

## The volcanic record in the ANDRILL McMurdo Ice Shelf AND-1B drill core

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**Summary** The 1285 m thick MIS core offers an invaluable opportunity to obtain a detailed record of volcanism in McMurdo Sound. Volcanic stratigraphy and preliminary petrologic data on volcanic rocks in the AND-1B core are reported here. Remarkable volcanic deposits include: a) a phonolitic pumice layer found at  $\approx 85$  mbsf which is not correlated to any known vent onshore; b) a black well sorted volcanic sands succession (132.83 to 146.79 mbsf) interpreted as being derived mainly from subaerial Hawaiian/Strombolian eruptions; c) a thick volcanic succession in the middle part of the core with an interbedded submarine lava flow. The flow may be derived from a nearby ( $\approx 4$  km) vent on the seafloor according to average length of the lavas with similar composition; d) deeply altered tuffs and minor sandstone below 1220 mbsf. Diagenesis and intense alteration at depths  $>600$  mbsf, hamper the interpretation of magma evolution and provenance.

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### Introduction

Between October and December 2006 the ANDRILL project drilled and cored the McMurdo Ice Shelf (MIS) AND-1B drill hole. Drilling used a riser with circulating drill fluids and had to penetrate 85 m of shelf ice that was moving at 0.5 m per day and 850 m of seawater before reaching the sea floor. The drill hole reached a record depth of 1285 m below sea floor with 98% core recovery. The drill site was situated on the McMurdo Ice Shelf 10 km east of Hut Point Peninsula and 15 km northwest of White Island. It is surrounded by eruptive centers of the Neogene Erebus volcanic province of the McMurdo Volcanic Group (Kyle, 1990) and is close to the active Erebus volcano (Fig. 1). The local alkaline volcanic rocks range in age back to a subvolcanic peralkaline trachyte dike complex at Mount Morning, which is over 19 million years old (Kyle, 1990, and references therein). A thick pumice lapilli tuff, dated at 22 Ma, was found in the Cape Roberts project CRP-2 drillhole (Armienti, et al., 2001; McIntosh, 2001). Aeromagnetic studies have also suggested the possibly of submarine volcanoes beneath the McMurdo Ice Shelf. Minna Bluff to the south of the drill site formed between 7 and 11 Ma and has since acted as an important barrier to the flow of the Ross Ice Shelf into McMurdo Sound (Kyle, 1981a). There is a major glacial unconformity dated between 10 and 11 Ma on Minna Bluff and it is interpreted as a result of erosion by an early Ross Ice Sheet. It was therefore expected that clasts from the Minna Bluff area would be common and important in glacial deposits in the MIS cores.

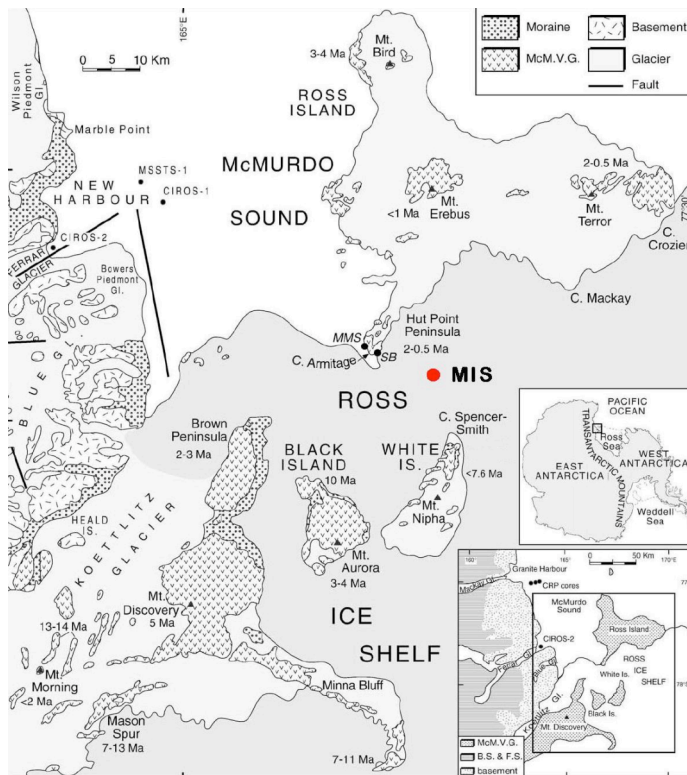
The AND-1B core offers an opportunity to get a much better time record of the nature, volume and timing of volcanism in McMurdo Sound. The study of volcanic rocks in MIS core will contribute to a better understanding of the volcanic and magmatic record in the southern Ross Sea and to shed light on the relationship between volcanism and glacial dynamics. Last, but not least, the nature and tempo of volcanism also provides insights into tectonic processes since it is strictly related to the rifting within the Ross Sea or to the ascent of a mantle plume /the effects of a hot spot. This report summarizes preliminary data on volcanic deposits in the AND-1B core, focusing on those stratigraphic units dominated by volcanic rocks.

### Nomenclature and occurrence of volcanic rocks

Volcanic rocks are found in the AND-1B core in a variety of lithologic units: as clasts in poorly sorted sedimentary rocks (diamictite, mudstone with clasts, breccia, conglomerate), as accessory grains in terrigenoclastic and biogenic sedimentary rocks, as primary constituents in well-sorted sedimentary rocks (volcanic sandstone, volcanic mudstone etc.), and as primary volcanic deposits (lava, lapilli tuff, tuff). All of the volcanic sediments are characterized as resedimented volcanic rocks. The degree of reworking is variable and some units are interpreted to be “near-primary” deposits. The designation of “near-primary” is based on the lithologic homogeneity and textural characteristics (sorting, rounding, clast shape etc.) of the unit.

Geological and geochemical studies have shown the lavas in McMurdo Sound area define several major fractionation lineages (Kyle, 1981b). Since about 10 Ma the lavas have mostly belonged to one of several basanite-phonotephrite-tephriphonolite-phonolite lava lineages and prior to 10 Ma their compositions were usually less

undersaturated and part of an alkali basalt-trachyte association (e.g. alkali basalt-hawaiite-mugearite-benmoreite-trachyte). Since at the present only few analytical data are available, for the sake of core characterization a simple classification was used for volcanic materials and was based on mineral assemblage recognisable by thin sections examination and on preliminary probe data collected on selected sample. Three rock types were recognized:



**Figure 1.** Geological map of the southwest corner of the Ross Sea (redrawn from Sandroni and Talarico (2006) showing McMurdo Volcanic Group exposures and generalized ages for the major volcanic centres within the Erebus Volcanic Province (Cooper, et al., 2007; Kyle, 1990). Inset map represents a geological sketch of the McMurdo Sound area, showing basement complex, cover complex (Beacon and Ferrar Supergroups) and McMurdo Volcanic Group outcrop areas. Locations of MSSTS-1, CIROS-1, CIROS-2 and CRP drill sites are also shown. Abbreviations: B.S. Beacon Supergroup; F.S. Ferrar Supergroup; McM.V.G. McMurdo Volcanic Group; Gl. Glacier; Is. Island; C. Cape; MMS. McMurdo Station; SB Scott Base.

crystals are also present in this deposit. Below ~100 mbsf the volcanic sediment is dominated by black and brown volcanic sandstone composed of mafic angular, vesiculated glass. The fine glassy shards typically show fluidal delicate shapes. Many of these glassy beds are normally graded with thin cross laminated fine layers at top of units. Compositions of glass are relatively variable but are all restricted within the the basanite field of the TAS diagram (Fig. 2).

### **LSU 3 (146.79-382.98 mbsf)**

In LSU 3, volcanic rocks are restricted to pebble clasts, to limestones in diatomite and to scarce subangular and subrounded brown glassy shards occurring in diamictite or in sandy mudstone. A short interval of stacked bedded and normally graded glassy volcanic sandstone and siltstone occur from 184.6-9 mbsf. These glassy shards show a basanitic composition (Fig. 2). Volcanics pebbles show sometimes red oxidised groundmass, while secondary calcite, silica and pyrite fill vesicles and/or veins. Free crystals, including acmite and kaersutite are also abundant.

- Mafic (basaltic) – characterized by phenocrystic olivine and clinopyroxene with or without plagioclase in the groundmass.
- Intermediate – phenocrysts of plagioclase ± kaersutite ± clinopyroxene
- Felsic (phonolitic, trachytic) – phenocrysts of K-feldspar ± kaersutite ± sodic clinopyroxene (acmite).

### **Petrology**

The distribution of volcanic rocks in the AND-1B core is described in the context of eight lithostratigraphic units (LSU 1-8), which were defined by the ANDRILL MIS sedimentology team. The core description phase included on-ice logging of volcanic layers and petrographic characterization of select thin sections, and post-ice electron microprobe (EMP) analysis of volcanic glass from select intervals.

#### **LSU 1 (0-82.74 mbsf)**

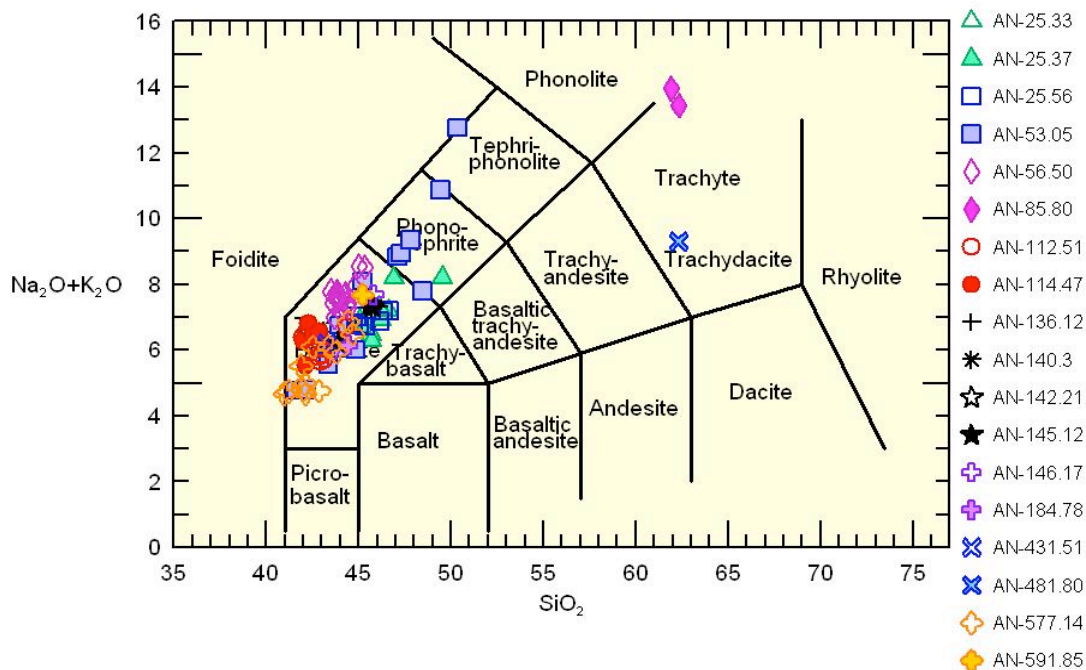
Well-sorted volcanic mud to coarse sand occur in the upper interval (<26.43 mbsf). These volcanic sediments tend to be horizontally well stratified and are composed of fresh brown glassy lapilli and ash shards. The glass shows a large range in vesiculation and the shape varies from very angular to subrounded. Glass has as large compositional variability ranging basanite to tephriphonolite (Fig. 2). More evolved compositions (up to tephriphonolite) appear concentrated in the lower part of the LSU (<50 mbsf).

#### **LSU 2 (82.74-146.79 mbsf)**

In this interval McMurdo volcanics form lapillituff, ash or volcanic sandstone deposits. Glassy shards are also abundant in diamictites. The thickest and best preserved lapilli tuff bed (85.27 to 85.87 mbsf) is composed of gray, angular, occasionally fluidal-shaped, tube pumice. Pumice show a fresh light phonolitic glass and contain few feldspar microlites. Black lithic clasts and euhedral feldspar

**LSU 4 (382.98-586.45 mbsf)**

LSU 4 contains volcanic pebbles, granules, rare pumice clasts and fresh glassy shards, mainly found in silt-bearing diatomite or in calcite-cemented volcanic sandstone. Shards are brown, vesicular and have subrounded to angular shapes. Compositions of glassy clasts are mostly confined within the basanite field, even though a clast with trachytic glass was also observed (Fig. 2). Secondary calcite form patches, commonly fills vesicles and replaces large (>2 mm) olivine crystals.



**Figure 2.** Total alkali-silica (TAS) diagram (LeMaitre, 2002) for selected volcanic glass compositions in AND-1B.

**LSU 5 (586.45-759.32 mbsf)**

LSU 5 comprises the largest volcanic succession within the core and includes two volcaniclastic interval separated by a subaqueous lava flow. In the upper part (<600 m bsf) homogeneous compositions of angular or subangular shards (basanitic) (Fig. 2), led us relate these rocks to the syneruptive resedimentation after limited transport of a primary autoclastic deposit. The lava flow (646.49-649.3 mbsf) is a fine-grained intermediate rock, with few large (>1mm) feldspar phenocrysts set in a felted groundmass. Upper and lower contacts show a thin glassy selvage, now replaced by clay minerals.

Beneath the lava flow, volcanic deposits are composed of rounded pumices and aphyric fine-grained felsic clasts, showing curvilinear edges. All these characters can be related to the reworking and resedimentation of autoclastic material related to the emplacement of a lava flow or to a volcanic dome. At the base of the LSU volcanics are present in siltstones and sandstone as angular to subrounded grains. Clasts include light glassy pumices, brown poorly vesiculated glass shards, or finely crystallized black or red lithics. Fragments of crystals (feldspars or green pyroxenes) are also present. On the whole glassy clasts below 600 mbsf appear totally palagonitized, which hampered even a rough estimate of the composition. In addition throughout this LSU, calcite, silica minerals, and sometimes K-Al sulfate (alunite) fills vesicles of volcanic rocks, or forms cement between clasts. This and lower units are black in color, due to a strong pyritic alteration overprint.

**LSU 6 (759.32-1220.15 mbsf)**

This interval is characterized by low content of volcanic detritus and, at least in the upper layers (<850 mbsf) by a large compositional variability. Volcanic rocks are present mainly as clasts in the diamictite. Pebble size clasts show a predominant felsic composition. These clasts include large (>1 mm) feldspar phenocrysts set in a trachytic groundmass. Acmite or Arfvedsonite crystals are sometimes present. Calcite filling of vesicles and veins are ubiquitous.

**LSU 7 (1220.15-1275.24 mbsf)**

Volcanic rocks in LSU 7.1 comprise tuffs, lapilli tuff and minor sandstone. Clasts in tuffs and lapilli tuffs appear to be mostly homogeneous in composition, though deep analcite alteration prevented a reliable evaluation. The clasts are palagonitized, angular to sub-angular, and variable vesicular. In the upper part of the interval (<1238 mbsf) clasts are made mostly of brown glass with some microphenocryst of feldspars and mafic phases. We classify these clasts as

intermediate in composition. Below 1238 mbsf volcanic rock compositions appear more felsic since brown glass contains only feldspar and some light-colored glassy grains are present. Between clasts and within vesicles, secondary calcite, silica minerals and pyrite are abundant. Sandstones, mainly concentrated at depth 1222 mbsf, are strongly heterolithic with volcanic clasts, basement grains and crystals.

**LSU 8.1 (1275.24-1284.87 mbsf)**

In this interval only few volcanic clasts in diamictite were found. They are felsic in composition and consist of medium grained porphyritic rock with large feldspars (> 2 mm) and subordinate acmite phenocrysts set in a trachytic groundmass.

**Interpretations and summary**

Highlights of the volcanic stratigraphy in the AND 1-B core include:

1. There is a significant amount of McMurdo Volcanic Group detritus in the core. This is consistent as the drill site is surrounded by numerous volcanic centers on Ross Island, White Island and vents to the south, especially Minna Bluff. Most of the volcanic detritus is related to the erosion, transport and deposition by glacial marine sedimentary processes.

2. The volcanic clasts are not diagnostic of any particular eruptive center but petrography and preliminary <sup>40</sup>Ar/<sup>39</sup>Ar dating (Ross and McIntosh, 2007), lead to exclude the contribution of eruptive materials derived from Mt. Erebus volcano.

3. There is not an extensive record of primary pyroclastic fallout deposits (volcanic ashes/tephra) which is consistent with the non-explosive nature of the McMurdo Volcanic Group vents in the area. One important exception is discussed below (see number 5).

4. A phonolitic pumice layer at 85 m depth and dated at 1.015 Ma (Ross and McIntosh, 2007) cannot be correlated to any known vent onshore but is likely to be derived from somewhere on Ross Island. Hut Point Peninsula is the closest possible source although the only exposed felsic rock is at Observation Hill which has a slightly older age of 1.2 Ma. Phonolite vents are widespread on Mt Terror, which is another possible source area.

5. The black well sorted volcanic sands in LSU 2 (132.83 to 146.79 mbsf) appear to have been mainly derived from subaerial Hawaiian/Strombolian eruptions. The graded bedding in the units may represent fall out of tephra through a water column. Sorting during settling through a water column would account for the normally graded beds. The delicate nature of the glass shards in 4 representative samples is not consistent with any mass flow process as this would destroy the classic shard forms. We interpret these volcanic sandstones as representing a very rapid accumulation perhaps from a nearby vent with minor reworking by traction currents. The source of these 1.65 Ma (Ross and McIntosh, 2007) tephra is unknown but is assumed to be from vents on Hut Point Peninsula.

6. The nature, origin and provenance of the thick volcanic succession in the middle part of the core (LSU 5) and possible relationships with the interbedded lava flow requires more detailed investigation. The occurrence of the 6.5 Ma submarine intermediate lava flow in this unit may be derived from a nearby vent on the seafloor (likely within 4 km, according to average length of the lava flow with similar composition (Walker, 1973)).

7. Alteration and diagenetic processes modified significantly textures and compositions of the lower section (>600 mbsf) of the core. This hampers every considerations on magma evolution and provenance, and makes difficult both radiometric and paleomagnetic age determinations

**Acknowledgments.** The success of the MIS drill hole would not have been achieved without the dedication and professionalism of drill team.

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