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THE LOSHUI FORMATION: DEEPER-WATER SANDSTONES ON THE HENGCHUN PENINSULA, SOUTHERN TAIWAN

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(With 4 text-figures and 6 plates)

ABSTRACT

A thick sequence of sandstones and turbidites of the Loshui Formation, exposed on the eastern coast of the Hengchun Peninsula, exhibits distinctive sedimentary structures of submarine fan deposit, and bears trace fossils of deep-sea community. The fine- to medium-grained sandstones show well parallel lamination throughout the most of compositive beds, while the turbidities generally show incomplete Bouma sequence. Channeling and dish structures are frequently observed in the bottom and middle part, respectively, of the thick and massive sandstone beds. Flute casts, grading, ripple marks, frondescent marks and loading structure the sandstone beds. The sandstone sequence could be correlated with the B facies of Mutti & Lucchi (1972) recognized in the fossil basin of submarine fan deposition, or the middle fan with suprafan sand lobes of the modern deep-sea fan of Normark (1978). The turbidites of the interchannel or levee deposits originally belonging to the D, E and G Facies have slumped as the F facies, and are conformably intercalated with the B facies sandstones.

Deep-water trace fossils of the *Nereites* community are observed in the Loshui Formation. Systemical measuring the vectors of flute casts shows that the direction of paleocurrent is from south to north.

INTRODUCTION

The Late Miocene Loshui Formation is exposed on the eastern coast of the Hengchun Peninsula, southern Taiwan (Fig. 1). The lithology of this formation is predominantly composed of fine- to medium-grained sandstones and subordinately flyschoid turbidites. The total thickness of the Loshui Formation is estimated about 1000 meters (Fig. 2).

In southern Hengchun Peninsula, the sedimentologic studies of the Late Miocene formations, except the Kenting Formation, have been neglected for more than five decades since Rokkaku & Makiyama (1934) investigated the general geology of this area. Even for the Kenting Formation, discrepant opinions about its sedimentologic setting were emerged in the recent literature (Tsan, 1974; Biq, 1977; Page & Lan, 1983; Cheng *et al.*, 1984 a, b). Based on the lithological affinity, the sandstone sequence of the Loshui Formation has been correlated with, or even mapped as, the Nanchung Formation, an upper coal bearing formation in northern Taiwan. (Tsan, 1974; Keng, 1974). To them the Loshui Formation seems to be deposited in a shallow water, littoral to lacustrine environment as that of the Nanchung Formation was.

In the summer of 1983, the present authors investigated the continuous exposures of the Loshui Formation between Chialoshui and Chiuping for several times. Some distinctive sedimentary structures of proximal turbidities and deep-sea trace fossils belonging to the *Nereites* assemblage (Seilacher, 1964) have been observed. These sedimentary structures

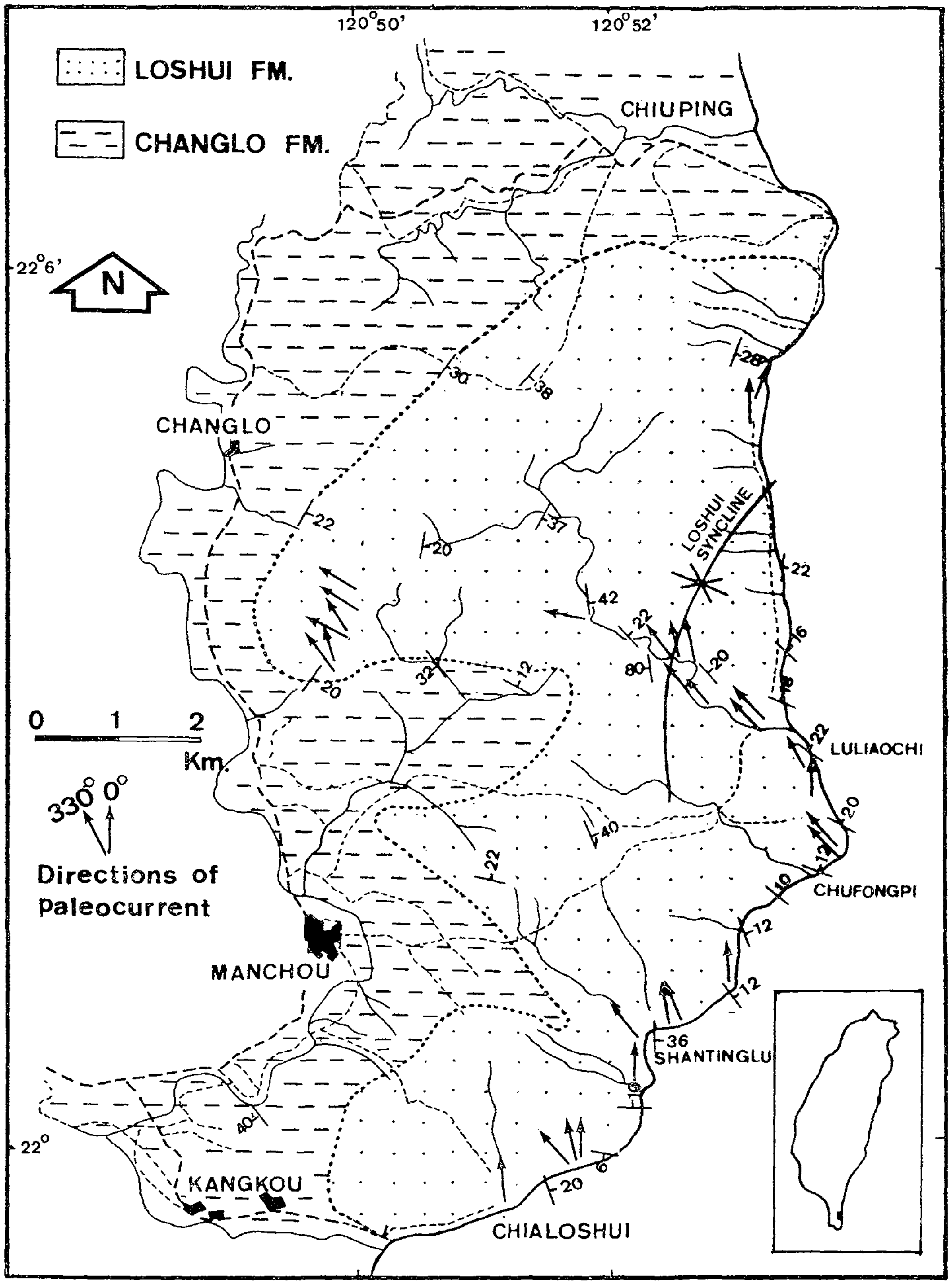
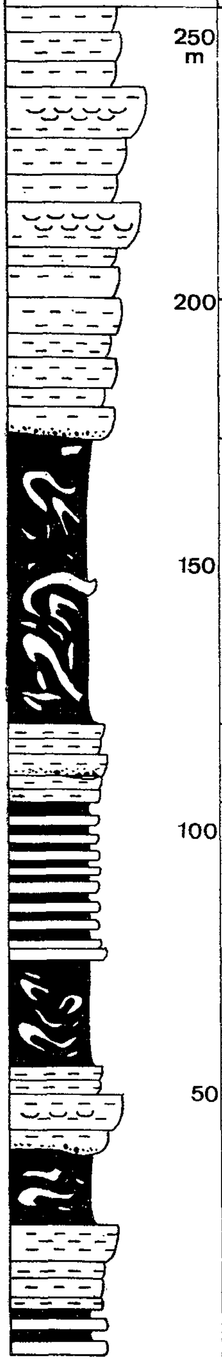


Fig. 1. Geologic map of the Loshui Formation on the eastern coast of the Hengchun Peninsula showing also the direction of paleocurrent.



thickness (m)	Facies	Sedimentary structures	Bed characters	sand/shale	Current direction	Trace fossils	physiographic region of fan
55	B	parallel lamination thick to massive dish structure crenent-ripple flute cast	each bed 1 — 5m	$\gg 1$			suprafan
25	B(C)	Bouma Tbae Tbcde Tabde ripple marks flute marks dish structure massive s.s. scouring	each bed 0.7–5 m thinning upward fining upward	$\gg 1$			suprafan
55	F	slumping	original D. E. G. facies				levee interchannel
15	B(D)	parallel lamination channlling	each bed 0.2 – 3m	1			suprafan
30	E (D)	Bouma Tcde Tbcde ripple marks Tae. pinch-and swell lenticular bedding	each bed 10 – 20 cm	1 : 1			levee
20	F	slumping	original E. D. facies				levee interchannel
15	B(D)	massive s. s. dish structure channeling	thinning upward fining upward	$\gg 1$			suprafan
15	F	slumping	original D.E.G. facies				interchannel
24	B(D)	Bouma Tbcde Tbde current-ripple parallel lamination	coarsening upward	$\gg 1$	1°		suprafan

Fig. 2. Geologic column of the Loshui Formation.

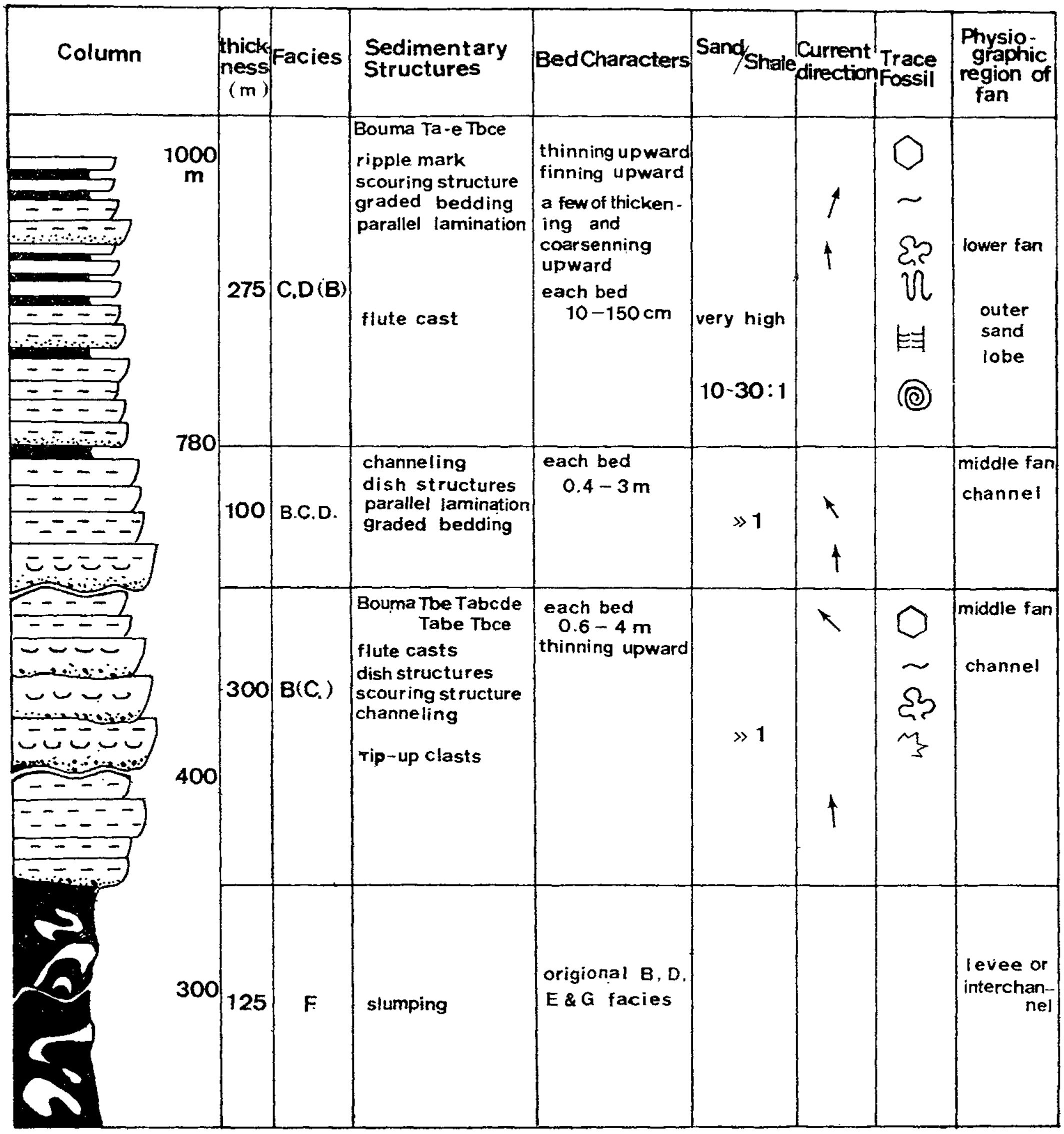


Fig. 2. Continued.

and trace fossils indicate that the Loshui Formation was deposited through a deep-sea submarine fan at the base-of-slope setting rather than in a shallow-water or lacustrine environment.

The purposes of this paper are to demonstrate the prominent sedimentary structures, trace fossils and the direction of paleocurrent of the Loshui Formation in order to understand better the sedimentological settings of the Hengchun Basin.

STRATIGRAPHY

The Loshui Fromation was named by Tsan (1974) for a sandstone predominant unit conformable to the underlying Changlo Formation and the overlying Kenting Formation.

This formation was mapped to be distributed in the following three areas: stratotype between Chialoshui and Chiuping, the peak of Ssulinshan in the north of Manchou, and the Lilungshan area in the north of Hengchun (Tsan, 1974, Fig. 1)

The sandstone strata of the Loshui Formation in the type section have strikes varing from N70° W to N40° W with gentle dipping to northeast in the south of the Loshui syncline, whereas in the north of syncline, the strike varies from N45° E to N4° E with 28° to 35° dipping to the southeast (Fig. 1). The top of the Loshui Formation could not be observed due to folding, conseqently, the stratigraphic relation between the Loshui Formation and the overlying formation is not clear. The Loshui Formation rests conformably on the massive shale of the Changlo Formation as observed in the several gullies in the east of the Manchoushan and in the Chiuping area (Fig. 1).

In Tsan's map (1974, Fig. 1), the conformably stratigraphic relationship between the Loshui Formation and overlying Kenting Formation was established from the stratigraphic sequence observed in the Li-lung-shan area. However, based on our current field observations and sedimentologic study (Cheng *et al*,. 1984a), both the sandstones of his Loshui Formation and Kenting Formation in the Lilungshan area were deposited through a southward submarine fan. This phenomenon is quite different from the type Loshui Formation deposited through a northward submarine fan, as described in paleocurrent section below. Meanwhile, the lithology of the sandstone and pebbles in the Lilungshan area and in the Loshui Formation also show somewhat different. The Lilungshan sandstone contains a lot of quartzite and schist pebbles, whiles, the metamorphosed pebble seems lacking in the type Loshui Formation. Therefore, we insist that the sandstones exposed in the Lilungshan area are discriminable from the typical Loshui Formation, and the stratigraphy in the Lilungshan area has to be restudy in future (Cheng *et al*., 1984b). Based on field observations and sedimentologic study, we favore the facies changing rather than conformable superposition between the Loshui Formation and Kenting Formation.

GENERAL LITHOLOGY OF THE LOSHUI FORMATION

The Loshui Formation is composed predominantly of fine- to medium-grained, parallel laminated to massive sandstones with subordinate of thin turbidites varing from several millimeters to tens of centimeters in thickness. Except some shallow-water mollusks like *Dentalium* and *Ostrea* fragments observed in two conglomerate beds in the upper part of the Loshui Formation, no megafossil has been found in the type section. Carbonaceous materials are frequently present at the bottoms of some thin paralleled sandstone layers. These carbonaceous materials and shallow-water mollusks are transported from shelf to the deeper depositional site through the submarine channels.

SEDIMENTARY STRUCTURES

The Loshui Formation as observed in the type section along the coast from Chialoshui to Chuiping and some gullies in between exhibits some prominent sedimentary structures, such as the parallel lamination, dish structures, channeling, convolution, loading, flute casts, slumping, ripple marks, frondescent marks, etc. Among these structures, some of characteristic features which are vital to evaluating the sedimentological setting of the Loshui Formation are briefly described as below:

Parallel Lamination

Parallel lamination is the most prominent sedimentary structure throughout the most of compositive sandstone beds in the Loshui Formation (Pl. I, fig. 1). The interval between laminated layers is usually several centimeters to few millimeters, and siltstone or fine sandstone is served as the diffused laminae. Such compositive sandstone beds usually have bed thickness less than 1.5 meters, the thicker beds are bearing dish structures as described below.

Parallel lamination is the most characteristic features in the B facies (Mutti & Lucchi, 1972) of the middle fan or suprafan deposits (Normark, 1978).

Dish Structures

Dish structures were first named and described by Wentwroth (1967) from the Gualala Formation in California. This structure is characterized by a series of cancave-up patterns of faint lines for 5–50 cm long, 1–5 cm thick, and oriented parallel with bedding increasing cancavicity upward. Dish structures are observed only in the coarse- and medium-grained sandstone for more than 1.5 meters thick in the Loshui Formation. Neither convoluted cross-bedding nor diffused laminae has been found beneath or above the dish structures (Pl. II. figs. 2, 3 & 4). The dish structures observed in the Loshui Formation are confined to the lower-middle part of the massive sandstone (Pl. II. fig. 2), similar to what Wentworth (1967) and Stauffer (1967) have described from other deep-sea sandstones. Pillars are observable when the rims of neighboring dish extend into verticle position.

Dish structures are resulted from postdepositional dewatering process (Stauffer, 1967; Corbett, 1972; Middleton & Hampton, 1973; Lowe & Lo Piccolo, 1974). They could occur in different depositional environments, including delta, fluvial channel, lacustrine (Nilsen *et al.*, 1977). However, dish structures are mostly reported from turbiditic sequence, especially deep-sea sandstones of submarine fan deposition (Hubert *et al.*, 1970; Chipping, 1972; Mutti & Lucchi, 1972; Crimes, 1977; Vedros & Visher, 1978; Link & Nilsen, 1980).

Channeling

Channeling is an erosional relief along the margins and floor of channels. Some channeling for about 2 meters in height and over 20 meters in width are observed in the

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Explanations of Plate I–VI

Pl. I. fig. 1. B facies sandstones exposed near Chu-fong-pi.
fig. 2. D facies turbidies exposed in the Luliaochi.
fig. 3. Channeling observed in the middle part of the Loshui Formation near Chu-fong-pi.

Pl. II. Sedimentary structures in the Loshui Formation.
fig. 1. Frondescent marks at the bottom of massive sandstone bed, current from south to north, top to bottom of figure.
fig. 2. 3 and 4. Dish structures in the middle part of a thick sandstone bed.

Pl. III. figs. 1 & 2. Slumpling structures in the turbidites.
fig. 3. Slumping in a thick sandstone of the Loshui Formation.

Pl. IV. fig. 1 & 3. Trace fossil *Scolicia* in the turbidite of the Loshui Formation.
fig. 2. Trace fossil *Cosmorhaphe* (Natural size).
fig. 4. Rip-up-clasts confined in the lowest part of thick sandstone beds of the Loshui Formation.

Pl. V. Trace fossils in the Loshui Formation (all natural size)
fig. 1. *Sublorenzinia*; fig. 2. *Helminthopsis*; fig. 3. *Cosmorhaphe*;
fig. 4. *Urohelminthoida*; fig. 5. *Chondrites*; figs. 6 & 7. *Paleodictyon.*

Pl. VI. Trace fossils in the Loshui Formation
fig. 1. *Spirodesmos*; fig. 2. *Cosmorhaphe* (Nature size)
fig. 3. *Planolite* (center) and *Paleodictyon* (in lower left corner)
fig. 4. *Paleodictyon* and *Planolite* (center)

bottom of some thick to massive sandstone beds of the Loshui Formation (Pl. I, fig. 3). Such a dimension of channeling is typically made by a small active channel on valley floor in the upper fan or the distributary channel developing on active suprafan (Normark, 1978; Walker, 1978; Howell & Normark, 1982).

Slumping

Slumping structures with internal deformation are the most distinctive features of the thin turbidites, which originally might belong to D, E or G facies of Mutti & Lucchi (1972) in the Loshui Formation (Fig. 2). With increasing the intensity of slumping, the thin turbidites exhibit structures from slight deformation to moderate slumped folding, or even completely distrupted, strongly sheared and reoriented slumped blocks looking like the chaotic occurrence as the F facies of Mutti & Lucchi (1972). Some thick sandstones also show slumping structure either in their upper part or in their lower part, in which convolution and truncation features are observed (Pl. III, fig. 3).

Slumping is the characteristic features of the turbidites piled up on the continental slope to base-of-slope settings due to the unstability on such steep slope. In the fossil submarine fan basins, the slumping and channeling features were frequently reported in upper fan and middle fan deposits (Mutti & Lucchi, 1972; Lucchi, 1975; Cook *et al.*, 1982).

Grading, Ripple Marks, Flute Casts and Frondescent Marks

Grading is one of the characteristic sedimentary structures in turbidites (Bouma, 1962). The channelized thick to massive sandstones frequently exhibit grading feature starting from the conglomerate size of rip-up clasts at the bottom, then succeeded by the coarse-grained sandstone and the medium sandstone on the top (Pl. IV, fig. 4).

Flute casts observed at the bottoms of the sandstone layers show well parallel in orientation. The systematical measurements of the flute casts disclose that the direction of paleocurrent is from south to north. The meaning of these measurements will be discussed in the following section.

Ripple marks and frondescent marks are observed on the top and at the bottom of the sandstone beds respectively. The radiated forms of frondescent marks at the bottom of some sandstones also show the direction of current is from south to north (Pl. II, fig. 1) similar to what is measured by flute casts and micro-cross-lamination.

TRACE FOSSILS

Trace fossils are the behavioural responses of animals. Such responses are mainly controlled by four factors: energy regime between the interface of sediments and water, depositional rate, lithology of the substratum and food availability. These four factors are more or less controlled by water depth. Since the trace fossils are all *in situ*, therefore, the assemblage or community of the trace fossils could indicate the water depth.

Based on studies of trace fossils in various lithology and sedimentological settings, Seilacher (1964, 1967) was able to recognized four main depth controlled trace fossil communities and correlated them with sedimentological settings throughout the Phanerozoic. These four communities are, *Glossifungites-Skolithos* (littoral zone), *Cruziana* (littoral zone to wave base), *Zoophycos* (wave base to turbidite zone) and *Nereites* (bathyal, turbidite zone). Kaiazkiewicz (1970) classified flysch trace fossils into nine groups. In the most proximal, spreiten trace are common, while in progressively more distal facies, first rosetted and winding trace predominate, and is followed by abundant meandering and patterned forms together with common winding trace. Such a trend as depth increases, the trace fossils gradually change from spreiten to rosetted, then winding and meandering forms and last patterned forms have been reported from many ancient turbidite basins (Crimes, 1970, 1973, 1978; Chamberlain, 1971).

The trace fossils (inchnogenera) observed in the Loshui Formation are shown in Fig. 3, and are listed as follows, according to their abundances (increasing upwards):

Paleodictyon	(Pl. V, figs. 6 & 7; Pl. VI, figs. 3 & 4)
Scolicia	(Pl. IV, figs. 1 & 3)
Chondrites	(Pl. V, fig. 5)
Spirodesmos	(Pl. VI, fig. 1)
Cosmorhaphe	(Pl. IV, fig. 2; Pl. V, fig. 3; Pl. VI, fig. 2)
Heminthoida	
Planolite	(Pl. VI, figs. 3 & 4)
Belorhaphe	
Sublorenzinia	(Pl. V, fig. 1)
Urohelminthoida	(Pl. V, fig. 4)
Helminthopsis	(Pl. V, fig. 2)

The inchnogenera listed above indicate that the trace fossils observed in the Loshui Formation could be correlated with the *Nereites* assemblage of Seilacher (1964, 1967) recognized in the distal turbidite basin.

SEDIMENTOLOGICAL SETTING

Based on the lithology, sedimentary structures and trace fossils, the Loshui Formation is interpreted to deposit in a middle fan including suprafan setting on continental slope to base-of-slope above CCD depth. In the modern submarine fan environments, the middle fan is a site of rapid sand deposition, on which small distributaries are developed as recorded in seismic reflection profile, and this is also true in the geology past shown in the thick channelized sandstone beds of fossil submarine fan deposition (Mutti & Lucchi, 1972; Howell & Normark, 1982).

Nereites trace community has been recognized from the Eocene middle fan deposits of the Monte Jaizkibel fan, northern Spain (Crimes, 1973). Among the trace fossils found in the Loshui Formation, *Spirodesmos* and *Heliminthopsis* have been photographed in modern deep-sea at 3500 meters and 4000 meters respectively (Hulsemann, 1966; Bourne & Heezen, 1965). Whereas *Chondrites* and *Planolites* have world records from 1555 to 6243 meters and from 1151 to 6243 meters, respectively, in the deep-sea cores (Ekdale, 1977).

PALEOCURRENT

Since the turbidites were interpreted as formed by the turbidity current, the study of paleocurrent soon became one of important tools in understanding the source and transportation of terrigeneous materials to the basin (Potter and Pettijohn, 1963). Among the current directional indicators, flute cast is one of the most useful tools in studying the vector of paleocurrent. Flute casts are well preserved at the bottoms of sandstone beds of the Loshui Formation, therefore, their vectors are measured in this study. However, flute casts are poorly preserved in the sequence exposed south of Shantinglu. Consequently, the direction of sharp "V - forms" of micro-cross-lamination (Hamblin, 1961) is measured for the sandstones exposured in the south of Shan-ting-lu and the vector of flute casts is measured wherever possible (Fig. 4).

The azimuthal vector of 1250 readings of flute casts at 57 localities is between 290°-20° with the two high frequency at 330° and 360°, and has a mean at 310°, whileas the vector

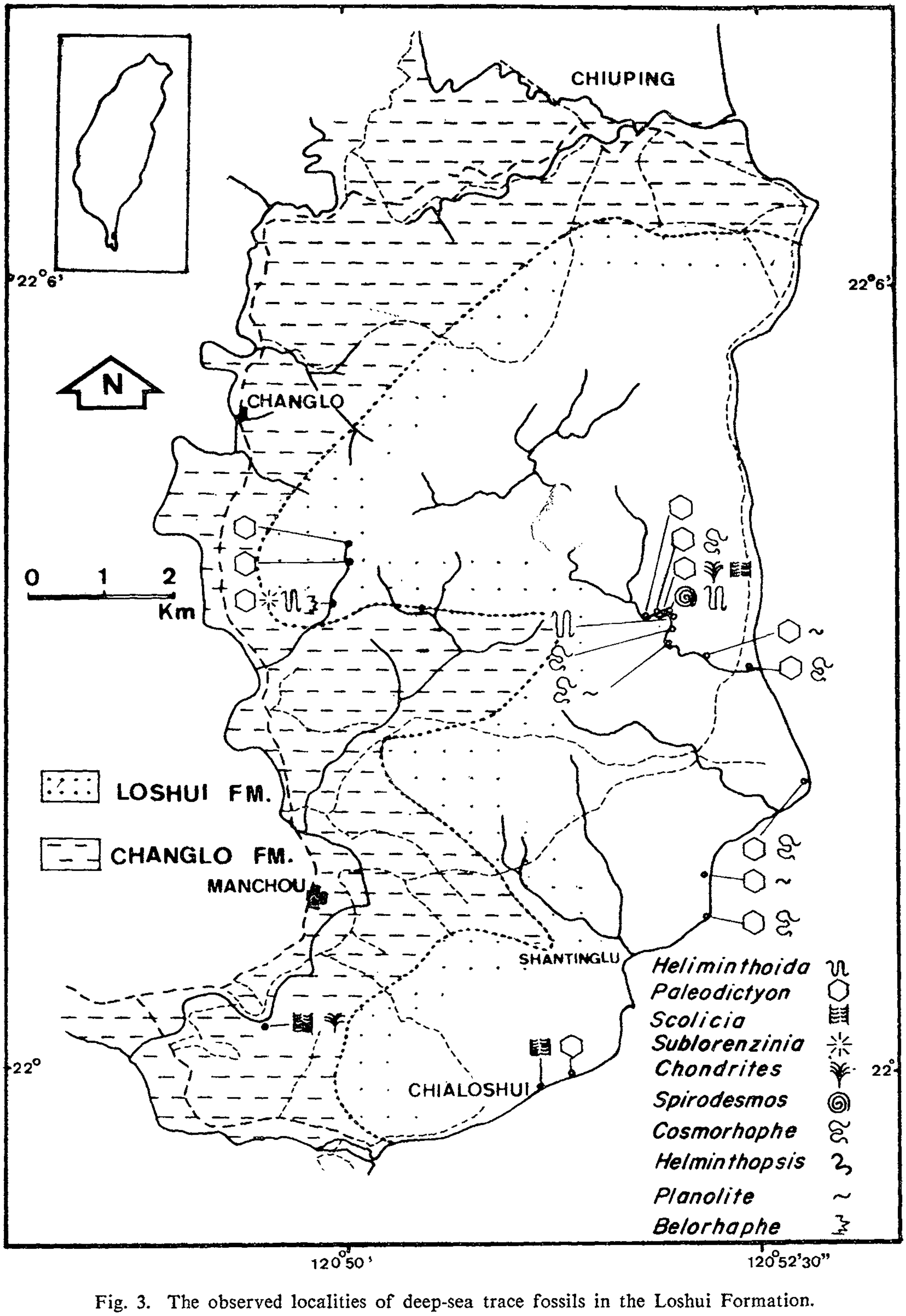

Fig. 3. The observed localities of deep-sea trace fossils in the Loshui Formation.

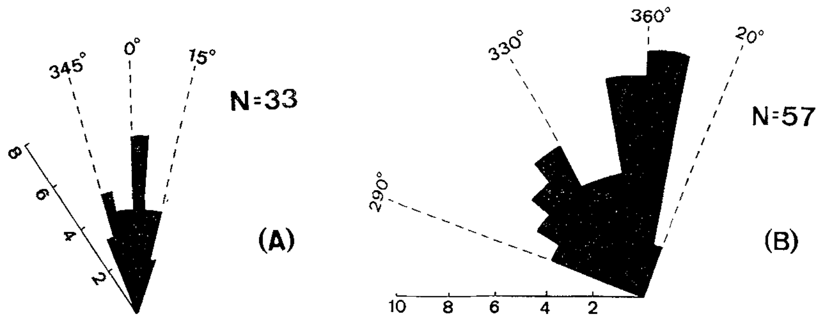

Fig. 4. Paleocurrent measured by (A) micro-cross-lamination and (B) flute casts in the Loshui Formation.

of micro-cross-lamination is between 340°-20° with a mean of 3° (Fig. 4). Both data show that the direction of paleocurrent of the Loshui Fomation is from south to north.

DISCUSSION

There are two alternative interpretations for the south-to-north paleocurrent in the Loshui Formation: 1) existing a S to N contour current along the continental slope, or 2) existing of a landmass or ridge south to the present Hengchun Peninsula as the source of the Loshui Formation. Both the reasonings have their own unsolvable difficulties. Firstly, if the northward flute casts were produced by a S→N contour current, along the continental slope, the southward paleocurrent observed in the sandstone at the Lilungshan area, now just about 12 Km east of the type Loshui Formation, would contradict the assumption that the northward flute cast were formed by a S→N contour current. Secondly, if there was a landmass or ridge south to the present Hengchun Peninsula as the source of the Loshui Formation, where is this landmass now? Could the landmass be the outer-sedimentary arc of the Manila trench-arc system? Further sedimentological studies including an analysis of heavy mineral composition and petrological study between the sandstones in the Lilungshan area and the Loshui Formation might help for better understanding the meanings of the two different systems of paleocurrents in the Hengchun Basin.

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節　　要

恒春半島東部沿佳樂水一帶海岸出露的樂水層具有明顯的深海冲積扇沉積構造，及深海相生痕化石組合。一般中粒至細粒砂岩層呈現平行疊置，而砂、頁岩互層之濁流岩保有完整或不完整之波馬層序。厚層砂岩之底部常有深海河道槽構造，而中部則有碟狀構造。其他尚有流槽鑄型、波痕、複葉鑄型、荷重鑄型和級層等沉積構造。基於砂岩中之沉積構造，樂水層之砂岩層序可與穆提、露奇(1972)於已出露之深海冲積扇沉積物中所定義的B相或諾馬克（1978）於現代深海冲積扇之中扇砂舌沉積相相對比，而樂水層中之原來可能屬D、E與G相深海河道區或河道堤脊沉積之濁流岩，因發生海底崩移，部份呈現大規模崩移沉積構造，可與穆堤、露奇（1972）之F相相對比。這些F相濁流岩均整合夾於B相砂岩層序間。

樂水層遍保存有深海相 *Nereites* 生痕化石組合。由生痕化石組合及沉積構造可以確認樂水層仍是在大陸斜坡至大陸斜坡底部沉積，又因含有鈣殼質有孔蟲化石，故應在碳酸鈣補償深度之上。

系統性量度樂水層砂岩底部流槽鑄型等古水流指標，顯示當樂水層沉積時，古水流水向是由南向北。