Slope apron deposits of the Lower Jurassic Los Molles Formation, Central Chile

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ABSTRACT

The Lower Jurassic Los Molles Formation in central Chile (32°15'S/71°30'W) is a 765 m thick succession of fine-grained clastic marine sediments. The mud-dominated succession was deposited below wave base by contour and turbidity currents. Deposition occurred on the steep, uneven and unstable slope apron of a small transtensional pull-apart basin. This basin formed in the fore-arc region of an active continental margin.

Key words: Central Chile, Lower Jurassic, Los Molles Formation, Turbidites, Contourites, Slope apron, Transtensional pull-apart basin.

RESUMEN

Depósitos de 'abanico de talud' de la Formación Los Molles del Jurásico Inferior en Chile central. La Formación Los Molles, del Jurásico Inferior, y expuesta en Chile Central (32°15'S/ 71°30'W), es una sucesión marina de 765 m de espesor de rocas sedimentarias clásticas de grano fino. La sucesión es predominantemente pelítica y fue depositada por debajo del nivel base del oleaje, por corrientes de 'contour' y turbidíticas. La acumulación tuvo lugar en una pendiente alta, irregular e inestable, de una reducida cuenca transtensional ('pull-apart'), conformando un 'abanico de talud' ('slope apron'). Esta cuenca se habría localizado en la zona de ante-arco de un margen continental activo.

Palabras claves: Chile Central, Jurásico Inferior, Formación Los Molles, Turbiditas,'Contourites', 'Abanico de alud', Cuenca transtensional.

INTRODUCTION

The Lower Jurassic Los Molles Formation (Cecioni and Westermann, 1968) of central Chile (32°15'S/ 71°30'W) provides a well-exposed and continuous record of sedimentation in an environment interpreted here as a deep-marine, mud-dominated slope apron (cf. Mitchell and Reading, 1986). The formation forms part of a thick succession of marine and continental sedimentary and volcanic rocks deposited on an active continental margin during Triassic-Jurassic times (Suárez and Bell, 1992).

The Los Molles Formation is well exposed along 2,5 km of low coastal cliffs, wave-cut platforms and beach outcrops between Arroyo El Chivato and Puente Ballena area to the south of the village of Los Molles (Fig. 1). The strata have a general dip of about 40° towards the east (Fig. 2). They are cut by a number of faults, but the evidence from ammonites collected during the present study (identified by V. Covacevich,

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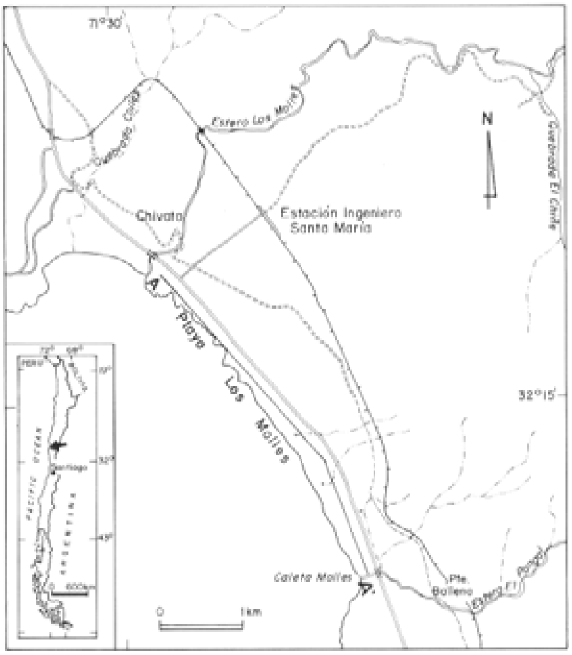


FIG. 1. Map showing the coastal location of outcrops of the Los Molles Formation.

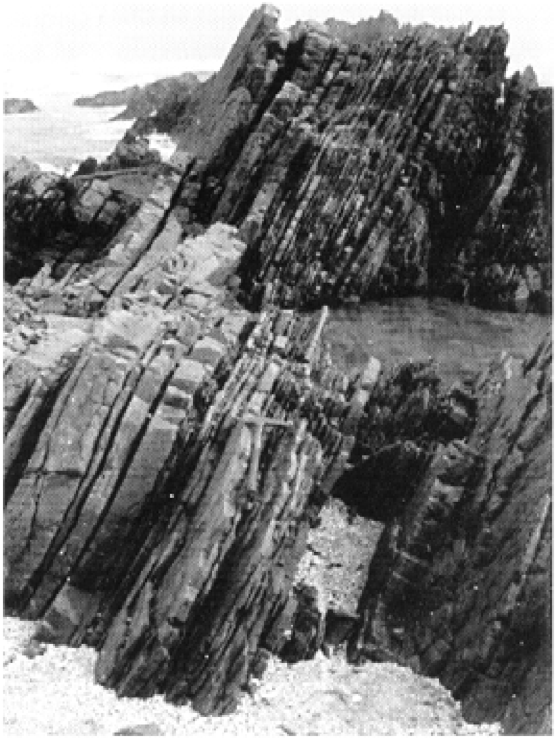


FIG. 2. Typical exposures of thinly-bedded sandstones and shales of facies 4 of the Los Molles Formation. Top towards left of photograph. Location at 240 m in figure 3.

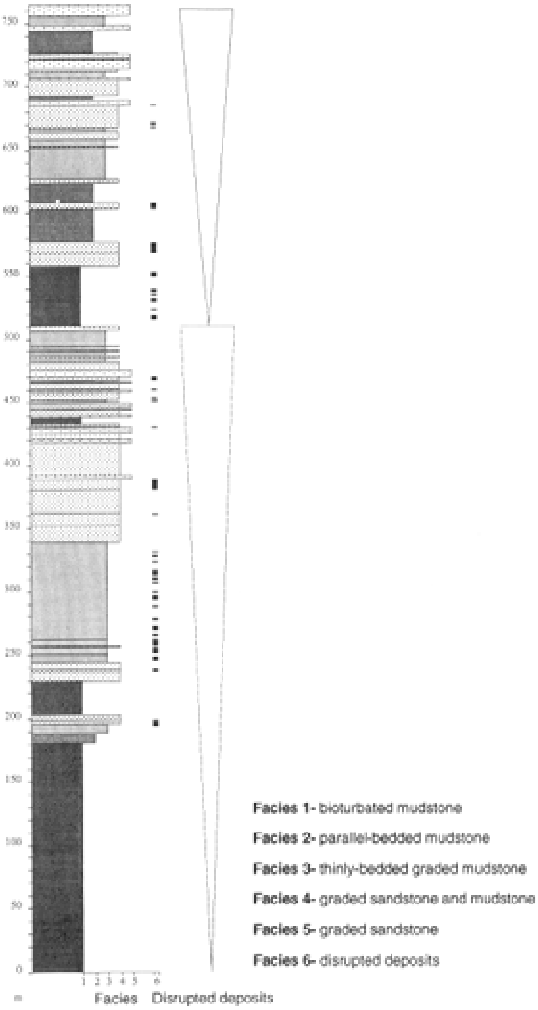


FIG. 3. Diagrammatic vertical section through the 765 m thick Los Molles Formation. Mudstones and sandstones deposited by contour and turbidity currents form two upwards-coarsening cycles, characterised by abundant soft-sediment deformation. (A-A' from base to top).

Servicio Nacional de Geología y Minería) indicates that there is no significant repetition or omission of strata. A weak slaty cleavage masks some of the finer structures in the pelitic sediments.

The field work for the present investigation included sedimentary logging, with bed thickness measured to the nearest centimetre, of 350 m of the succession (between 150 m and 500 m in Fig. 3). The remainder of the succession (below 150 and above 500 m in Fig. 3) was recorded as lithological facies, with the thickness of each unit measured to the nearest metre. Vertical sections measured through part of the succession (between 449 and 476 m in Fig. 3) at three different locations over a distance of 170 m along the strike provide a two dimensional picture of facies changes (Fig. 4).

A stratigraphic thickness of 747 m recorded by Cecioni and Westermann (1968) agrees well with the thickness of 765 m measured during the present investigation (Fig. 3). An Early Jurassic age is indicated by ammonites ranging from Hettangian near the base (200 m in Fig. 3) to Upper Sinemurian near the top (600 m in Fig. 2).

GEOLOGICAL SETTING

The Los Molles Formation forms the upper part of a 3.000 to 4.000 m thick succession of volcanic and sedimentary strata. Although the contacts are not exposed, it probably overlies a sequence of Middle to Upper Triassic strata consisting of the El Quereo (marine, over and underlying probable deltaic deposits), Pichidangui (mainly continental) and El Puquén (lacustrine) Formations (Cecioni and Westermann, 1968). The sedimentary facies of these underlying Triassic formations indicate a predominantly continental (fluviatile and lacustrine) depositional environment, with a marine interval during Anisic time. The Los Molles Formation marks a change from a Triassic continental margin characterised by extensional rifting, to a Jurassic margin dominated by subduction-related processes (Suárez and Bell, 1992; Bell and Suárez, in press).

SEDIMENTOLOGY OF THE LOS MOLLES FORMATION

FACIES DESCRIPTIONS AND INTERPRETATIONS

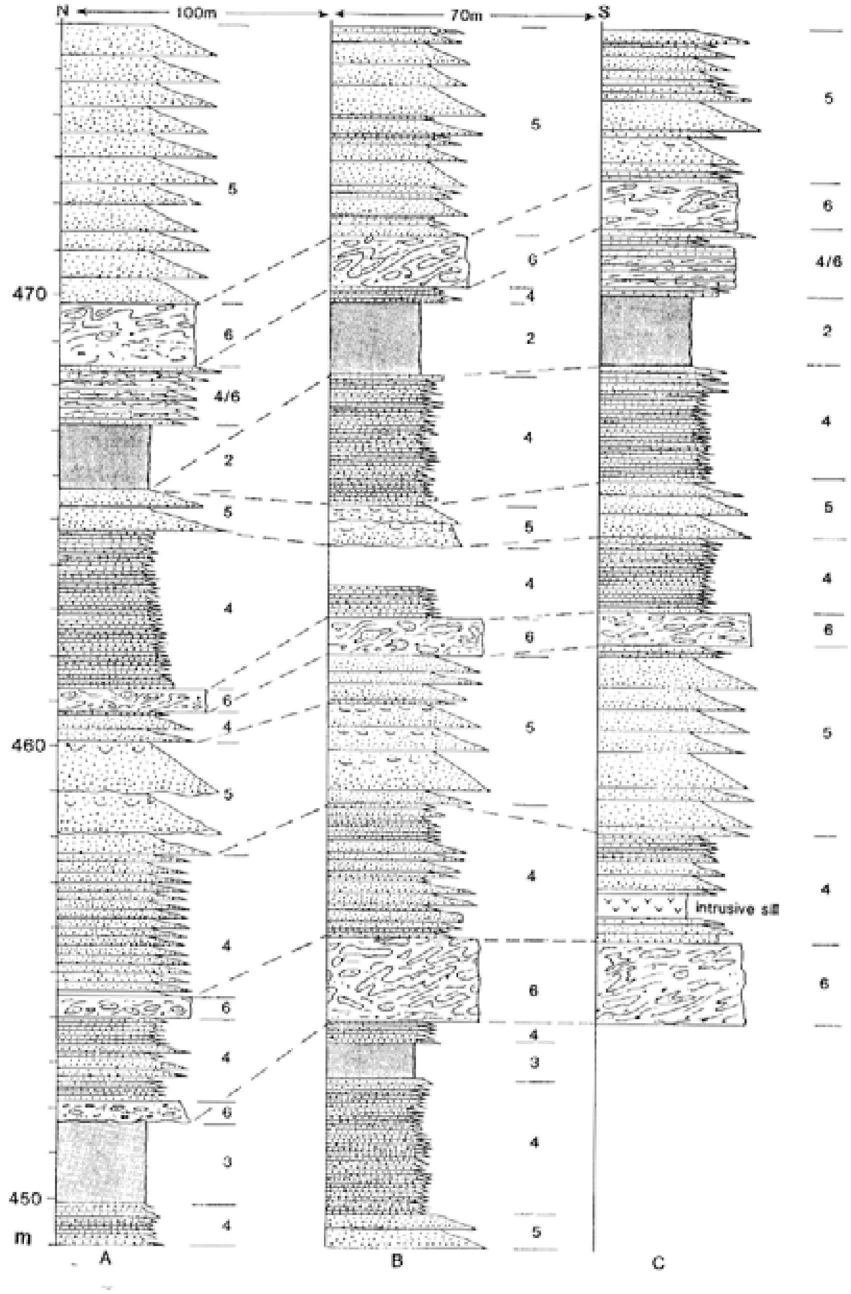
The Los Molles Formation is a fine-grained clastic sedimentary succession. The strata comprise about 85% mudstone (both silt and clay grade material) and 15% sandstone. Granules and pebbles are very rare. Six facies have been distinguished (Table 1) with a facies classification based on Pickering *et al.* (1989). Facies 1, 2 and 3 are mud dominated and facies 4 and 5 are interbedded graded sandstones and mudstones. Facies 6 comprises disrupted strata produced by the soft-sediment deformation and disaggregation of the other five facies.

Facies 1- bioturbated mudstone. Dark grey bioturbated mudstones form about one third of the total measured section. The sediments include facies E1.3 (mottled mudstone) and D1.3 (mottled siltstone and mudstone) of Pickering *et al.* (1989). Beds are 10 to 30 cm thick, with fine to very fine laminations. Bedding planes and laminations are parallel and persistent, but in most places they are very poorly preserved and indeterminate. A few layers and wisps of fine-grained sandstone, less than 1 cm thick, are interbedded with the mudstones.

Most of the sediment has been totally reworked by intense bioturbation, including interlocking masses of *Chondrites* burrows. Small carbonaceous plant fragments are randomly distributed in some beds. Invertebrate fossils comprise ammonites and bivalves, including *Trigonia*. Small, black, disc-shaped calcareous nodules are concentrated in beds between 1 and 10 cm thick. Iron-staining has been produced by the oxidation of small pyrite crystals.

The facies comprises two thick units, each of which forms the base of a large-scale upwards-coarsening succession (Fig. 3). The 180 m thick lower unit (base of Fig. 3) lies with a sharp conformable contact above a succession of shallow-water sands and shales. Thinly-bedded turbidites of facies 2 and 3 are interbedded near the top of this unit.

Interpretation of facies 1- bioturbated mudstone. The land-derived muds of the bioturbated mudstone facies have the sedimentary characteristics of contour current deposits (Bouma and Hollister, 1973; Stow and Lovell, 1979; Stow and Piper, 1984; Faugeres and Stow, 1993; Hollister, 1993). The dark grey mudstones with *Chondrites* and pyrite crystals are indicative of minimal oxygenation. The majority of



Facies 2- parallel-bedded mudstone with very little fine-grained sandstone. Interpreted as the deposits of high-concentration mud-dominated turbidity currents.

Facies 3- thinly-bedded graded mudstone with some fine-grained sandstone. Interpreted as the deposits of low-concentration turbidity currents.

Facies 4- graded sandstone with minor mudstone. Interpreted as the deposits of dilute and high-concentration turbidity currents.

Facies 5- fine to medium-grained graded sandstone. Interpreted as the deposits of high-concentration turbidity currents.

Facies 6- disrupted deposits produced by superficial downslope sliding.

FIG. 4. Three measured sections through the same 30 m of the Los Molles Formation. Each vertical section shows the frequent, abrupt and random facies changes characteristic of the formation. Although the sections are only 170 m apart, they show lateral facies variations, indicative of deposition on an irregularly eroded and probably channelised surface.

TABLE 1. SEDIMENTARY CHARACTERISTICS AND INTERPRETATIONS OF FACIES.

Facies	Pickering and others (1989); Bouma (1962)	% Succession	Thickness of units	Lithology	Sedimentary structures	Fossils	Interpretation
1 Bioturbated mudstone	E1.3 and D1.1	35	Up to 20 m	Mudstone. Very little fine to very fine-grained sandstone	10-30 cm thick beds with fine to very fine laminations. Homogenized. Nodules	Extensive bioturbation. *Chondrites* ammonites bivalves	Low energy marine conditions Contour current deposits on shelf or slope
2 Parallel-bedded mudstone	D1.1 and D1.2	10	Up to 20 m	Mudstone. Very little fine to very fine-grained sandstone	Beds several mm to 12 cm thick. Massive mudstones separated by laminated mudstone. Graded bedding, erosive bases. Rare mudflakes	Some bioturbation Ammonites Belemnites	High-concentration mud-dominated turbidity currents
3 Thinly-bedded graded mudstone	D2.1 and D2.2 Td	16	Up to 70 m	Mudstone with some very fine to fine-grained sandstone	Very thinly to thinly-bedded graded mudstone. Bedding parallel, some massive, some finely laminated. Graded bedding	*Chondrites* Ammonites Bivalves	Low-concentration turbidity currents. Low oxigenation
4 Graded sandstone and mudstone	C2.2 and C2.3 Tabc(d) and Tbcd	22	Up to 20 m	Coarse to very fine-grained sandstone. Mostly fine to medium grained. Some mudstone	Very thinly to thickly bedded. Grading common. Eroded bases. Flutes. Parallel and ripple beds. Amalgamation. Water escape	Little bioturbation	Dilute and high-concentration turbidity currents
5 Graded sandstone	C2.1 Tabc(d)	5	Up to 10 m	Coarse to very fine-grained sandstone. Mostly fine to medium grained. Very little mudstone. Few granules	Beds 20 to 135 cm thick averaging 20 cm. Graded bedding. Eroded contacts, amalgamation common Mudflakes. Water escape	Little bioturbation	High concentration turbidity currents
6 Disrupted deposit	F2.1 and F2.2	12	Up to 6.3 m	Sandstones and mudstones with granules and pebbles Diamictite	Folding, boudinage, faulting Diamictite	Some bioturbation	Superficial downslope sliding

the marine bivalves and the ammonites are pelagic animals. The plant material was washed in from a terrestrial source.

Facies 2- parallel-bedded mudstone. Parallel-bedded mudstones comprise about 10% of the Los Molles Formation. These sediments include facies D1.2 and D1.1 of Pickering *et al.* (1989). Beds vary from several mm up to 12 cm in thickness and form successions up to 20 m thick. Dark grey structureless mudstones are separated by 1 to 2 cm thick parallel-laminated mudstones. The laminations become more distinct upwards through each bed. A few beds (approximately one in each metre of sediment) of very fine to fine-grained sandstone, between 0.5 and 6 cm thick, grade up into finely-laminated siltstone. Some sandstones have erosive bases and contain rare mudflakes. Bioturbation, in the form of irregular, narrow burrows, is much less prevalent than in facies 1. Ammonites and belemnites are rare. A few small, scattered black calcareous and ferruginous nodules are present.

Interpretation of facies 2- parallel-bedded mudstone. The parallel-bedded mudstones of facies 2 are the deposits of mud and silt dominated turbidity currents. Initially rapid deposition from a concentrated dispersion or suspension was followed by traction transport along the bottom to form the laminations (Piper, 1972, 1978; Middleton and Southard, 1984; Pickering *et al.*, 1989; Jones *et al.*, 1992; Walker, 1992). Some beds may be the product of bottom-current deposition, with the resulting interbedding of contour and turbidity current deposits (Bouma and Hollister, 1973; Faugeres and Stow, 1993). The thin sandstones are turbidity current deposits. The scarcity of bioturbation indicates a biologically hostile environment with little oxygen.

Facies 3- thinly-bedded graded mudstone. Normally-graded mudstones, in units up to 70 m thick, form about 16% of the Los Molles Formation. The facies includes facies D2.1 and D2.2 of Pickering *et al.* (1989). Mudstones comprise more than 95% (in most places more than 99%) of the sediment with the remainder consisting of thin beds and irregular wisps of fine-grained sandstone. Beds are parallel and between 1 and 5 cm thick. Some are structureless but others show fine parallel laminations. Grading is distinguished by colour variations, from lighter-coloured silt up into darker clay. Nodules are rare. A few ammonites and small, thin-shelled bivalves are present. Some beds are intensely bioturbated by *Chondrites*.

Graded sandstones and mudstones of facies 4 form upwards-fining successions into facies 3, on a scale of metres to tens of metres. In many places the mudstones of facies 3 have been disrupted by soft-sediment deformation to form facies 6.

Interpretation of facies 3- thinly-bedded graded mudstone. Facies 3 was deposited from muddy turbidity currents. Successions dominated by Bouma Td were deposited from suspension and traction (Middleton and Southard, 1984; Walker, 1992) . The presence of *Chondrites,* together with an absence of benthic organisms, suggests conditions of low oxygenation.

Facies 4- graded sandstone and mudstone. Graded sandstones and mudstones comprise about 22% of the Los Molles Formation, in successions up to 20 m thick. The facies includes interbedded graded sandstones and mudstones of facies C2.2 (Bouma Tabc(d)) and C2.3 (Bouma (Tbcd)) of Pickering *et al.* (1989) (Figs. 2 and 5). Beds vary from very thin to thick (0.5 to 15 cm) with most about 2 to 3 cm thick. The sandstones range from coarse to very fine grained. Most beds are graded, with erosive, flute-marked bases and parallel tops.

Thinly-bedded successions dominated by Bouma Tbcd (facies C2.3 of Pickering *et al.*, 1989) form units up to 15 m thick. The sand to mud ratio is approximately 1:1. The very fine to medium-grained sandstones seldom show basal Bouma units (Ta). Some beds are parallel and continuous, but most are lenticular with undulatory boundaries. In many beds parallel-laminated sandstones (Tb) are overlain by rippled sandstones (Tc), and these, in turn, overlain by parallel-laminated mudstones (Td) on a scale of centimetres. Many of the parallel-laminated mudstones contain thin isolated symmetrical lenses and wisps of very fine sand (Fig. 6). In plain view, the ripples are linguoid and indicate northerly-directed paleocurrents. Some beds show load casts and convolute laminations. Bioturbation is common in places.

Facies 4 also includes more thickly-bedded successions dominated by Bouma Tabc(d) (facies C2.2 of Pickering *et al.* (1989)). Medium to thickly bedded, graded, coarse to very fine sandstone is interbedded with mudstone, with a sand to mud ratio of about 5:1. The beds range from 10-50 cm with an average thickness of about 20 cm. Beds show eroded bases with flute marks. Some beds are amalgamated. Many of the sandstones contain mudflakes or mudflake breccias. Water escape structures and convolute laminations are common.

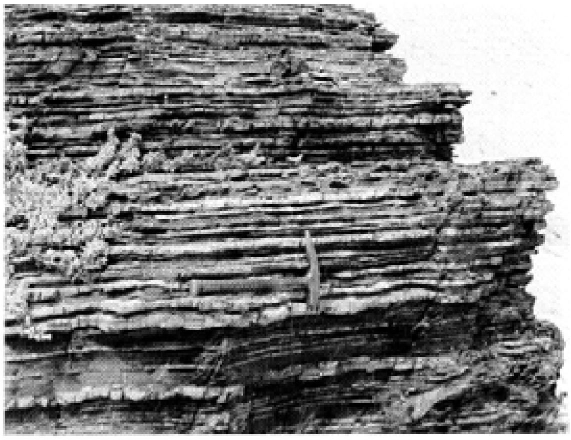


FIG. 5. Thinly-interbedded sandstones and shales of facies 4. Location at 364 m in figure 3.

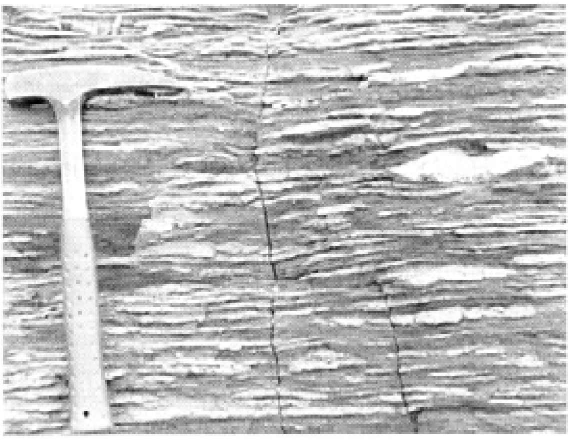


FIG. 6. Parallel-laminated mudstones with isolated laminations, lenses and wisps of fine-grained sandstone. Facies 4.

FIG. 7. Thick beds of coarse-grained graded sandstone of facies 5. Location at 470 m in figure 3.

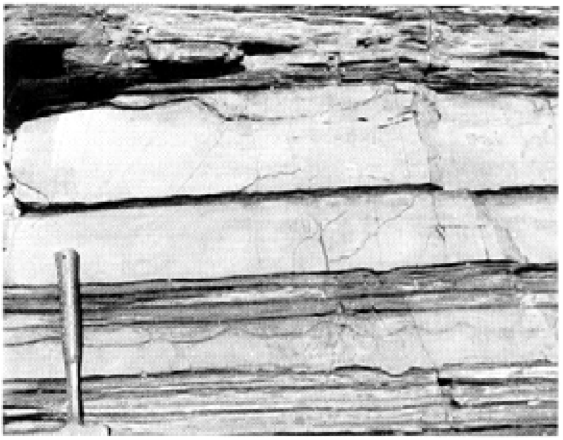


FIG. 8. Parallel-bedded medium to fine-grained sandstone of facies 5. Tops of thick beds show convolute laminations. Location at 560 m in figure 3.

Interpretation of facies 4- graded sandstone and mudstone. Deposition of the graded sandstone and mudstone facies was from suspension and traction from turbidity currents (Pickering *et al.*, 1989; Middleton and Southard, 1984; Walker, 1992).

Facies 5- graded sandstone. Thickly to very thickly bedded graded sandstones (Bouma Tabc(d); facies C2.1 of Pickering *et al.* (1989)) comprise about 5% of the formation, in units up to 10 m thick. The sandstones are commonly interbedded with facies 4. Beds are between 20 and 135 cm thick with an average of about 40 cm. The sandstone ranges from coarse to very fine grained but most is medium to fine grained. Scattered well-rounded granules and pebbles are present near the base of a few beds. Mudstones form thin partings or discontinuous wisps between the sandstone beds. Some beds show grading (Fig. 7), with a structureless base (Ta) overlain by a parallel bedded or low-angle cross-laminated top (Tbc). Mudflakes are common at the base of beds. Dish and pillar structures and convolute laminations were produced by water escape and sediment liquefaction (Fig. 8). Many beds show amalgamation and erosional contacts.

Interpretation of facies 5- graded sandstone. The graded sandstones (Ta) of facies 5 are the suspension deposits of sandy turbidity currents. Some beds exhibit tractional bedload deposition (Tbc) (Middleton and Southard, 1984; Pickering *et al.*, 1989; Walker, 1992).

Facies 6- disrupted deposits. Both large and small-scale soft-sediment deformation is very common, with more than 12% of the total succession showing evidence of disruption. The deformation affects all lithologies throughout the formation. Individual deformed successions vary from centimetres up to 6.3 m thick. The degree of disruption ranges from slight faulting and gentle folding to complete disaggregation and mixing of the strata. The disrupted horizons exhibit boudins, breccias, sandstone dykes and tight to isoclinal folds, with irregularly refolded fold axes. The direction of 34 fold axes show a poorly defined preferred orientation trending southwest-northeast.

The thickest disrupted deposit comprises a basal diamictite, with well-rounded quartz and felsic volcanic pebbles in a sand and mudstone matrix, overlain by folded mudstone enclosing balls and rootless folds of fine sandstone and shale (Fig. 9). In several places (*e.g.*, between 467 and 469 m in Fig. 4, column A) successions of interbedded disrupted and undisrupted strata of facies 4, indicate that turbidite deposition was followed by superficial disruption, prior to the deposition of the overlying beds (Fig. 10). Further evidence for the superficial nature of the disruption is provided by bioturbation which occurred both before and after the disturbance of the strata.

FIG. 9. Diamictite produced by disaggregation and mixing of sediment during superficial slumping. Facies 6. Location 470 m in figure 3.

FIG. 10. Beds of disrupted sandstone and mudstone interbedded with thin undisrupted beds of mudstone. This soft-sediment disruption of the stratification is indicative of repeated surface sliding of unstable material of facies 4. Location at 471 m in Section C, figure 4.

Interpretation of facies 6- disrupted deposits. Most of the disrupted deposits were produced by superficial downslope movement of material deposited by turbidity currents. The relatively small scale of the disrupted horizons (up to 6,3 m thick), together with their repetition, suggests the movement of an unstable surface apron rather than the large slumps and debris flows originated from major scarp failures (Damuth and Embley, 1981). Although some disruption may have resulted from diapiric or intrastratal movement of water-saturated muddy sediment (Vernette *et al.*, 1992), most was the product of surface slumping. The abundant and repeated disruption is indicative of sliding as a result of depositional overloading on a slope, rather than earthquake shocks (Gorsline, 1984; Pickering, 1984; Mutti *et al.* 1984).

Pebbly diamictites indicate that in some cases mass flow events followed the initial disturbance of the sediment. These diamictites contain larger and more abundant detrital clasts than those recorded

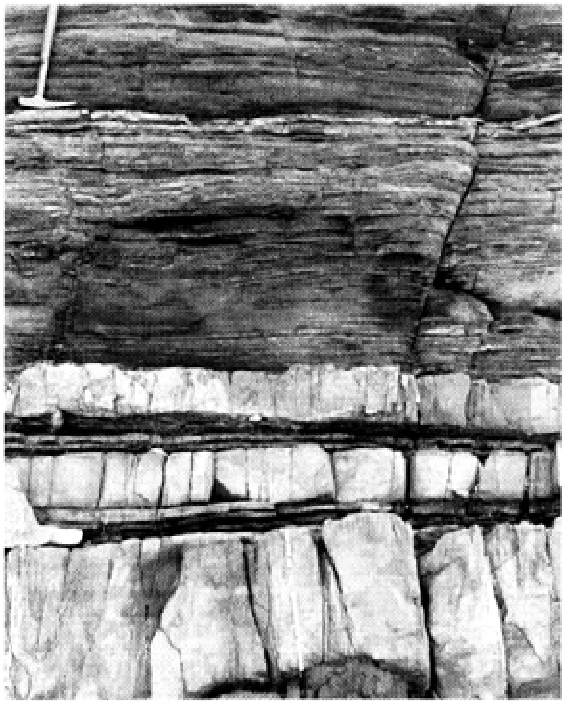


FIG. 11. Parallel-bedded sandstones of facies 5 overlain by thinly-bedded sandstones and shales of facies 4. A typically abrupt facies change. Location at 465 m in figure 3.

elsewhere in the succession. Mass flow was able to transport coarser material than the turbidity currents, and some of the slides travelled a significant distance from their source. By contrast, blocks of stratified sediments in other slump deposits suggest relatively short transport distances (Walker, 1992).

PALEOCURRENTS AND PALEOSLOPES

The orientation of 14 flute and groove marks and 26 ripple foresets were recorded in turbidites of facies 4. The flutes and grooves show a unimodal distribution with currents directed towards the north-northeast. All readings, except one, were directed between 000° and 034°, with a vector mean of 021°. The orientation of ripple foresets shows a unimodal distribution also directed towards the north. A broad range of values probably resulted from the linguoid shape of the ripples. Four readings of ripple foresets near the top of the succession suggest a change in current direction towards the southeast. However, flute marks at this level still indicate northerly currents.

The orientation of fold axes in slumps in facies 6 shows a wide distribution, with the majority trending between 000° and 090°, suggesting a southwest to northeast preferred orientation. Asymmetrical folds have a northerly sense of overturning.

These current and slope indicators suggest that a northerly to north-northeasterly paleoslope was maintained during deposition of the whole formation.

LATERAL FACIES VARIATIONS

Figure 4 illustrates three adjacent correlated measured sections (between 449 m and 476 m on Fig. 3). This was the only part of the section where lateral facies variations could be recorded in detail over a distance of more than a few metres. Sections A and B are spaced 100 m apart and B and C 70 m apart. The north-south location of the three sections is in a down-current direction. Three disturbed horizons provided markers which can be traced between the sections.

Each vertical section shows abrupt and apparently random facies changes. Similar changes are a characteristic feature of other parts of the formation (Fig. 11). Sections A, B and C (Fig. 4) show marked variations in the thickness of individual beds over very short horizontal distances. The number of beds making up parts of the succession is variable and the omission of beds and sets of beds is apparent. In many cases, the beds appear to have been eroded prior to the deposition of the overlying strata. These features indicate that deposition occurred on an irregularly eroded and probably channelized surface and that each bed or set of beds was deposited over a relatively small area.

DEPOSITIONAL ENVIRONMENT

The Los Molles Formation is a mud-dominated turbidite succession. The deep-water marine mudstones at the base of the formation suggest a significant deepening of the seas from the predominantly continental and shallow marine environment of the underlying successions (Cecioni and Westermann, 1968).

The formation comprises two upwards-coarsening successions of mudstones and sandstones (Fig. 3), the lower about 500 m and the upper about 250 m thick. Each succession represents a change from contourites and muddy turbidites to progressively coarser-grained and more thickly bedded sandy turbidites. Each sequence indicates a change from dilute mud suspensions to low and then to high concentration turbidity currents (Lowe, 1982; Walker, 1992; Middleton and Southard, 1984). Each upwards coarsening sequence is possibly the product of deepening of the sea, followed by filling of the sedimentary basin (Shanmugam, 1980; Blair and Bilodean, 1988; Walker, 1992). As the Hettangian and Sinemurian were periods of relatively low global sea level (Haq et al., 1987), deepening of the sea (during a period of low sea level) is indicative of localised tectonic subsidence.

The scale and limited nature of the exposures invalidates detailed attempts to fit the sequence into a modern depositional analogue (Shanmugam *et al.*, 1985). The upwards coarsening turbidite successions may be the product of advancing sediment lobes or other autocyclic processes. However, their large scale indicates that they are more likely allocyclic. Tectonic activity may have produced sea level changes which in turn may have influenced the size of turbidity current events (Mutti, 1985).

No statistically significant repetition of facies sequences or associations has been identified. There are a few low order sediment cycles (variations in grain size or bed thickness) on a scale of metres or tens of metres (Bourrouilh and Gorsline, 1984) (Fig. 12). The formation is characterised by lateral bedding thickness changes and the omission of beds and sets of beds (Fig. 4), features which contrast markedly with the more normal lateral continuity of turbidite deposits (Pilkey *et al.*, 1980). In the vertical sections most facies changes occur over a few metres or less. The changes are repeated, abrupt and, apparently, at random (Fig. 4). These features are explained both by frequent and significant variations in depositional processes and by deposition on an irregularly eroded and channellised surface. Seismic and sonar studies have emphasised the morphological complexity of the surface of the Amazon and other deep-sea fans at a large scale (Damuth *et al.*, 1983; 1988; Walker, 1992). The present observations indicate that a similar surface complexity of irregular channels can be a feature of turbidite depositional environments at a much smaller scale.

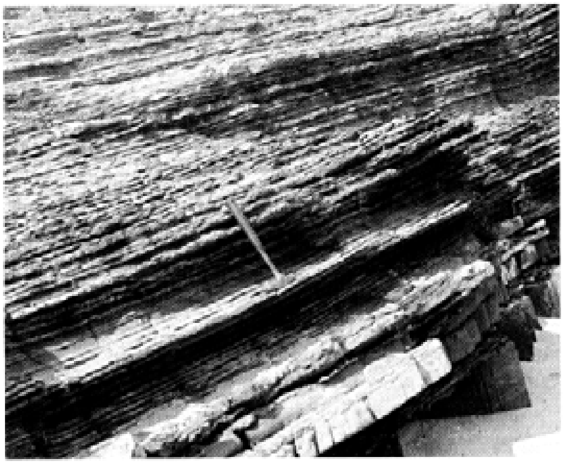


FIG. 12. Parallel-bedded and rippled sandstones and shales of facies 4 showing a poorly-defined fining-upwards sequence. Location at 368 m in figure 3.

Soft-sediment deformation is very common with most disruption produced by repeated small to medium-scale surface slides (Fig. 10). This suggests high rates of sediment accumulation on steep and unstable slopes, with frequent surface sliding of unstable material, rather than periodic major slope failures (Gorsline, 1984; Damuth and Embley, 1981; Pickering, 1984; Walker, 1992).

The abundance of land-derived mud, together with the absence of carbonates, indicates a temperate, humid climate with sediment derived from a large river system. The complex pattern of interbedded facies suggests overlapping sediment distribution systems resulting from more than one point of sediment input. The feldspathic sandstones and volcanic clasts are the product of a predominantly volcanic provenance. It is probable that the sedimentation occurred on an uneven slope apron (Bourrouilh and Gorsline, 1984; Pickering, 1984).

TECTONIC SETTING

Rift basins, many with associated magmatism, were formed during widespread Triassic extensional tectonism on the South American active continental margin prior to the fragmentation of Gondwana (Suárez and Bell, 1992). Most Triassic syn-rift sediments in Chile are continental, and in many places they are overlain by marine sediments. These marine deposits resulted from a diachronous (mid Triassic to early Jurassic) transgression produced by thermal subsidence following uplift and extension associated with the rifting (Suárez and Bell, 1992). According to Dalziel (1986), a well-defined subduction-related magmatic arc had developed parallel to the present-day coastline by Jurassic times. However, Gana (1991) has provided evidence for an Upper Triassic-Lower Jurassic interruption of the Andean subduction system in this area. The volcanic rocks may, therefore, have been related either to subduction or to rifting of the active margin. The Los Molles Formation was probably deposited in a fore-arc position relative to the magmatic arc.

Assuming that no terrane rotation has occurred, the persistent northerly paleocurrents, both in the Los Molles and the underlying formations, indicate sediment derived from the south. This direction, parallel to the north-south orientation of the Jurassic magmatic arc, suggests that sedimentation occurred in a relatively small slope basin orientated parallel to the plate margin. The basin was possibly a transtensional pull-apart related to oblique subduction (cf. Bourrouilh and Gorsline, 1984; Mitchell and Reading, 1986; Ingersoll, 1988; Bell and Suárez, in press).

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