Geol. Soc. Malaysia, Bulletin 15, December 1982; pp. 19–30

Stratigraphy and sedimentology of Middle Triassic rocks exposed near Lanchang, Pahang, Peninsular Malaysia

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Abstract: Middle Triassic (Ladinian) sediments (dated by bivalves and ammonites) in a recently exposed section of the Semantan Formation near Lanchang consist of interbedded dominant dark grey mudstone and subordinate coarse and fine quartz-bearing tuff.

Normal graded bedding in tuffs, some of which exceed 1m in thickness, and the presence of outsize tabular mudstone clasts in some tuffs which show erosive bases, indicate deposition by turbidity currents and high energy mass flows. Small-scale cross bedding, overturned load structures and flame structures in silty mudstones indicate an original westward or southwestward down-flow direction. The dark mudstones, which contain transported neritic bivalves, indicate deposition in a 'black shale' environment at a moderate or great water depth. All the coarse and much of the fine materials in the sediments are of volcanic origin, and the site of deposition is interpreted as being located on the western or southwestern flank of a Triassic volcanic island or island chain.

INTRODUCTION

A few years ago a new and rather extensive artificial cutting in the Triassic stratified rocks of west-central Pahang (Fig. 1) was brought to our attention. Just over one hundred meters long and oriented approximately at right angles to the strike of the beds, this cutting exposed more than 65 m of stratigraphic section (Fig. 2). It formed the back wall of a large excavated and levelled building site on the north side of the Kuala Lumpur–Kuantan highway, 4.3 km (2.7 miles) east of the turnoff to Kampong Bungsu and about 10 km (6 miles) east of Lanchang (see Fig. 1), and is located at grid reference 188234 on the 1:63360 topographic map of Sheet 88 (Temerloh and Mentakab) published by the Directorate of National Mapping Malaysia in 1966.

The section was studied by the authors and by the Third Year class in stratigraphy from the University of Malaya during September and October, 1978. Since then the cutting has suffered considerable erosion and partial destruction by earth-moving machines, and the site in front of it is now occupied by a large brick factory (Golden Bricks Sdn. Bhd., with offices in Mentakab).

The rocks exposed in the cutting are part of a stratified marine sequence of Triassic age mapped as Kerdau Formation by Burton (1973) but subsequently included in the Semantan Formation of Jaafar (1976). Jaafar gives the age of the Semantan Formation, based mainly on the study of bivalves, as Middle (Anisian) to Upper (Norian, possibly Rhaetian) Triassic.

The exposure which is the subject of this paper was also included in a B.Sc. (Hons.) thesis (Lum, 1976), where it is noted as a fossil locality but not separately described.

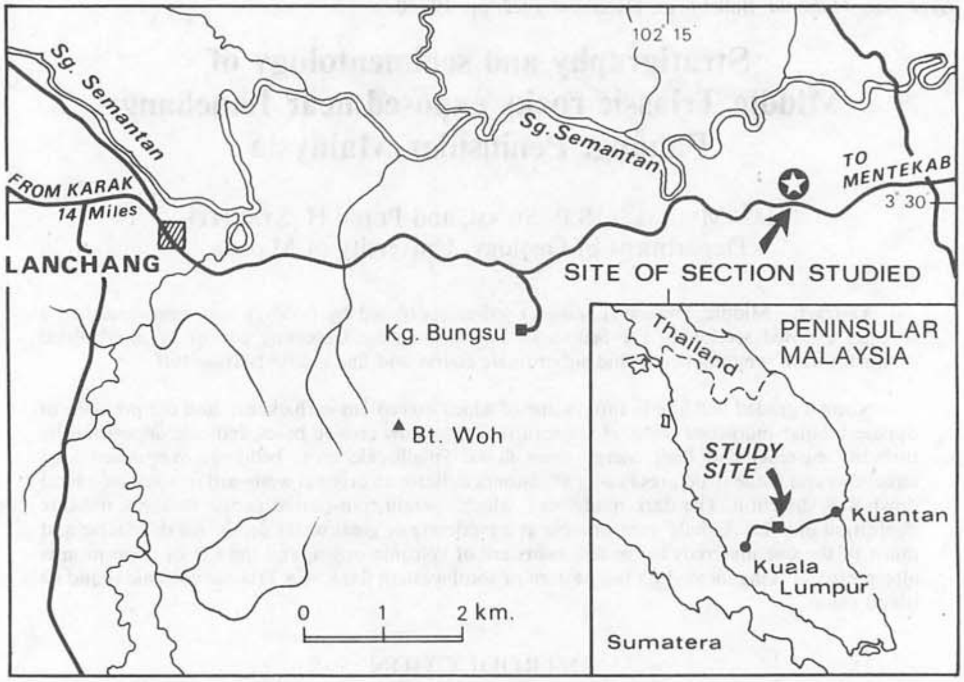


Fig. 1. Index map of part of central Pahang, showing location of section studied.

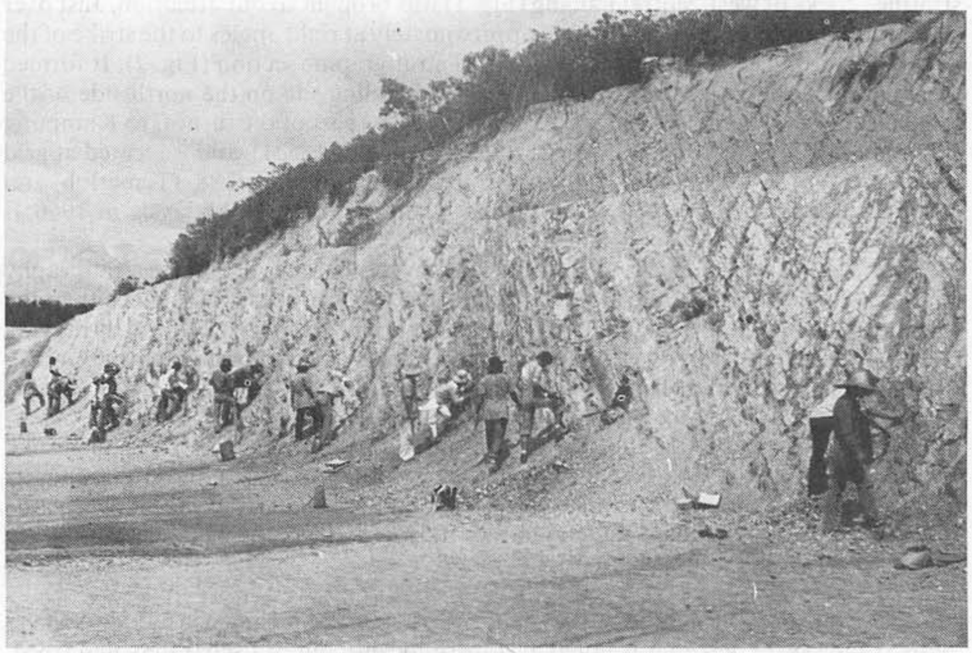


Fig. 2. The section near Lanchang being examined by the Third Year stratigraphy class, University of Malaya. View looking northwest. Bedding dips to right.

STRATIGRAPHY AND LITHOLOGY

The cutting is oriented with a trend of 80°, nearly at right angles to the strike of the beds, which have throughout its length a fairly constant strike and dip of approximately 330°/40°E. The section exposed measures 65.4 m of stratigraphic thickness and is an interbedded sequence of the following three rock types (see Fig. 3).

Coarse tuff: Deeply weathered rock now largely altered to clay but still showing a fragmental texture. Blocky to irregular white phenoclasts, mostly 1–5 mm in size, but sometimes up to 1 cm or more are inferred to represent original feldspars and pumice fragments. These are set in a finer-grained light grey matrix including smaller white grains, dark grains, and grey fine-grained matter. Disaggregation and wet-sieving of a specimen of such rock yielded 31% by weight of material coarser than 62.5 μm, consisting of (1) grains of volcanic quartz (extremely clear and inclusion-free and sometimes showing bipyramidal habit), (2) grains of weathered feldspar (coherent, blocky aggregates of white to yellowish clay), and mainly (3) grey to yellowish aggregate grains, most of which probably represent cemented matrix in the tuff, but a few of which may represent altered pumice or lithic volcanic fragments. Small flaky masses of waxy yellowish material in the aggregates (rarely as separate grains) may be zeolites. No trace of non-volcanic terrigenous debris was seen.

Many beds of coarse tuff contain large (up to 150 cm long) dominantly tabular outside clasts of dark grey mudstone similar to the interbedded mudstone.

Finer-grained tuff: Deeply weathered rock now largely clay but showing a fragmental texture. Similar to the coarse tuff, but containing virtually no particles coarser than sand size (2 mm). A few beds contain tabular outsize mudstone clasts.

Mudstone: Soft silty clay rock, grey to dark grey, commonly showing good lamination, with frequent very thin interbeds of fine-grained tuff. In the lowest part of the section, the mudstone shows traces of a metamorphic cleavage, which has become invisible elsewhere because of the advanced state of weathering. Some mudstone beds show thin layers rich in dark ovoid pellets, 1–2 mm across and up to 1 cm long. A sample of the mudstone which has disaggregated and wet-sieved yielded only 1% by weight of material coarser than 62.5 μm, consisting of (1) small grains of volcanic quartz (clear and sometimes bipyramidal), (2) small clusters of euhedrally terminated authigenic smoky quartz, (3) numerous small bladed or rod-like purplish to reddish cemented aggregates of quartz silt possibly representing organic burrow fillings or faecal casts, and (4) numerous grey to yellowish aggregate grains (up to 5 mm) consisting largely of silt-size quartz, some of which may represent altered pumice fragments, but most of which are possibly fragments of burrow fillings or even just local iron-oxide cementations of the silty mudstone.

Fossil bivalves are found abundantly at many horizons within the mudstone, and ammonites occur more rarely. Unidentifiable plant fragments, now reduced to carbon films, are also commonly found in the mudstone (see Fig. 3).

In the 65.4 m of total section measured, 21 beds of coarse tuff aggregating 15.9 m (24.3% of the total thickness) were observed, giving an average thickness of 75.8 cm for

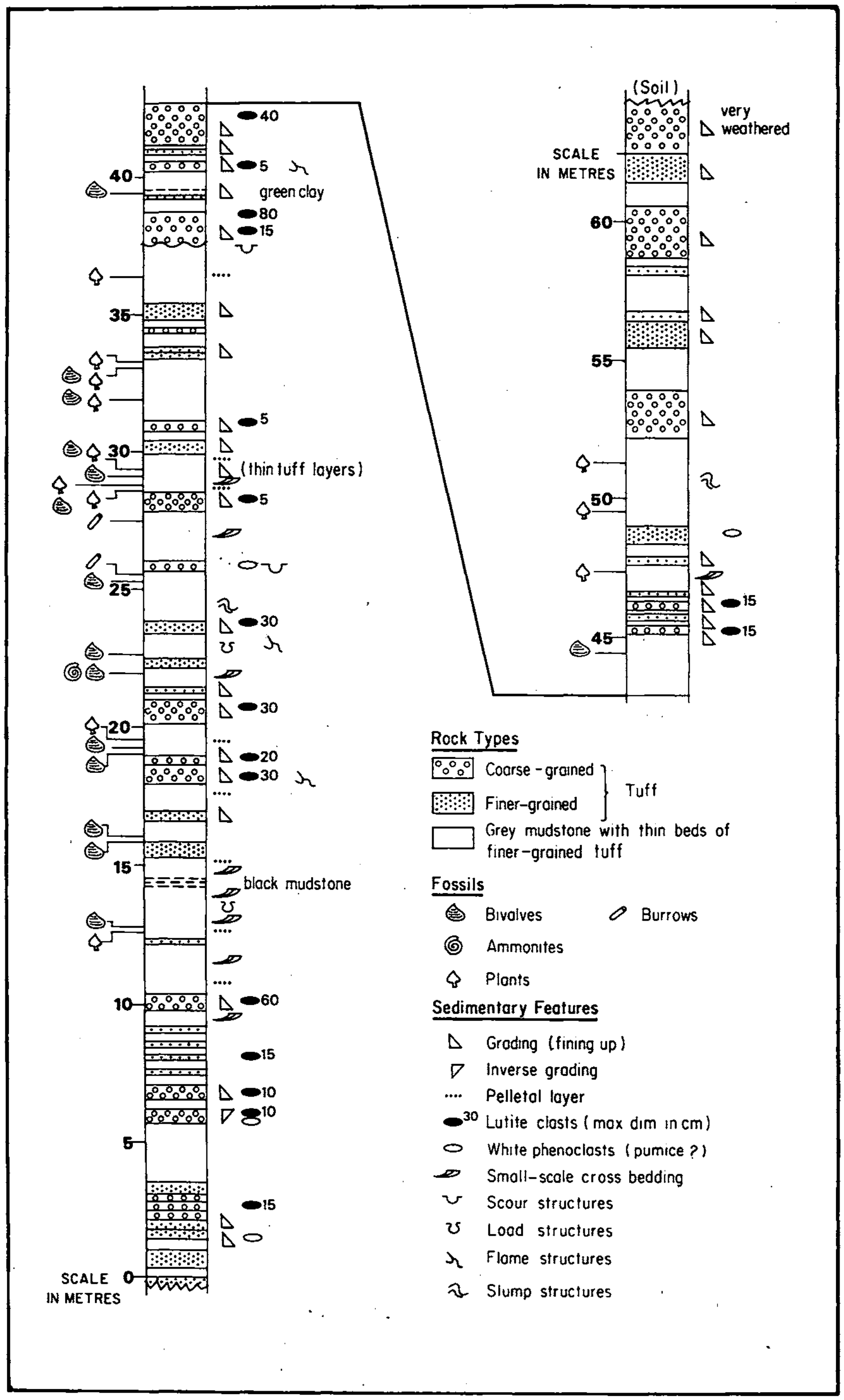


Fig. 3. Stratigraphic column for the section near Lanchang, showing fossiliferous horizons and sedimentary features of interest.

coarse tuff beds. The thickest bed of coarse tuff was 195 cm thick (though the uppermost bed fades into soil after 190 cm without its top being seen and is probably thicker), and 4 other beds are over 1 m thick.

Finer-grained tuff is present as 28 beds aggregating 11.0 m thickness (16.8 %), with an average thickness of 39.3 cm. The thickest bed of this type was 108 cm and no other exceeded 1 m.

Mudstone constitutes the remaining 38.5 m (58.9 %) of the section in 47 intervals (not properly beds, as they contain thin interbeds of finer-grained tuff) of average thickness 81.9 cm.

The entire sequence appears to be conformable and to represent essentially continuous deposition, apart from minor erosion and scour at the bases of some of the coarser beds (see under 'Sedimentology' below).

PALAEONTOLOGY

Bivalves, ammonites, plant fragments and trace fossils (burrows) are recorded from the section. Seven shell layers were located in the section, all within the mudstones (see Fig. 3). The invertebrate fossils recorded from these layers are:-

Metres above base of section	Invertebrate fossils
44.45	Small *Posidonia* sp., *Daonella* sp.
25.45	*Daonella lommeli*, *Posidonia* sp.
22.04	Abundant well preserved *Daonella sakawana*, *Arpadites* sp.
22.00	Abundant poorly preserved *Daonella* sp., *Arpadites* sp.
16.15	Abundant *Posidonia* sp.
16.02	Abundant small *Posidonia* sp.
12.85	Abundant small *Posidonia* sp.

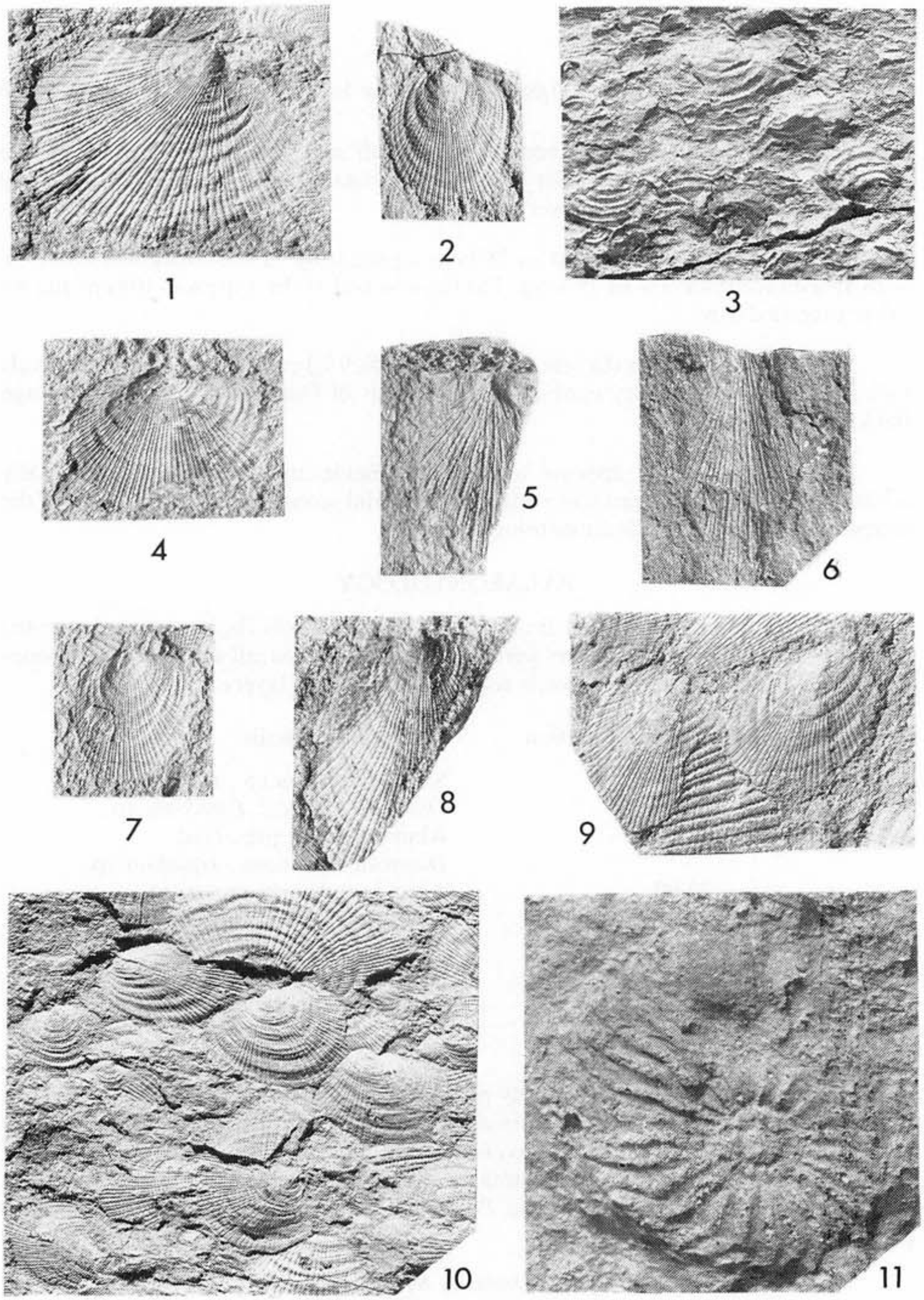
Bivalves

The bivalves are generally poorly preserved except in the shell layer at 22.04 m where external casts of *Daonella sakawana* are fairly well preserved. Specimens in this layer are all disarticulated and lie convex upwards indicating they were transported by currents. Most of the valves are undamaged. Slight tectonic deformation of the shells has occurred (see pl. 1, fig. 10). The *Posidonia* sp. are generally small and poorly preserved.

Genus *Daonella* Mojsisovics
Daonella lommeli (Wissmann)
Plate 1, figs. 5, 6.

For synonomy see Kobayashi (1963).

Remarks: The specimens from Lanchang are approximately 2 cm in length and 3 cm in height. The umbo is situated at about mid length on the straight hinge line and is not



All figured specimens are deposited in the Department of Geology, University of Malaya, Kuala Lumpur.

Figs. 1,2,4,7–10. *Daonella sakawana* Mojsisovics. All from the shell layer at 22.04 m, and all X1.
2,7,10. Specimen A. 586
1,4,8. Specimen A. 587
9. Specimen A. 588

Fig. 3. *Posidonia* sp. Small specimens from the shell bed at 16.02 m.
Specimen A 589, X2.5.

Figs. 5,6. *Daonella lommeli* (Wissmann)
5. Specimen A 590, 25.45 m, X1.
6. Specimen A 591, 25.45 m, X1.

Fig. 11. *Arpadites* sp. Specimen A 592, 22.04 m, X4.5.

visibly protruded above it. The hinge line is almost as long as the shell. Ornamentation consists of radial ribs which are characteristically fasciculate (see pl. 1, fig. 5).

Material: 2 specimens, figured, A590, A591.

Daonella sakawana Mojsisovics
Plate 1, figs. 1, 2, 4, 7–10.

For synonomy see Kobayashi (1963).

Remarks: The shell is ovate to sub-elliptical in outline. The hinge margin is long and straight, being approximately two thirds the length of the shell. The umbo is located about one third the length of the hinge margin from the anterior end and projects slightly above it. The shell is ornamented by concentric growth wrinkles which are fairly well developed (particularly in the umbonal half of the shell) and by radial ribs which increase in number towards the margin by bifurcation. The present specimens show considerable variation in their length (L) to height (D) ratio (Fig. 4A) but show much less variation in the ratio of the length of hinge margin (LH) to distance of umbo from anterior end of hinge margin (LU) (Fig. 4B). Table 1 gives parameters measured on fifteen specimens of *Daonella sakawana* from the shell bed at 22.04 m. The large variation in L to D ratio is considered to be due to secondary tectonic compression of more or less randomly oriented shells. The ratio of LH to LU remains constant during such deformation since they both lie in the same straight line.

Material: Abundant specimens on bedding planes, figured, A586, A587, A588.

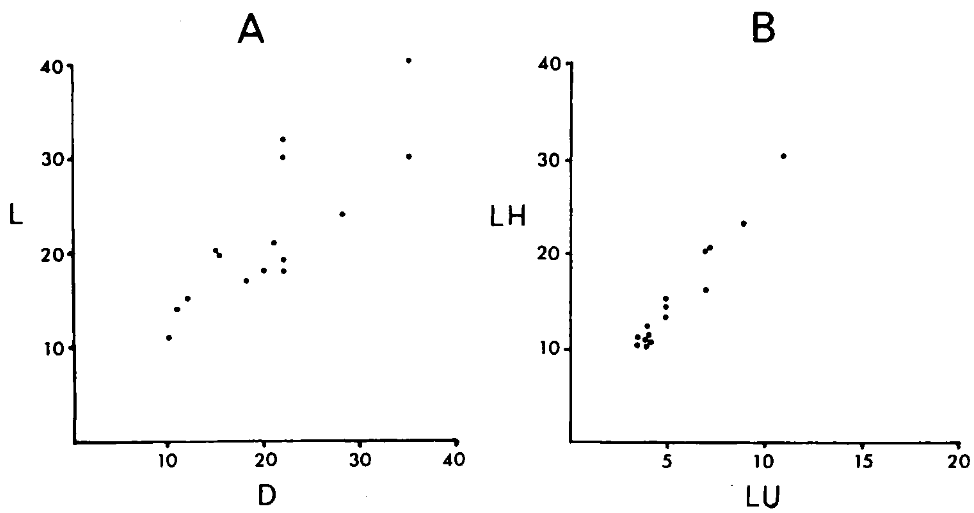


Fig. 4. Scatterplots of dimensions measured on fifteen specimens of *Daonella sakawana* from the shell bed at 22.04 m (data in Table 1). All measurements in mm. A. Length (L) against height (D). B. Length of hinge margin (LH) against distance of umbo from anterior end of hinge margin (LU).

TABLE 1.

Measurements made on fifteen specimens of *Daonella sakawana* from the shell bed at 22.04 m. All measurements are in mm.

L	30	20	40	30	21	18	20	14	18	19	17	11	24	32	15
D	22	15	35	35	21	22	15	11	20	22	18	10	28	22	12
LH	20	15	30	20	10	10	13	10	14	11	12	9	16	23	10
LU	7	5	11	7	4	4	5	4	5	4	4	3.5	7	9	3.5

Genus *Posidonia* Bronn
Posidonia sp.
Plate 1, fig. 3.

Remarks: The specimens of *Posidonia* from Lanchang show well developed concentric plications but no radial striae. Most of the specimens are fragmentary and small and specific identification is not possible.

Ammonites

Two specimens of ammonites were collected, one rather poorly preserved specimen from 22.00 m and one relatively well preserved specimen from 22.04m. These are both identified as *Arpadites* sp.

Genus *Arpadites* Mojsisovics
Arpadites sp.
Plate 1, fig. 11.

Remarks: The shell is discoidal, compressed and evolute. The ribs are slightly sigmoidal and umbilical and ventrolateral tubercles are present. No suture lines are observed. The specimens from Lanchang resemble the specimen described by Sato (1963) as *Arpadites* cf. *cinensis* from Temerloh, Pahang. However, the ribs on Sato's specimen appear to be more closely spaced than in those from Lanchang. The genus *Arpadites* ranges from Ladinian to Carnian.

Material: 2 specimens, figured A592.

Plant fragments

A number of horizons were found in the section where plant fragments were common (Fig. 3). Unfortunately none of these were well preserved and no identifications could be made.

Trace fossils

Horizontal animal burrows were recorded at some horizons (see Fig. 3). They are elongated, cylindrical and have a circular or slightly oval cross-section of about 3 mm diameter. Branching occurs but is not common. Small vertical burrows of < 1 mm diameter and up to 2 cm length were also observed at one or two horizons.

Age of the fauna

The genus *Arpadites* is known to have a range from Ladinian (late Middle Triassic) to Carnian (early Late Triassic). In Malaysia it has been reported from the Ladinian of Temerloh, Pahang and Pokok Sena, Kedah by Sato (1963). The genus *Daonella* ranges through much of the Triassic and Kobayashi (1963, p. 58) recognised five *Daonella* horizons in Southeast Asia as follows:

Carnian	*Daonella sumatrensis* horizon
Ladino-Carnian	*Daonella lilintana* horizon
Uppermost Ladinian	*Daonella indica* horizon
Ladinian	*Daonella lommeli* horizon
Anisian	*Daonella elongata* horizon

Daonella lommeli is restricted to the Ladinian and its presence in the fauna from Lanchang suggests a Ladinian age. *Daonella sakawana* has been recorded from the Ladinian and Carnian.

In conclusion, the sediments of the section under study, on the basis of the occurrence of *Arpadites* sp., *Daonella lommeli* and *Daonella sakawana*, are considered to be Ladinian (late Middle Triassic) in age.

SEDIMENTOLOGY

The sedimentary sequence seen in this exposure gives evidence of having been deposited in a slope-influenced marine environment and largely by means of turbidity currents and related gravity mechanisms.

Coarse beds: The relatively coarse-grained beds in the section (coarse tuffs, finer-grained tuffs, and also thin beds of fine tuff within the mudstone intervals) exhibit a number of features indicating their final emplacement by mechanisms of gravity resedimentation ranging from turbidity currents to debris flows.

Graded bedding is extremely common. Definite grading of 'normal' type (i.e. fining upwards) was observed in some 30 tuff beds, being nearly ubiquitous in the coarse tuffs and very common in finer-grained tuffs. The thin tuff interbeds within the mudstone intervals also commonly show grading. Some beds of tuff grade at their tops imperceptibly into the overlying mudstone (e.g. at 31.20 m).

Inverse grading (coarsening upwards) was observed in one 50-cm bed of coarse tuff (at 5.08 m in the section). This grading is marked by the distribution of white phenoclasts a few mm in size, which may represent pumic fragments. Because of the low density of such material, pumice-bearing tuffs often show such inverse grading.

Outsize clasts, in the form of tabular to rounded fragments of dark mudstone, occur commonly in the tuff beds, roughly one third of such beds in the section showing this feature. The material making up these clasts appears to be identical to that interbedded with the tuffs themselves: dark silty mudstone, commonly laminated and sometimes with layers of dark ovoid pellets. One 20-cm mudstone clast in a tuff bed at

23 m even yielded a number of fossil bivalves similar to those found elsewhere in the section. The condition of these mudstone clasts at the time of their formation was evidently stiff but not rigid. Although most are tabular in shape, the ends are commonly rounded and a few were observed to be bent or distorted into smooth curves (e.g. at 41.50 m), implying plastic behaviour.

These outsize clasts are clear evidence of mass movement of the sand-size material containing them. Such large fragments could not have been moved by a current depositing the sand from traction, but must have been 'rafted' along, with physical support from the solid particles rather than the interstitial fluid. The transport mechanism must have been sufficiently energetic to erode the bottom and quarry out large fragments of the underlying semi-consolidated mud. A few of the thicker beds of coarse tuff show irregular erosive bases (with up to 30 cm relief at 37.60 m) where the underlying mudstone is seen in process of being ripped up in this manner. The bed of coarse tuff starting at 37.06 m, which is 130 cm thick, shows, in addtion to its erosive base, abundant mudstone clasts throughout, with tabular ones reaching 80 cm in size near its top, rounded ones more common in the middle, and tabular ones standing at all orientations, including vertical, in its middle part. This bed would appear to be an example of deposition by debris flow or other high-energy mass flow mechanism (Middleton & Hampton, 1973). The top of this bed shows a gradual transition (over about 10 cm) to the mudstone above, suggesting that this upper part was the result of deposition from suspension, i.e. a true turbidity current.

The outsize mudstone clasts frequently occur in swarms or groups occupying particular levels within a tuff bed. Where they occur near the base, it may indicate recent removal from the eroding bottom and incorporation into the lower portion of a moving mass flow immediately before deposition. Where they occur near the top, it may be the result of upward translation by dispersive stress in a moving grain flow or downward infiltration of fines in a 'kinetic sieve' (see Middleton & Hampton, 1973). Occasionally they occur confined to a zone within a bed, such as in the 45-cm coarse tuff bed at 45.09 m in the section, where mudstone clasts up to 15 cm in size are concentrated in a zone from 15 to 25 cm above the base of the bed. In this case they most likely are actually in the basal part of a flow deposit which has amalgamated on top of a previous flow. Quite possibly a number of the thicker tuff beds may represent additional but unrecognized examples of such compound beds.

Some of the finer-grained tuffs (e.g. between 30 and 31 m) show rather faint flat lamination, possibly a result of grain flow. However, the thickest bed of coarse tuff (185 cm thick, starting at 52.15 m), which also exhibits flat lamination in the uppermost 60 cm, may be a very thick ordinary turbidite. The laminated upper part of this bed is graded, fading into the overlying mudstone, while the lower 125 cm are massive and ungraded. These may represent, respectively, the "a" and "b" horizons of the Bouma sequence in a turbidity current deposit (see Middleton & Hampton, 1973). This bed, it might be noted, lacks any outsize clasts, even though it is the thickest bed in the section.

The thin (usually about 1 cm) beds of fine tuff within mudstone intervals commonly show small-scale cross bedding. The orientation of this cross bedding was noted at 8 separate levels scattered through the section, and the inferred original down-current direction (assuming simple folding) was in every single case westward or southwestward. The bases of these thin tuff beds in places show small load structures and flame structures (e.g. between 21 and 24 m). The direction of over-turning in both asymmetric load structures and the flame structures is consistently westward. Small (1 cm deep) scour channels occur rarely on the bases of thin tuff beds (e.g. near 26 m).

Mudstone: The finer-grained intervals in the section are grey silty mudstone in 5 to 10 cm thick beds separated by thin (1 cm $\pm$) tuff beds. The mudstone is generally laminated and the flat laminae show little disturbance from bioturbation. Only rare small vertical to horizontal burrows are seen. The implication of an environment rather inhospitable to life is consistent with the grey to dark grey color of the mudstone in the weathered outcrop. The fresh rock is almost surely a 'black shale.' Apart from these rare burrows (and the concreted probable burrows recovered from sieving the disaggregated sample), the only evidence of indigenous benthos are the scattered layers of small, dark, possibly faecal pellets.

The benthonic molluscan fossils present in the mudstone show some evidence of transportation. Where bivalves occur, they tend to be mainly single valves, dominantly convex-up, and to be concentrated in very thin layers—indeed sometimes, as at 22.00 and 22.04 m, plastered on single bedding planes. Lum (1976) noted these features and inferred some reworking of the shells. Distance of transport of the shells was probably somewhat limited, however, because most valves are unbroken, as already noted by Jaafar (1976).

The mudstone intervals may themselves represent in part resedimentation by turbidity currents. Evidence of instability, probably related to original slope of the depositional site, is seen in a thin slump-folded layer of laminated mudstone at 50.40 m in the section, and also in a slumped interval, from 24.00 to 24.50 m, which involves both mudstone and tuff beds and exhibits convolute folds and injection wedges of the tuff. In a few of the tuff beds, mudstone clasts at the top of the bed merge into broken laminated mudstone of the overlying bed, suggesting formation by lateral movement of a sequence of beds, presumably by liquifaction of the tuff after deposition of the overlying mudstone.

DISCUSSION

A few comments and inferences may be made concerning some aspects of the origin of these Triassic sediments.

Water depth at depositional site: Evidence of downslope transport (gravity resedimentation of tuffs, and slumping), evidence of lack of oxygen and paucity of life (dark colour of mudstones, general absence of bioturbation), and total absence of primary structures of shallow-water traction origin (larger-scale cross bedding, etc.) indicate that deposition took place in water of at least moderate depth. The bivalves would appear to belong to a deeper neritic biofacies, as suggested by Jaafar (1976), but if they have been transported some distance down a slope, the final depositional site could have been below neritic depths, possibly in an oxygen minimum zone on a bathyal marine slope.

Slope direction: All indicators of slope direction in this sequence (small cross beds in thin tuff turbidites, overturning of load structures and flame structures) agree in giving a downslope direction to the west or southwest. There would appear to be no doubt that the depositional site was on a north-south or northwest-southeast oriented slope with deepening of the water toward the west or southwest. This inference is consistent with Jaafar's (1976) interpretation that a shallower water biofacies (*Myophoria* assemblage) occurs in the Semantan Formation only at outcrops in a north-south belt some 5 to 10 km to the east of the Lanchang cutting.

Provenance and geographic setting: The coarse material in this sequence appears to be entirely of volcanic origin. Some or even most of the fine material (the mudstone) may also be derived from fine ash and altered volcanics. The absence of any non-volcanic turbidites implies that the upslope source area to the east or northeast lacked non-volcanic rocks. All of this is consistent with the site of deposition of this Lanchang section being located on the western or southwestern flank of a Triassic volcanic island or island chain.

ACKNOWLEDGEMENTS

We are grateful to K.R. Chakraborty for initially drawing our attention to this interesting exposure, to Golden Bricks Sdn. Bhd. of Mentakab for allowing us access, and to students of the Third Year stratigraphy class (1978/79) for finding some of the fossils and features noted in this paper. The figures were drafted by the Drafting Section, Department of Geology, University of Malaya, the photographs were reproduced by Mr. Jaafar bin Haji Abdullah, and Mr. S. Sandrasagaram assisted with the disaggregation of the samples.

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Manuscript received 16 September 1981.