ORIENTATED CALCAREOUS CONCRETIONS FROM JAMES ROSS ISLAND, ANTARCTICA

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Abstract. Calcareous concretions are abundant within fine-grained sediments of the Upper Cretaceous Marambio Group, James Ross Island, Antarctica. At one locality, over 300 concretions are exposed on a single bedding plane, showing a marked major axis orientation parallel to the palaeocurrent. The spatial distribution of the concretions was found to be non-random with concretions either showing the maximum spacing possible at the concretion densities observed, or being aligned into parallel rows at approximately right angles to the major axis orientation. This non-random distribution is possibly related to the occurrence of large scale bedforms, controlling the distribution of organic matter, and hence sites for concretion growth.

Introduction

Although calcareous concretions are a common diagenetic feature throughout the geological record, the processes controlling concretion distribution are poorly known. Previous studies have shown that concretions sometimes show a preferred major axis orientation (Colton, 1967), and that their spatial distribution is random (Raiswell and White, 1978). However, during recent field work on James Ross Island, Antarctica (Fig. 1), where a single bedding plane exposing some 300 concretions was examined, the concretions show a significant long axis alignment, although their spatial distribution is non-random. This locality may provide insight into the processes controlling concretion distribution and orientation.

Calcareous sandstone concretions are abundant throughout the Marambio Group, exposed on James Ross Island. The Marambio Group (Ineson and others, 1986) was deposited within a back-arc basin to the east of an emergent volcanic arc, now represented by the Antarctic Peninsula (Farquharson and others, 1984). The group consists of predominantly unconsolidated fine-grained sediments deposited in a shallow marine environment. Calcareous sandstone concretions commonly occur, ranging in size from 5 to 244 cm in diameter. Septarian concretions and carbonate concretions also occur but are numerically less important. The concretions commonly contain well preserved fossils including large wood fragments, ammonites, bivalves, crabs and gastropods, but many are devoid of biogenic debris other than granule to sand-grade detrital wood fragments, and calcareous foraminifera.

The concretion horizon, at Crame Col, James Ross Island (Figs 1, 2), is 90 m above the base of the Marambio Group, and is of mid-Senonian age (M. R. A. Thomson, pers. comm., 1986). The concretions occur at a sharp bed boundary (Fig. 3) between siltstone and flame-cast, fine- to medium-grained sandstone. This sandstone bed is a lith-arenite following the scheme of Pettijohn and others (1973). The dominant framework grains are altered andesitic lithic volcanic fragments, plagioclase, K-feldspars, glass shards and rare quartz. Calcite occurs both as an alteration product within the lithic fragments and as a sparry calcite cement. Grain contacts are rare, and approximately 10% of the framework grains show clay rims. The sharp loaded/flame cast bed boundary is obvious within the concretions, but it is hard to

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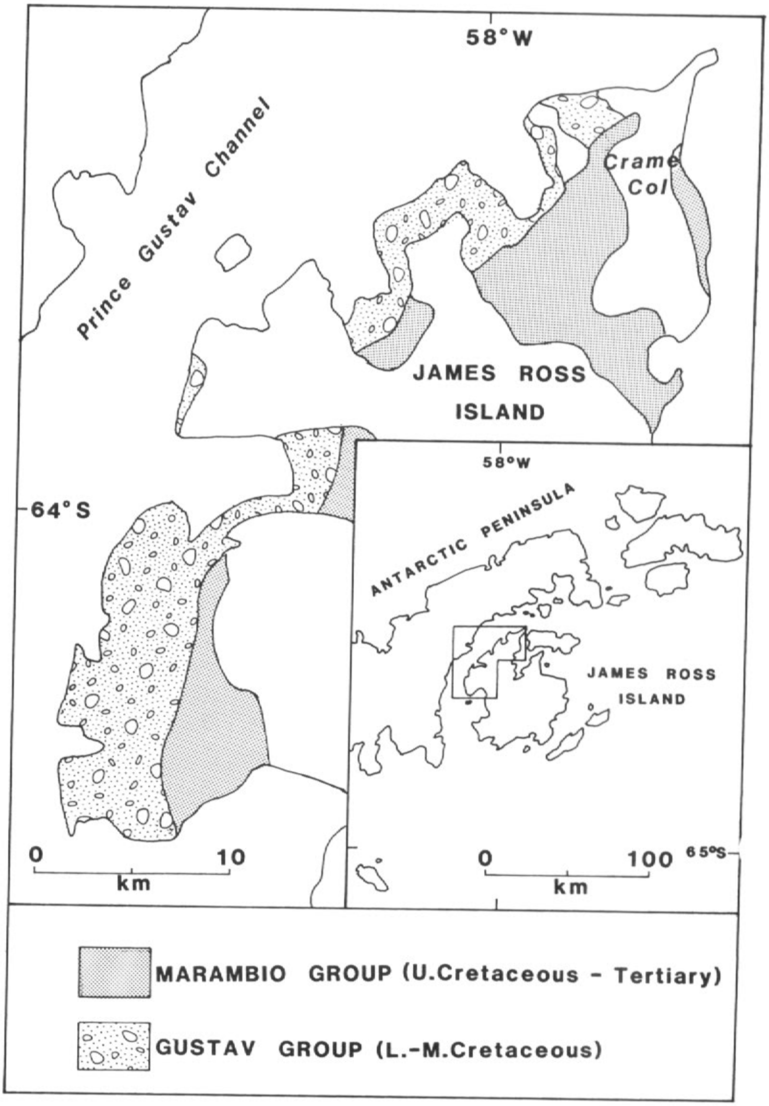

Fig. 1. Sketch map showing the location of James Ross Island (inset), and the distribution of the Upper Cretaceous Marambio Group.

detect within the surrounding unconsolidated sediment. Large fossil wood fragments up to 4.4 m long also occur at this horizon. They are calcified, but occur independently from the surrounding calcareous sandstone concretions. No wood fragments larger than granule to sand grade occur within the sandstone concretions.

MORPHOLOGY

Of the 200 concretions observed, 151 were well enough exposed to allow measurements of size and orientation. All concretions measured were partially embedded

Fig. 2. Crame Col, James Ross Island. The concretion horizon is indicated by the arrow. The Marambio Group sediments are 190 m thick at this locality, and are overlain unconformably by the lavas of the James Ross Island Volcanic Group, which form the cliff tops.

within unconsolidated sediment, hence only the two axes in the plane of bedding were measured. Of the concretions measured, 96% were asymmetrical in the plane of bedding, apparently with considerable flattening in the vertical axis (*c*). In plan view, the long axis (*a*) ranged between 40 and 244 cm with a mean of 88 cm, the short axis (*b*) ranged between 30 and 140 cm with a mean of 71 cm (Fig. 4). The axial ratio (a/b) ranged between 1 (circular) and 2.44 (ellipse), with a mean of 1.24. Raiswell (1971) noted that concretions in sandstones are most commonly spherical whilst concretions in shales are flattened ellipsoids ($a > b > c$). The concretions measured in this study range between oblate ($a \approx b > c$) and prolate ($a > b > c$) ellipsoids.

The long axis orientation was measured on all asymmetrical concretions in the field, but for the interpretation of the orientation data, only those measurements from concretions showing marked asymmetry ($a/b \geqslant 1.05$) were used. Of the concretions measured, 90% showed asymmetry of $\geqslant 1.05$. Two main concretion shapes were observed, Type A (Fig. 5a), forming 93% of the population, are spherical to oblate spheroids. Type B (Fig. 5b), forming 7% of the population, are elongate with a raised rim and a concave central depression.

LONG AXIS ORIENTATION

The orientation of concretion long axes (Fig. 6a) shows a cluster in the range 050°–110° with the mode in the class 080°–090° (vector mean 092°). Limited palaeocurrent data are available from the concretion horizon. However, the long axis orientation can be compared with palaeocurrent data obtained from an underlying bed (Fig. 6b), wood clast long axis alignment from the concretion horizon (Fig. 6c)

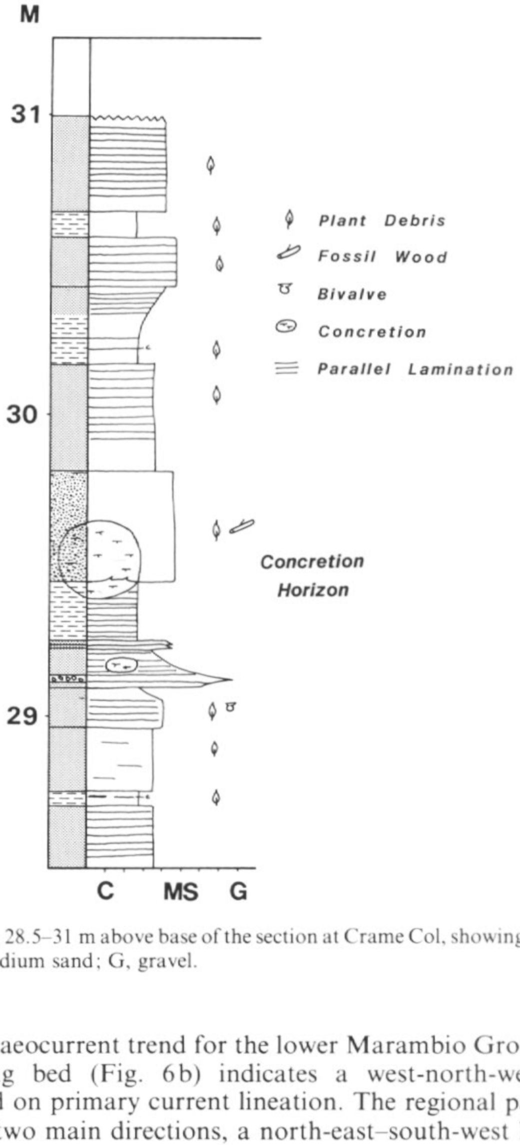

Fig. 3. Sedimentary log, 28.5–31 m above base of the section at Crame Col, showing the concretion horizon. C, clay; MS, medium sand; G, gravel.

and the regional palaeocurrent trend for the lower Marambio Group (Fig. 6d). Da[illegible] from an underlying bed (Fig. 6b) indicates a west-north-west–east-south-ea[illegible] palaeocurrent based on primary current lineation. The regional palaeocurrent trend (Fig. 6d) indicates two main directions, a north-east–south-west longshore current, and a secondary north-west–south-east offshore current, which compares well with that obtained from the primary current lineation (Fig. 6b). The concretion long-axis alignment, which is broadly east-north-east–west-south-west approximates to the longshore palaeocurrent. The orientation of large fossil logs from the concretion horizon is shown in Fig. 6c. These data show a spread of values, but there is a weak cluster in the range 330°–020°, approximately at right angles to the palaeocurrent. Although it is thought that the orientation of fossil wood can be a useful palaeocurrent indicator (Macdonald and Jefferson, 1985), larger wood fragments tend to show less current parallel alignment, due partly to the current velocities at which the fragments are deposited and partly to lodgement of logs within bedforms. The concretion long axes, do, therefore, show a weak palaeocurrent parallel orientation.

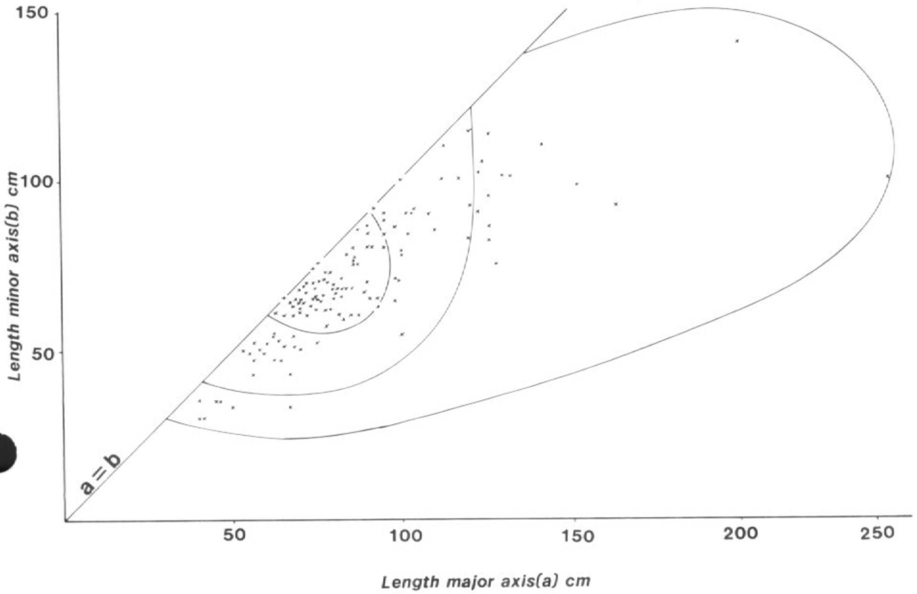

Fig. 4. Diagram showing concretion size distribution. Contouring indicates relative size distribution.

SPATIAL DISTRIBUTION

The sites for concretion growth are, by definition, atypical of the surrounding host sediment (Dickson and Barber, 1976), thus their distribution spatially is of importance in the understanding of concretion growth. Raiswell and White (1978) found that concretions from the Upper Lias of Yorkshire showed a random distribution. The concretions from Crame Col show two distinct non-random distributions. At the northern end of the exposed bedding plane, the concretions occur in parallel rows (Fig. 7), trending towards 013°, with a spacing of 6 m. The rows of concretions are orientated at about 080° to the mean direction of concretion long axes. Farther south, this linear distribution of concretions is absent (Fig. 8). Statistical 'nearest neighbour' analysis (Raiswell and White, 1978; Pemberton and Frey, 1984) showed that the spatial distribution was non-random, and that the concretions were spaced at the maximum spacing possible, at the observed concretion density.

DISCUSSION

Although many authors have discussed the formation of concretions, few have described concretion orientation and spatial distribution, largely due to a paucity of suitable bedding-plane exposure. Detailed study of these features may indicate the processes and controls of concretion formation.

Most sandstone concretions described in the literature are near spherical indicating subequal permeability and fluid migration throughout sandstone bodies (Raiswell, 1971). The alignment of concretion long axes close to the palaeocurrent direction at Crame Col indicates that maximum permeability and therefore, a preferred pathway for fluid migration, is parallel to the palaeocurrent, similar to that noted by earlier workers elsewhere (Colton, 1967). This may be due to grain alignment increasing permeability parallel to the palaeocurrent. However, 10% of the concretions measured

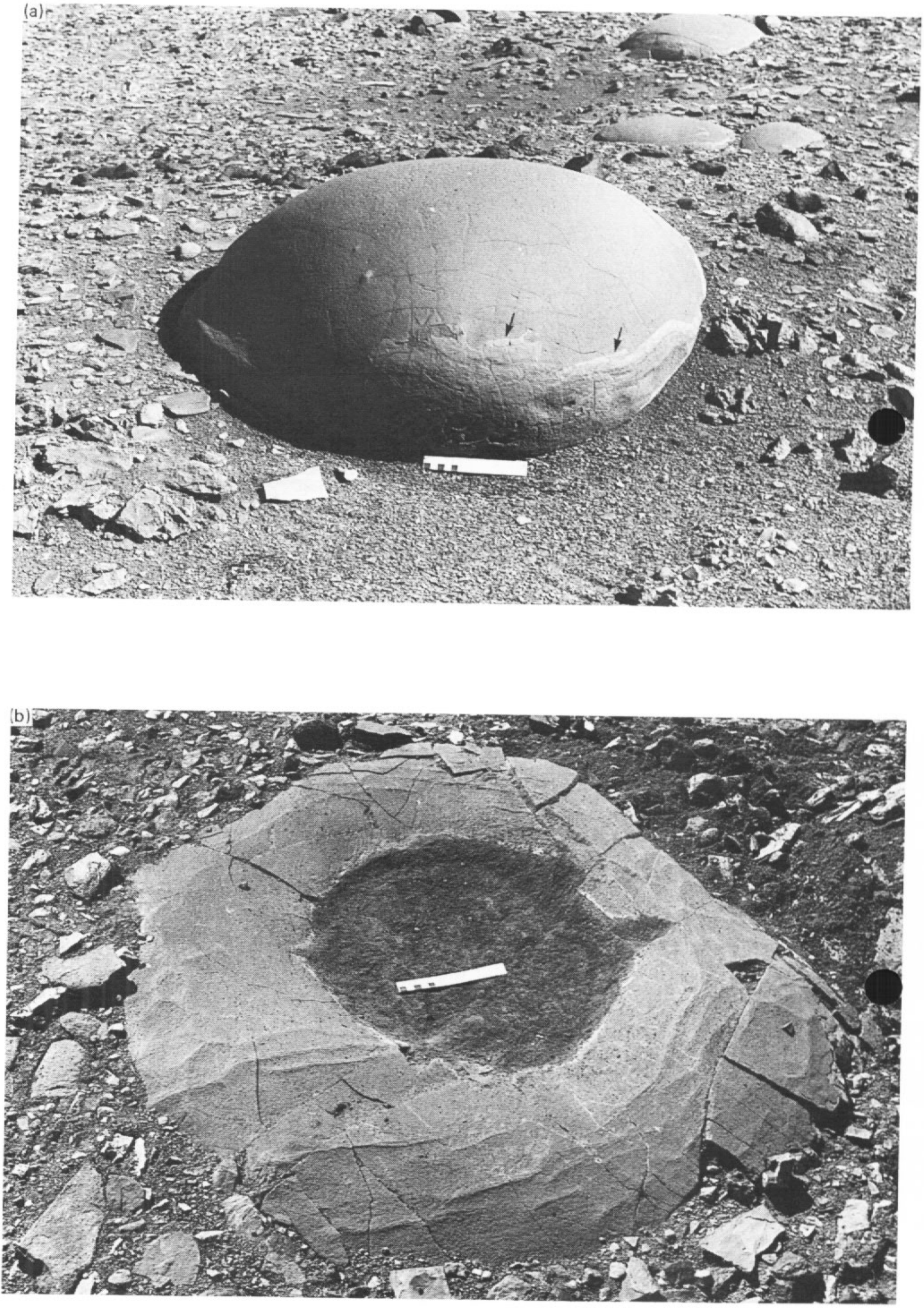

Fig. 5. (a) Concretion morphology type A. Note the sharp flame cast bed boundary (arrowed). Scale bar, 15 cm. (b) Concretion morphology type B. Scale bar, 15 cm.

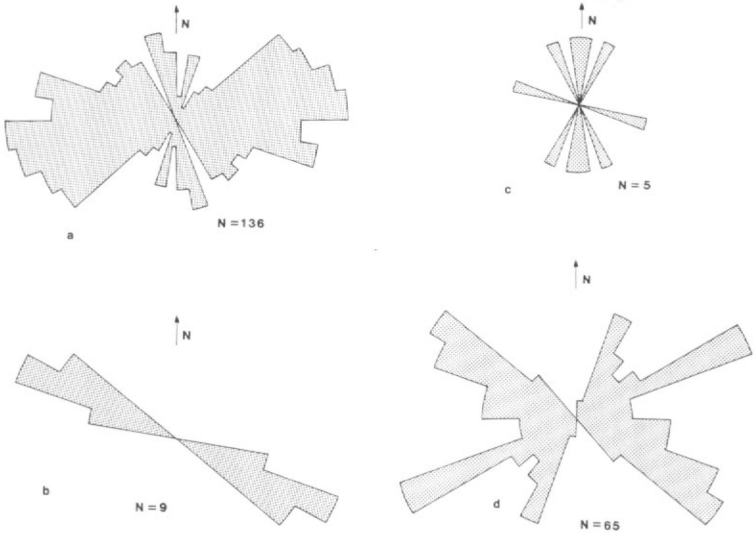

Fig. 6. (a) Rose diagram showing concretion long-axis orientation, with class intervals of 010°. (b) Rose diagram showing primary current lineation and palaeocurrent. Class intervals of 010°. (c) Rose diagram showing wood fragment long-axis alignment, from the concretion horizon. Class intervals of 010°. (d) Rose diagram showing the regional palaeocurrent trend for the lower Marambio Group, James Ross Island. Class intervals of 010°.

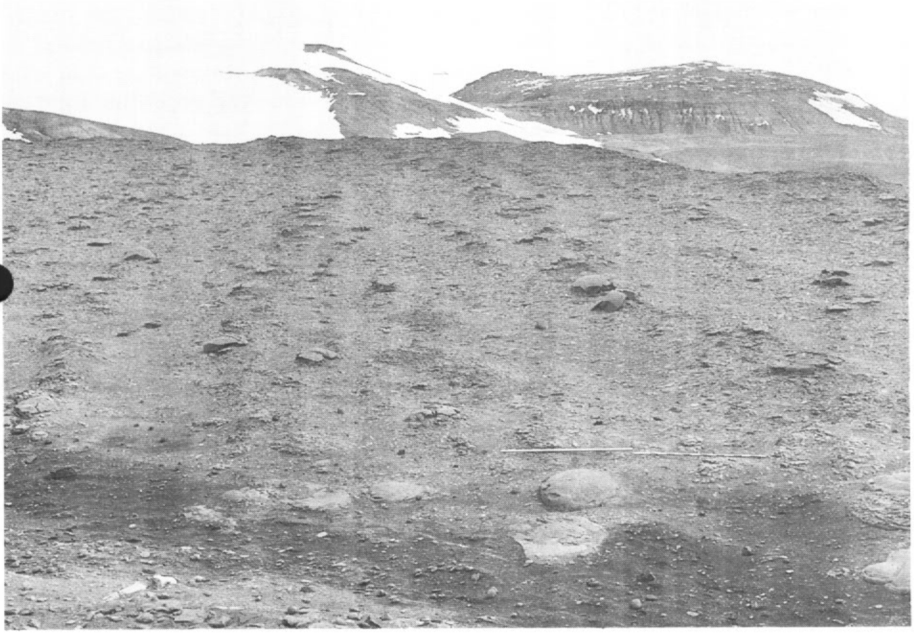

Fig. 7. Photograph showing concretions aligned in parallel rows at the northern end of the exposed concretion horizon. Two measuring staffs = 3 m.

Fig. 8. Distribution of concretions at the southern end of the exposed bedding plane. Quadrat base line = 3 m.

are spherical in plan view, indicating uniform permeability within the plane of bedding. Thus, permeability distribution across the bedding plane was irregular with zones of uniform and non-uniform fluid migration. The occurrence of the concretions at a sharp sandstone/siltstone bed boundary indicates enhanced pore-fluid migration along this horizon. Pore waters, expelled from the underlying compacting shales, appear to have shown preferential lateral migration along this horizon, the site of a marked change in the permeability gradient of the sediment. Concretion elongation due to the precipitation of cement around an originally elongate nucleus, for example a wood fragment, can be demonstrated elsewhere within the Marambio Group, but no concretions at Crame Col yielded an elongate nucleus.

It is widely accepted that carbonate concretions form at sites of localized microbiological activity, which establish micro-environments supersaturated in carbonate (e.g. Curtis and others, 1972; Raiswell, 1976; Raiswell and White, 1978). Raiswell and White (1978) predicted that, if favourable sites for the development of microbiological activity, and therefore concretion growth, were located uniformly throughout the sediment, or if growth of one concretion decreased the probability of another concretion site being established, then concretions would be spaced at the maximum possible spacing from each other at the observed concretion density. This type of non-random distribution occurs over the southern area of the exposed bedding plane at Crame Col.

In the north, where concretions occur in parallel rows, the zones favourable to concretion formation must have been restricted. This alignment of concretions may indicate rows of increased permeability at right angles to the palaeocurrent. However, the concretions within these zones show long axis orientations parallel to the palaeocurrent, and do not show a circular plan view. This does not, therefore, support the view of increased permeability. A second possible control on concretion distribution is bedform. Fig. 9 indicates the concretion distribution (A) and the envisaged depositional environment (B) prior to concretion formation. Following deposition of the sand bed by sediment gravity flow processes, current reworking modified the upper part of the bed, giving planar bed conditions to the south and undulatory bedforms to the north. Organic debris would be concentrated within troughs to the north, and evenly distributed across the bed to the south. The organic debris would provide a favourable medium for the development of microbiological activity and therefore, concretion growth. Thus to the south the concretions show an even distribution at maximum spacing, whilst to the north the concretions are concentrated within parallel rows.

Sediment stability may also control concretion development. Holme and Wilson (1985) describe zones of mobile and stable sediment from the central English Channel. Concretion formation is more likely within zones of stable sediment where localised g[illegible]chemical micro-environments can develop.

CONCLUSIONS

(1) The long axis orientation of calcareous concretions indicates anisotropic permeability within the concretion horizon. Maximum permeability parallels the palaeocurrent and may be due to grain alignment during deposition, or later current reworking.

(2) The occurrence of calcareous concretions along a sharp sandstone/siltstone bed boundary may indicate enhanced pore fluid migration at this level.

(3) The spatial distribution of calcareous concretions is non-random. The distribution of favourable sites for microbiological activity, and therefore, the favoured

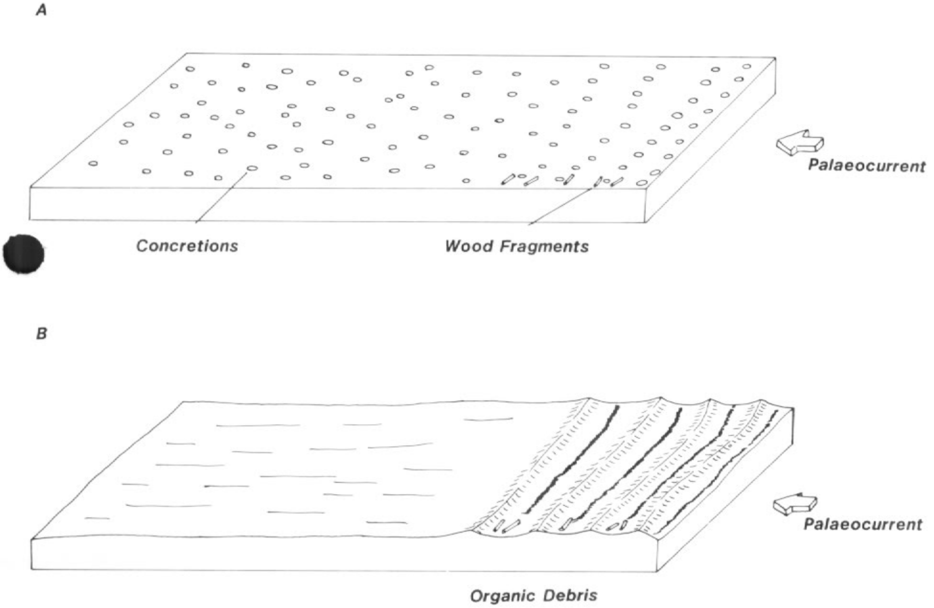

Fig. 9. Schematic diagram showing (A) the distribution of concretions across the exposed bedding plane, and (B) the envisaged bedforms controlling the distribution of organic debris.

sites for nucleation and growth of concretions, may be related to bedform and sediment mobility.

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