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The Discovery and Geological Significance of Pebbly Mudstone in Hurd Peninsula, Livingston Island, West Antarctica

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ABSTRACT. The Miers Bluff Formation consists mainly of sandstones, mudstones, conglomerates and shales, and is interpreted to be a turbidite sequence. The sequence is overlain by Mid-Cretaceous volcanic rocks and intruded by Eocene tonalites, but its age is poorly constrained (Late Carboniferous - Early Jurassic?). Pebbly mudstone is common in the Trinity Peninsula Group in Graham Land, Antarctic Peninsula, but is scarce in the Miers Bluff Formation. Four beds of pebbly mudstones were distinguished near the Spanish Antarctic Station in Hurd Peninsula, Livingston Island by the end of 1997. The layers of pebbly mudstones are massive with poor-traction flow structure and usually over 10m thick, and pebbly mudstones contain a great amount of igneous, sedimentary and metamorphic pebbles. Pebbly mudstone is bounded by upper and lower massive sandstone beds. This discovery of pebbly mudstone shows that the Miers Bluff Formation has the same tectonic setting and the same history of sedimentation and metamorphism as the Trinity Peninsula Group. Pebbly mudstone should be debris flow sediments, and might deposit in the channel of the mid-fan of a submarine fan.

Key Words: Pebbly Mudstone, Miers Bluff Formation, Hurd Peninisula, Livingston Island, West Antarctica

Introduction

Livingston Island (62°40′S, 60°23′W) is the second largest island of South Shetland Islands, West Antarctica, and consists of pre-volcanic basement, arc-volcanic sequences, plutonic intrusions and post-subduction volcanic rocks. The pre-volcanic basement is lower grade metamorphic sedimentary rocks that mainly compose of sandstones intercalated with mudstones and shales, which are interpreted as a turbidite sequence and named the Miers Bluff Formation (MBF) (Adie, 1964; Hobbs 1968; Dalziel 1969; Arche *et al.* 1992; Doktor *et al.* 1994; Smellie *et al.* 1995). The thickness of the MBF is believed to be more than 3000m, but the top and base of the MBF are not exposed because of a lack of precise mapping and the presence of a large glaciated area (Hurd Peninsula) in its central part limiting exposure (Dalziel 1969; Arche *et al.* 1992; Smellie *et al.* 1995).

The MBF has some correlatives, such as the Trinity Peninsula Group (TPG) in Graham Land, Antarctic Peninsula and the Greywacke-Shale Formation (GSF) in the South Orkney Islands. They display the same lithology and tectonic style, and share a common provenance, and are possibly similar age (Smellie 1991, 1995), but their ages are poorly constrained and are believed to be Late Carboniferous — Early Jurassic. Some plant remains were found by Hobbs (1968) and Dalziel (1969), however their poor preservation prevented precise identification suggest a post-Carboniferous, possibly a Mesozoic age for sedimentation (Schopf 1973). Imprecise Rb-Sr, K-Ar and U-Pb isotopic ages indicated from Late Carboniferous to Early Jurassic

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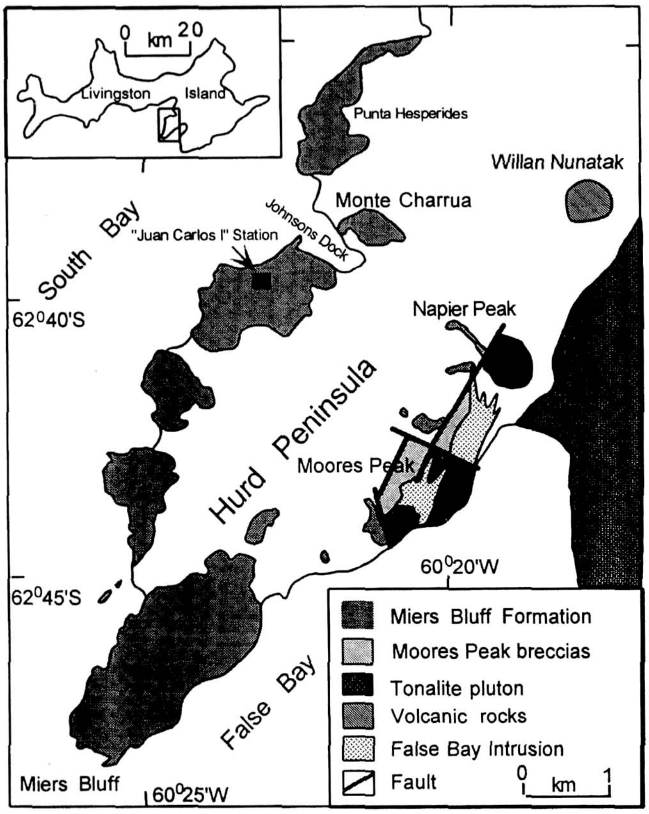

Fig. 1. The exposed map of the Miers Bluff Formation in Hurd Peninsula, Livingston Island (after Willan et al., 1994)

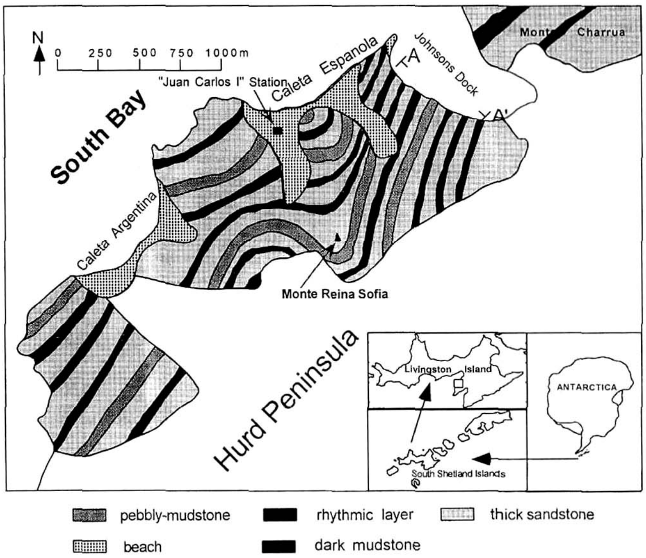

Fig. 2. Sketch map of lithology near "Juan Carlos I" Station in Hurd Peninsula, Livingston Island

(322-197Ma) (Dalziel 1972, 1982; Pankhurst 1982, 1983; Rex 1976; Herve *et al.* 1991; Gledhill and Rex, 1992; Willan *et al.* 1994; Trouw *et al.* 1997), but the interpretation of these data remains problematic. Petrofabbric and provenance studies show that the U-Pb age of detrital zircons from the sandstones of the TPG and MBF has a Middle-Late Carboniferous age (322+8/-7Ma), the age has been interpreted as a provenance age and hence a maximum age of sedimentation (Loske *et al.* 1988). Four specimens from a single layer of slaty shale yielded a Rb-Sr isochron of 19±23Ma (Dalziel 1972), the age appears to represent a minimum age for deformation and metamorphism (Dalziel 1984). In Hope Bay of Antarctic Peninsula, Upper Mesozoic volcanic and sedimentary strata rest unconformably on rocks of the Trinity Peninsula Group (Dalziel 1972, 1984).

The MBF crops out on the Hurd Peninsula of Livingston Island (Fig.1). It is in a series of laterally extensive exposures along the south eastern coast of South Bay, from Punta Hesperides in the north to Miers Bluff in the south, and then there are some smaller outcrops of the MBF along the north western coast of False Bay. The MBF was firstly studied in the Geophysics Year of 1957-1958, which is called the Miers Bluff Series (Hobbs 1968). Dalziel regarded as the Miers Bluff Formation in 1969, and ascertained the majority of the MBF strata are inverted (Dalziel 1972). Since 1990, geologists from the different countries worked on rocks of the MBF. By the end of 1997, authors investigated the MBF and found that there are four layers of pebbly mudstones near Spanish Antarctic Station (Fig. 2). This is the first discovery for the pebbly mudstones layers in the MBF of Livingston Island. A scarcity of pebbly mudstone was reported by previous workers in a few sites in Hurd Peninsula (Arche *et al.* 1992; Doktor *et al.* 1994). We, therefore, considered the pebbly mudstone to be an important indicator for the depositional environment of the MBF and for comparing South Shetland Islands with Antarctic Peninsula.

The lithology of the Miers Bluff Formation

Since 1990, geologists from many countries had worked on the MBF, and had also found the majority of the MBF strata are overturned which strike northeast - southwest and dip to northwest (Arche *et al.* 1992; Doktor *et al.* 1994; Smellie *et al.* 1995). The MBF is divided into three lithostratigraphic divisions (Pallas *et al.* 1992), Smellie *et al.* (1995) named the lower two divisions as the Johnsons Dock and Napier Peak members, but the upper division (Moores Peak breccias) is ambiguous correlation with the lower two divisions. Doktor *et al.* (1994) divided the Johnsons Dock member of Smellie *et al.* (1995) into three members (South Bay Member, Johnsons Dock Member and Glaciar Rocoso Member) and distinguished six facies associations (massive sandstones, bedded sandstones, sandstone-mudstone association, sandstone/mudstone rhythmites, mudstones, chaotic association).

The MBF is dominated by massive sandstones and turbidites, may represent sedimentation in upper and lower mid-fan of submarine fan. The sedimentary rocks of the MBF have been surveyed in detail near the Spanish Antarctic Station- "Juan Carlos I" by authors in December, 1997. The MBF in this area mainly consists of massive sandstones, dark mudstones, rhythmical layers and pebbly mudstones (Figs. 2 and 3). In the Jonsons Dock Section (Fig. 3), compared with the facies associatons of Doktor *et al.* (1994), massive sandstones and bedded sandstones called massive sandstones, sandstone/mudstone rhythmites is rhythmical layers, but the pebbly mudstone bed is distinguished by authors in here.

Massive sandstones: They are medium to coarse grained sandstones, which are usually structureless, although sometimes they display planar and trough cross-stratification and current ripples. The thickness of sandstone bed is generally more than 1m, but individual bed shows conspicuous lateral thickness changes. The most remarkable feature of these sandstones is the common presence of mudstone clasts with the size varying from several millimeters to over 30 centimeters.

Dark mudstones: They consist of homogeneous, dark gray, massive clay and silt, laminae intercalated lenticular fine sandstones. The lamination reflects subtle grain size differences and fining-upwards lamina. The thickness of dark mudstone beds is from several meters to up to 20 m.

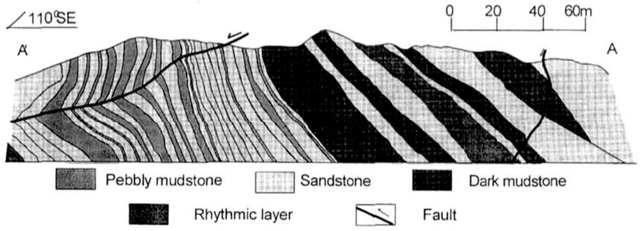

Fig. 3. The profile of the Miers Bluff Formation in the southwestern coast of Jhonsons Deck

Rhythmical layers: They are composed of rhythmical alternations of mudstones and sandstones. Sandstones are very fine- to fine-grained and each bed shows sharp base and mostly gradational top. The sandstone beds display normal grading with some planar to ripple cross-lamination, and their thickness are between a few and ten centimeters. The mudstones range from a few millimeters to several centimeters in thickness. Each rhythmical layer generally displays incomplete Bouma sequences (Tcd, Tcde, Tce, Tde). The sand/shale ratio varies between 3:1 and 1:4.

Characteristics of pebbly mudstone

Four layers of pebbly mudstones are observed from the MBF near the Spanish Antarctic Station - "Juan Carlos I". These pebbly mudstone beds are bounded by massive sandstones, with sharp contacts in both upper and lower with the over- and underlying sandstone beds (Figs. 2 and 3). The occurence strikes NE-SW, and dip to the northwest. The layers of pebbly mudstones are massive without any traction flow structure. The thickness of pebbly mudstone is usually over ten meters. The density of pebbles varies from several to over 100 per square meter.

Pebbles of pebbly mudstones include quartz, chert, sandstone, mudstone, granite, volcanic rock, metamorphic rock etc., but those of acidic and intermediate volcanic rocks are the most frequent. In general, the average size of pebbles is 4 - 7 cm long, but the largest is up to 85 cm in size, and the smallest is less than 1cm. Boulder-size clasts pebbles (>50cm) are sparse and are preserved near the

Fig. 4. Pebble in Pebbly mudstone in south of "Juan Carlos I" Station (scale - 5 cm)

Fig. 5. Pebble in pebbly mudstone in Caleta Argentina (hammer - 28 cm)

upper surface in common. The sorting is bad, but the sphericity is better and usually is well-round and ellipsoid (Figs. 4 and 5). The long axis of pebbles orients near south-north.

Matrix of pebbly mudstone is composed of mud and clay, and the matrix content is between 50-90% in thin section. The most clasts within the matrix of pebbly mudstones are quartz, feldspar, mudstone and volcanic rocks. The shape of these clasts is angular and subangular, scarce in round and subround, and the size is from less than 1mm to 6mm.

Discussion and geological significance

As pebbly mudstone is common in the Cape Legoupil Formation (part of the TPG) in north Graham Land, Antarctic Peninsula (Ribeiro *et al.* 1994; Andreis *et al.* 1997), but is scarce in the MBF. The newly discovered pebbly mudstone beds suggest depositional environment of the MBF makes the comparision of depositional features of South Shetland Islands with those of Antarctic Peninsula.

Sedimentary facies of the MBF have been interpreted to indicate a mid-fan depositional environment in a marginal basin of uncertain tectonic setting (Dalziel 1982, 1984; Semllie 1991, 1995; Arche *et al.* 1992; Pallas *et al.* 1992), that is, the MBF is deep sea sediments. It is known that debris flow and glaciomarine are two kinds of processes for the formation of pebbly mudstones in deep sea. From the present data, both processes are possible, but it is more possible for debris flow. The main features of debris flow sediments are poor-sorting, massive structure, high muddy content, matrix-support, larger pebbles preserved near upper surface. The features are typical in pebbly mudstone beds. The features of pebbly mudstones in the MBF are consistent with debris flow sediments.

From the isotopic chronological data, the MBF was considered to be late Paleozoic - early Mesozoic (Dalziel 1972, 1982; Pankhurst 1982, 1983; Rex 1976; Herve *et al.* 1991; Gledhill and Rex 1992). It was known that there was the glacial period in Carboniferous-Permian period, but in the latest isotopic chronological data and sparse fossils, the age for the formation of the MBF may be Triassic (Schopf 1973; Thomson 1975; Willan *et al.* 1994; Trouw *et al.* 1997). Furthermore, there are no glacial feathers, such as dropstone and striation. Hence, pebbly mudstone could not be glaciomarine sediments. From the above discussion, pebbly mudstone, therefore, would be debris flow sediments.

Second, it is known that depositional environment for the MBF and TPG was submarine fan, probably developed on a transitional crust along the continental margin of the Gondwana supercontinent, with an old dissected magmatic arc in the continental source area (Arche *et al.* 1992; Doktor *et al.* 1994; Smellie *et al.* 1995; Trouw *et al.* 1997; Andreis *et al.* 1997). Depositional environment of the MBF is the upper and lower of mid fan of submarine fan in the

Hurd Peninsula (Smellie *et al.* 1995). The depositional environment of pebbly mudstone in deep sea may be the mouth of canyon, the channel of mid-fan and upper-fan, and the boundary between the deep sea basin and the cliff of continental shelf. Hence, pebbly mudstone may deposit in the channel of the mid-fan of a submarine fan.

Third, Ribeiro *et al.* (1994) interpreted the turbidite successions in the Cape Legoupil Formation of the Antarctic Peninsula as middle to distal submarine fan deposits with pebbly mudstone intercalations of local debris flows. Andreis *et al.* (1997) reported the layers of pebbly mudstone in Antarctic Peninsula, but the pebbly mudstone layers were not reported in the MBF, debris-flow deposits are scarse in the MBF. Hence the new discovery of the pebbly mudstones layers in Hurd Peninsula furthermore suggest that there is the same tectonic setting between Antarctic Peninsula and South Shetland Islands before the formation of the Mesozoic-Cenozoic magmatic arc..

Conclusions

The new discovery of four pebbly mudstone layers in the MBF indicates that: (1) pebbly mudstone might be debris flow sediments; (2) the deposited environment of pebbly mudstone would be in the channel of the mid-fan of the submarine fan; (3) the discovery shows that South Shetland Islands and Antarctic Peninsula were at the same tectonic setting before the formation of the Mesozoic-Cenozoic magmatic arc.

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