

Evidences for syn-depositional tectonism in the Tertiary boulder beds of Batu Arang

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Abstract: Based on a preliminary sedimentological and deformational study, the Tertiary Boulder Beds of Batu Arang can be divided into two distinct sequences — the Red and the Gray Conglomeratic units, separated by an angular unconformity. The Red Conglomeratic Unit was deposited sub-areally, whilst the Gray Unit was deposited in a reducing, subaqueous environment.

Numerous evidences for the interplay between tectonism and sedimentation are found within the Boulder Beds. These includes:

1. the immaturity of the sediments, compositionally and texturally;
2. cyclicity of the fining-upward sequences;
3. the occurrence of the intrabasinal angular unconformity between the Red and the Gray Units;
4. the presence of syn-depositional structures.

These evidences suggest that the Boulder beds were deposited in a fault-controlled basin. The presence of post-depositional strike-slip faults suggest that tectonism out-lasted sedimentation and together with the proximity of the basin to the Kuala Lumpur Fault zone, may suggest that the basin may have developed along a strike-slip fault.

INTRODUCTION

Batu Arang town is located about 50 km north of Kuala Lumpur, in the northwestern part of Selangor (Fig. 1). The Tertiary sediments of Batu Arang occupy a rounded triangular-shaped basin covering an area of about 15 sq km (Stauffer, 1973). The Tertiary Batu Arang Basin has been divided into two stratigraphic units — 'The Coal Measures' and the overlying 'Boulder beds'. These two unit are separated by an angular unconformity (Roe, 1953). The coal measures yield a age of Eocene to Oligocene based on palynomorphs studies (Ahmad Munif, 1993). Since the Boulder Beds is younger than the coal bearing unit, Mahendren (1991) suggested an age ranging from Pliocene to Pleistocene(?) while Intan Suhaila (1998) revised it Miocene to Pleistocene(?). Geophysical studies by Mahendran (1991) revealed a half-graben geometry for the Tertiary Basin as reported by Mahendran *et al.* (1992).

Recent development projects in Batu Arang involving several hill-cuts have exposed thick sequences of the Boulder Beds. A preliminary sedimentological and structural study was undertaken on these new outcrops. This paper describes some characteristic sedimentological and syn-depositional deformational features as well as post-depositional structures observed within the Boulder Beds, and comment on their significance.

THE BOULDER BEDS

The Boulder Beds of Batu Arang unconformably overlies the Coal Measures. Roe (1953) gave a thickness of nearly 1,300 ft for the Boulder Beds, based on measurement of core. This preliminary report is based on investigation carried out on a large hill-cut on the western part of Batu Arang (Fig. 2).

Stratigraphy and sedimentology

The investigated hill-cut exposes about 35.0 m of Boulder Beds. The succession is distinctly divided into two sequence, a lower red unit and an upper gray unit (Figs. 3 and 4). Figure 5 is a representative graphical log of the hill cut modified from Intan Suhaila (1998). The log can be differentiated into three parts — a lower red-unit of 0.5 to 3.0 m of 'apparently-fining-upward-cycles' of clast-supported, petromict orthoconglomerate-pebbly sand-silty sand succession, a middle flat-bedded, gray pebbly-sand layers with basal conglomerate and an upper gray 'fining-upward-cycles' of conglomerate-pebbly sand-silty sand succession.

Red conglomeratic cycles

Red colouration. The red colouration of these cycles are pervasive, indicating that it is depositional or post depositional and not due to weathering. The colouring of these cycles suggest that they have been deposited subareally.

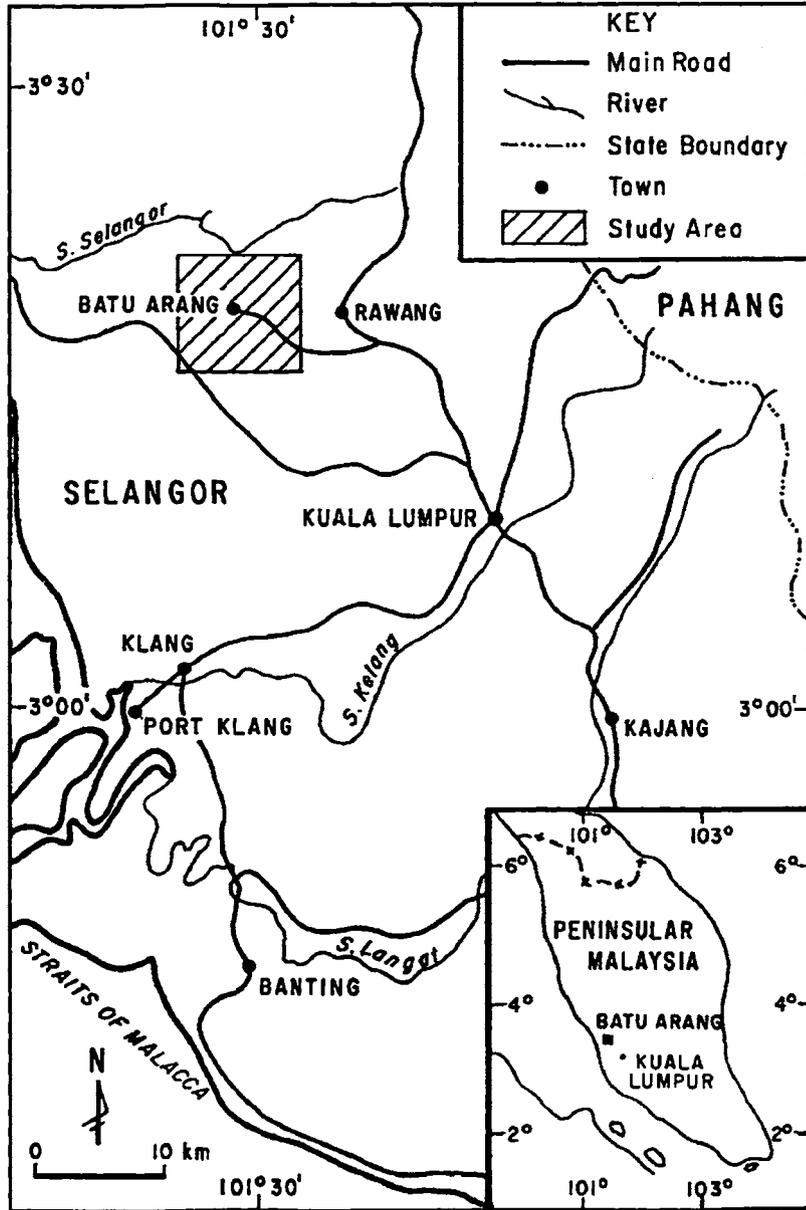


Figure 1. Location map of Batu Arang area in Selangor.

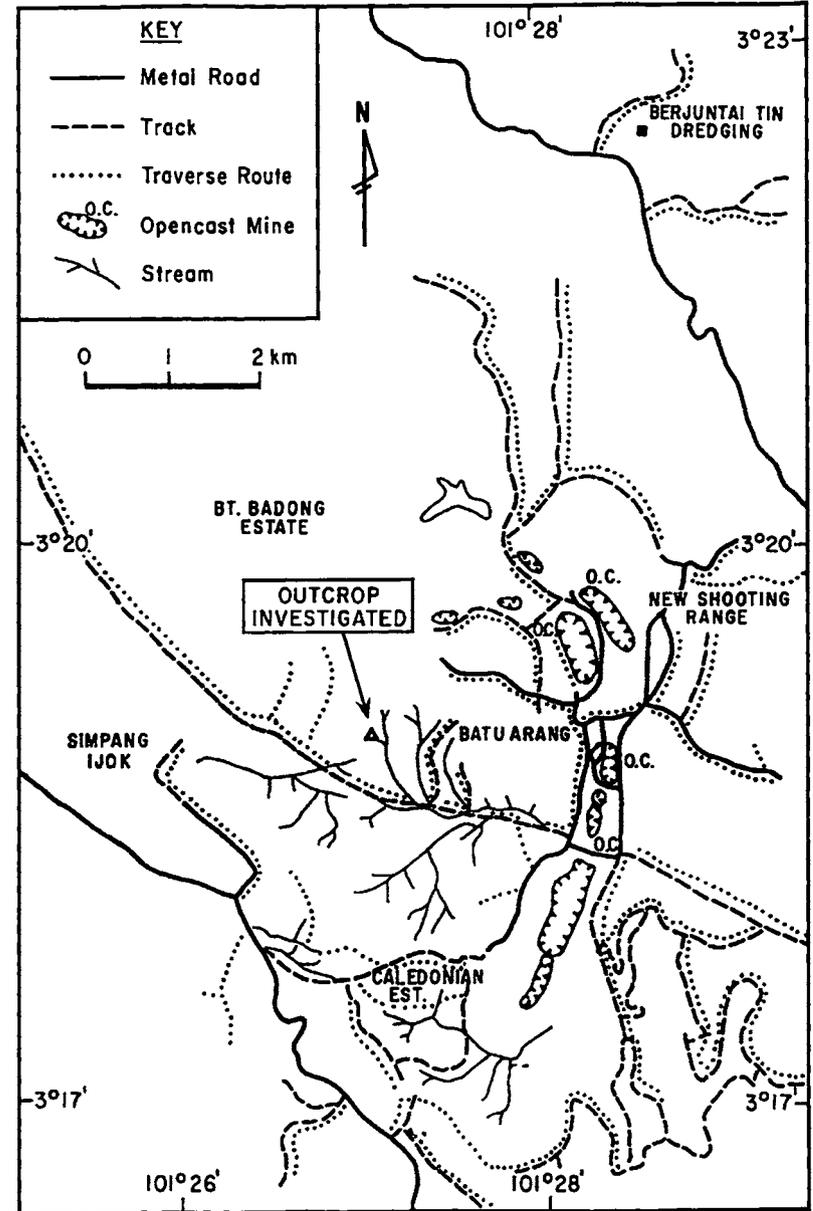


Figure 2. Map of Batu Arang showing the location of the hill cut investigated.

Decreasing thickness of the 'fining-upward-cycles'. These red conglomeratic cycles exhibit marked decrease in thickness up-section (Figs. 3 and 5), until its final termination below the gray, flat-bedded pebbly sandstone unit. This reflect a gradual decrease in the amount of material supplied into the environment, which is mainly a function of the strength of the transporting agent and the availability of debris material in the source area.

Character of the red petromict orthoconglomerate. The basal conglomerate of the cycles are clast-supported, with clasts ranging from pebbles to boulders. However, the dominant clast size is between 10 to 30 cm, and these clasts are subrounded to fairly well rounded with moderate to good sphericity (Fig. 6). Compositionally, the conglomerate is made up of a mixture of quartzite and sandstone, vein quartz, schist and phyllite.

Gradual and diffused boundary between the cycles. Although the 'fining-upward-cycles' can be

fairly easily traced at the outcrop, closer inspection reveal that the surface of contact between the different cycles are not sharp and erosive but gradational and diffused. In places, inverse grading can be clearly seen. This seem to suggest a more gradual fluctuation in the strength of transporting current rather than a catastrophic mechanism.

Gray, flat-bedded pebbly sand

The flat-bedded pebbly sandstone, with uneven lenses of basal conglomerate, unconformably overlies the red conglomeratic unit. The discussion on the unconformity is included in the next section. The deposition of these flat-bedded sandstone indicate a marked change in character of the depositional regime operating within the environment, as well as a change in the type of material supplied into the basin. The gray colouration of these beds, with patches of yellowish stain in places resulting from the weathering of

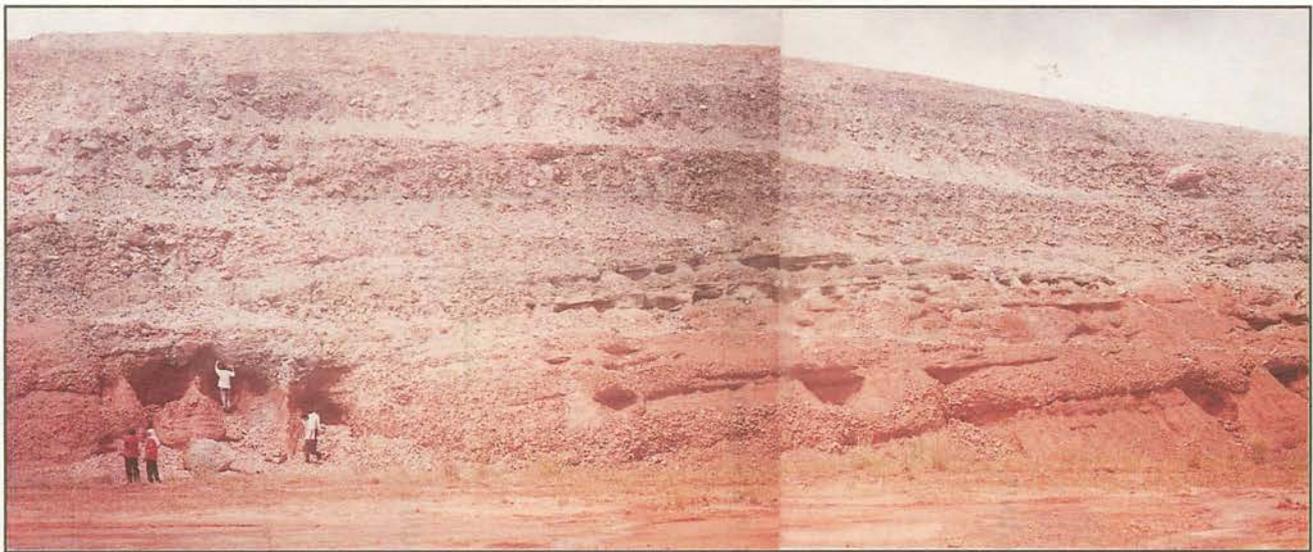


Figure 3. A photograph of the hill-cut, distinctly showing the lower Red Unit and upper Gray Unit.

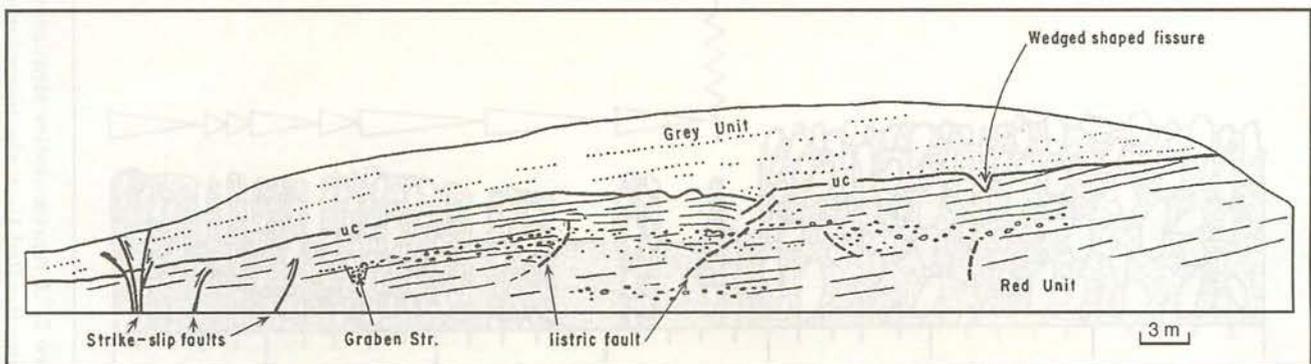


Figure 4. A generalised field sketch of the Boulder Bed outcrop showing the Red Unit, the Gray Unit and the various deformational features.

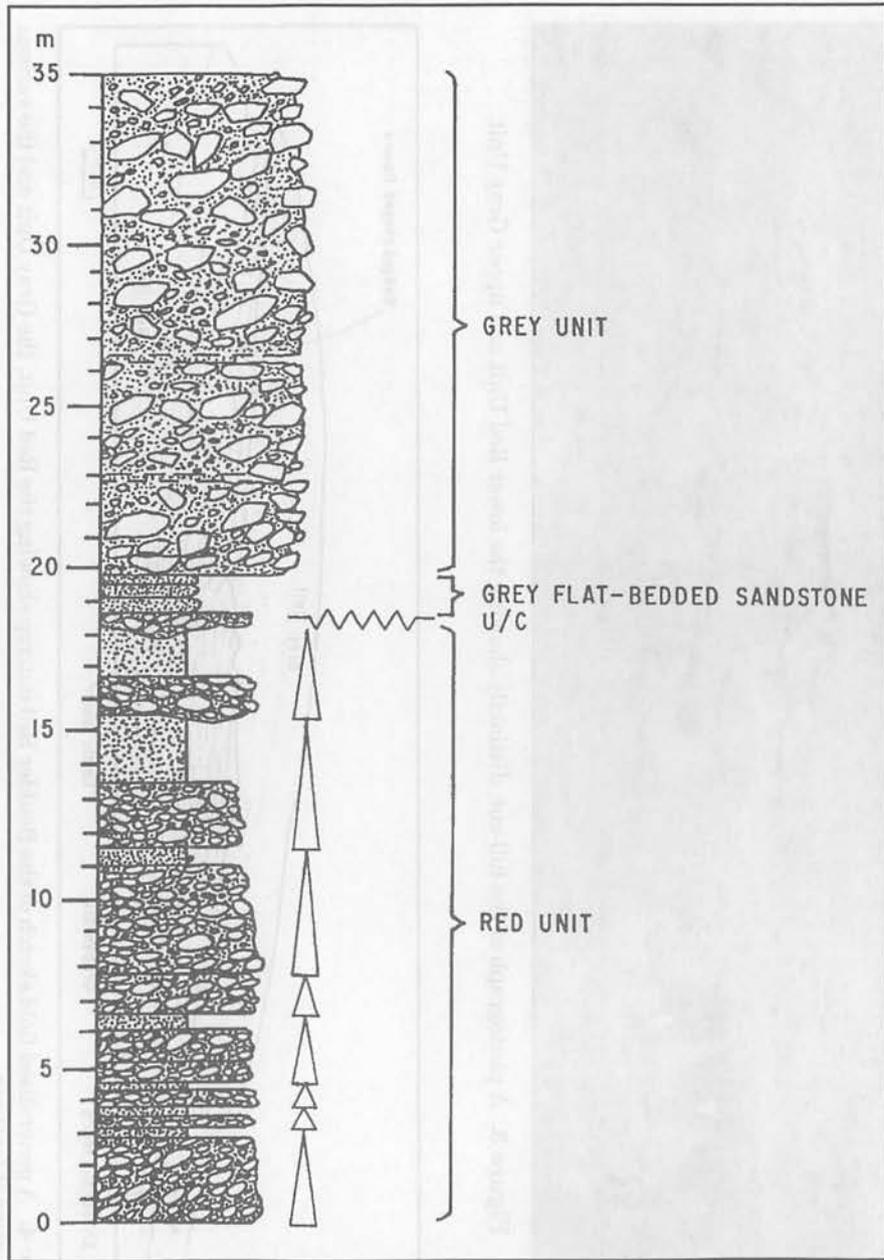


Figure 5. A representative stratigraphic log of the Boulder Bed at the hill-cut, showing the Red Unit, the unconformity, the flat-bedded pebbly sand and the Gray Unit (partly modified from Intan Suhaila, 1998).



Figure 6. Photograph showing the fairly well-sorted petromict orthoconglomerate belonging to the Red Unit.

pyrite, indicate that deposition occurred subaqueously in a reduced environment. This indicate that during this period, which succeed the period of subareal deposition of the red conglomerate, some kind of flooding of the basin has occurred.

Evidences for unconformity

1. Discordance in attitude of the grey and red units — the upper gray unit displayed a lower angle dip than the underlying red unit (Fig. 4);
2. Truncation of the underlying red unit below the base of the overlying gray unit. This truncation zone is marked by distinct grain/clast size and colour change. The top of the red unit here is silty sand while the base of the gray unit is conglomeratic (Fig. 7a, b);
3. The boundary between the lower red unit and the upper gray unit is marked by a distinct erosional surface as seen by the irregular and sharp contact between the two unit (Fig. 7);
4. The underlying red layers show wavy or undulating beds and warping, while the upper gray layers are almost flat bedded (Fig. 8);
5. The differences in lithology and texture of the sediments below and above the erosional surface contact indicate a distinct change in the environment of deposition. The ferrigenous red colouration of the lower unit indicate subaerial oxidation, whereas the gray colouration, with yellowish stain, indicate a subaqueous, reducing environment.

Gray conglomeratic cycles

This upper unit of gray conglomeratic cycles characteristically exhibit 'paraconglomeratic texture' (Figs. 5 and 9). However, closer inspection reveal that they are clast-supported but contains a lot of outsize, angular and elongated, clasts. Compositionally, these petromict orthoconglomerate, comprising a mixture of quartzite, chert, vein quartz, polymict conglomerate and phyllite (Intan Suhaila, 1998). The unit show similar fining-upward cycles, with cycle thickness decreasing upward.

The differences in texture and clast mineralogy reflect a different provenancial and depositional regime for this unit in comparison to the lower red unit. The abundance of angular and outsize quartzitic clasts indicate the availability and proximality of the source area.

Deformational features

A. Syn-depositional structures

The syn-depositional structures are listric faults, conjugate faults and wedge-shaped tensional

fissures. These structures are found either at the unconformable surface between the red and gray units or very close to it.

i. Listric faults

The traces of these faults are spoon-shaped and exhibit normal displacements. They are characterized by an abrupt variation in facies and thickness across the faults in a single stratigraphic horizon (Fig. 10). The hanging-wall block strata are commonly tilted towards the fault forming a roll-over anticlinal structure. The space between the tilted beds and the fault trace are commonly filled by coarser channel-filled sediments forming a distinctive wedge-shaped body. The beds on the hanging wall block may also show warping as a result of drag along the fault. Vertically, these faults commonly terminated beneath horizontally-bedded undeformed horizons.

ii. Conjugate normal faults

Figure 11 (a, b) shows an example of a conjugate normal fault. The 'graben' portion of the fault exhibit thicker sediments than their lateral equivalent on the upthrown side, suggesting that the faulting occur during sedimentation.

iii. Wedge-shaped tensional fissures

A distinct wedge-shaped tension fissures occur at the base of the gray unit, along the unconformity surface as shown in Figure 12. The fissure surface occur entirely within the red unit and terminated below the base of the gray unit but the open fissure had been filled well stratified gray unit. The well-bedded nature of the infilling suggest that the fissure are syn-depositional features.

B. Post-depositional structures

A 4 m wide fault zone is exposed at the southern end of the outcrop (Fig. 13). The fault zone consist of a network of faults trending NNE to EW. On the plane of the outcrop face, these faults show both normal and reverse separation, with variable magnitude and sense of separation for different horizons offset by the same fault. The zone is also characterised by upward diverging and rejoining splays.

Along individual faults, the fault trace are marked by up to 5 cm wide shear zone characterised by a well developed foliation oblique to the fault zone, asymmetric and rotated deformed clasts and asymmetric shear bands (Fig. 14).

Based on these features, it is determined that the NNE trending faults exhibit sinistral sense of movement while the E-W trending faults are dextral faults.



Figure 7a. Photograph showing the distinct erosional surface of contact between the lower Red Unit and the upper Gray Unit.

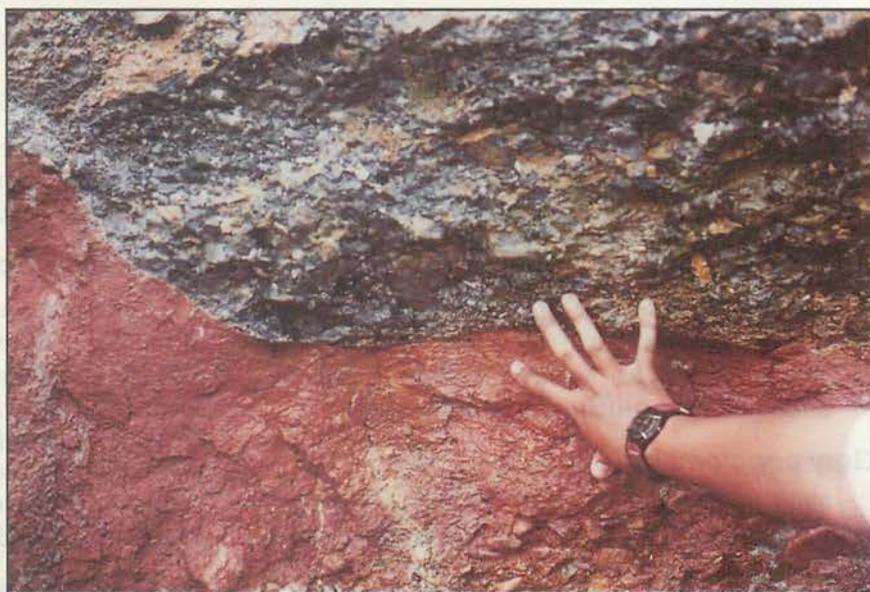


Figure 7b. Close-up view of the unconformity — the erosional boundary. The lower Red Unit of silty sand is unconformably overlain by the basal conglomerate of the pebbly sand layer of the Gray Unit.



Figure 8. The lower red layers show wavy or undulating beds, while the upper gray beds are almost flat bedded.



Figure 9a. The 'paraconglomeratic texture' of the basal conglomerate of the fining-upward cycles of the Gray Unit.



Figure 9b. Close-up view of an outside, angular and elongated clast of the Gray Unit.

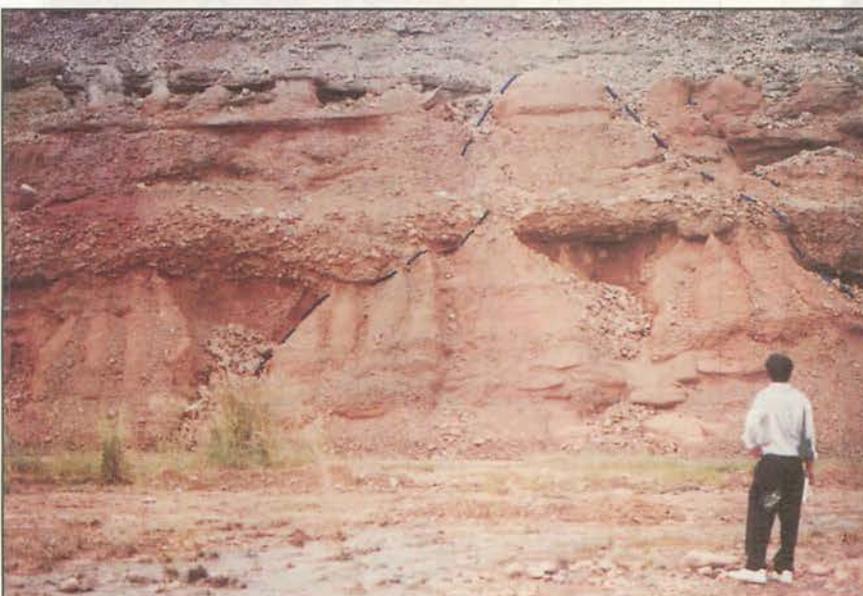


Figure 10. Syn-depositional faults. Note the variable thickness across the fault along the same horizon, the warping of layering in the hanging wall block and the abrupt truncation below the flat-bedded strata.



Figure 11a. A syn-depositional graben structure. Note the discontinuous nature of the layering and the variable thickness along the same horizon across the fault.



Figure 12. A wedge-shaped syn-depositional tensional fissure filled with well-bedded sediments of the overlying horizons. Note also the conjugate normal faults within the stratified wedge fillings.

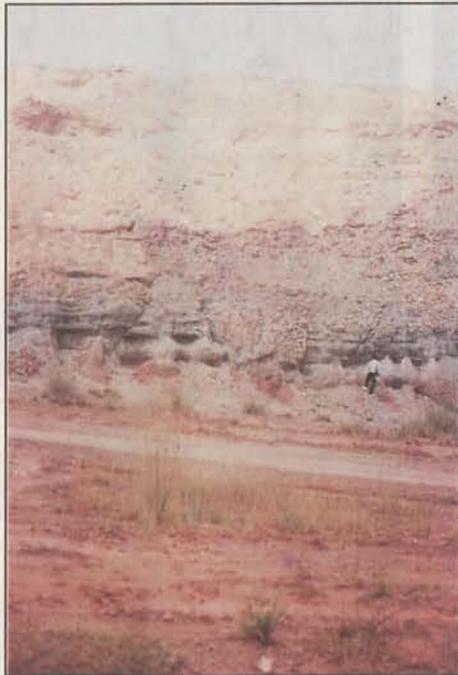


Figure 11b. Another syn-depositional graben structure infilled with overlying materials. Note the termination of the faults beneath undeformed strata.



Figure 13. A strike-slip fault zone exhibiting positive flower structure geometry. Note the diverging upward splays and the variable sense of displacements.

INTERPRETATION

1. Immature petromict orthoconglomerate

These are the coarse-grained equivalents of lithic and arkosic sandstones (Pettijohn, 1975). These are basin-margin accumulation of gravels, brought down rapidly from sharply elevated source terrane. The high relief of the source area could have been brought about by uplift along basin margin fault/fault zone. Deposition within this basin is primarily a function of the local tectonic regime. Tectonism has created basin margin fault, and large vertical offset result in a significant topographic relief of the source area.

2. Cyclicity of sedimentation

Two orders of cyclicity can be recognised in the Boulder beds.

i. First-order cyclicity

The first-order cyclicity is represented by the thinning-upward red and gray cycles. The minimum thickness of these cycles are around 30 m, but no

complete first-order cycles are exposed in the field. These are primarily tectonically-controlled cycles, governed by the movements of the basin margin faulting. The presence of the unconformity indicate that at least two major movements have occurred during the deposition of the Boulder Beds.

ii. Second-order cycles

These are the 0.5 to 3.0 m, 'fining-upward cycles' of both the red and gray units. The repetition of the fining-upward pattern in both sequence imply initial deposition in a high energy regime followed gradually by lower energy regime. The diffused and gradational boundaries between these cycles indicate that the high energy-low energy deposition is repeated, without any break in sedimentation. This further imply that tectonic activity followed by quiescence followed by erosional lowering of the source area was repeated several times. Seasonal climatic fluctuations must have also played important role in the deposition of these cycles. These are possibly tectonically- and climatically-driven cycles.

iii. Local intrabasinal unconformity

The presence of a local, intrabasinal angular unconformity within the Boulder Beds separating the red and gray units is a possible indicator that syndepositional tectonism has occurred. The presence on an angular unconformity can be attributed to the abrupt subsidence or sinking of the basin floor. This abrupt subsidence could explain the difference in facies characteristics between the red and gray unit. The red being deposited within a subareal environment undergo a sudden subsidence that resulted in the tilting of the beds. This events deepened the depositional environment which were later flooded. The gray unit was later deposited subaqueously, in a reducing environment unconformably over the drowned and eroded red unit. This interpretation would be attractive if similar unconformity could be found at the same horizon at several adjacent outcrops.

iv. Syndepositional deformational structures

Some deformation structures have clearly formed in a post-depositional stage, which means that the deformational process was not directly related to the process of sedimentation. The majority of the structures, however, apparently formed during deposition, and as a result of continuing depositional process, should be considered penecontemporaneous. The non-existence and the termination of these structures beneath relatively undeformed horizons and the difference in thickness and facies across these faults



Figure 14. An example of a shear zone along each fault following well developed foliation and rotated clasts.

along the same horizon suggest that tectonic activities in the basin has influenced both the sedimentary pattern and the deformational process.

v. Post-depositional structures

The post-depositional faults are characterized by a network of upward diverging and rejoining splays that show both normal and reversed separation. The fault plane is marked by a highly sheared zone giving indicators of sinistral sense of slip, suggesting that the fault zone is a positive flower structure developed in a sinistral strike-slip regime.

CONCLUSION

The deformation history of the Boulder Beds had already begun at a metadepositional stage (i.e. penecontemporaneously s.s.) and continued post-depositionally, both during the deposition of the younger layers of the same unit and later.

The depositional basin of the Boulder Beds was repeatedly affected by tectonic activity alternating with quieter periods. Differences in tectonic activity also played a role in the resulting changes of the sedimentary pattern. The most obvious consequence were rapid vertical facies transition between subareally deposited sediment and sub-aqueously deposited facies culminating in the occurrence of a local angular unconformity between the two units.

Earthquakes or in general tectonic activity may have been common and possibly served as a trigger for the development of syn-depositional structures. Therefore, endogenic activity in general must be considered to be responsible for most of the deformational structures within the Boulder Beds. Consequently the occurrences of these tectonic activity could suggest that the Batu Arang Tertiary Basin or at least the Boulder Beds could have been deposited in a graben or half graben structure as

modelled geophysically by Mahendran and Mahendran *et al.* The presence of faults with distinct shear zone suggest that the tectonism outlasted sedimentation. This imply that the quaternary geology of Peninsular Malaysia may not be as stable as popularly believed.

The Batu Arang Basin is situated tangential to the Kuala Lumpur strike-slip fault zone. This proximity to the major fault zone supports the interpretation that tectonism played a significant role in the development of Batu Arang Tertiary Basin. It is probably a strike-slip controlled basin.

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