# STORM-GENERATED SANDSTONE BEDS FROM THE UPPER CRETACEOUS OF SOUTH CHILE AND THEIR REGIONAL SIGNIFICANCE

DAVID I.M. MACDONALD

British Antarctic Survey, Natural Environment Research Council, High Cross, Madingley Road, Cambridge CB3 OET, Gran Bretaña.

## ABSTRACT

Convolute-laminated sandstone beds with hummocky cross-stratification are described from Upper Cretaceous strata near Punta Arenas, Magallanes Province. These beds were formed by storm surges which moved sand offshore and deposited it on a muddy shelf, under combined unidirectional and oscillatory flow. Water depths were probably no more than 100 m. This implies that the Late Cretaceous palaeogeography of the Magallanes Basin was complex; shallow marine and shoreface environments co-existed with deep marine areas (previously interpreted on the basis of foraminiferal work).

Key words: Storm beds, Shallow marine, Upper Cretaceous, Palaeogeography, Magallanes basin, Chile.

## RESUMEN

Se describen areniscas del Cretácico Superior, expuestas en las cercanías de Punta Arenas, sur de Chile, las que exhiben laminación convoluta y estratificación cruzada, tipo "hummocky". Estas capas se formaron por tormentas que movilizaron arenas desde alta mar depositándolas en una plataforma marina barrosa, bajo condiciones tanto de flujo unidireccional como oscilatorio. Las profundidades de las aguas fueron probablemente inferiores a 100 m. Esto implica que la paleogeografía de la cuenca de Magallanes, durante el Cretácico Superior, era compleja; ambientes de mar somero e incluso de litoral, coexistieron con áreas marinas profundas (interpretadas previamente en base a estudios de foraminíferos).

Palabras claves: Capas de tormenta, Mar somero, Cretácico Superior, Paleogeografía, Cuenca magallánica, Chile.

## INTRODUCTION

Upper Cretaceous (Campanian-Maastrichtian) sedimentary rocks are well-exposed at Punta Santa Ana, 52 km south of Punta Arenas, Magallanes Province. This short note describes some unusual sandstone beds, which appear to be storm deposits, and discusses their regional significance.

### Stratigraphic setting

Campanian-Maastrichtian strata crop out in a virtually continuous belt through Magallanes Province from the Argentine border at 51°S to Isla Grande of Tierra del Fuego. They are involved in the foreland fold and thrust belt that marks the

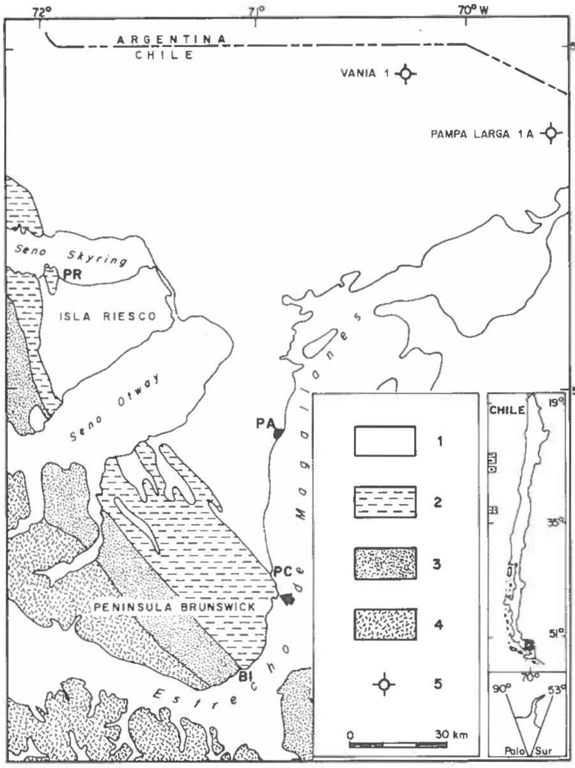


FIG. 1. Geological sketch map (after Servicio Nacional de Geología y Minería, 1982) of the area around Punta Arenas showing the location of Punta Santa Ana (arrowed). BI: Bahía del Indio; PA: Punta Arenas; PC: Punta Carrera; PR: Punta Rocallosa. 1. Tertiary and Quaternary; 2. Campanian-Maastrichtian; Albian Campanian; 4. Pre-Albian and igneous; 5. Wells.

eastern foothills of the main Andean Cordillera (Winslow, 1981) and forms the western edge of the Magallanes basin (Natland *et al.*, 1974). This Campanian-Maastrichtian belt is at its widest on the eastern side of Península Brunswick, where strata crop out between Bahía del Indio and Punta Carrera (Fig. 1).

The whole Campanian-Maastrichtian interval has been included in the Riescoian stage by Natland *et al.* (1974) on the basis of foraminiferal zonation. The type subsurface section is provided by the Vania 1 and Pampa Larga 1A wells (Fig. 1) where the Lutitas Arenosas span the Santonian-Maastrichtian interval. There is also a type surface section at Punta Rocallosa on the north coast of Isla Riesco where the interval is divided between the Tres Pasos and Rocallosa Formations (lithostratigraphy after ENAP geologists, quoted by Natland *et al.*, 1974). The Lutitas Arenosas comprise "hard dark to medium gray silty glauconitic shale with some dense brown lime" (Natland *et al.*, 1974).

## PUNTA SANTA ANA SECTION

At Punta Santa Ana, Península Brunswick, a 450 m sedimentary section, dipping WSW at 50-60°, and forming part of the lower portion of the Rocallosa Formation and upper portion of the Fuentes Formation, crops out.

The section is formed of silty mudstone with fine sandstone and brown and orange carbonate concretions. There is a sparse fauna of belemnites with rare ammonites and abundant comminuted shell debris. The upper part of the section (200-450 m) is formed of silty sandstone and subordinate siltstone, commonly bioturbated, in irregular but laterally persistent beds 10-20 cm thick. This unit is of no direct relevance to this paper, and is not considered further here.

The lowest 200 m are dominated by structureless silty mudstone, with variable amounts of dispersed sand-grade material and interbedded fine sandstone beds which vary from 5-70 cm thick. Carbonate concretions of various sorts are common within this unit. Both sandstone beds and concretions are more common below 90 m (Fig. 2).

### Mudstones

The bulk of the lower unit is formed of light-medium grey structureless silty mudstone. This appears to be throughly bioturbated with trace fossils *Palaeophycus* and *Chondrites* common and a single record of *Zoophycos*. The amount of dispersed sand within the mudstone increases up section to about 100 m, then declines towards the

FIG. 2. Eastern side of Punta Santa Ana, looking north, showing the lowest 90 m of the section. Strata dip steeply to the WSW (left) and the location of the well-exposed storm sandstones is arrowed.

FIG. 3. Sandstone bed showing relatively simple convolute lamination truncated by undulating lamination. Pen is 15 cm long.

top of the unit at 200 m.

**Sandstones**

The intercalated sandstone beds provide the only direct evidence for the depth of deposition. Although there are sandstone beds throughout the 0-90 m interval, the best-exposed occur in the basal 12 m of the section. In this part of the section, sandstone beds are 20-35 cm thick.

Sandstones are light brown to honey-coloured, fine to very fine grained. Bed bases are sharp and can be erosive into the underlying mudstone; some bed bases carry tool marks indicating broadly E-W flow. The sandstones are generally well sorted, but there seems to be a slight grading throughout each bed, from medium to fine sandstone. The internal structure of the beds appears highly variable but there are common elements. All have one or more convolute laminated intervals making up *ca.* 90% of the bed, and all are capped by a 3-5 cm thick interval of undulating parallel lamination.

Figure 3 shows one of the simpler beds, 22 cm thick, with a single set of convolute lamination forming the lowermost 19 cm. These convolutions are clearly truncated by the overlying undulating lamination which forms a 3 cm unit, concordant with the undulating bed top. The latter is formed of a series of isolated hummocks with a spacing of 25-35 cm and an amplitude of 2-4 cm.

More complex beds (Fig. 4) generally have two or more units of convolute lamination. Complexity of convolution always decreases upward and there may be low angle curved intersections within the top undulating lamination (Fig. 4). In some cases the undulose lamination is not continuous over the whole bed top (Fig. 5), forming the hummocks and being absent from the swales. As before, however, the undulating lamination is concordant with the topography of the bed top. Figure 5 also shows a vertical burrow penetrating the convolute lamination. Such burrows are relatively common, and appear to be escape burrows (*fugichina*: Simpson, 1975).

All beds are laterally continuous. The thickness of the internal units may vary, but they have constant characteristics along strike.

**Interpretation**

The sharp, erosive bases and grading show that the sandstone beds were deposited intermittent, waning sediment-laden flows. Within the marine realm such density currents are usually either driven by gravity (turbidity currents) or are the product of storm surges (Walker, 1984). The former class are probably most common in deep water, although there is no theoretical reason why they should not occur on shelves (Walker, 1984). Storm-driven currents are restricted to shelf depths. The distinction between these two possibilities could have important consequences for palaeogeographic reconstructions of the area.

It is quite clear that the sandstone beds are not turbidites, because they display none of the structures that make up the classical Bouma (1962) sequence. The complex internal structure implies more than one depositional event for these beds, and Figure 6 shows one way in which an upward decrease in the complexity of convolute lamination could be achieved. This reconstruction owes much to the work of Allen (1977) who showed that liquidization of a sand bed under any form of shock loading could result in gravitationally unstable vertical density gradients even in cases where the bulk density gradient was originally stable.

The upper, undulating interval of parallel lamination is identical to the structure called hummocky cross-stratification (HCS: Swift *et al.*, 1983) although on a smaller scale. HCS usually has a wavelength of 1-5 m and hummock amplitude of tens of centimetres. In this case, although the structures are one third or less of "normal" size, they are clearly the product of rapid deposition from in-phase waves.

Since the introduction of the term HCS by Harms *et al.* (1975) there has been much debate

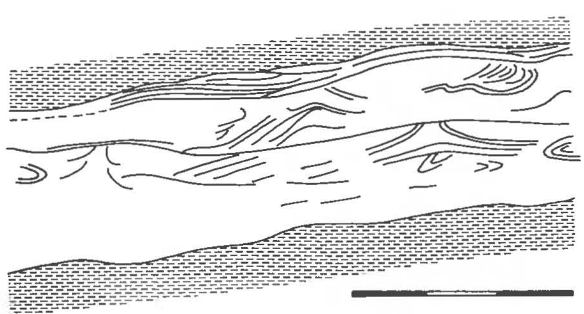

**FIG. 4.** Sketch of a bed composed of two convolute laminated intervals and a unit of undulating lamination. Note the low angle curved intersections in the swale area. Drawn from a photograph. Scale bar is 30 cm long.

FIG. 5. Complex sandstone bed with discontinuous upper laminated unit. Note escape burrow (arrowed) in lower left. Pen is 15 cm long.

on its origin (Dott and Bourgeois, 1982; Swift *et al.*, 1983; Walker, 1984). There is general agreement that the action of storm waves below fair-weather wave base is necessary for the generation of the structure. HCS most likely forms in response to a combination of waning storm-generated unidirectional flow with superimposed oscillatory storm wave action (Swift *et al.*, 1983). Recent theoretical work by Allen (1985) supports this conclusion. The small size of the structures in this case is probably a reflection of small wave orbital diameter. This could be due to a relatively short fetch to the generating waves.

In the Punta Santa Ana section the bulk of the succession is biotubated, silty mudstone with no other wave-generated structures such as ripples. This is typical of other known examples, where HCS is almost always associated with biotubated mudstone (Walker, 1984), interpretated as the ambient sedimentation below normal waves base (McCave, 1985). The trace fossils *Chondrites*, *Palaeophycus* and *Zoophycos* found in this section are noted from storm-related ichnofacies elsewhere (Ekdale *et al.*, 1984).

The evidence suggests that Campanian-Maastrichtian sediments in the Peninsula Brunswick area were deposited in water between fair weather wave base and storm wave base. This would imply shelf depths (probably no more than 100 m).

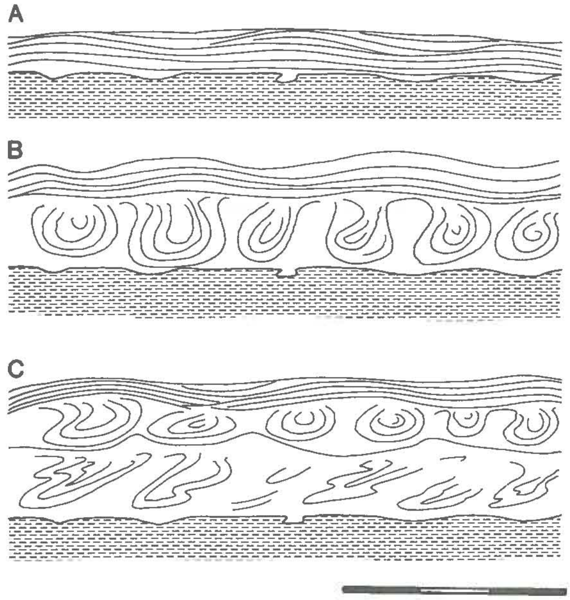


FIG. 6. Model to show formation of multiphase beds by successive storm surges.
A. Deposition of initial laminated or hummocky bed above scoured base.
B. Second surge deposits upper laminated or hummocky bed but shock loading liquefies previously deposited bed and leads to formation of convolutions.
C. Third surge repeats process, two lower intervals are both liquefied and convoluted.

## REGIONAL IMPLICATIONS

Natland *et al.* (1974) used foraminifera both to establish a system of stages for the Magallanes basin and to provide a palaeoecological interpretation of water depth. For the Riescoian stage (Santonian-Maastrichtian) they interpreted water depth of 1000-2000 m, and in their summary chart (Natland *et al.*, 1974, Table 1) they showed a water depth of 1400 m. This result is clearly incompatible with the sedimentology of the Punta Santa Ana section.

There is other evidence for shallow marine conditions in the Riescoian interval. Pérez and Reyes (1978) report several species of trigoniid bivalves from the Tres Pasos Formation (Middle Riescoian); the family Trigoniidae are almost exclusively shallow marine (Stanley, 1977). Glauconitic sandstones are common within the Upper Cretaceous rocks (Zambrano, 1981). Although glauconite can be transported into deep water, it requires shallow marine conditions for formation. Its occurrence within strata of this age implies at least the coexistence of a shelf area.

It is likely that the palaeogeography of the Riescoian was complex, with much more variety than suggested by Natland *et al.* (1974) who were working principally with material from more than 100 km from Punta Santa Ana. The SW margin of the Magallanes Basin underwent progressive deformation during the Late Cretaceous as the foreland fold-and-thrust belt propagated basinward (Winslow, 1981) and the depocentre shifted NE. In such a dynamic setting it is unlikely that any stratigraphic interval would have common characteristics across the whole of this large basin. Indeed, Natland *et al.* (1974) themselves pointed out that molasse sediments were being deposited in the northern part of the basin (Cecioni, 1957) in response to a general regression, while flysch was being deposited elsewhere in the basin.

The presence of storm sandstone beds implies that there were co-existing shoreface deposits within the basin, and that there may be thick sandstones within Riescoian-age strata. The problems of the palaeogeography of the Lutitas Arenosas will only be resolved by a detailed sedimentological study of the whole outcrop.

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