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The stratigraphy, structure and significance of the Nenering Tertiary beds, Pengkalan Hulu (Keroh), Hulu Perak

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Abstract: The study area which is located at the northern most part of Peninsular Malaysia neighbouring Thailand, displays outcrops of a series of rocks with ages that range nearly the entire Paleozoic Era and Cenozoic Era, that is, the Kroh Formation (Early Ordovician-Early Devonian), Kati Formation (Carbo-Permian?) and Nenering Tertiary Beds (Tertiary). The older Kroh Formation act as the basement unit for the other two younger formations. The strata of the Kroh Formation are extremely folded and deformed, whereby lying above it is the broadly folded Kati Formation which is limited to the SE portion and the Nenering Tertiary Beds to the NE portion of the study area. Both of the younger formations lie above clearly exposed basal planes of unconformity which are angular in nature. The Nenering Tertiary Beds which is an alluvial-fluviatile continental deposit comprises three main units, namely:-

i) The Lower Unit
ii) The Middle Unit
iii) The Upper Unit

The lithology consists of well-consolidated to semi-consolidated gravel beds, sandstone, silt and mud. Structurally the study area has undergone two periods of tectonic deformation, both of which are subjected to an east-west compression force that resulted in the two phases of folding of the strata of the Kroh Formation and the broad folds of the Kati Formation. The area has also gone through an active period of faulting during the pre-Tertiary which play an important role in the development of the sedimentary basin of the Nenering Tertiary Beds. Faulting remained active during the Tertiary periods and resulted in the tilting of the Tertiary beds to a broad open fold structure and exposing the primary plane of unconformity between the related formations.

INTRODUCTION

The study area, better known as the Betong-Lepang Nenering Border Area, located about 34 kilometres to the north of Grik (Fig. 1) along the Malaysia-Thailand border, displays a remarkable relationship of a series of rocks ranging from as early as Early Ordovician till Tertiary. All of these rocks are of sedimentary origin.

GENERAL GEOLOGY

The area is underlain by three formations, namely the Kroh Formation (Burton, 1967, 1970 and 1986; Hamdan Ariffin, 1993) the Kati Formation, (Teh and Azhar Hussin, 1994) and the Nenering Tertiary Beds, (Chaodumrong, 1983; Che Aziz Ali *et al.*, 1994; Ibrahim Abdullah *et al.*, 1991; Teh, 1994; Qalam Azad Rosle, 1995; Rushdan Abdul Latif, 1994; Sia, 1990; Zahir Yahya, 1993) The stratigraphic relationship between the three are summarised in Table 1. The older Kroh Formation act as the basement unit for the other two younger formations. The distribution of the three formations are shown in Figure 2. Structurally, the area has undergone two periods of tectonic deformation as depicted by the secondary structural elements within each formation. Periods of active faulting have exposed the primary contact between the related formations at several locations. The planes of unconformity can be seen outcropping nicely along the highway from the village of Felda Nenering to Pengkalan Hulu and along the border route from the PPH (Pasukan Polis Hutan) sentry post near the Betong end towards the SE end of the border route stretch. All the unconformity planes are angular in nature. The outcrop of the plane of unconformity between the Kati Formation and the Kroh Formation can only be seen at km 16.9, km 18.4 to km 18.5, and km 19 along the border route (Fig. 3), whereas the contact between the Nenering Tertiary Beds and the Kroh Formation can be seen at km 2.0, km 2.8 and km 3.0 (Fig. 4) along the border route, and at km 6.0 and km 9.6 from Keroh along the Kg. Lalang-Kg. Air Panas highway (Fig. 4)

NENERING TERTIARY BEDS

The Nenering Tertiary beds which can be seen along both the highway and the border route are

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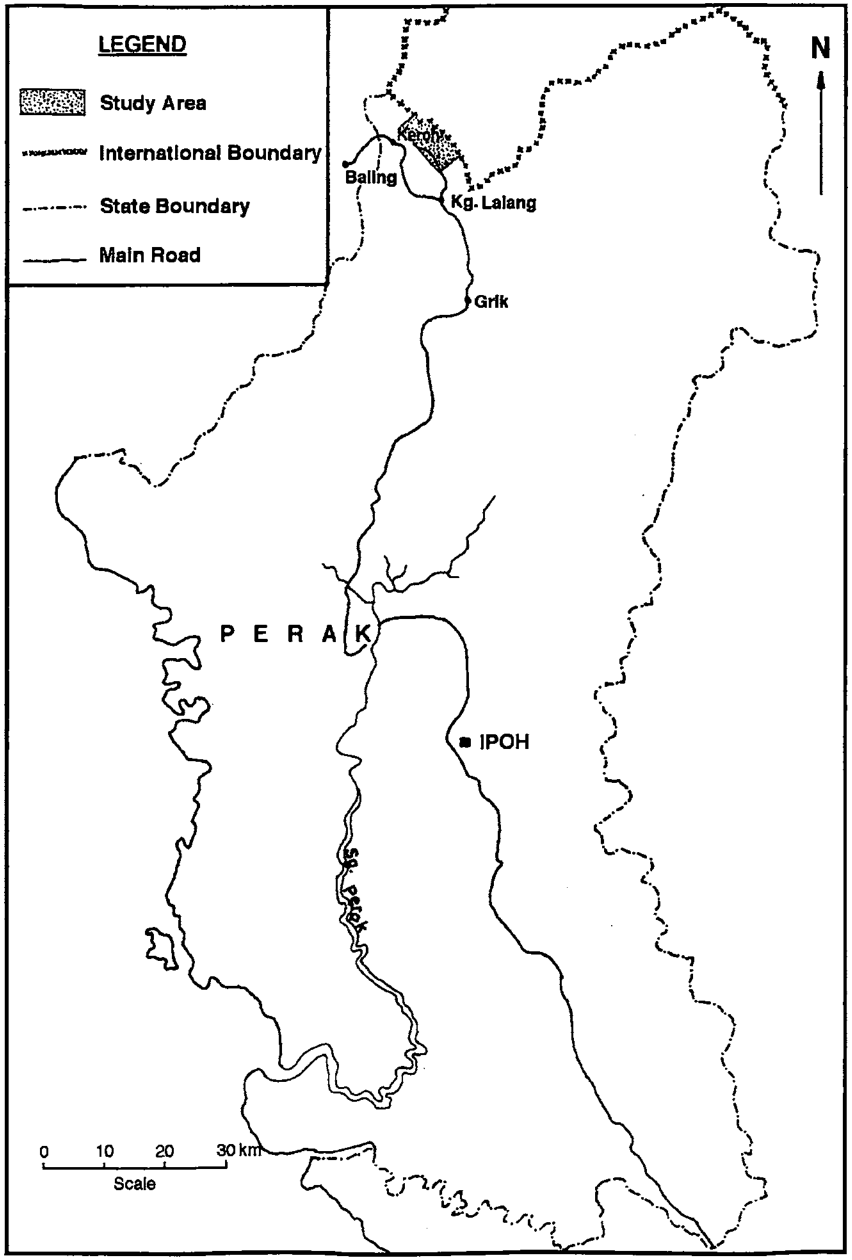

Figure 1. Location map of the study area.

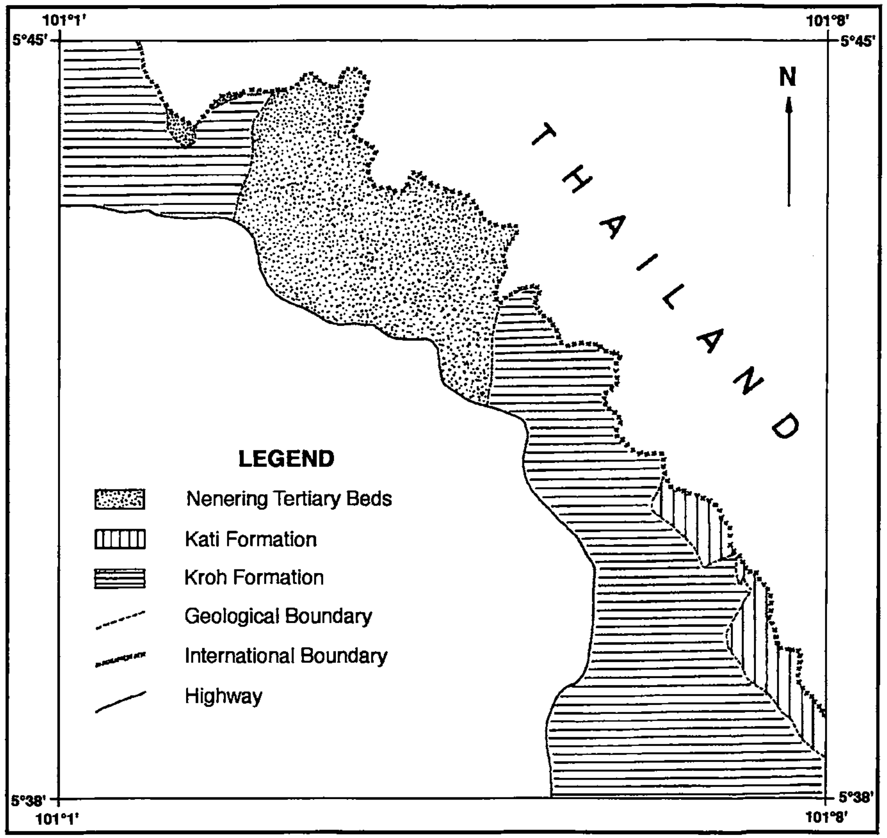

Figure 2. Distribution map of the related formations of the study area.

Figure 3. Photo showing outcrop of the Basal Conglomerate Facies of the Kati Formation lying above the extremely folded strata of the Kroh Formation. Location: kilometer 18.5, border route.

Table 1. Stratigraphic Column of the Betong-Lepang Nenering border area.

FORMATION/AGE	DESCRIPTION
NENERING TERTIARY BEDS (Tertiary) Angular Unconformity	Continental deposits, consists of well consolidated to semi-consolidated extraformational conglomerate, pebbly sandstone, sandstone and siltstone. Three main units:- i) The Upper Unit ii) The Middle Unit iii) The Lower Unit
KATI FORMATION (Carbon-Permian ?) Angular Unconformity	Turbiditic formation, consists of intraformational chert conglomerate succeeded by an alternating beds of sandstone, siltstone, shale and clay. Two main facies:- i) Rhythmite facies ii) Basal conglomerate facies
KROH FORMATION (Early Ordovician-Early Devonian)	An euxinic, restricted, basinal formation, consists of shale, siliceous shale, chert, siltstone, sandstone, limestone and argillite. Four distinguishable facies:- i) Argillaceous facies ii) Siliceous facies iii) Calcareous facies iv) Arenaceous facies

typical continental deposits. It consists mainly of semi-consolidated or a loose framework of mud/sand supported boulder, gravel and pebble, and argillaceous beds. The rudaceous sediments are mainly of quartzite, sandstone, recycle conglomerate, breccia, vein quartz, and, minor chert, argillite and some of granitic origin (Teh and Sia, 1991). Generally, all the clasts are highly abraded and appear well to very well rounded. Stratigraphically, based on the differences in their modal sedimentary composition and features they can be divided into three distinguishable units, namely;

i) The Lower Unit
ii) The Middle Unit
iii) The Upper Unit

The relationship between the three units are shown in Table 2.

The lower unit which is very restricted in occurrence can only be found along the border route between km 2.0 and km 2.2, and consist of massive, well-lithified paraconglomeritic beds (Fig. 5). The outcrop is more extensive across the border in Thailand where it forms a karst like ridge (Fig. 6).

The Middle Unit differs greatly from the Lower Unit by their sedimentary features and are also found only along the border route, from km 3.8 to km 4.6. This unit comprises mainly of semi-consolidated boulder, gravel and pebble in sandy to clayey matrix. It displays a rather well bedded feature and vary in thickness from as low as 0.5 meter to tenths of meters thick. The thicker beds are more common and associated in them are the relatively thinner beds which are restricted in their lateral extensions and appear as lenses within the massive beds (Figs. 7 and 8). Being located close to

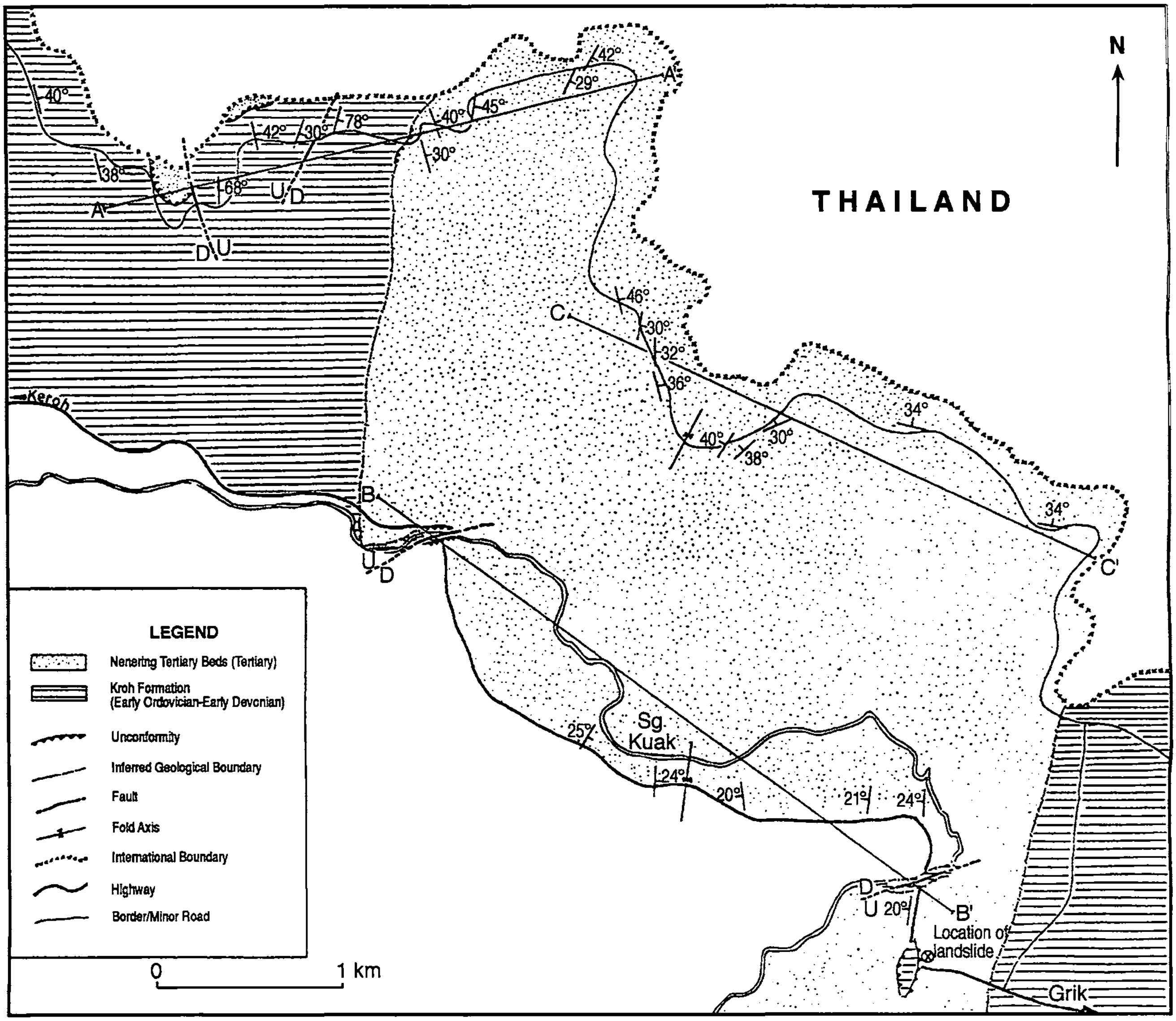

Figure 4. Distribution map of the Nenering Tertiary Beds and the older Kroh Formation.

Table 2. Stratigraphic Column of the Nenering Tertiary Beds.

UNIT	REMARK
The Upper Unit	Braided channel pattern of fluviatile deposits.
	~~ slightly unconformable ~~~~~~~~~~
The Middle Unit	Generally thick stratification of boulder/ gravel beds, pebbly and coarse sandstone deposited above basal unconformity.
	~~ not known nature of contact ~~~~~~~~
The Lower Unit	Well indurated massive conglomeritic deposits

the margin of the sedimentary basin, and lying above the plane of unconformity they possess quite steep dips, the current dip is very likely the result of faulting throughout the study area.

As for the Upper Unit, its occurrence is more extensive compared to the other two units. This unit was observed from km 4.6 along the border route where it lies slightly unconformable above the Middle Unit (Figs. 9 and 10) until approximately at km 11.3. The same unit is also found throughout the road cuts of the Kg. Lalang-Kg. Air Panas highway from km 6 to km 9.6 (from Keroh) where they poised some threat of landslide to road users along the highway (Teh and Sia, 1991). Compared to the Middle Unit, strata of the Upper Unit show gentler dipping beds, and at certain locations the beds are sub-horizontal to nearly horizontal. Generally strata of the Upper Unit along the Kg. Lalang-Kg. Air Panas highway possess steeper dipping beds compared to the strata along the border route. This is due to the two fault planes which occur along the Kg. Lalang-Kg. Air Panas highway approximately at km 6.0 and km 9.0 (from Keroh) where Sg. Kuak cuts across the road (Fig. 4).

STRATIGRAPHIC LOGGING

Several stratigraphic logs were done pertaining to these units, however no logging was possible with the Lower Unit due to its scarcity and limited observable parameters.

The Middle Unit

From the stratigraphic logs, the succession of the Middle Unit was initiated by a thick layer of orthoconglomeritic beds lying above a basal plane of unconformity followed by paraconglomerate. These conglomeritic beds show a bad sorting nature, with a wide range of clast size from a few mm to 0.3 m big boulders (Figs. 11a, 11b and 11c). The well stratified conglomeritic beds possess varieties of sedimentary structures such as cyclical stratification, clast imbrication, pebbles/clast alignment, channelling with channel cut and fill, interfingering beds, cross bedding and some of these directional structures provide useful clues of the ancient paleocurrent regime. The orthoconglomerate and the paraconglomerate beds reoccur several times in the same manner as the succession builds up, and intervening these massive, thick conglomerate layers are the thinner layers of sandstone to pebbly sandstone beds.

The Upper Unit

Due to its extensive occurrence, and most of the time appearing as small and very low relief outcrops along the border route, only one representative stratigraphic log of the Upper Unit was done (Fig. 12). Generally, the Upper Unit is made up of alternating layers of paraconglomeritic, muddy to silty sand and muddy to silty beds. Compared to the Middle Unit, this particular unit was deposited in a relatively low energy and flat lying sedimentary

Figure 5. Photo showing outcrop of the Lower Unit along the border route on the Malaysia side. Location: kilometer 2.2, border route.

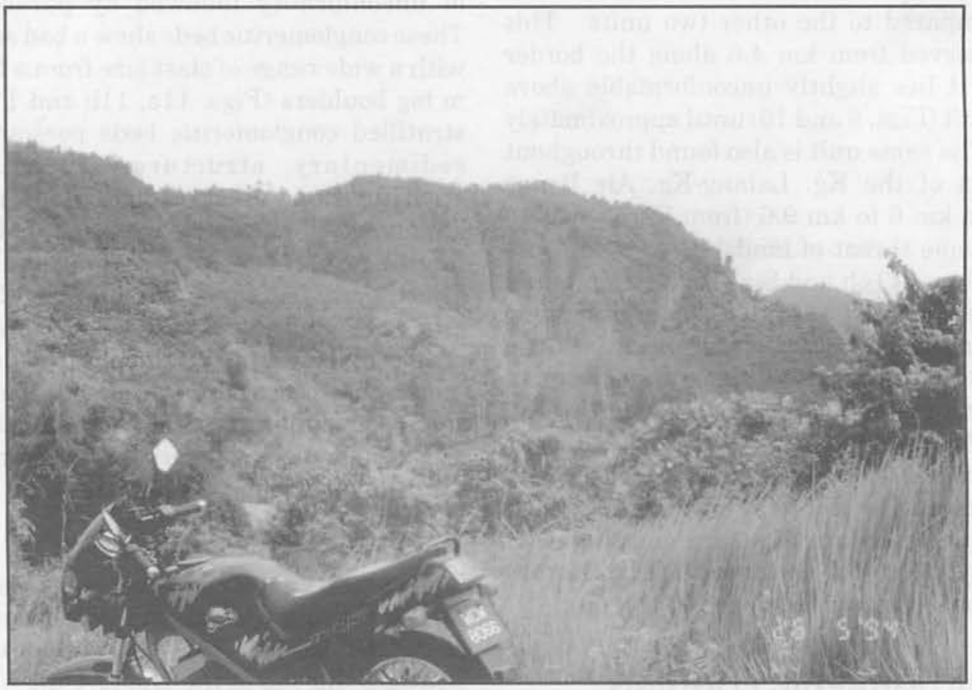

Figure 6. Photo showing the karst-like ridge of the Lower Unit across the border in Thailand. Location: from kilometer 5, border route.

Figure 7. Photo showing outcrop of the Middle Unit lying above angular basal plane of unconformity with weathered material of the Kroh Formation below. Location: kilometer 3.8 border route.

Figure 8. Photo showing the typical appearance of the Middle Unit. Location: kilometer 3.9, border route.

Figure 9. Outcrop showing the beginning of the Upper Unit that lies slightly unconformable above the Middle Unit. Location: kilometer 4.6, border route.

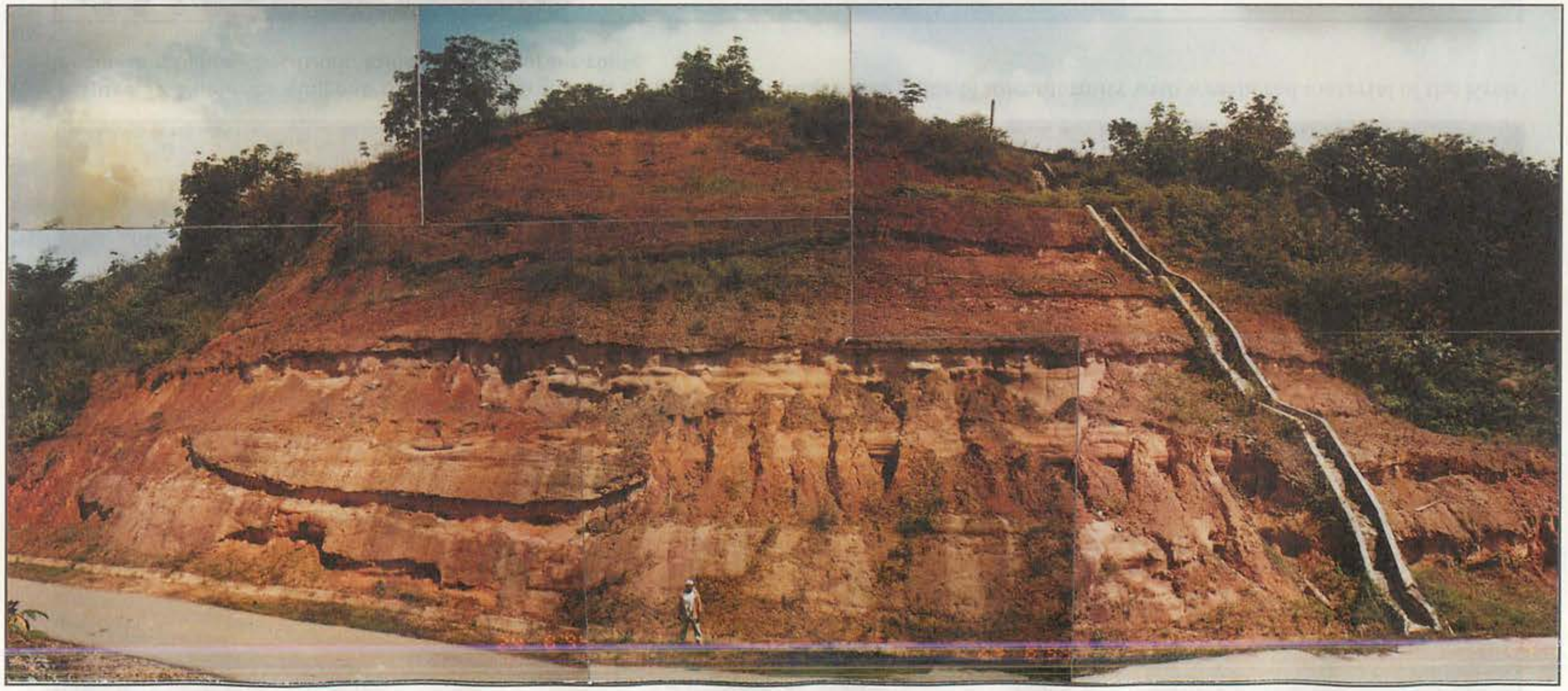

Figure 10. Photo showing the typical appearance outcrop of the Upper Unit. Location: kilometer 8.2, border route.

platform as depicted by its modal sedimentary composition and features, which consists mainly of mud/silt, sand and pebble size sediments, however there is no sharp contact with the Middle Unit as this particular unit was initiated by rather clean sandy beds. The sediments gradually change in composition and appear soil-like as the road (border route) stretches towards the SE. The soil-like appearance is likely to be extended as a result of weathering of the silt and mud rich bed deposits. The prominent feature is the build up sequence of a series of beds, where one stratification unit is initiated by a number channels at the bottom of each bed. These channels are often filled by sand and pebble size components. There are not many sedimentary structures found besides the prominent occurrence of channels, channel cut and fill, whereby the channel beds load are commonly filled by sandy, pebbly to gravely size sediments. However they also provide an important clue in interpretations of the ancient paleocurrent directions.

To conclude from all the data available, from the combination of the Middle Unit and the Upper Unit, the environment of the sedimentation is a large alluvial system that is continental alluvial-fluviatile in nature, this relationship is shown in Figure 13. The development of the stratigraphic succession of the Nenering Tertiary Beds progresses towards SSE direction as evidenced by the overall clast imbrication, channel strike trend and the distribution pattern of the modal sedimentary composition which is dominated by gravel-sand deposits at the NNW end of the basin and gradually dominated by pebble-silt deposits at the SSE end.

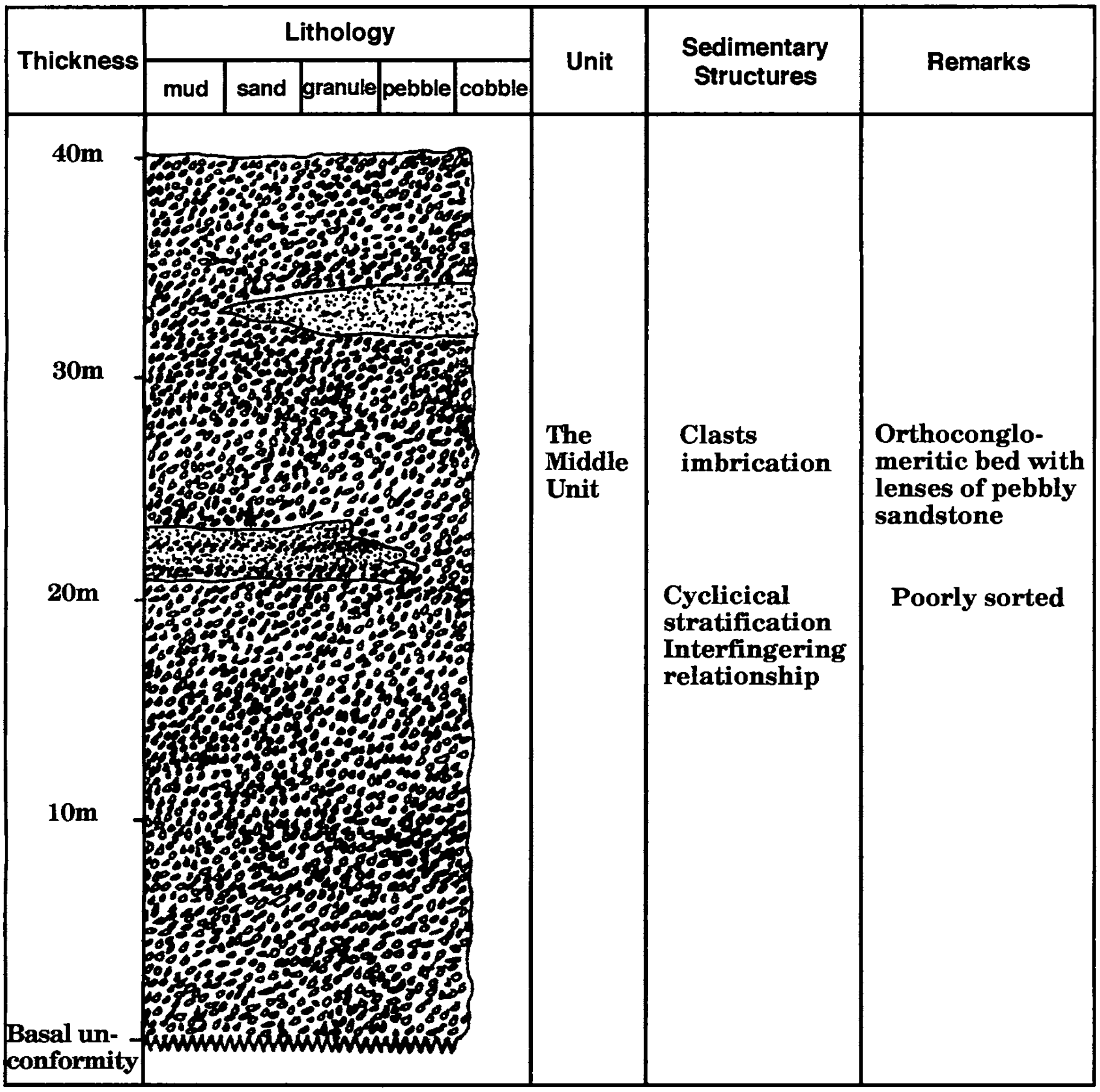

Figure 11a. Stratigraphic log of the Middle Unit of the Nenering Tertiary Beds. Location: kilometer 3.8, border route.

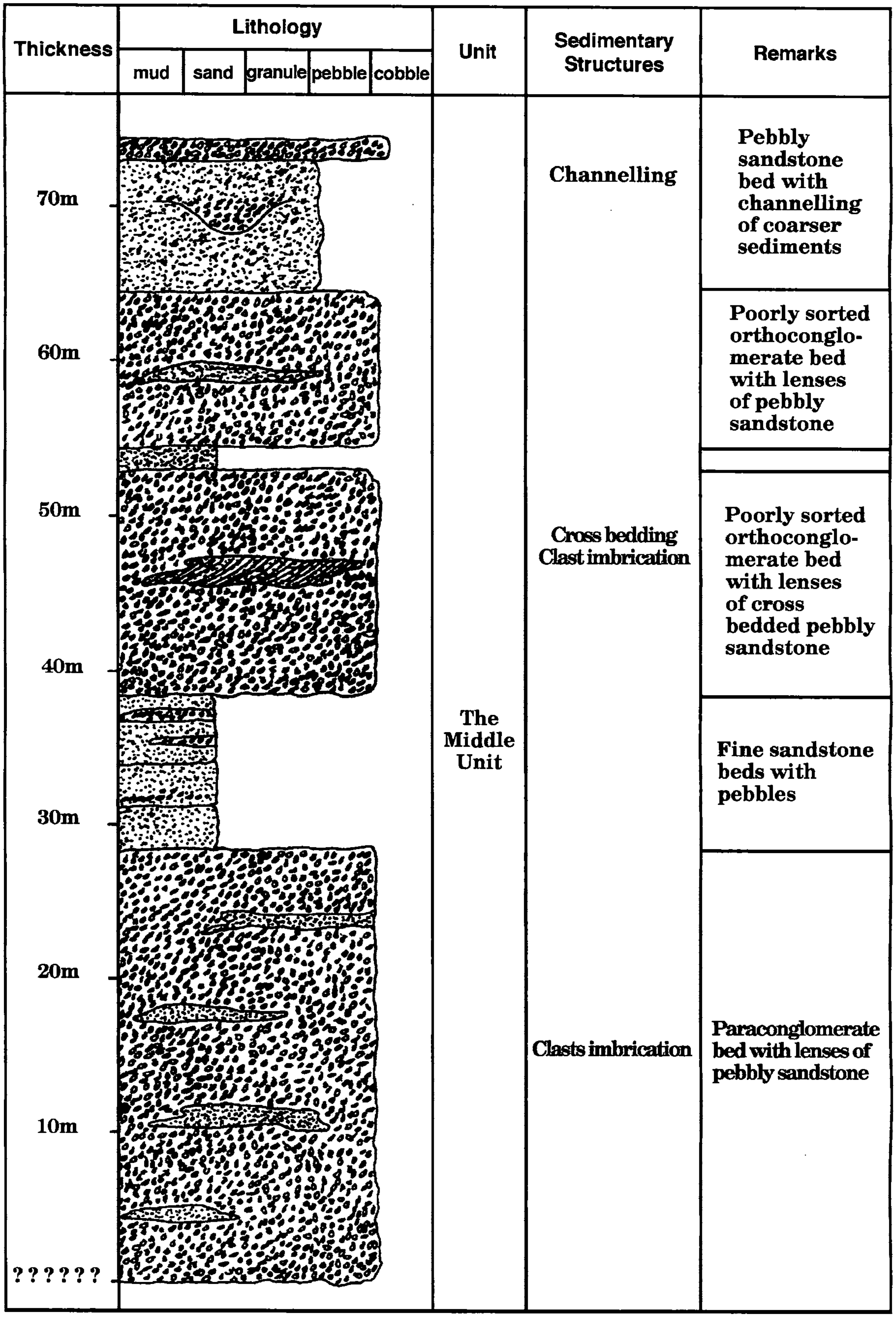

Figure 11b. Stratigraphic log of the Middle Unit of the Nenering Tertiary Beds, continuation of Figure 11a. Location: kilometer 3.9, border route.

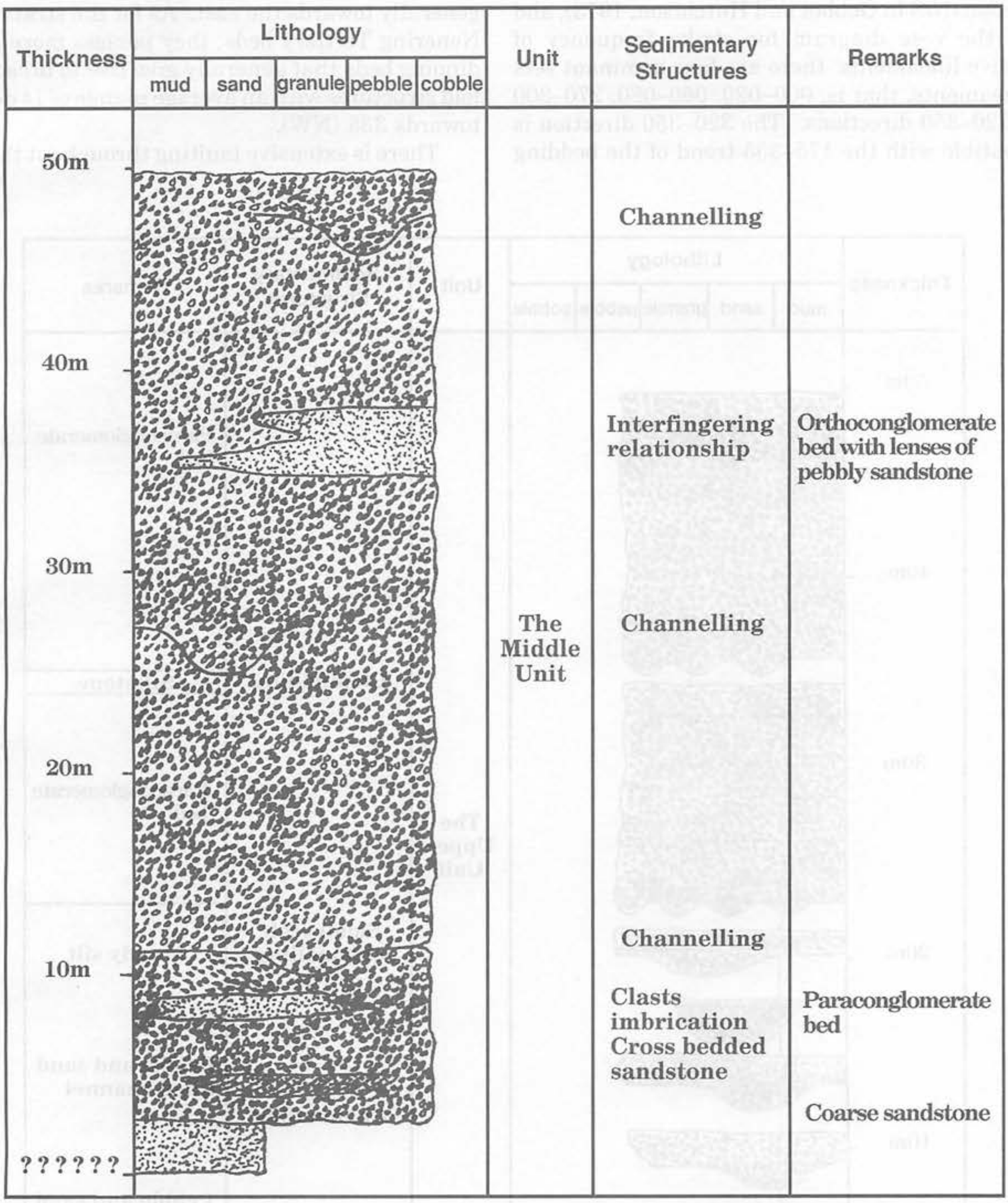

Figure 11c. Stratigraphic log of the Middle Unit of the Nenering Tertiary Beds, continuation of Figure 11b. Location: kilometer 4.0, border route.

STRUCTURAL ELEMENTS

Generally the study area is influenced by a west-east direction tectonic vergence. This is well-marked by the general strike of bedding planes throughout the study area which is in the 355–175 direction (N/S in Gobbet and Hutchison, 1973), and from the rose diagram for strike frequency of negative lineaments, there are four dominant sets of lineaments, that is, 000–020, 060–080, 270–300 and 320–350 directions. The 320–350 direction is compatible with the 175–355 trend of the bedding planes. The basement unit for the younger Nenering Tertiary Beds, that is, the Kroh Formation is extremely folded. Generally, the strata of the Kroh Formation are folded twice with the average plunge of 29 degrees towards 026 (NE), while all the fold structure and strata of the Kroh Formation inclined generally towards the east. As for the strata of the Nenering Tertiary beds, they possess more gently dipping beds that generally give rise to broad open fold structures with an average plunge of 14 degrees towards 335 (NW).

There is extensive faulting throughout the area

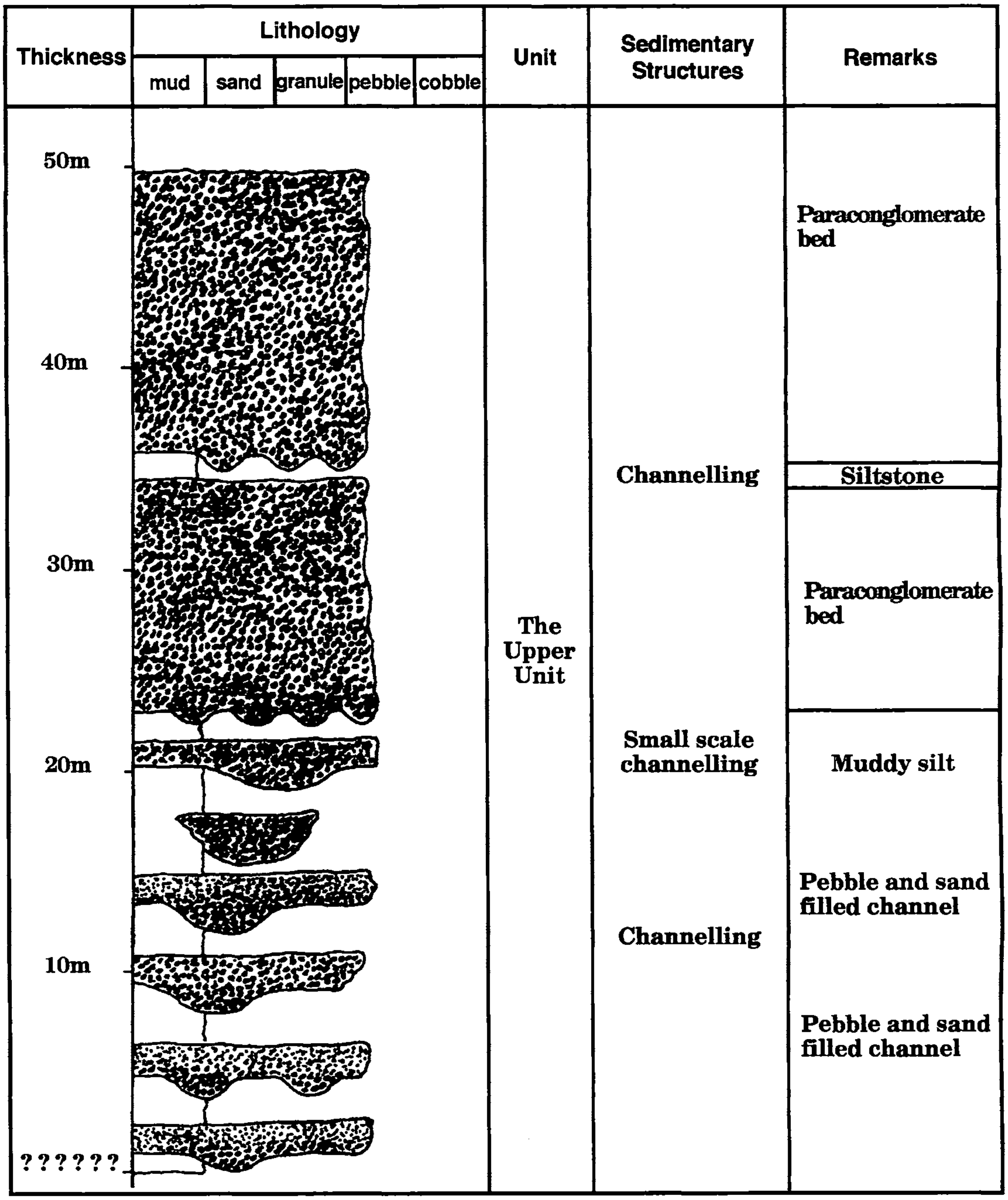

Figure 12. A representative stratigraphic log of the Upper Unit of the Nenering tertiary Beds. Location: kilometer 8.2, border route.

which may have occurred during the Tertiary and the Pre-Tertiary time. These faults may have played a significant role in the initiation of the formation of the sedimentary basin of the Nenering Tertiary Beds. This is evidenced by an occurrence of a fault margin which displays a remarkable example of a multiple faulted rock outcrop (Fig. 14). The petrographic study of rock sample from this particular fault margin revealed at least three periods of displacement (Figs. 15, 16 and 17), whereby the first deformation is ductile faulting resulting in the formation of ultramylonite (Sibson, 1977), followed by two latter brittle faulting resulting in the brecciation of the rock in the particular margin. Such an example of a rock is evidence for a major faulting event throughout the study area. From the orientation of this particular fault plane which is striking in 028/208 (NE/SW) direction, dipping 68 degrees towards the east and in relation with the strike of the unconformity planes that separated the Middle Unit of the Nenering Tertiary Beds and the Kroh Formation (Fig. 4) it is favourable to established a half graben origin for the sedimentary basin of the Nenering Tertiary Beds, (Fig. 13). It is also made possible by taking into consideration the distribution and the elevation of every formation in the study area, whereby the low lying Nenering Tertiary beds is flanked by two higher elevated older formation that is the Kroh Formation at the north-western side and the Kati Formation at the south-eastern side (Fig. 2). This may also serve as an indirect evidence of a full graben origin for the sedimentary basin of the Nenering Tertiary Beds. More recent field excursions in the Pengkalan Hulu area found the same rock sample in the newly excavated slopes along the highway near the Malaysian Customs/ Immigration Complex. Petrographic study of rock sample from the well lithified Lower Unit of the Nenering Tertiary beds, stunningly revealed the presence of clasts similar to the rock sample from the fault margin, which gives evidence that the occurrence of fault throughout the study area commenced far back before the Tertiary time. This is very much in favour supports the idea that the generation of many small isolated inland Tertiary basins are resulted from the reactivation of a pre-existing basement structure. The post-Tertiary faulting event have most likely exposed the primary contact between the Nenering Tertiary Beds and the older Kroh Formation besides broadly folding the former (Fig. 18).

DISCUSSION

There are no significant economic values that can be gained from studying Nenering Tertiary Beds, however they serve as important outcrops in the study of an ancient continental sedimentary basin which provides significant and useful

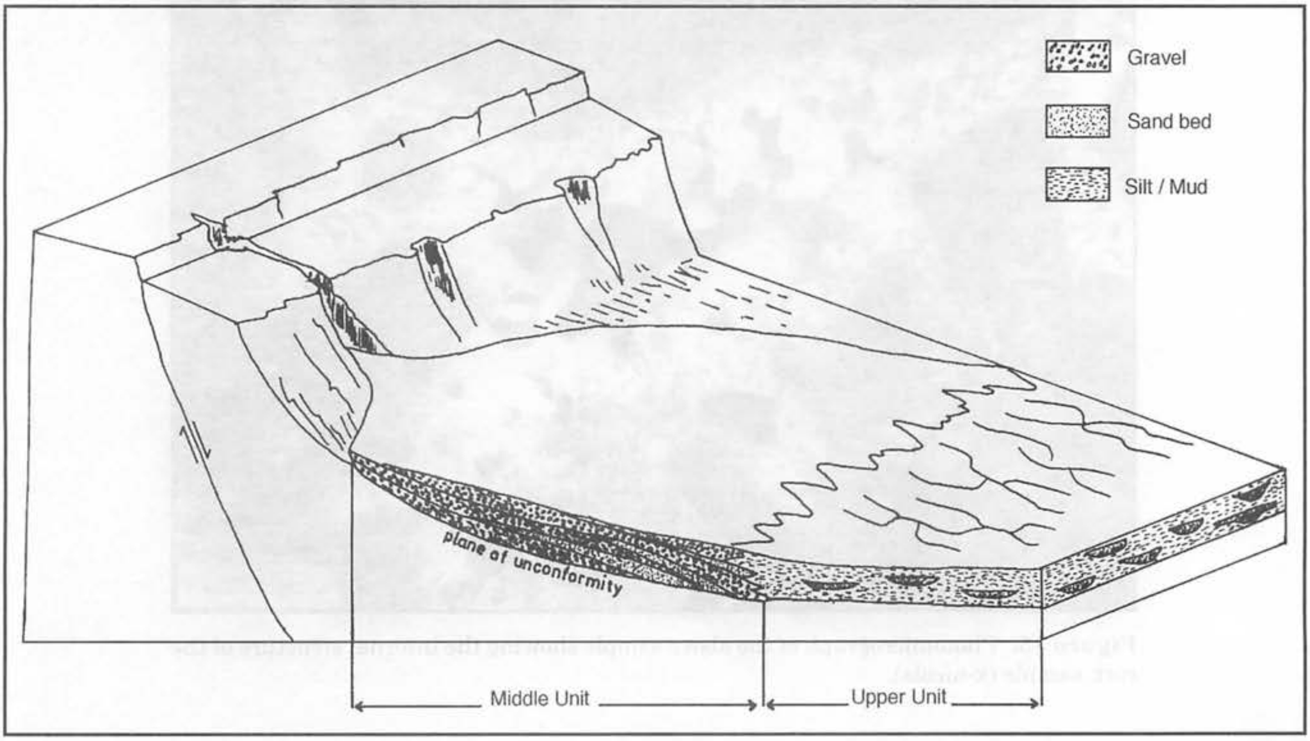

Figure 13. Diagram illustrating the relationship between the Middle unit and the Upper Unit of the Nenering Tertiary beds and the half graben origin of the sedimentary basin.

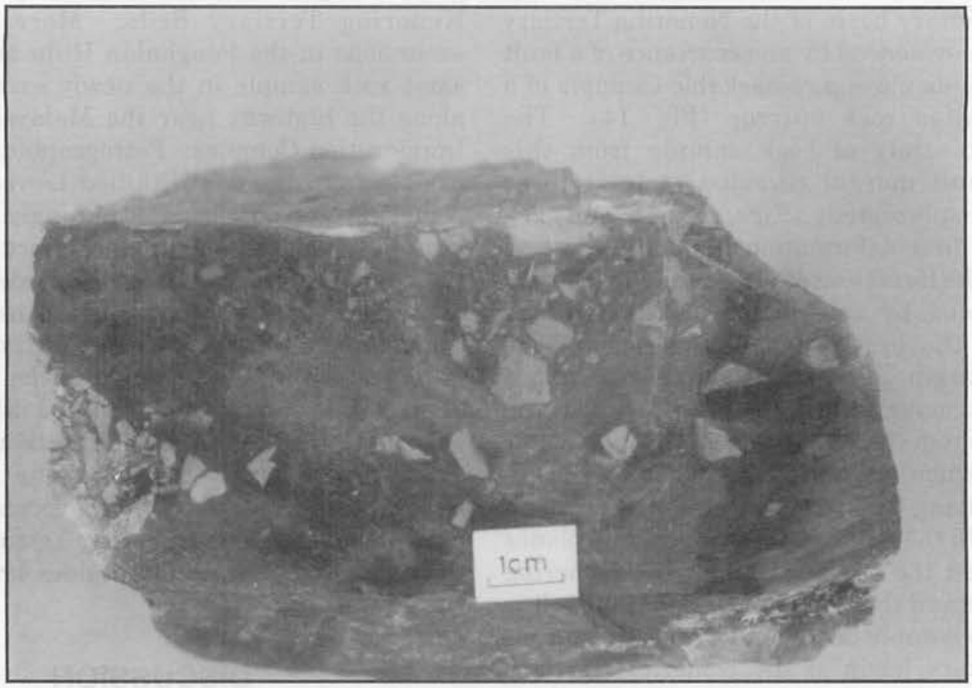

Figure 14. Megascopic sample of the multiple faulted rock taken at kilometer 3.3, border route.

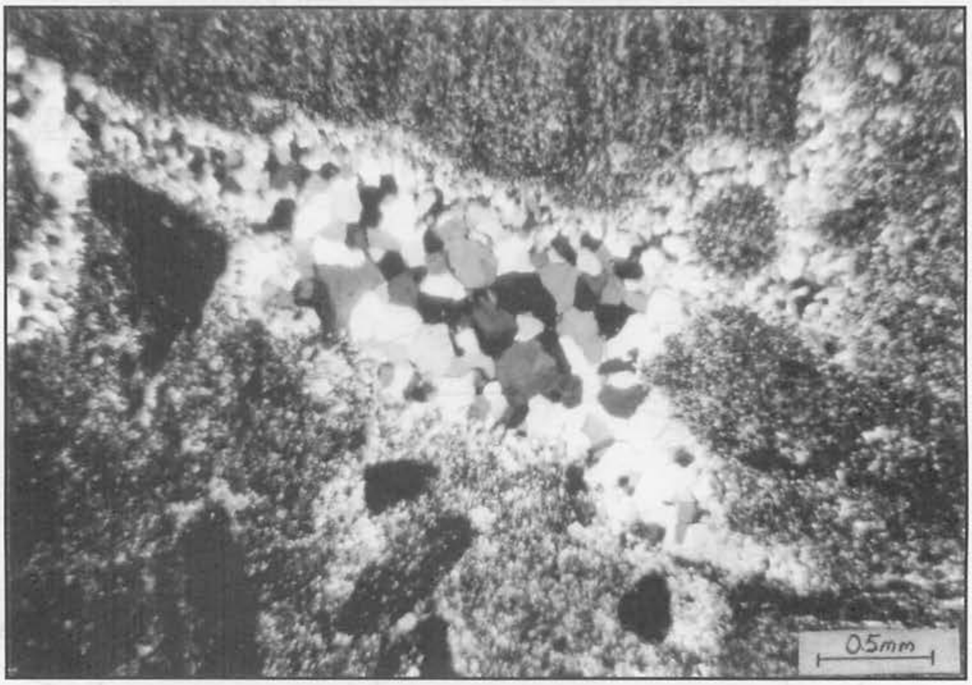

Figure 15. Photomicrograph of the above sample showing the internal structure of the rock sample (x-nicols).

Figure 16. Photomicrograph showing flow texture within the ultramylonite resulting from the first ductile deformation (x-nicols).

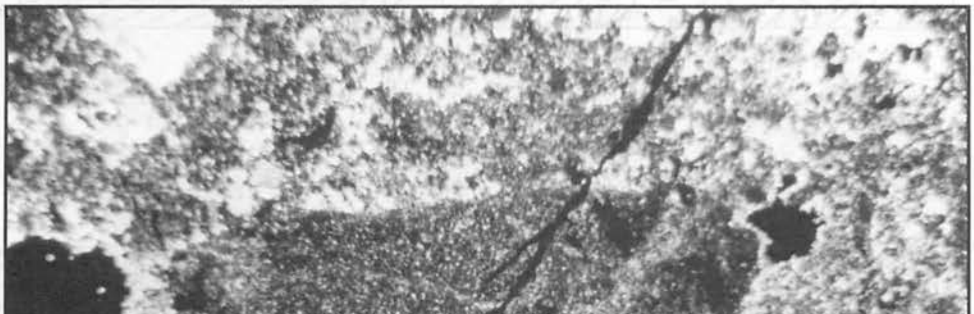

Figure 17. Photomicrograph showing the internal structure that resulted from the brecciation of the rock material during the two later stages of brittle deformation (x-nicols).

information on the paleoenvironment, formation stratigraphy, paleocurrents, the relationship with the older Kroh Formation and many more. Accordingly their spectacular outcrops provide an opportunity for students of geological science to comprehend the subject better. The authors were able to witness a massive landslide that occurred along the Kg. Lalang-Kg. Air Panas highway (Fig. 4) during a recent trip to the area. The massive slides which involved the rather loose pre-weathered and weathered material of the Nenering Tertiary Beds above the underlying Kroh Formation occurred along a pre-existing failure plane, that is, the unconformity plane (Fig. 4). The highly permeable weathered top layer provided a passage for meteoric water to flow through which was then stopped by the highly competent grade I-II limestone of the Calcareous Facies of the Kroh Formation. The excessive accumulation of water at the base of the weathered material along the unconformity plane could no longer withstand the shear stress from the burden above and resulted in the massive slide. A further and more detailed Engineering Geology study along this highway should be carried out for the purpose of academic interest and public safety.

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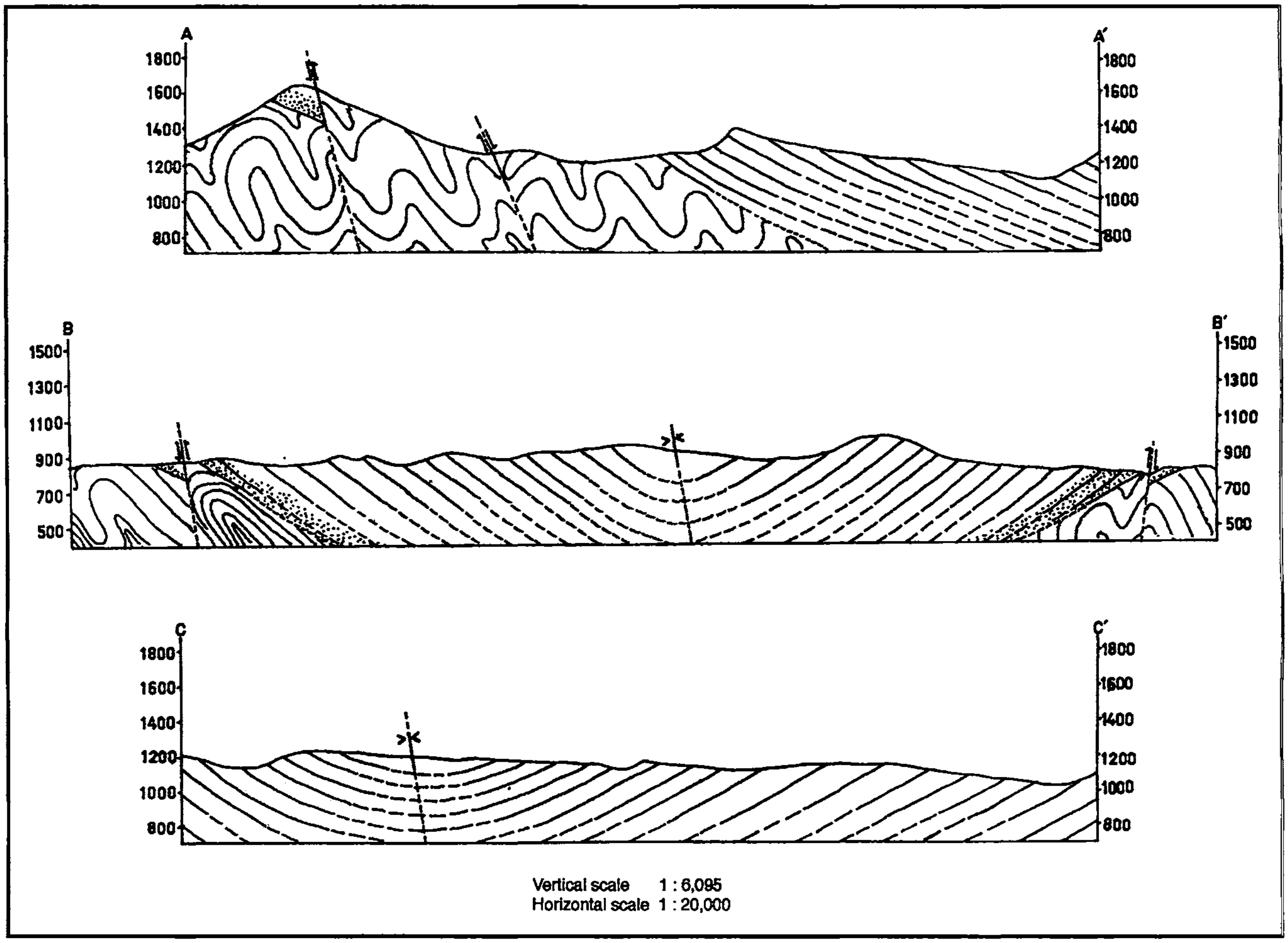

Figure 18. Cross sections through AA', BB' and CC' in Figure 4.

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