SEDIMENTOLOGY OF THE MIERS BLUFF FORMATION, LIVINGSTON ISLAND, SOUTH SHETLAND ISLANDS

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Abstract: The Miers Bluff Formation, a series of arkoses, arkosic-wackes, shales, conglomerates and breccias, has been interpreted to be a sequence of turbidites since the first geological studies of the South Shetland Islands. Its base and top are not exposed but a thickness of more than 3000 m has been suggested and seems plausible. The turbidites are overlain by mid-Cretaceous volcanic rocks and intruded by Eocene tectonites, but their age is poorly constrained (Late Carboniferous-Jurassic?). Sections along the western part of Hurd Peninsula, Livingstone Island, show three coasting and thickening sedimentary cycles with channelized and non-channelized facies. Channelized facies have lenticular geometry, erosional bases and thinning upwards cycles; the non-channelized facies consist of Bouma sequences, massive, amalgamated sandstone beds and muddy intervals. The cycles are interpreted to be the result of the progradation of turbidite fans placed in a marginal basin of Gondwana, with paleocurrents trendling both normal and parallel to the axis of the basin, in some ways similar to the present day sediment transport processes in the Chile trench.

Key words: sedimentology, turbidites, Miers Bluff Formation, Livingston Island, South Shetland Islands

Introduction
The Miers Bluff Formation crops out on Hurd Peninsula, Livingston Island (62°40′S, 60°23′W) in a series of laterally extensive exposures along the SE coast of South Bay, from Hespérides Point in the north to Miers Bluff in the south, and in smaller outcrops along the north-western coast of False Bay (Fig. 1). The rocks of the type section at Miers Bluff, the southern tip of Hurd Peninsula, have been interpreted as a turbiditic deposit (Adie, 1964; Hobbs, 1968; Dalziel, 1969). The section was thought to be about 3000 m thick, a figure difficult to ascertain, but certainly not excessive.

The sediments are tightly folded and affected by low-grade metamorphism. The detailed structure of the Miers Bluff Formation is unknown, due to a lack of precise mapping and the presence of a large glaciated area (Hurd Glacier) in its central part limiting exposure. The true thickness of the Miers Bluff Formation is unknown, but the interpretations of Dalziel (1972) and Smellie et al. (1984) assume a thickness of about 3000 m and their field criteria agree with our observations: i.e., most of the outcrops have inverted beds which strike NE-SW, and dip to the northwest, and form the inverted flank of a kilometer-scale syncline with a subhorizontal axis and an axial plane dipping at 10°-30° to the west. The syncline is deformed by many smaller folds, it is intruded by tectonites, cut by at least two generations of quartz veins and dolerite dykes and by very recent, active tensional and strike-slip faults.

The age of the Miers Bluff Formation is poorly constrained and ages ranging from Late Carboniferous to Early Jurassic have been proposed. Some plant remains were found by Hobbs (1968) and Dalziel (1969), but their poor preservation prevented precise identification and Schoff (1973) suggests a Mesozoic age. Absolute age determinations on the clay fraction (Dalziel, 1972, 1982; Pankhurst, 1983) yielded a Triassic age, but the interpretation of these figures remain problematic, as they can represent a period of diagenesis or very low metamorphism, younger, of course, than the true age of deposition. Late Jurassic - Early Cretaceous volcanic and sedimentary rocks lie unconformably on the Trinity Group of the Antarctic Peninsula (Dalziel, 1972, 1984) and are widely considered to be a lateral equivalent of the Miers Bluff Formation. Petrofabric and provenance studies (Miller et al., 1987; Loske et al., 1988; Smellie, 1991) show that the age of detrital zircons from the low-grade metamorphic sandstones of the Trinity Peninsula Group and the Miers Bluff Formation have a Middle-Late Carboniferous age. According to these criteria an Early Mesozoic age for the Miers Bluff Formation seems plausible. We have found no fossil remains in these sediments.

The Sediments
Different sedimentary facies are recognized on the basis of field observations and thin-section studies. A short lithological description will be followed by a sedimentological interpretation.

Lithological description
Dark mudstones: These consist of clay and silt fractions, dark-gray, with parallel lamination, massive bed ding or bioturbated horizons. The lamination reflects subtle grain size differences and fining-upwards laminae have been observed in thin section. Planolites-type trace fossils, very simple, smooth straight or twisting horizontal tubes, are abundant in the bioturbated horizons.

Dark mudstones and fine sandstones: These consist of mudstone layers up to 4 cm thick and fine to very fine sandstone layers up to 1.5 cm. They show parallel lamina tion or current ripples. Bioturbation is scarce.
Fig. 1. Maps to show the location of Livingston Island, Hurd Peninsula and the studied profiles. BAE: Spanish Antarctic Base. Profiles: 1) Johnsons Dock, 2) Reina Sofia Peak, NE Face, 3) BAE depot ridge, 4) Punta Polaca ridge.
Graded sandstones: These display good internal organization as complete (T-a-e) or incomplete (Tc-e) Bouma sequences, 3–45 cm thick. The bases of individual beds are sharp, but the tops usually grade into dark mudstones. The sand fraction is medium to coarse in the lower part of the sequence and very fine in the upper part. In some cases the incomplete Tc-e sequences display flaser bedding. There are many sole marks including flute casts, chevron marks, tool marks and rills.

Non-graded sandstones: Medium to coarse sandstones, usually structureless, although sometimes they display planar and trough cross-stratification and current ripples. Bases and tops of the beds are sharp and amalgamations are frequent. They contain some rounded clay pellet horizons, either near the base or in the middle part of the sequence. Sorting is poor and angular grains are common; normal grading is occasionally found. Beds show lenticular geometry, 0.3–1.7 m thick and 60–300 m wide, and a general thinning-upwards organization in sequences up to 35 m thick.

Polygenetic conglomerates: These consist of well-rounded pebbles, 1 to 12 cm in diameter, of quartz, granitoids, porphyric rocks, sandstones, slates and volcanic rocks. Normal grading is always present, and thickness varies from 0.7 to 1.5 m. The base of the units is erosive and shows lenticular geometry, pinching out laterally in a few tens of meters. A sandy matrix infills the pores and the clasts are oriented randomly. They are intercalated in graded and non-graded sandstones and crop out only in some outliers along or near False Bay coast.

Monomictic breccias: There are two types of clay pellet breccias: thin, centimeter horizons intercalated in sandstone bodies and much thicker (3–7 m) massive, matrix supported breccias. Pellets are well-rounded in general, up to 7 cm in diameter, and discoidal in shape, sometimes imbricated into the first type of breccia; matrix is massive, structureless in the later type of breccia.

Polygenetic breccias: They consist of heterometric contorted fragments of sandstones and dark mudstones floating in a dark gray muddy matrix (F. Sábat and J. A. Muñoz, personal communication). They crop out in two hills near the northwest shore of False Bay, in the upper part of the exposures of the Miers Bluff Formation. They show clear normal gradation above an erosive base with extrabasinal, well rounded pebbles at the base (quartz and volcanics), intrabasinal fragments with well preserved internal structures and sandstones at the top.

Paleocurrents

Our field data in the sections measured in detail show a predominant transport from north to south, with some isolated directions toward the south-southwest. Measurements were performed on sole marks and flutes. Dalziel (1984, 1989) indicates transport towards the northwest and the southwest in northwest Hurd Peninsula and towards the south and the east in south Hurd Peninsula.

Sedimentology

The sedimentary rocks of the lower part of the Formation have been surveyed in detail near the Spanish Antarctic Base “Juan Carlos I” and many local observations were made on the outcrops of Hurd Peninsula (Figs. 1 and 2).

The lower part of the Formation can be divided into three coarsening and thickening sedimentary cycles, the last one being not totally exposed. The polygenetic conglomerates and breccias at the northwest coast of False Bay are younger than the South Bay exposures, but the exact relationship is still unknown. Minor cycles of coarsening and thickening or fining and thinning character of the sedimentary sequence can be distinguished within the major cycles. As the sediments contain many complete or incomplete Bouma sequences and sole marks but do not contain marine fossils nor wave-induced structures or evidence of subaerial exposure, we follow the general interpretation of these sediments as turbidites sensu Walker and Mutti (1973) and Walker (1976).

There are two main types of facies: channelized and non-channelized.

Channelized facies have flat erosional bases (these beds are very rarely observed), lenticular geometry, are up to 35 m thick and show a general thinning-upwards in the sedimentary sequences. Sequences inside the channel consist of intercalated thick to thin beds of arkoses and arkosic wackes (Facies B2, Walker and Mutti, 1973) with some dark grey mudstone horizons; there are rare beds with trough cross-stratification and current ripples, or matrix-supported conglomerates (Facies A3).

Within the channel facies or in beds flanking the channels there are fine-grained sandstones with stacked current ripples and mudstones, forming centimeter-scale couplets repeated several times (Facies E). Their small thickness could be explained by partial erosion by lateral migration of the turbiditic channels. These facies associations are interpreted as channel fills (Facies B2 and A3) with associated overbank or levee deposits (Facies E) because they compare well with the distal parts of channelized complexes of some classical examples described by Mutti and Ghibaudo (1972), Mutti (1977), Walker (1975), Hiscott (1980) and Pickering (1981). The general thinning-thinning trend of the sedimentary units reflects the progressive infill and abandonment of the channel. They form the upper part of each of the three major cycles. The chaotic bodies of sedimentary rocks containing contorted fragments of intrabasinal sediments found in the upper part of the exposed outcrops (Facies A1) could be interpreted as a proximal channel deposit or, more probably, as slumps at the toe of the continental slope.

Non-channelized facies are dominated by thin- to medium sandstone beds, either massive or with complete or incomplete Bouma sequences (Facies C and D) (Fig. 3). There are some rare clay pellets breccias and matrix-supported breccias. Thickening-upward trends were observed in some bed successions, similar to the “compensation cycles” of Mutti and Sonino (1981). The cycles are up to 17 m thick, but 8–12 m is more typical. These cycles are also coarsening-upwards.

Non-channelized facies are interpreted as suprafan lobes in the outer part of a turbiditic fan, because they compare well in size, geometry and internal structures and facies associations with some of the classical examples (i.e. Normark, 1970; Mutti and Ghibaudo, 1972; Walker, 1978). Monomictic breccias probably resulted from the impact of
Fig. 2. Logs of studied profiles of the Miers Bluff Formation and tentative correlation.
turbidity currents on semi-indurated fine-grained sediments on the floor of the lobes, and the breccias represent debris flows that occasionally escaped from the feeding channel. The presence of frequent current ripples in the thin mudstone-fine sandstone intervals of the sequences could be interpreted as the result of deep geostrophic marine currents reworking previously deposited turbidites (the product of this process is usually termed “contourites”). However, only detailed correlations with other areas as the Antarctic Peninsula, not available at present, could help distinguish between the two origins. A few meters of mudstones have been observed at the contact between the non-channelized and the channelized facies. They could correspond to the hydraulic jump zone described between channel and lobe by Mutti (1977), and observed in flume experiments by Garcia and Parker (1989).

Paleogeography and Provenance

The turbidite basin, where the Miers Bluff Formation was deposited, was dominated by non-channelized bodies of arkosic sandstones, at least in the lower part of the Hurd Peninsula outcrops. It could correspond to a Type I turbidite system (Mutti and Normark, 1987), formed along the trench of the converging Pacific margin of Gondwana during the Early Mesozoic, with enough fines to maintain turbidite currents flowing very long distances. As the volcanic fragments and plagioclast clasts are fresh and of similar size and roundness to the slate, sandstone or granitic fragments, it is possible that the source area consisted of active volcanoes and low-metamorphic and granitic terranes.

The turbidites were probably transported to the south along the Gondwana margin, although a more proximal source could be postulated for the levels with paleocurrent direction towards the west. This interpretation is compatible with a source area in southern Chile. Miller et al. (1987), Loske et al. (1988) and Hervé et al. (1991) described the presence of several types of zircons in the turbidites of the Miers Bluff Formation in Livingston Island and the Trinity Peninsula Group of the Antarctic Peninsula and dated them as of Carboniferous age. The only possible source rocks of these minerals are Late Hercynian granitoids in southern Chile; other possible source area as South Africa or the Ellsworth Mountains lacks this type of rocks and is discarded as an alternative to the aforementioned area (Hervé et al., 1991; Smellie, 1991).

The present-day Chile trench, where subduction has occurred along the western Gondwana margin, since, perhaps, the Triassic, could be a comparable basin. Here the turbidite fans are fed by transverse submarine canyons and by longitudinal transport by gravity and geostrophic currents redistributes large amounts of sediments (Thornburg and Kulm, 1987).

The thinning and fining cycles of the channelized outer mid-fan deposits are interpreted as the infilling of feeding channels and the thickening and coarsening sedimentary cycles in the non-channelized outer fan deposits as the result of the progradation of suprafan lobes (Ricci Lucchi and Parea, 1973).

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