided stream complex deposited on the eroded Temburong Formation surface. During this time, immature stream profiles resulted in coarse-grained sedimentation in a nonmarine fluvial setting. The deep-water sediments provide the source of sediment for the fluvial deposition on the rugged and relatively steep, newly uplifted terrain. The dominance of coarse-grained sediments indicates active tectonics in the region during deposition of this unit.

Unit II: Floodbasin lacustrine and crevasse splay deposits

Unit II consists of thinly-interbedded grey lenticular-bedded mudstone with starved ripples and sheet sandstones containing parallel low-angle inclined stratification and ripple cross-lamination. Straight-crested asymmetrical ripple marks on bedding surfaces consistently strike NW and suggest palaeocurrents flowing mainly to the northeast. Each sheet sandstone bed appears to the north along the face of the outcrop, but the thickness of sandbodies increase upward within the unit. Internal stratification varies from ripple cross lamination in the lower part to plane lamination on the middle to ripple cross-lamination at the top. Sideritic mudclasts occur in the planar laminated sandstone. The two lowermost sandstone beds show well-developed low-angle foreset with asymptotic toesets dipping to the northeast, pinching out to the west and grading into lenticular bedded mudstone. The thin sandstone-mudstone beds are truncated by a sharp-based, very thick (ca. 6 m) sandstone body with large-scale inclined stratification surfaces and trough cross-bedding, which indicate palaeocurrents flowing to the northwest.

Unit II is interpreted as comprising floodbasin and associated crevasse-splay deposits, characterised by mixed bed-load and suspended sediment. It represents a mature phase of alluvial plain development during a more tectonically quiet environment and lower depositional gradients as a result of prolonged denudation of the uplifted/deformed terrain. Coarse-grained pebbly braided stream sediments are replaced by sand-dominated, possibly meandering stream deposits with associated overbank and splay sediments.

Unit III: Mixed-load channel fill complex

Unit III is interpreted as major meandering channel fill complex deposited in a similar environment as that of Unit II. Sandstone bodies are truncated by a deep concave-upward sandstone body (of Unit III) with trough cross-stratification. Internally, Unit III consists of trough cross-bedded sandstone with some lower order erosional surfaces. The cross-beds show foresets dipping to southwest. Pebbles occur along the toesets in the cross-strata. The fine-grained nature of the sandstones and the lack of pebbles in the channels suggest a mixed suspended and bed load mode of deposition in a meandering stream, unlike in Unit I.

Unit IV: Overbank crevasse splay deposits

Sediments in the topmost unit are interpreted as overbank and crevasse-splay deposits which show thickening and coarsening upward trends. The predominantly heterolithic facies of thinly bedded very fine sandstone and carbonaceous layers represents low-energy sedimentation in a floodplain environment punctuated by crevasse splay events during flood stages. Millimetre-thick parallel stratification alternates with small-scale wave or current ripple cross-stratification, often with climbing ripples, overlain by trough and planar cross-bedded sandstones, which represent minor distributaries or crevasse channels. Unit IV is overlain by coal-bearing strata which are exposed on top of Bukit Kubong.

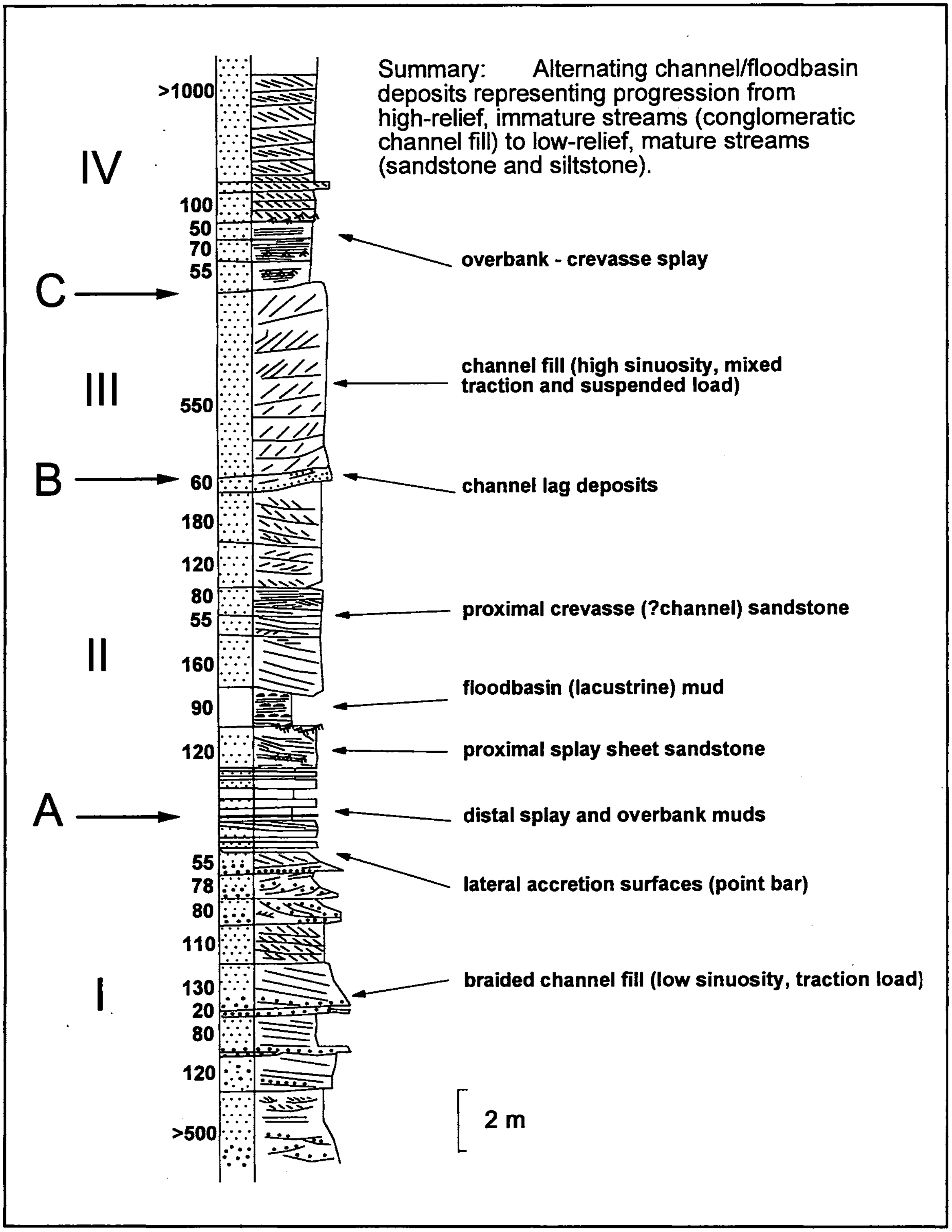


Figure 12. Sedimentological log and interpretation of basal Belait Formation exposed at the Chimney road-cut, near Tg. Kubong (Loc. F). Numbers alongside the log represent thickness in centimetres. Roman numerals I to IV refer to depositional units bounded by surfaces A, B and C (which are explained in the text). Lithological symbols in Fig. 20.

Shallow marine deposits

The fluvial sequence of the basal Belait Formation passes upwards (northwards) into shallow marine deposits via a heterolithic muddy facies, poorly exposed in small outcrops at Kg. Lubok Piasau, where channel-based sandstone bodies exhibiting tangential cross-stratification and reactivation surfaces interbedded with wave-rippled heterolithic mudstones (Fig. 14). Dark grey pyritiferous shales collected from exposures just north of the Chimney outcrop were found to contain brackish water arenaceous foraminifers.

Shallow marine deposits form the overlying remaining part of the Belait Formation in northern Labuan. These deposits are best exposed in the coastal outcrops from Kg. Lubok Piasau to Bethune Head, in road-cuts along Jln. Lubok Temiang, and in less accessible exposures on Bukit Kubong. Features that indicate shallow marine sedimentation include: (1) The presence, though not abundance, of shallow marine microfossils (Wilson, 1964; Lee, 1977). Samples collected for this study have also yielded some foraminifers. (2) The generally high bioturbation of the sandstones and interbedded shales, including the presence of *Ophiomorpha*. (3) The abundance of wave-formed sedimentary structures, such as hummocky cross-stratification, which are common in ancient shallow marine storm deposits (Cheel and Leckie, 1993).

In the coastal exposures between Kg. Lubok Piasau and Bethune Head, gently dipping shale and sandstone sequence exhibit a stepped-like cuesta topography whereby the more resistant sandstones form the northward slope of the cuestas (Fig. 15). The sequence consists of almost cyclical alternation of coarsening-upward shale-sandstone units (Fig. 16). Indeed, the tops of some of these units form some of the northward sloping cuesta tops, being more resistant to weathering than the shales.

The dominant sandstone facies occur as sharp-based sandbodies ranging between 0.3 and 1.5 m thick, alternating with fissile mudstone (shale) which may be as much as 11 m thick in some places. The sandstones exhibit typical hummocky cross-stratification that has a wavelength between 0.7 to 1.0 m (Fig. 5). The individual beds are heterogeneous; they contain siltstone layers a few centimetres thick. The hummocky cross-stratification is often cut by numerous subvertical solitary or branching *Ophiomorpha*. The base of sandstones sometimes have erosive steep-sided gutter casts which contain abundant mud-flake breccia and leached out shell fragments (Fig. 17).

Mudstones form the "background" against the seemingly intermittent sandstone deposition in the Belait shallow marine deposits. In detail, the mudstones consist of very thinly interbedded heterolithic facies of mudstones and sandstones less that a few cm thick. There are also common development of ferruginous concretions forming thin but laterally continuous bands which are regularly spaced within the mudstone.

Slump features are common in some parts of the upper Belait, as seen in the road-cuts along Jln. Lubok Temiang (Fig. 2). The slump deposits are evidently shallow marine sandstones which have undergone soft-sediment deformation and was re-deposited as a result of slope instability. In one outcrop, gravity-induced slumping is clearly indicated by the curved (listric) sliding surfaces along which mass transport has occurred (Fig. 18). In places, the sandstones slid down the palaeo-slope to form large sandstone "balls" enclosed in mudstones. The apparent direction of this palaeo-slope is to the north and northwest.

DEPOSITIONAL HISTORY

In neighbouring onshore areas, the Temburong Formation have been interpreted as deep water shales and turbidites (e.g. James, 1984) while in others the sediments appear to have been deposited in environments ranging from brackish shallow water embayment or lagoon to lower alluvial floodplain (Tate, 1994). Palaeontological evidence is lacking from the Temburong outcrops in Labuan. The sedimentological features in the coastal exposure near Tg. Layang-Layangan suggest deposition under a regressive environment in a shelfal regime, but never bathyal. The sequence represents moderately deep probably prodelta environment passing upwards into shallower marine to nearshore as the region was affected by deformation of the NW Sabah margin during middle Miocene times. Abundant soft-sediment deformational structures within the Temburong are the result of penecontemporaneous tectonics during sedimentation on the once actively-deforming continental margin.

The basal Belait Formation were deposited in fluvial systems developed over an eroded Temburong landscape in an overall transgressive regime (Fig. 19). The road-cut exposure at the Chimney near Tg. Kubong contains an example of a transgressive fluvial system developed within the basal part of the Belait Formation. Facies development in the basal Belait reflects the gradually changing base level and stream profile from a coarse-grained braided fluvial system to a fine-grained, mixed bed- and suspension-load, meandering fluvial system. The coastal section

A B C D

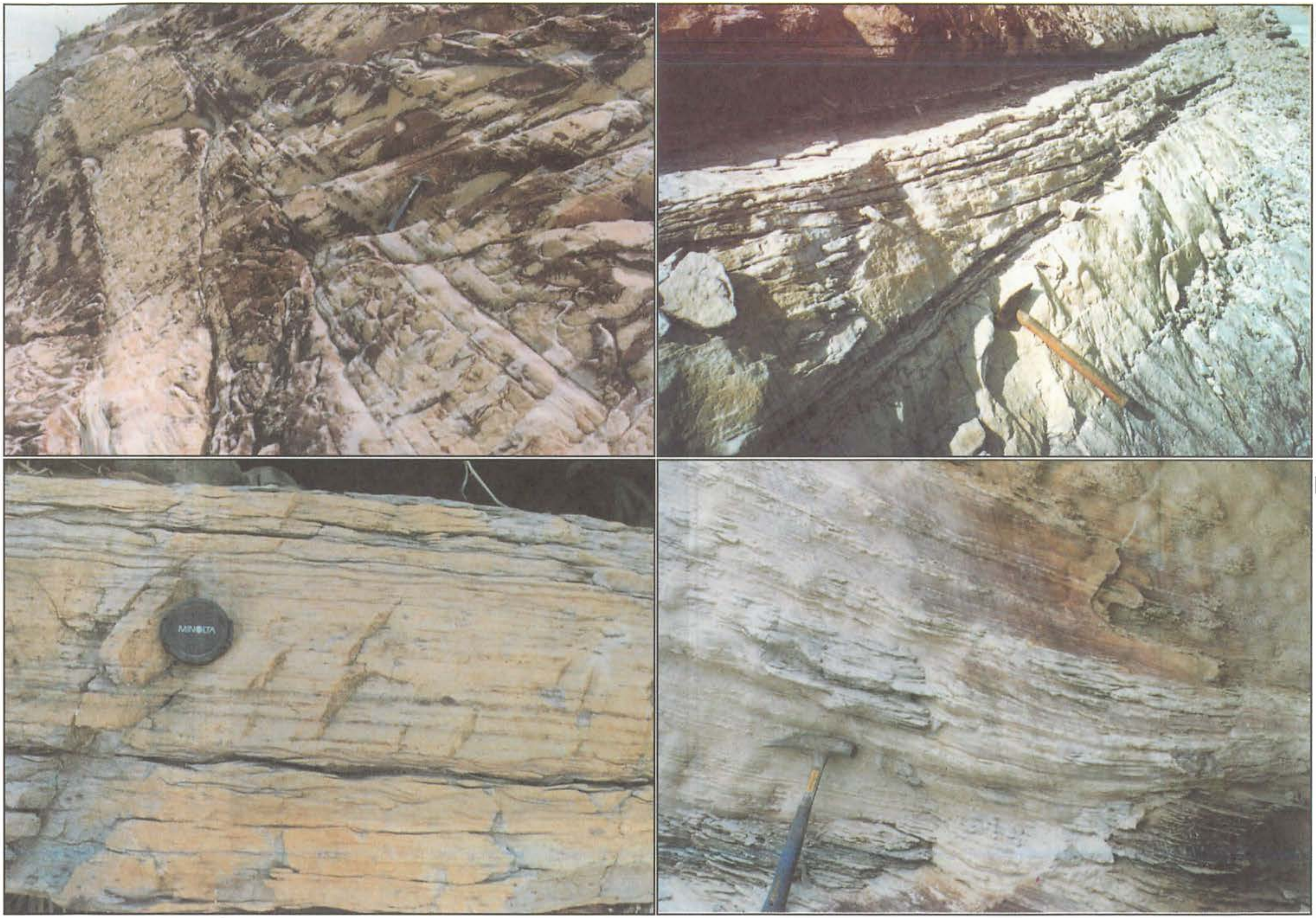


Figure 13. Facies in basal Belait observed at the Chimney and Tg. Kubong. (A) Erosive channel-cutting features in unit I sandstone and conglomerate, interpreted as 3rd order bounding surfaces. (B) Asymptotic foresets in fine-grained sandstone at top of Unit I, interpreted as laterally accreting point-bar deposit. (C) Ripple cross-laminated sandstone facies at base of Unit II, interpreted as proximal splay sheet sand deposit. (D) Lenticular siltstone-mudstone facies in Unit II, interpreted as floodbasin lacustrine deposit.

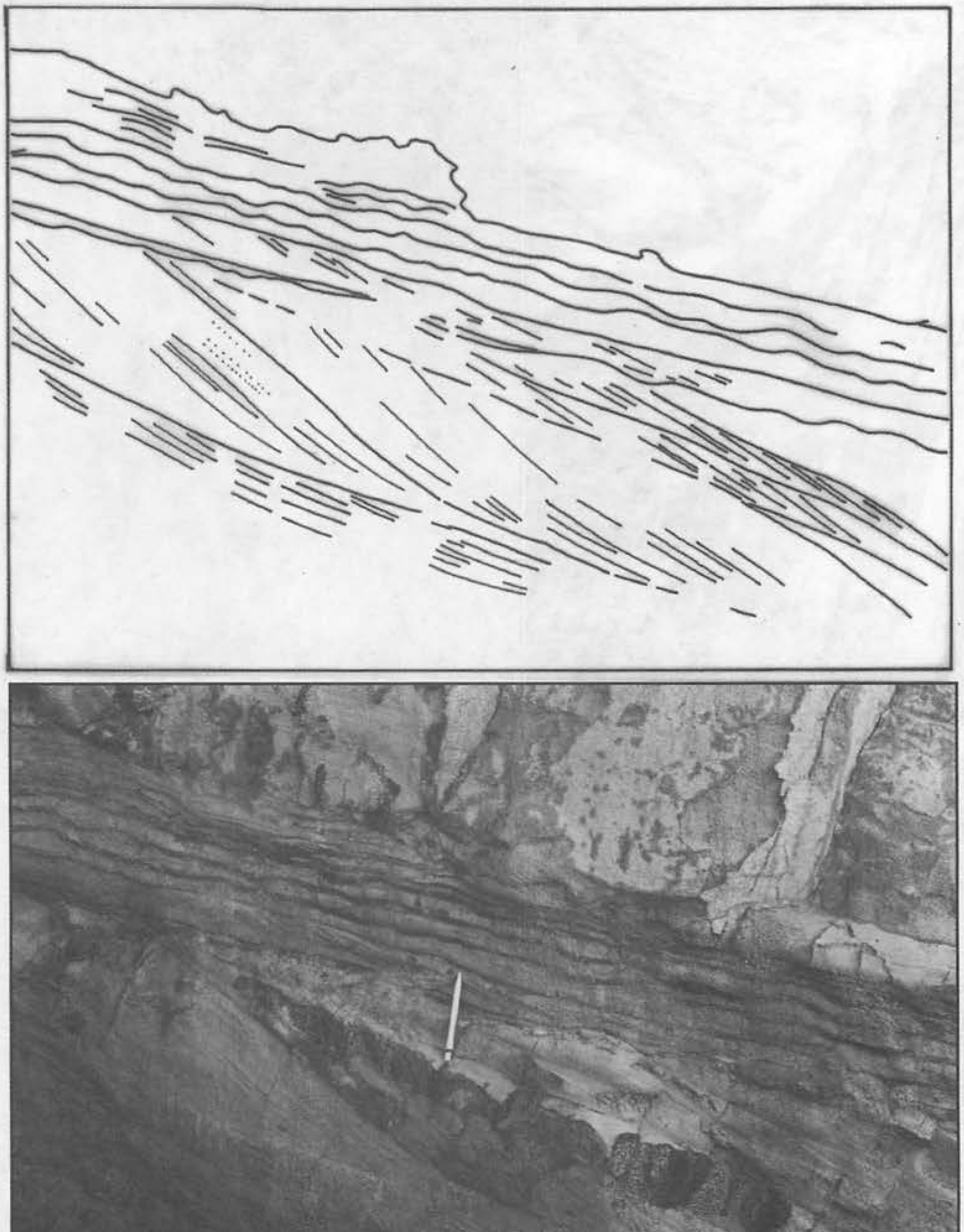


Figure 14. Heterolithic sandstone-mudstone facies interpreted as being deposited in fluvial-to-marine transition with tidal influence, Belait Formation. Cross-stratified fine-grained sandstone with asymptotic foreset lamination and reactivation surfaces overlain by thinly-bedded wave-rippled sandstone-mudstone.

Figure 15. Belait Formation between Tg. Kubong and Bethune Head. (A) Topographic ridges formed by two coarsening-upward parasequences in Belait Formation. Near Bethune Head. (B) Lenticular hummocky-stratified sandstone bed intercalated with bioturbated offshore mudstone, Belait Formation. Bethune Head.

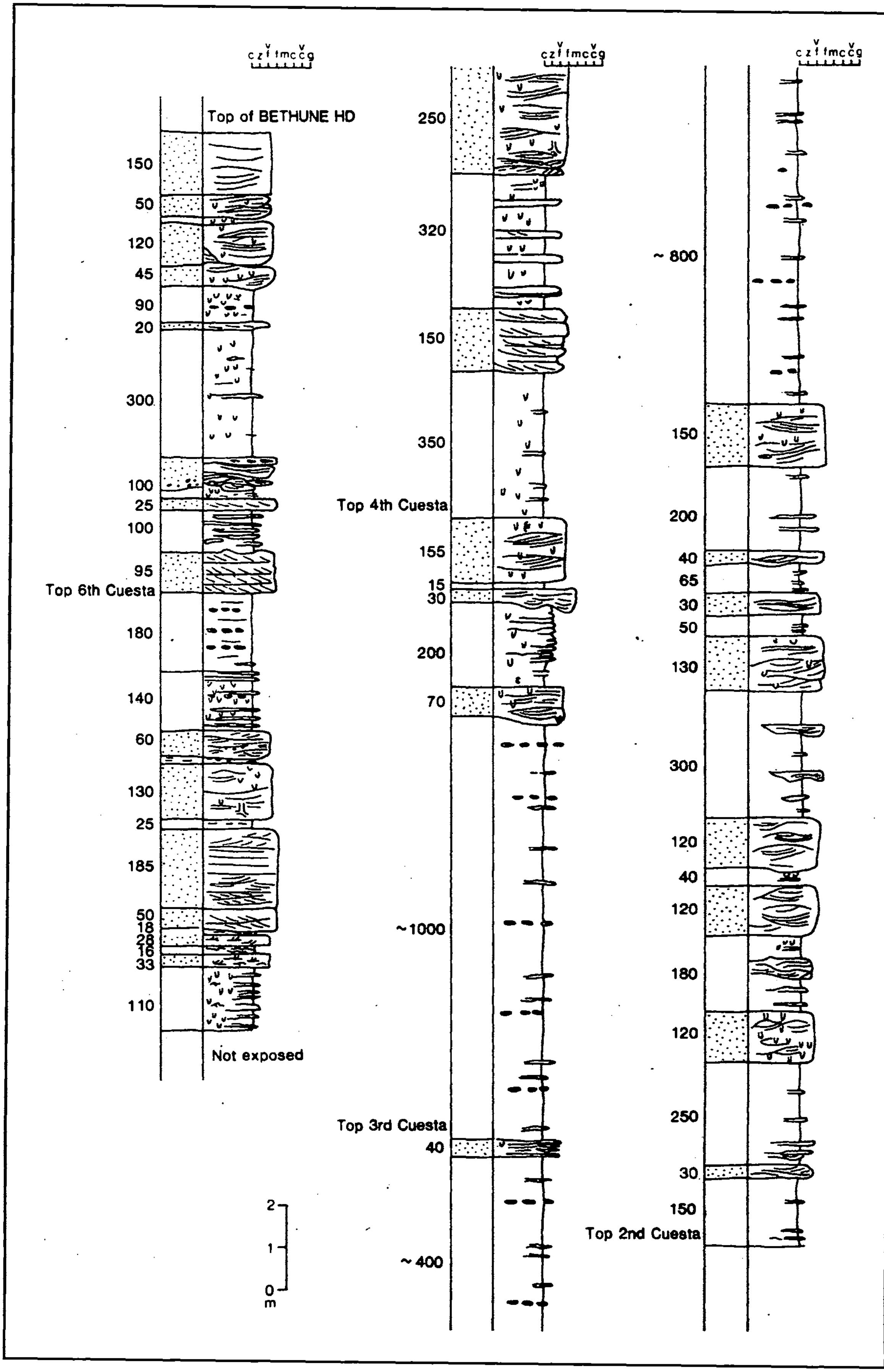


Figure 16. Sedimentological log of shallow marine parasequences in Belait Formation between Kg. Lubok Piasau and Bethune Head. Lithological symbols in Fig. 20.

A

B

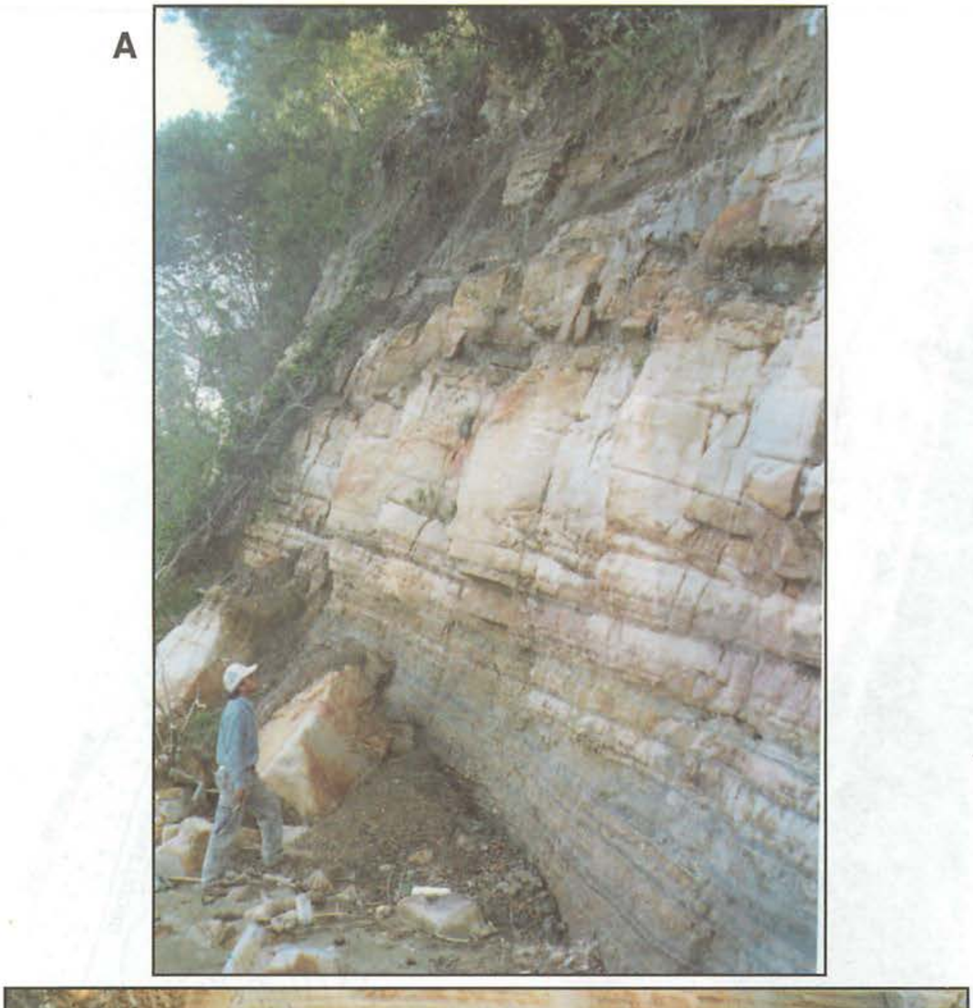


Figure 17. Shallow marine deposits of Belait Formation. (A) Coarsening-upward parasequence of offshore shale to shallow marine cross-stratified sandstone, Belait Formation. Near Bethune Head. Author for scale (1.65 m). (B) Gutter cast at the base of hummocky-stratified sandstone, Belait Formation. Bkt. Kubong:

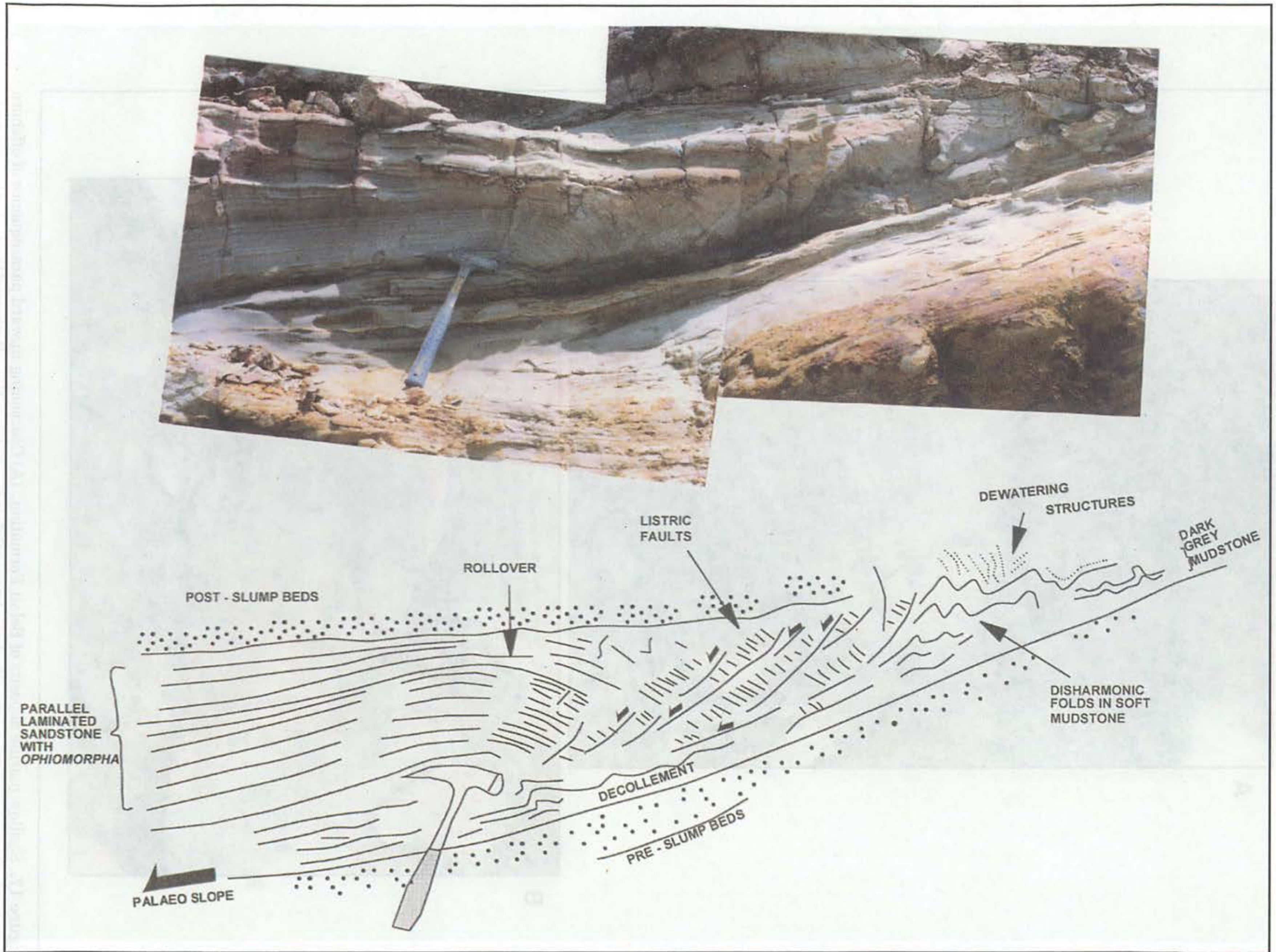


Figure 18. Slump structures in Belait Formation, roadcut exposure along Jln. Tg. Kubong, near Bkt Kubong (Loc. G). Soft-sediment deformational features associated with slumping on an unstable slope, include listric faults and rollover features. Both the pre- and post-slump beds are undisturbed. Note that the listric faults sole out at a decollement surface formed by mudstone. Folding and dewatering structures occur in the muddy horizons. North is approximately to the left of picture.

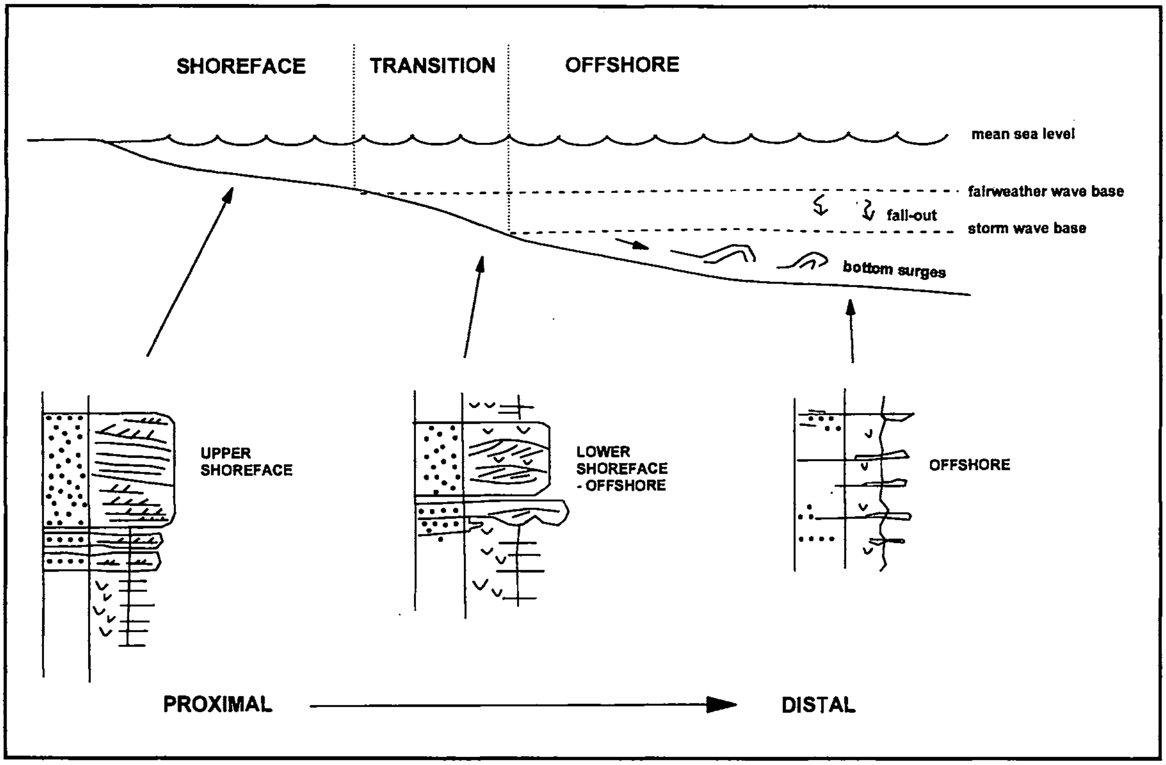


Figure 19. Depositional model for shallow marine sedimentation in the Belait Formation.

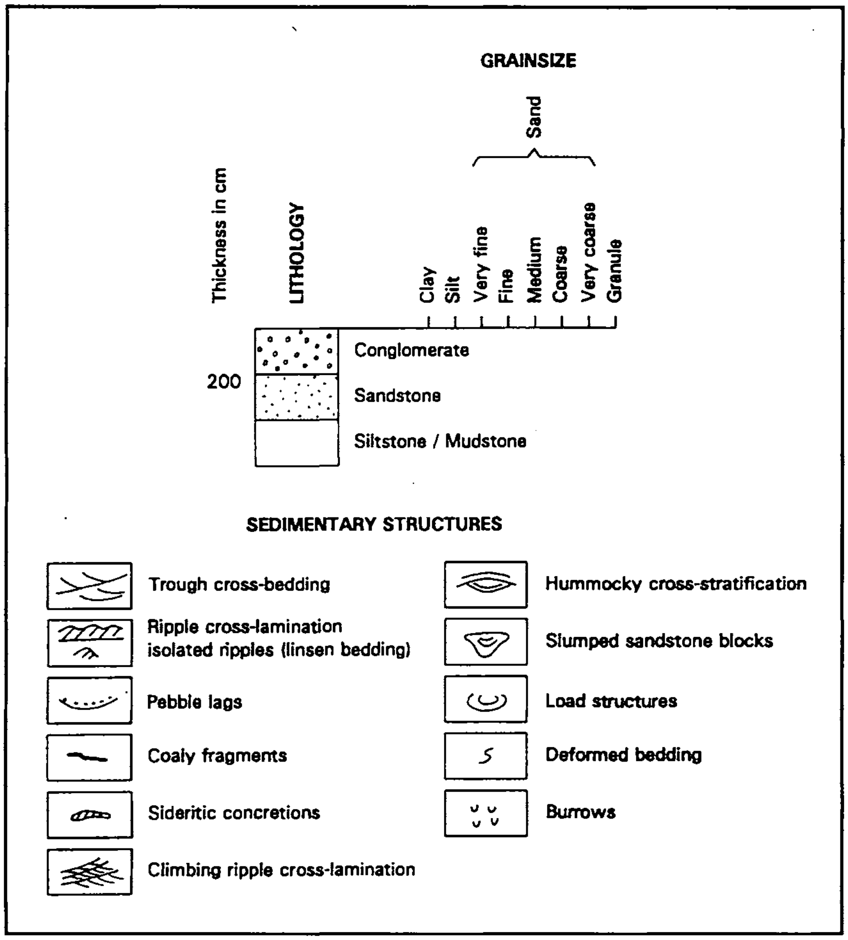


Figure 20. Symbols for use with sedimentological logs in Figs. 6, 7, 12, and 16.

between Tg. Kubong to Bethune Head consists of fluvial deposits that pass upwards into transgressive shallow marine sequence punctuated by 4th and 5th order progradational cycles (parasequences) represented by coarsening-upward offshore shales to shoreface sandstones.

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