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A fossil carbonate contourite drift on the Lower Ordovician palaeocontinental margin of the middle Yangtze Terrane, Jiuxi, northern Hunan, southern China

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ABSTRACT

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The Early Ordovician (Tremadocian) in part of Jiuxi, northern Hunan Province, comprises a succession of deep-water carbonate sediments deposited on a palaeocontinental margin at the southern edge of the Yangtze Platform. A distinctive elongate mound-like form, some 350–450 m thick, can be recognized lying between shallow-water platform carbonates and deeper-water mudstones. This elongate body, here called the Jiuxi drift, is made up dominantly of sediments interpreted as contourites on the basis of their mid to base-of-slope location, alongslope current indicators, features of traction flow processes coupled with intense bioturbation, and distinctive contourite sequences (typically 30–80 cm thick). Five contourite facies are recognized: calcilutites, calcisiltites, calcarenites, calcirudites (possibly contourite lag deposits), and bioclastic contourites. Hemipelagites and turbidites make up only a small proportion of the drift, which accumulated at an average sedimentation rate of 38 m/m.y. Large-scale cross-stratified units found in parts of the calcilutitic contourite section are believed to result from seafloor development of mudwaves and/or erosional furrows under the influence of a semipermanent bottom-current regime.

Introduction

Much progress has been made in the study of contourites since Heezen and Hollister (1964) and Heezen et al. (1966) first recognized their importance (Stow and Lovell, 1979; Stow and Piper, 1984; Pickering et al., 1989). The studies of ocean circulation and modern contourites, especially detailed surveys of modern contourite drifts, have greatly improved our understanding of aspects of contourites such as lithology, sedimentary textures and structures, facies variation and their relationship to bottom (contour) currents (Stow and Holbrook, 1984; Gonthier et al., 1984; Faugères et al., 1984; McCave and Tucholke, 1986). However, reports of ancient contourites and contourite drifts are rare. One exception are contourites described from the Cretaceous Talme Yafe Formation which formed part of the continental margin of the Arabian Shield (Bein and Weiler, 1976).

There are numerous criteria for identifying contourites which can be summarized as follows: (1) occurrence in relatively deep-water (oceanic) environments; (2) features of traction flow processes, such as erosive surfaces, fabric orientation, etc.; (3) palaeocurrent indicators showing

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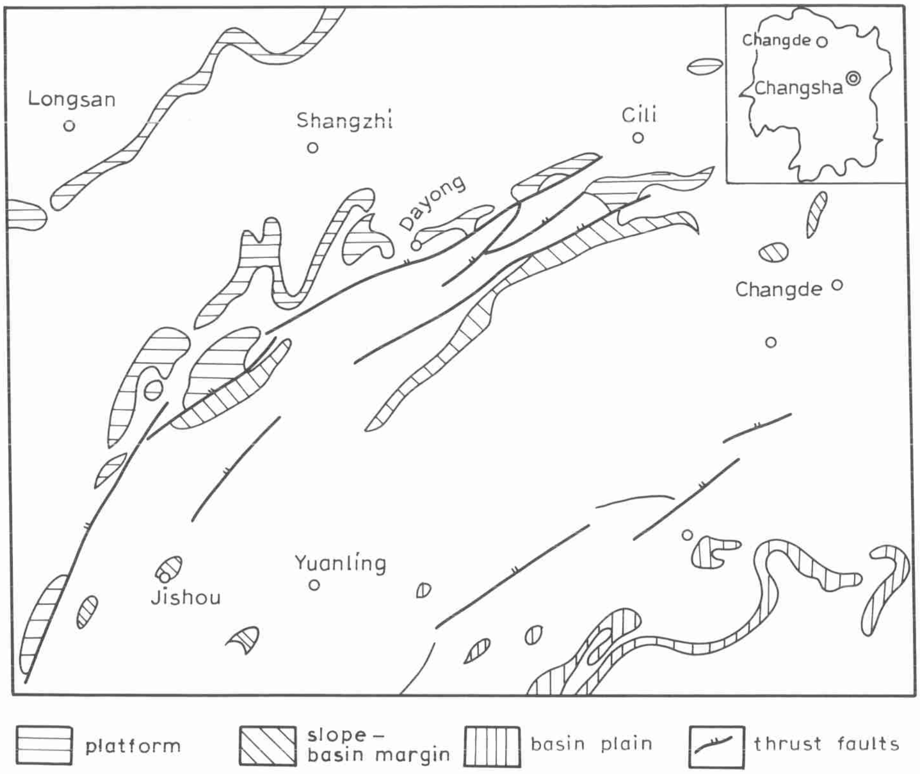


Fig. 1. Location map and distribution of Lower Ordovician rocks in the study area.

long-slope currents; (4) distinctive contourite se-uences; (5) intense bioturbation. In addition, the omposition and grain-size distribution of con-ourites, when compared with those of interbed-led turbidites, pelagic and hemipelagic sediments lso contribute to this identification.

The present study is based on careful observa-ion of fourteen different sections through part of a palaeocontinental margin in South China. One section has been measured in detail, together with descriptions of over 300 thin sections and 54 polished slabs. Firstly, we describe the different carbonate contourite facies and distinctive contourite sequences recognized. Secondly, from the distribution of the various contourites in the succession and the geometry of the whole, we infer

ABLE 1

he division and correlation of the studied strata

eries	Stage	Deep-water type	Shallow-water type
rdovician	Tremadoc	Madaoyu Formation *Asaphopsis* *Dictyonema*	Fengxiang Formation *Psilocephalina* *Asaphopsis*
		Panjiazui Formation *Szechuanella* *Hysterolenus* *Monocostadus*	Nanjingquan Formation *Lohanpopsis* *Dactylocephalus* *Nanorthis*
ambrian		Shengjiawan Formation	Sanyoudong Formation

the presence of the Jiuxi carbonate contourite drift during the Tremadoc period, Early Ordovician.

Geological setting

The study area is located in Jiuxi, Taoyuan County, northern Hunan, China. In Early Ordovician time, the area was part of the Huanan (South China) passive continental margin or southern margin of the Yangtze microplate (Duan et al., 1988). In this period, the depositional framework of the margin was relatively regular and stable, and the distinct subenvironments can be recognized. In the northern part of the region stood the Yangtze shallow-water carbonate platform; to the south were a deep-water slope and a basin. Two types of formations are distinguished in each of these two regions, and these are separated by a series of thrust faults with ENE–WSW or E–W

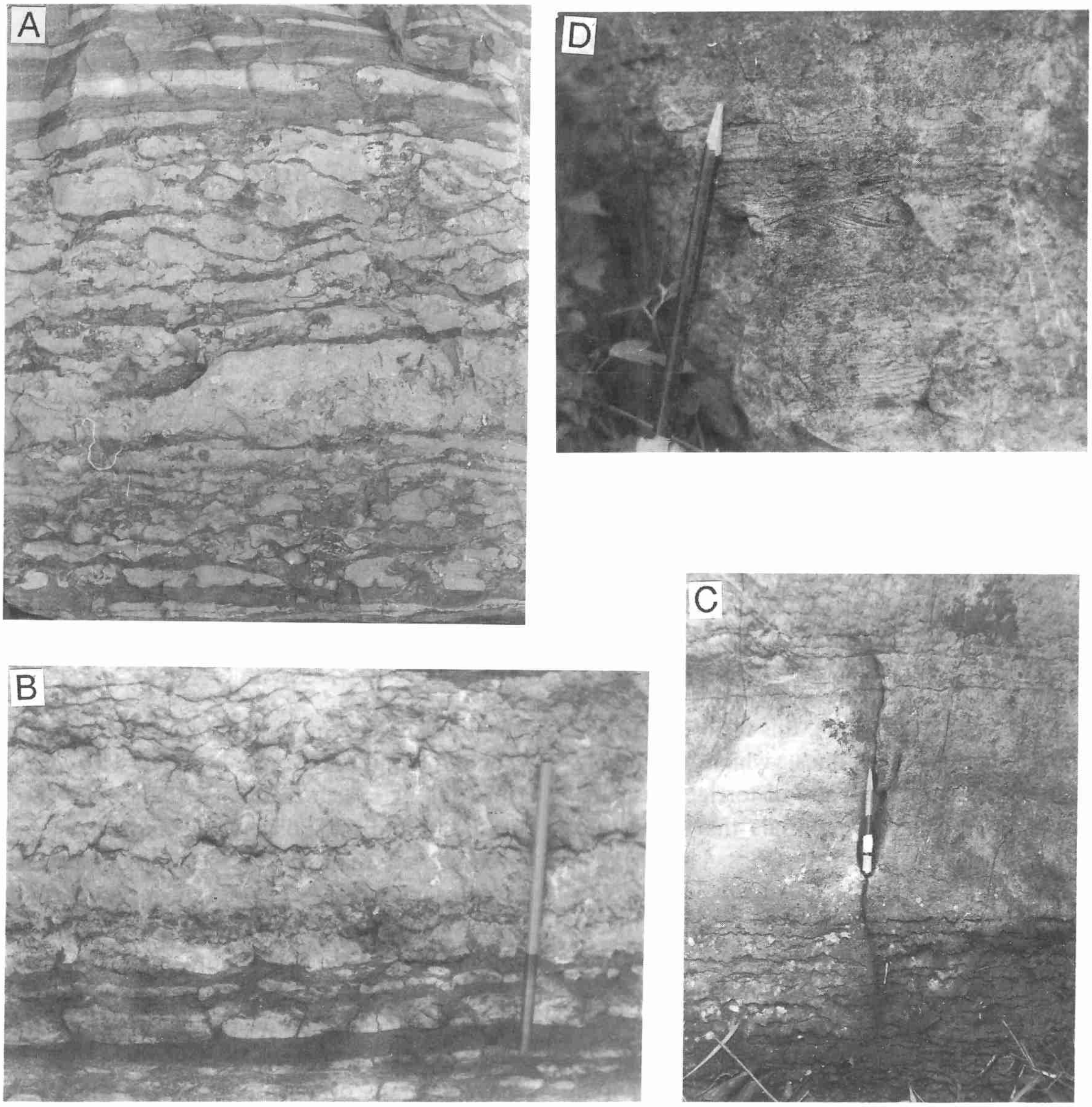


Fig. 2. Contourite facies and facies sequences form the Jiuxi contourite drift. A–C. Various examples of the coarsening-up to fining-up contourite sequence, including calcilutite, mottled calcisiltite and calcarenite contourite facies. D. Calcisiltitic contourites with isolated ripple.

trends (Fig. 1). The strata involved in this article mainly concern the Panjiazui Formation and lower part of the Madaoyu Formation (Table 1).

The full succession comprises, in addition to the contourites discussed below in detail, a range of gravity flow deposits, and pelagic and hemipelagic sediments with abundant fine (mm scale) lamination (Fig. 2). The fossil assemblage indicates deep-water environments in this region during the Early Ordovician. Body fossils dominate including trilobites, graptolites, a few small brachiopods and cephalopods, together with a variety of conodonts. The trace fossils are very abundant but a little monotonous, and are represented by *Glockeria* and a Scribble grazing trace (Fig. 3). These are also typical of deep water.

Contourite facies

Based on detailed observations of outcrops and the studies of thin sections and polished surfaces, five types of contourite facies have been identified as follows: (1) calcilutitic contourites; (2) calcisiltitic contourites; (3) calcarenitic contourites; (4) fine calciruditic contourites; and (5) bioclastic contourites. The first three of these are equivalent to the sandy, silty and muddy contourite facies, respectively, of Gonthier et al. (1984).

Calcilutitic contourite facies

Most of the studied succession consists of this type of facies. On the whole, this facies comprises (muddy) micritic limestones, which commonly contain a variable proportion of terrigenous silts, calcisilts and bioclastic materials that constitute mottling, laminae or thin beds (Figs. 4 and 5). On average, calcisilts or silts make up 30% of the facies, bioclastics 2–20% (being mainly relatively unbroken trilobite fragments), muds 3–30%, and micrite 45–65%. Pyrite is very common, associated with the walls of burrows. Calcisilt or silt laminae are generally 1–3 mm thick and laterally discontinuous, with a sharp or erosive base and a sharp or gradational upper contact.

One evident feature of this facies is the common occurrence of bioturbational structures and burrows. Most of the burrows are horizontal, some oblique or vertical, filled with calcisilts, micrites or sparite cements; their diameters are 1–5 mm and their observed lengths from several mm to more than 10 mm. Otherwise, bioturbation creates a generally chaotic aspect such as mottled calcisilts, irregular beds and abrupt termination of laminae. Based on estimates from polished slabs, at least 60% of the original textures and structures have been destroyed by bioturbation.

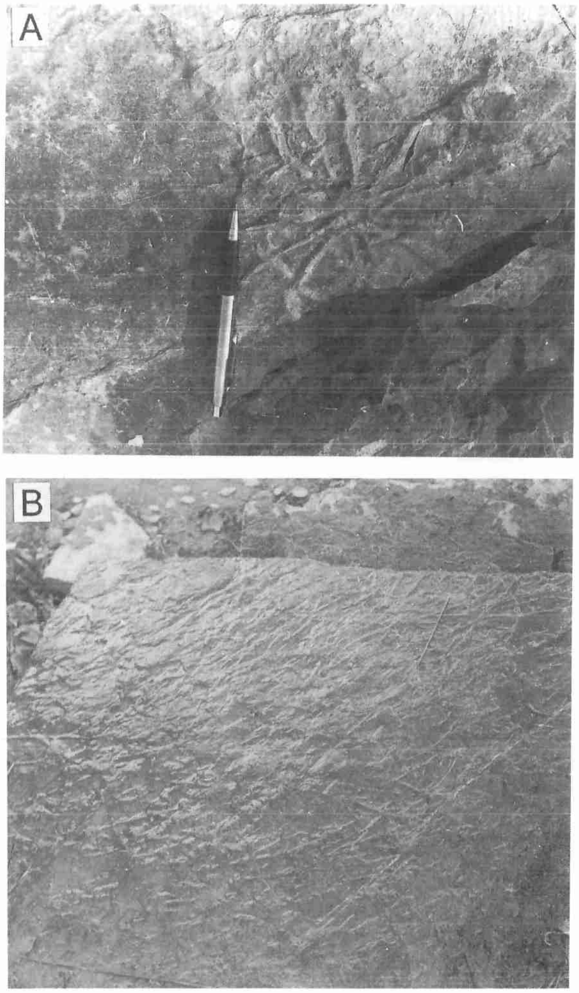


Fig. 3. Trace fossils on contourite bed surfaces. A. *Glockeria*. B. Scribble grazing trace.

Two types of large-scale cross-stratification have been discovered in this facies. One example, shown in Fig. 6A, is about 80 cm thick with “S-shaped” progradational laminae, which become thinner and are convergent in the direction of the progradation. The current direction indicated by the cross-laminae is approximately coincident with the strike of the regional palaeoslope (80°). The other type is composed of both "S"-laminae and truncated "S"-laminae (Fig. 6B), both of which thin progressively in the direction of the progradation, showing clear convergence. In the example shown, the 80–180 cm thick cross-bedded unit is overlain (conformably on the right (south) of the photo, and unconformably on the left (north) of the photo) by a 50 cm thick drape of beds of similar lithology. The cross-bedded unit can be traced laterally at least 9.8 m before its outcrop is lost. The direction of progradation is approximately 360°, i.e. from the deep-water basin towards the shallow-water carbonate platform, or at right angles to the presumed bottom-current flow.

Calcarenitic contourite facies

These types of contourites are much coarser-grained than the calcilutites and their features are correspondingly more evident, so that it is much easier to identify them in outcrop sections. The calcarenitic contourites (Fig. 5B) generally contain 40–60% carbonate sands, 10–30% carbonate silts, 3–18% bioclastics (mainly trilobite fragments), 20–40% micrite matrix and/or 2–13% sparite cement, and rarely 8–20% fine quartz sands. The carbonate sands are made up of very fine micrite intraclasts. Sorting ranges from poor to good, and even to very good locally. The grains are commonly subrounded. Trilobite fragments are typically concentrated locally (Fig. 4B). Small erosive surfaces are very common in calcarenitic contourite beds (Fig. 4C) and, although carbonate sands may be present both below and above the erosive surface, they are quite different from each other in their grain size, sorting, and colour.

This facies typically exhibits an irregular parallel-stratification with millimetres- to centimetres-thick sets, and either flat or somewhat irregularly set boundaries. These are commonly small lenses, irregular streaks and even thin irregular beds which are locally coarser-grained and well-sorted; in this case, the sand content is over 80%, and the matrix is almost completely carbonate sparite cement. Bioturbational structures and burrow similar to those in calcilutitic contourites, ar very common.

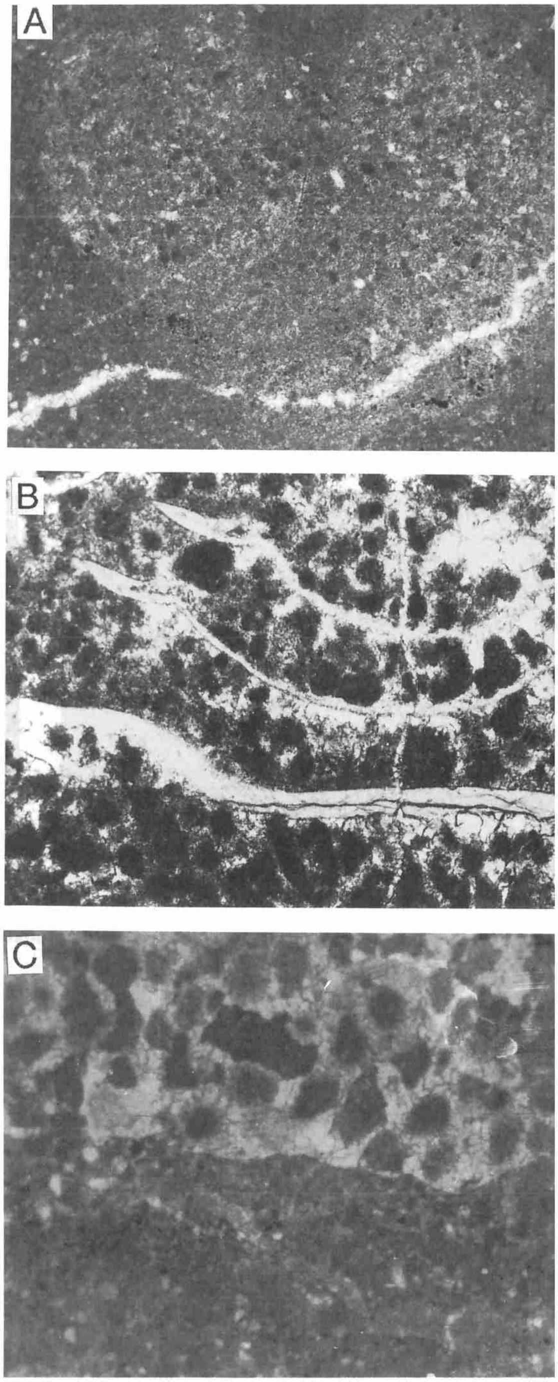


Fig. 4. Thin-section photomicrographs of calcicontourite fa cies. A. Mottled calcilutitic contourite. B. Trilobite fragment in calcarenitic contourite. C. Calcarenitic contourite erosiv over calcisiltitic.

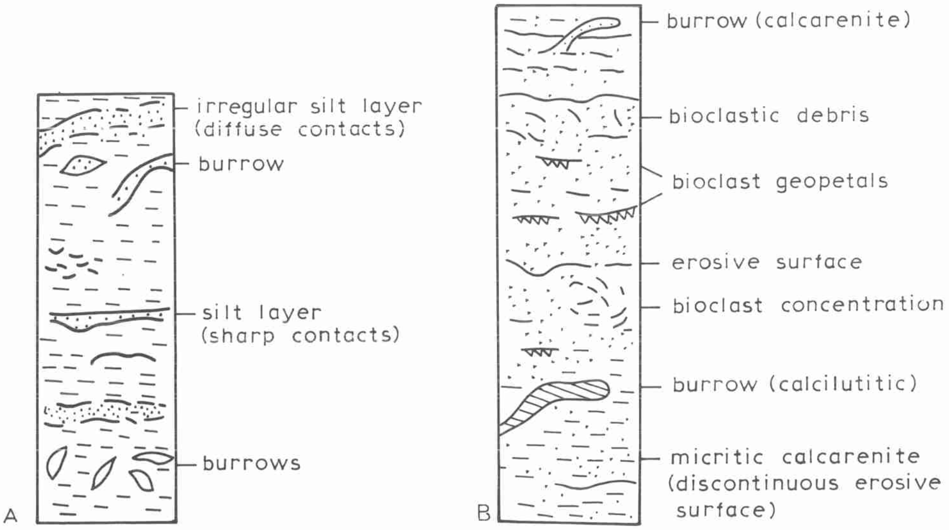
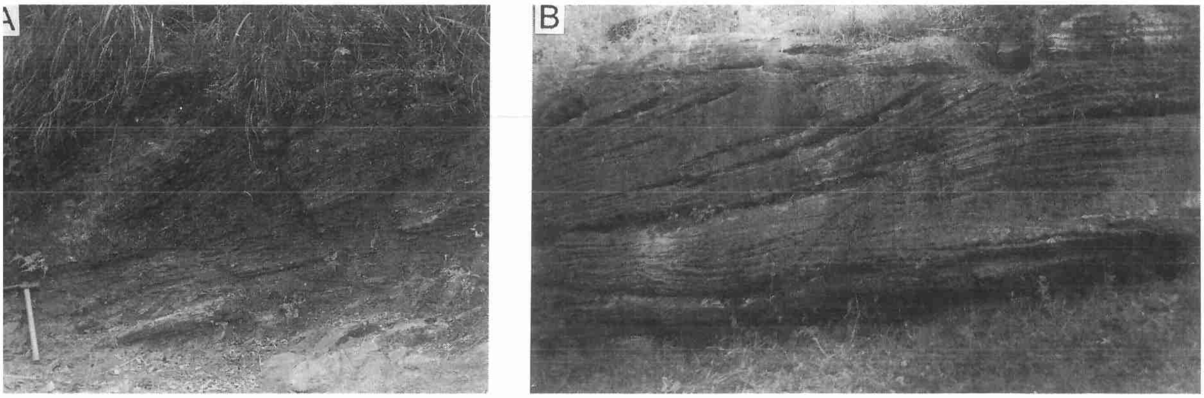


Fig. 5. Typical textures and structures in (A) calcilutitic and (B) calcarenitic contourites.



ig. 6. Large-scale cross-stratification in calcilutitic contourites with (A) simple S-shaped progradational lamination and (B) S-shaped lamination and truncation surfaces.

ABLE 2

rain orientation data for calcarenitic and calciruditic contourites shown by sections parallel to bedding planes, Jiuxi, northern unan

ample No.	Lithology	Grain strike	Notes
y-21-D1	bio-micritic calcisiltite	80°	very evident
y-26-D1	fine bioclastic calcarenite	69°	very evident
y-30-D1	fine calcirudite	80°	very evident
-01p-D5	calcisiltite	78°	less evident
-01p-D6	calcisilt–calcilutite	77°	less evident
-01p-D7(1)	calcisilt–lutite with bioclasts	73°	evident
-01p-D7(2)	calcisilt–calcilutite		no orientation
-01p-D7(3)	calcisilt–lutite with bioclasts	65°	two perpendicular mainly 65°
-01p-D8(1)	fine bioclastic calcarenite	65°	evident
-01p-D8(2)	calcisilt–lutite with bioclasts	68°	two perpendicular mainly 68°
he strike of the palaeoslope		76°	from regional palaeogeography

In this facies, fabric analysis of oriented samples shows very significant current features. On the surfaces cut perpendicular to bedding, long-axes of grains are generally parallel to the bedding. In surfaces parallel to bedding, elongate grains exhibit an evident orientation as shown in Table 2; the long axes in nine out of ten samples collected all display consistent mean orientations of 65–80°, coincident with the strike of the regional palaeoslope (76°) determined from regional palaeogeographic analysis. Perhaps more significant is the fact that in the sections perpendicular to bedding but approximately parallel to the palaeoslope strike (i.e. 95°), there is a very clear imbricate arrangement of grains, which indicates flow direction of palaeo-contour currents along slope from west to east in the area.

In this type of lithofacies, individual beds are several centimetres to tens of centimetres thick, rarely over one hundred centimetres thick. The beds extend laterally with little variation over hundreds of metres. If the small erosive surfaces, which are very common in this facies, are taken as the boundaries of the beds, the bed thickness is several centimetres to tens of centimetres and very irregular laterally. Vertically, there are marked changes of grain size, and both normal (Fig. 2) and reverse grading are very common. The calcarenitic contourite facies tends to occur as distinct intervals within the finer-grained lithofacies, with either transitional or quite abrupt contacts between the two. The top contacts are more often the abrupt ones, which is different from the nature of many turbidites.

Calcisiltitic contourite facies

This facies is intermediate between the two facies described above, and has a generally mottled aspect at first look. Detailed examination shows that the facies consists of an irregular alternation of calcisiltites on a mm- to cm-scale. The boundaries between each lithology range from sharp to gradational, forming irregular mottles and streaks, which, together with distinct burrows, suggest intense bioturbation. Moreover, some ripples (Fig. 2D) can be found in this facies, with a set height of 3–5 cm and inferred palaeocurrent direction of 70–120°. On average, this facies contains 40–60% calcisilts, 2–8% bioclastics and 30–55% micrites. It is almost always associated with calcarenitic and calcilutitic contourites, and forms part of typical contourite sequences (Figs. 2A–2C).

Calciruditic contourite facies

This type of facies is the coarsest found in the area and is quite rare. It is composed of 75% framework grains set in a finer matrix. The former are entirely made up of the micrite intraclasts, with a dominant grain size of 1–6 mm, moderately good sorting and fair to good roundness. Mostly, clasts tend toward a spherical shape; some are plate-like. On the bedding planes, the long axes of elongate grains are aligned parallel to the strike of the palaeoslope (mean 80°, Table 2). In vertical section, most of the grains are parallel to bedding. Some imbricate fabrics have been found showing the westward dip of maximum planes which indicates palaeoflow direction of the current along the palaeoslope from west to east. The matrix, about 25%, is almost completely composed of fine carbonate sands and silts with moderate sorting and a lack of any micrite. Some of the larger gravel clasts have formed geopetal cavities in which silts fill the lower parts of sheltered voids and blocky cements fill the remaining space above.

The calcirudite beds with erosive lower and abrupt upper contacts are lenticular or banded. The lenses are 1–3 m wide across the palaeoslope and they extend up to 4–20 m along the palaeoslope; their thickness ranges from 10 to 20 cm. This type of calcirudite bed might be interpreted as lag sediments deposited in small submarine furrows by contour currents; with the matrix silts and fine sands being deposited in the shelter of larger clasts. However, it is also possible to interpret this facies as of downslope gravity flow origin (i.e. turbidite or debris), although the grain alignment and imbrication would not support this contention.

Bioclastic contourite facies

The composition of this facies is somewhat different from those described above. Bioclastic material forms more than 70% of the total, together with minor carbonate sands, silts and quartz sands, and some 5–10% micrite matrix. The bioclast composition is very mixed, with dominant trilobite and echinoderm fragments. The grain sorting is moderate and state of roundness very variable. The high degree of rounding of some quartz sands indicates long-distance transportation or a long period of reworking of the sands.

Bioclastic beds are lenticular and the diameters of lenses are from 1 cm to over 1 m. The lenses are usually interbedded with calcilutite or bioclastic calcilutite beds. The smaller lenses, 0.8–3 cm thick, generally occur in thicker bands; some cross-lamination can be found in bigger lenses (few centimetres bed thickness). The bottom contacts are commonly erosive and the tops flat or wavy. Based on the features above, the authors suggest that the lenses are formed by the concentration by winnowing of coarser materials during periods of low sediment supply. Although the bioclastic beds are relatively thin, the number of the beds in each band is quite high and they

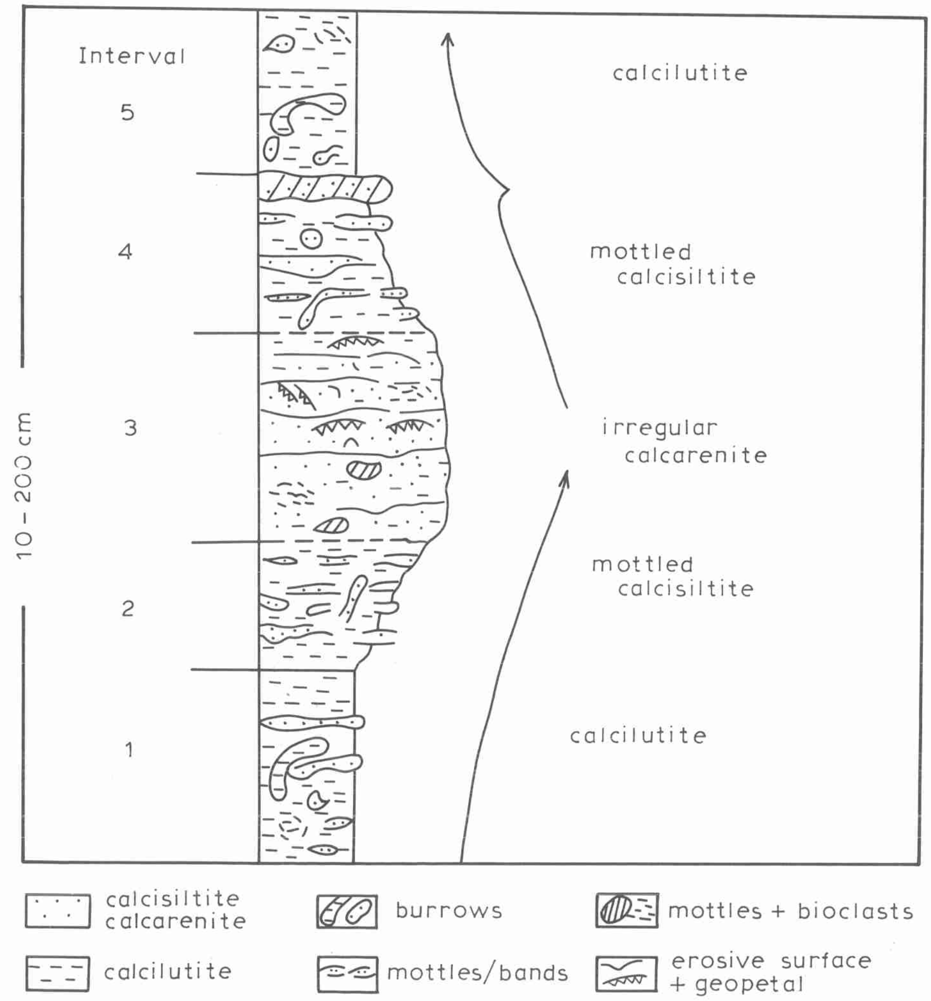


Fig. 7. Typical contourite sequence from the Jiuxi contourite drift.

appear to be the dominant form during periods of weak to moderate contour currents.

Contourite sequences

The present study has demonstrated that the contourite sequence described by Gonthier et al. (1984) is very common in this area. A complete contourite sequence or a characteristic vertical arrangement of the facies (Figs. 2A–2C and 7) is composed of the first three facies above showing a coupled, symmetric, negative and positive grading from top to bottom as follows.

5: Calcilutitic facies. Clear burrows more dominant than bioturbation; calcisilt or silt mottling, streaks or laminae common; irregular mud laminae; small erosive surfaces.

4: Calcisiltitic facies. Alternating irregularly banded, mottled thin calcisilt beds and more muddy beds; bioturbation and burrows common; a few bioclastic geopetal structures; rare ripples.

3: Calcarenitic facies. The coarsest grain size of the sequence; maximum amount of bioclastics; irregular horizontal stratification common; abundant small erosive surfaces; significant coarser-grain mottling, bands or thin beds with local development of big sheltered pores and sparite cements, and so a local increase of sorting, porosity and grain roundness; common mottled muds with different origins; bioturbation more dominant than burrows; chaotic fabric or grain orientation along-slope; frequent grading or inverse grading in grain size.

2: Calcisiltitic facies. Similar to 4.

1: Calcilutitic facies. Similar to 5.

The contacts between any two intervals described above may be gradational, sharp or erosive. The thickness of a sequence is 10 to 200 cm, generally 30 to 80 cm. The complete sequence is quite common in outcrops. Incomplete sequences are also distributed widely; those lacking Interval 4 are the most common, those lacking Intervals 4

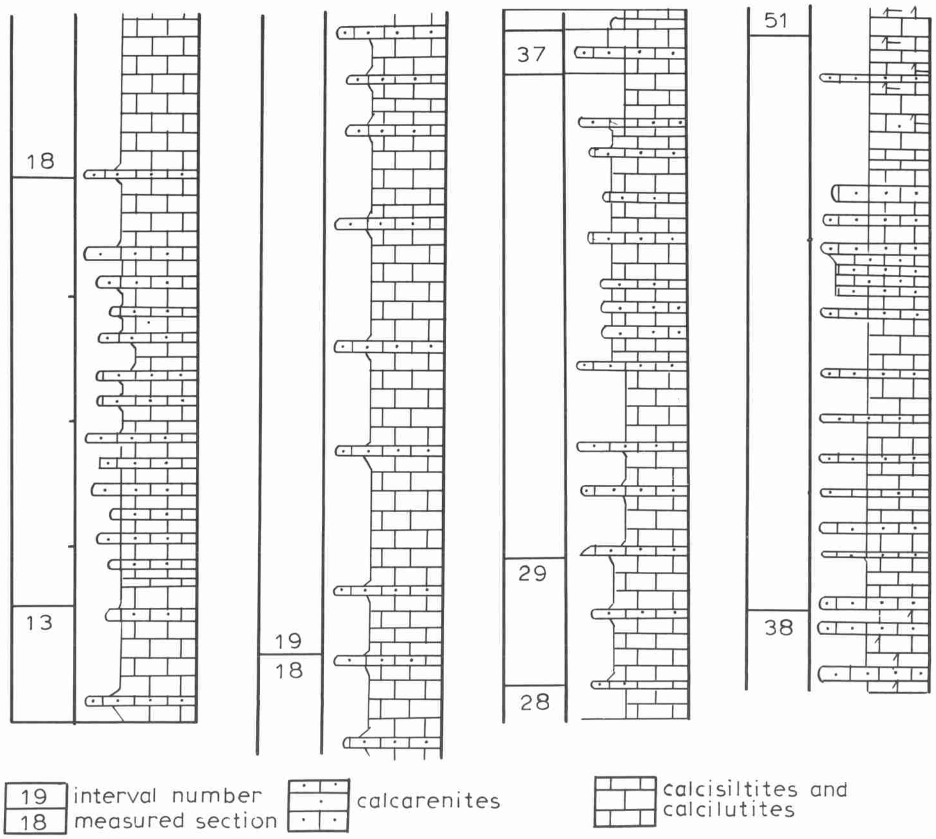


Fig. 8. Vertical section through part of the Jiuxi contourite drift, showing distribution of calcarenitic and calcilutitic contourites.

and 2 are less common, and those lacking Interval 2 are rarely found. All these features are quite different from those of either turbidites or tempestites (e.g. Aigner, 1985).

Evidently, the sequence described above has a completely different hydrological significance from either the Bouma sequence or the tempestite sequence. The Bouma turbidite sequence represents sedimentation from a single short-term event. But in the contourite sequence, thorough bioturbation and burrows, abundant internal erosive surfaces and common features of winnowing indicate slower, more continuous sedimentation under variable current conditions. However, the repetition of the same sequence implies that its formation is controlled by repetition of the same process. The larger grains of the contourites in this area are mainly micrite intraclasts, quite distinct from the observed platform facies. It is therefore most probable that the variation in grain size reflects variation in the strength of currents, but not variation of supply source or other factors.

Therefore, the authors agree with Gonthier and her coworkers in suggesting that the long-term changes of the strength of contour currents may be the direct cause of the formation of such sequences. As the current strength increases, calcilutitic (Interval 1), calcisiltitic (Interval 2) and calcarenitic contourites (Interval 3) develop successively; then, as the strength decreases again, the formation of calcisiltitic (Interval 4) and calcilutitic contourites (Interval 5) is repeated. In the process, any sudden variation of current strength may result in the formation of internal erosive surfaces or grading, or the complete lack of certain intervals from the sequence. The maximum current strength in Interval 3 will favour the transport of coarser grains and the development of sorting and winnowing, which leads to the concentration of bioclasts and the occurrence of higher porosities and subsequent sparite cements. The periodicity of sequence development can be estimated from the Panjiazui Formation. The section measured lasted about 10 Ma (half of Tremadoc), in which 53 sequences (marked by calcarenitic contourites) have been found; this gives an average periodicity of one sequence every 200,000 years. The average sedimentation rate for the thicker part of the Jiuxi drift is 3.8 cm/1000 years.

Vertical pattern and geometry of the contourite drift succession

Comparable with the formation of submarine fans by turbidites, contourite drifts can be formed by the accumulation of contourites over long periods of time. We suggest that the section measured in the area represents part of a contourite drift that was constructed during the early Lower Ordovician (Tremadoc), based on two important facts: the vertical pattern and the geometry of the succession studied. We have called this the Jiuxi drift.

Vertical pattern of the succession

The succession studied (Panjiazui Formation and lower part of the Madaoyu Formation) in which the above-described contourites occur is 380 m thick in the measured Baiyan section in Jiuxi. Within the Panjiazui Formation, the calcarenitic contourites constitute 10.7% of the section, calcisiltitic contourites at least 21.4%; the gravity flow deposits coarser than silt size, about 6%; and the other facies, including calcilutitic contourites, fine-grained turbidites, pelagites and hemipelagites, together make up about 61.9%. Most of these fine-grained facies we interpret as contourites, based on the criteria proposed by Stow and Lovell (1979) and Stow et al. (1986), despite the admitted difficulties in distinguishing precisely between fine contourites, very low density turbidity current deposits and pelagites or hemipelagites. It is clear, therefore, that contourites are the most abundant facies in the succession studied. In addition, the contourite sequences are almost uniformly distributed throughout the succession at approximately 3–4 m intervals (Fig. 8), with the coarser-grained calcarenitic units separated by the finer but thicker calcisiltitic and calcilutitic contourite beds. Overall, the succession shows no coarsening- and thickening-upwards or fining- and thinning-upwards megasequences, as commonly observed in turbidite successions.

Lateral distribution of the succession

The succession studied is located in the deep-water region in front of the carbonate platform in an area equivalent to a present-day continental rise or lower slope apron (south of the two 300 m isopach lines as shown in Fig. 9). The latera distribution of facies in the succession provide important evidence to support the proposed existence of the Jiuxi contourite drift. The latera variation in thickness of the whole of the lowes (Tremadoc) Ordovician (Fig. 9, upper part) quit clearly shows the geometrical characteristics of contourite drift. It is an east–west-trendin ridge-shaped sediment body, extending along th

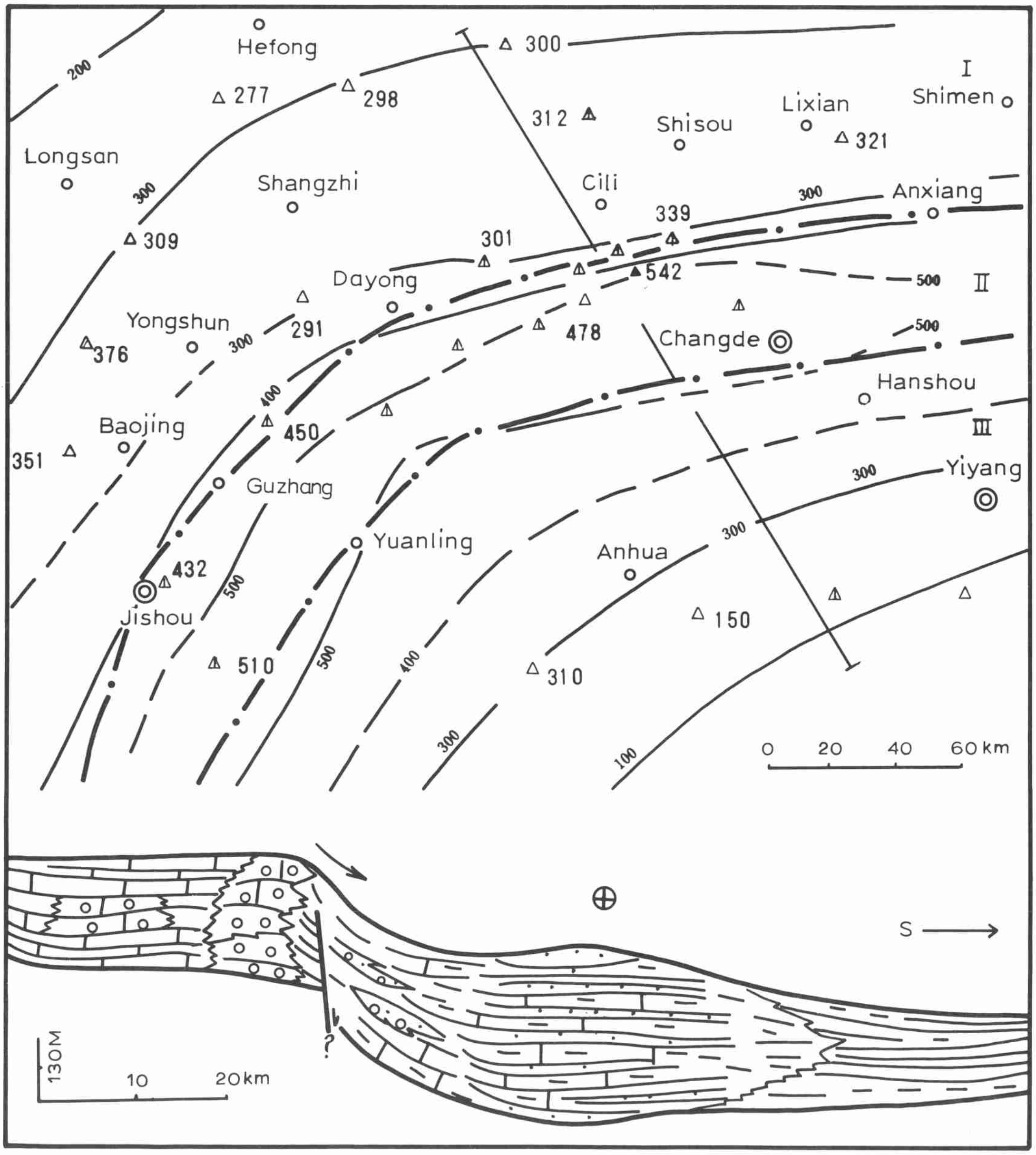


Fig. 9. Isopach map of the Panjiazui and Madaoyu Formations (Tremadoc), together with a reconstructed cross-section across th palaeocontinental margin.

alaeocontinental slope. At present, it is difficult trace the whole shape of the contourite drift ccession alone, which includes only the lower art of the Lower Ordovician (less than remadoc), because of the limits of the outcrops nd the lack of the precise correlation for the ower Ordovician in the area. Nevertheless, the ariation of regional lithofacies from platform to asin can be quite precisely reconstructed as own in the lower part of Fig. 9. To the north y a carbonate platform, characterized by the evelopment of bank calcarenites, oolitic limeones and bioclastic limestones, about 250 m ick. In the central part (on the presumed alaeoslope) the contourite drift developed, composed of various contourite facies together with me gravity flow deposits, pelagites and emipelagites, generally 350–450 m thick in total. urther south was a basin plain dominated by ales, about 200 m thick. This variation is quite ifferent from that of the Middle and Upper ambrian in the same region, which was domiated by gravity flow deposits (Gao and Duan, 85).

In summary, the succession studied is compable with those of known modern and ancient ntourite drifts in terms of the regional setting, thofacies, vertical section pattern, and geometry. is similar in many respects to the modern rbonate contourite drift identified by Mullins et . (1980) off Florida, and to the Cretaceous alme Yafe Formation and the equivalent strata at the continental margin of the Arabian craton (Bein and Weiler, 1976), which is one of the very few cases of contourite drift deposits recognized in the rock record to date (Stow and Holbrook, 1984; Pickering et al., 1989).

Evolution and sedimentary model of the Jiuxi contourite drift

Considering the chronology of various contourite occurrences and their proportions in the section, particularly the relative abundance of easily identified calcarenitic contourites, we suggest three stages for the evolution of the Jiuxi contourite drift.

(1) Rudimentary stage. Previous work has shown that the study area was in a deep-water environment dominated by gravity flow sedimentation in the Middle and Upper Cambrian. Some distinct contourites can, however, be identified in the top of the Upper Cambrian Shengjiawan Formation. In the basal part of the overlying Panjiazui Formation, the proportions of calcilutitic, calcisiltitic and, especially calcarenitic contourites increase upwards, and become dominant from about 50 m up from the base. The Jiuxi contourite drift therefore became established in the earliest Ordovician.

(2) Mature stage. The major part of the Jiuxi contourite drift was formed during the deposition of the Panjiazui Formation (early Tremadoc). The stage was characterized by: (a) abundant con-

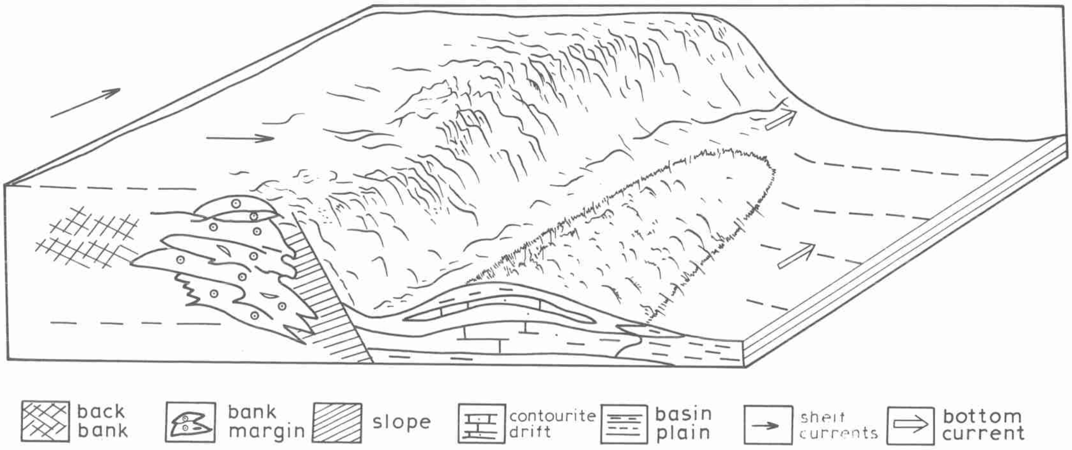


Fig. 10. Model of the Jiuxi carbonate contourite drift.

tourites of different types with dominant calcilutites; (b) coarse-grained contourites (calcarenitic) distributed at intervals of 3–4 m throughout the section; and (c) abundant burrows, bioturbation and identifiable trace fossils.

(3) Declining stage. Contour current activity decreased markedly during deposition of the lower Madaoyu Formation (late Tremadoc). In this stage, calcarenitic contourites greatly decreased in abundance, whereas pelagites or hemipelagites increased notably; the common development of small lenticular bioclastic contourites represented the general lack of sediment supply. During deposition of the upper Madaoyu Formation (the latest Tremadoc) typical contourites were almost completely absent and were replaced by fine-grained mudstones. Therefore, it can be concluded that the Jiuxi contourite drift came to an end at this time. The sedimentary model of the Jiuxi contourite drift, shown in Fig. 10, represents the case of the drift at its mature stage.

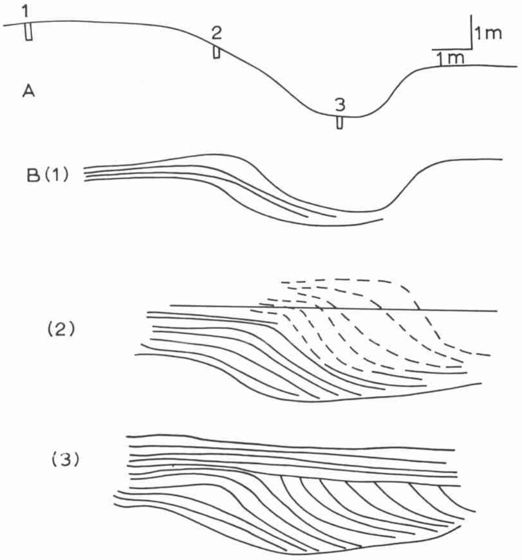


Fig. 11. A. Cross-section of a submarine furrow in which the deposition rates are greatest on the flank (*2*), intermediate on the left crestal portion (*1*) and least in the axis (*3*) (originally from Flood and Hollister, 1980). B. The formation of large-scale cross-stratification as a result of lateral migration and eventual filling of a submarine furrow.

Origin of large-scale cross-bedding in cohesive sediments

It is well known that various types of cross-bedding are common in granular sediments. However, we have found large-scale cross-stratification in cohesive fine-grained sediments (calcilutitic contourites), whose features have been described above. It seems evident that they are primary current-induced sedimentary structures because of the clear sigmoidal convergence of their sets, and the lack of difference in lithology between cross-beds and overlying/underlying beds. They appear too regular and without an obvious truncation surface to be of slump origin. Their origin as a cross-cutting tectonic fabric picked out by differential compaction and dissolution does not appear compatible with the surrounding strata.

A number of seafloor surveys carried out in areas of ocean under the influence of bottom currents has shown that both depositional bedforms such as mud waves and erosional furrows are commonly formed in cohesive fine-grained sediments (Lonsdale and Spiess, 1977; Flood and Hollister, 1980). The scale of such features (10–20 m wavelength/1–2 m amplitude for mudwaves and 0.25–3 m floor width/2–10 m height for furrows) is comparable with the cross-beds observed in this study.

It is therefore believed that the simpler cross-beds (Fig. 6A) were formed by downcurrent migration of mud waves, whereas the more complex cross-beds with internal truncation surfaces (Fig. 6B) were formed by a process of aggradation and lateral progradation of seafloor furrows across the path of current flow (Fig. 11).

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