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Clast provenance and variability in MIS (AND-1B) core and their implications for the paleoclimatic evolution recorded in the Windless Bight - southern McMurdo Sound area (Antarctica)

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Summary Granule- to cobble-grade clasts in the uppermost 575 m of the MIS drill-core (AND-1B) highlight significant downcore modal and compositional variations, which provide direct information about the potential source regions and evidence of an evolving provenance, most likely as results of variable ice conditions and ice-flow directions during the deposition of recovered diamictites. In addition to a significant contribution from the McMurdo Volcanic Group, the dataset indicates a compositionally varied clast assemblage including several basement rock types which are comparable to the main geological units exposed in the area SW of the drillsite, between the Skelton and Byrd Glaciers. Based on these provenance inferences and sedimentological constraints, the deposition of the diamictite units in the upper 575 m section recovered by the AND-1B drillcore would imply several oscillations of a grounded Ross Ice Shelf, possibly coupled with major phases of expansion of the West Antarctic Ice Sheet.

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Introduction

In the McMurdo Sound area, the petrological study of clast (granule- to boulder-grain size class) assemblages and distribution data in CRP (Cape Roberts Project) and CIROS (Cenozoic Investigations in the Western Ross Sea) cores have contributed useful data and interpretations to unravel the complex interplay between tectonic, volcanic and glaciomarine sedimentary processes during the formation of the Victoria Land Basin (VLB) and uplift of the Transantarctic Mountains (TAM) in the Oligocene-lower Miocene time window (Talarico et al., 2000; Sandroni and Talarico, 2001, 2004, 2006). However, both CRP and CIROS demonstrated the lack of long and continuous Plio-Pleistocene glacimarine drillcore records in western VLB, which, as interpreted by Naish et al. (2005), probably reflect a lack of accommodation, and/or erosion of these younger strata during periodic glacial expansions of the West Antarctic Ice Sheet and grounding of the Ross Ice Shelf over the last 5 my. In contrast, the MIS (McMurdo Ice Shelf) drill hole (AND-1B) of the international Antarctic Geological Drilling (ANDRILL) Program in the Windless Bight region revealed a good preservation of a thick (at least 1287 m) Neogene sequence (Naish et al., in press). These sediments have provided an unparalleled opportunity to recover clast variability and provenance data which will greatly enlarge the regional meaning of the limited record so far documented in clast dataset of CRP-1, CRP-2/2A and CIROS-2 cores. This paper include preliminary modal and compositional data and interpretations, based on the study of the clast assemblages occurring in the uppermost 575 m of the MIS drillcore (AND-1B). These data are the first results of an on-going investigation aimed to contribute to constraints on the paleogeography and the ice-shelf dynamics of the McMurdo Sound area over about the past 10 my.

Geological setting

The McMurdo Ice Shelf (MIS) Project obtained a continuous 1284.87m-deep drillcore (AND-1B) through a thick sequence of Neogene (ca. 0-10 Ma) glacimarine, terrigenous, volcanic and biogenic sediment that has accumulated in the Windless Bight region of a flexural moat basin around Ross Island (Fig. 1) (Horgan et al., 2005). The MIS drill hole drillcore (AND-1B) was recovered from the bathymetric and depocentral axis of the moat in 943 m of water from an ice shelf platform (the McMurdo Ice Shelf), corresponding to the NW corner of the Ross Ice Shelf, in an area dominated by volcanic centers belonging to Cenozoic alkalic Erebus Volcanic Province (Kyle, 1990), extensively cropping out at Ross Island, White Island, Black Island and Mount Discovery–Mount Morning peninsula (Fig. 1). Volcanic activity occurred during two main phases, the first (19 to ca. 10 Ma) characterized by trachytic rocks, and the more voluminous second (last 10 m.y.) comprising basanitic to phonolitic sequences (Kyle, 1990). The mountain region west and south of the drillsite, comprised between the Ferrar Glacier and Nimrod Glacier, represents a ca. 800 km long segment of TAM, composed of a Late Precambrian to Early Paleozoic crystalline basement (Ross Orogen) (Stump, 1995), which mainly occupies the coastal area, and shows significant differences in both lithological assemblages, metamorphic grade and dominant fabrics of granitoids (see below). An overlying cover complex, including the Devonian to Triassic Beacon Supergroup and the Jurassic Ferrar Supergroup, with dolerite sills and dykes, accompanied by an extrusive phase

(Kirkpatrick Basalt) not present only within the Dry Valley region (Kyle et al., 1981), is restricted to the inner part of the on-shore region (ca. 25–40 km from the coast; Gunn and Warren, 1962).

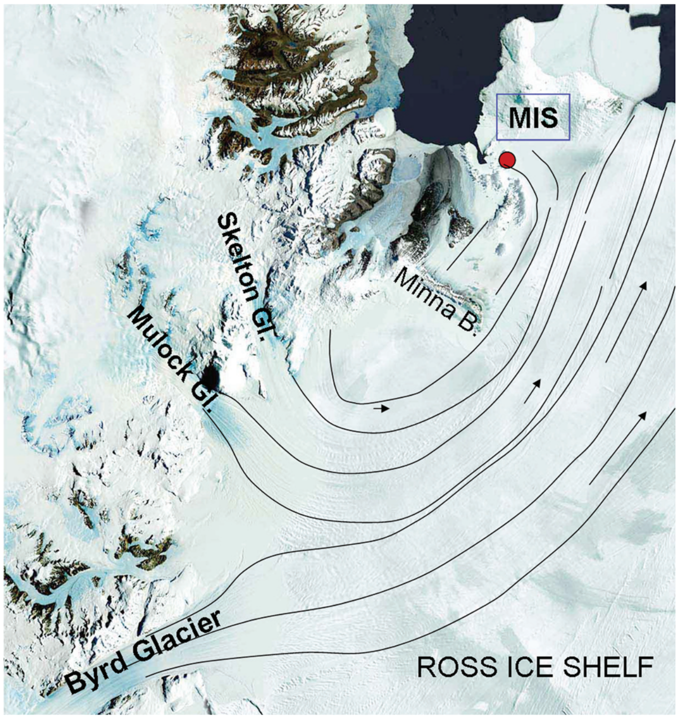

Figure 1. Location of MIS (AND-1B). The region between Skelton and Byrd Glaciers is identified as the potential area for the supply of pebble and cobble-grade detritus during the deposition of diamictites in the upper 575 m of the Neogene section recover.

Distribution of clasts and main lithological types

In the uppermost 575 m of the AND-1B drillcore 32 869 clasts were logged and counted on the basis of both lithology and grain size. The total number of clasts per unit length shows major variations from 0-10 counts per metre for mud- or sand-rich intervals and in diatomite units (e.g. lithostratigraphic unit (LSU; Naish et al., in press) 4.1), in the range ca. 50-150 counts per metre for diamictite units (up to 300 in LSU 4.3). Sharp variations across lithological boundaries are commonly present, as well as within-unit fluctuations. Prominent down-core variations of the number of clasts were detected within the thick diamictite intervals in LSU 1.1, consistently with the further subdivision of these thick units according to facies analysis.

We distinguished seven main lithological groups. Their main features and clast dimensions can be summarized as follows:

- *Volcanic rocks*. This group includes a variety of aphyric to porphyritic varieties, some vesicular and/or amygdale–bearing, ranging in composition from mafic to intermediate and felsic. All of these varieties mainly form granules to small and medium-sized pebbles.
- *Granitoids*. These consist mainly of biotite with or without hornblende granitoids (e.g. granites, syenogranites, granodiorites) showing either isotropic fabrics or foliated to strongly mylonitic fabrics, with minor occurrence of deformed felsic porphyries and gabbroids; they are mostly represented within the pebble and small cobble class. Minor lithologies include: biotite-hornblende tonalite, isotropic or foliated biotite-hornblende quartz-diorite and gabbro, biotite-hornblende alkali feldspar granite, mylonitic or foliated muscovite-bearing granite and felsic granitoids possibly derived by dyke swarms (e.g. microgranites, leucogranites, granophyres, mylonitic felsic porphyries).
- *Metamorphic rocks*. All of these rock types occur as granule, pebbles and cobbles. The group of metamorphic clasts includes both rocks of felsic to mafic meta-igneous nature (e.g. mylonitic biotite with or without garnet orthogneiss, biotite granitic orthogneiss, metadiorites) and metasedimentary rocks derived by a wide range of protoliths and under a rather wide spectrum of metamorphic conditions. Orthogneisses, garnet-bearing biotite gneisses, amphibolites and marble show mineral assemblages and microstructures consistent with upper amphibolite-facies (medium- to high-grade) regional metamorphic conditions. These clasts are particularly widespread in the core section below 511 mbsf (LSU 4.3) but some other occurrences were detected in a thin clast-rich interval at ca. 454 mbsf (lower part of LSU 4.1). Biotite±calcite±Ca-amphibole metasandstones, biotite slates/phyllites, metagraywackes and metalimestones are characterized by decussate, spotted microstructures diagnostic of contact metamorphism, or more often by oriented fabrics indicative of syn-tectonic recrystallizations; in these rocks, mineral assemblages are indicative of biotite-zone (greenschist facies/low-grade) metamorphic conditions. The low-grade metasediments are scattered throughout the core, at places mixed only with foliated granitoids (e.g. LSU 1.1).
- *Sedimentary rocks*. These include at least two major lithological types: quartz-arenites and poorly- to moderately-sorted sandstone with granule-grade clasts (most likely reworked diamictites); these clasts mainly belong to the granule and small-pebble classes.
- *Dolerites*. Generally fine or medium-grained and with variable alteration, ranging from granule to sub-rounded pebbles and cobbles.
- *Quartz*. It occurs as granules or small pebbles, some of them carrying minor micas, most likely interpreted as fragments of coarse grained granitoids.

- *Intraclasts*. Grey to black mudstones and minor sandstones were found to form the most common intraclast lithologies. These clasts are generally represented within the granule and small pebble class. Although logged and described, these clasts were omitted from quantitative provenance analysis but could be considered as a quantitative tool to investigate intrabacinal sediment recycling processes.

Based on semi-quantitative analyses of the dataset, the main distribution patterns can be summarized following the subdivision in LSU as reported in Table 1. Both volcanic and granitoids are ubiquitous in most of the core, with volcanic rocks persistently forming the dominant lithology throughout the core apart from the diamictite units of LSU 1.1 (lower part) where basement clasts of various composition constitute the dominant component. In contrast, all other lithologies show a more restricted distribution. Note that granitoid counts include quartz counts, assuming that most of quartz granules are derived from granitoids. Moreover, both intraformational clasts and sedimentary clasts were not considered. The latter can represent up to 35% of the clasts population in LSU 1.1, where sedimentary clasts are mainly clasts of reworked diamictite, but in most of the core they constitute a very minor component and are mainly represented by scattered small pebbles of quartz-arenites (most likely derived from the Beacon Supergroup).

Discussion

Clast logging and preliminary petrological investigations indicate that the clast assemblage in the upper 575 m of the MIS drillcore includes not only lithologies (volcanic rocks) of local provenance but a wider lithological range including distinctive TAM rock types, as well as reworked Cenozoic sediments and intraclasts. Basement clasts are highly variable throughout the cored interval and pebble- to cobble-sized clasts consist of a significantly wide range of

Table 1 Lithostratigraphic units (LSU) and clast relative proportions among the main rock types in the uppermost 575 m of the MIS (AND-1B) drillcore (Vo: volcanic; Bas: basement clasts (Gr: granitoid; Met: metamorphic; Dol: dolerite); mbsf: metres below the sea floor).

LSU	Depth – top (mbsf)	Depth – base (mbsf)	Unit Thickness (m)	Lithology	Estimated average clast proportions and basement clast compositions
1.1	0.00	82.74	82.74	Muddy diamictite with mudstone and sandstone	Vo (10-90%) – Bas (90-10%) (Bas: Gr≈Met>>Dol)
2.1	82.74	86.63	3.89	Claystone and volcanic ash/tuff	Vo (ca. 100%)
2.2	86.63	94.52	7.89	Mudstone-rich diatomaceous ooze	Vo (100-70%) – Bas (0-30%) (Bas: Met >> Gr, rare Dol)
2.3	94.52	132.83	38.31	Diamictite, volcanic sandstone, and silty claystone	Vo (50-100) – Bas (50-0%) (Met≥Gr)
2.4	132.83	146.79	13.96	Volcanic sandstone, siltstone, and mudstone	Vo (> 95%) (Met 5%)
3.1	146.79	169.40	22.61	Muddy diamictite with diatomite	Vo (20-100%) – Bas (80-0%) (Met>>Gr)
3.2	169.40	181.93	12.53	Silty claystone and mudstone alternating with diatomite	Vo (100-50%) – Bas (0-50%) (Met>>Gr)
3.3	181.93	292.66	110.73	Alternating diamictite and diatomite	Vo (40-100%) – Bas (60-0%) (Met≥Gr, rare Dol)
3.4	292.66	347.19	54.53	Biosiliceous-bearing diamictite	Vo (≈ 85 %) – Bas (≈ 15%) (Met≥Gr, rare Dol)
3.5	347.19	363.37	16.18	Silty claystone, sandstone, and muddy diamictite	Vo (> 95%) (Met<5%)
3.6	363.37	382.98	19.61	Biosiliceous-rich diatomite, mudstone, and diamictite	Vo (55-100%) – Bas (45-0%) (Met≥Gr)
4.1	382.98	459.24	76.26	Diatomite	Vo (> 95%) (Met + Gr <5%) ; Vo 60% - Bas 40% (Met≥Gr) at ca. 454 mbsf
4.2	459.24	511.18	51.94	Diamictite, mudstone, and diatomite	Vo (70-100%) – Bas (30-0%) (Gr≥Met)
4.3	511.18	575.12	63.94	Volcanic diamictite, mudstone, and diatomite	Vo (50-100%) – Bas (50-0%) (Gr≥Met, rare Dol)

lithological types, indicating that several basement lithologies were involved as sources of basement clasts in the recovered sedimentary strata. As in CRP and CIROS cores (Talarico and Sandroni, 1998; Talarico et al., 2000; Sandroni and Talarico, 2001, 2004, 2006), the granitoid pebbles can be closely match to source-rock units belonging to the Cambro-Ordovician Granite Harbour Igneous Complex, which is the dominant component in the Ross Orogen in South Victoria Land (Gunn and Warren, 1962; Allibone et al., 1993a, 1993b). The occurrence of pebbles of phyllites and low-grade metasandstone scattered throughout the core is noteworthy as the on-shore exposures of these rocks are rather limited, and restricted to areas of the Skelton Group (Grindley and Warren, 1964) between the Skelton and Mulock Glaciers, about 100 km southwest of the AND-1B drillsite. Medium- to high-grade metamorphic rocks such as biotite-garnet gneiss, coarse-grained marble and orthogneiss are known to be a common rock types in the amphibolite facies Koettlitz Group between Koettlitz Glacier and the Mackay Glacier (Grindley and Warren, 1964; Findlay et al., 1984; Talarico et al., 2005) but other medium- to high-grade metamorphic areas are exposed between the Darwin and Byrd Glaciers and, further south, in the upper Nimrod Glacier. At the present stage of knowledge and based on the preliminary characterization of low- to medium-grade metamorphic clasts and of foliated and mylonitic granitoids, the most likely source for these pebbles can be identified in the region between Skelton and upper Byrd Glaciers (Fig. 1). Future petrological investigations in both metamorphic and plutonic pebbles and a detailed comparison with all the potentially similar on-shore rock units in the Transantarctic Mountains will test and eventually confirm these provenance inferences. Based on this interpretation and sedimentological constraints, the deposition of the diamictite units in the upper 575 m section recovered by the AND-1B drillcore would imply several cycles of advance/retreat of a grounding Ross Ice Shelf, possibly coupled with major phases of expansion of the West Antarctic Ice Sheet.

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