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# Preliminary chronostratigraphy for the upper 700 m (upper Miocene – Pleistocene) of the AND-1B drillcore recovered from beneath the McMurdo Ice Shelf, Antarctica

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## Preliminary chronostratigraphy for the upper 700 m (upper Miocene – Pleistocene) of the AND-1B drillcore recovered from beneath the McMurdo Ice Shelf, Antarctica

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**Summary** Chronostratigraphic data available for the preliminary age model for the upper 700 m for the AND-1B drill core include diatom biostratigraphy, magnetostratigraphy, <sup>40</sup>Ar/<sup>39</sup>Ar ages on volcanic material, <sup>87</sup>Sr/<sup>86</sup>Sr ages on calcareous fossil material, and surfaces of erosion identified from physical appearance and facies relationships recognized in the AND-1B drill core. The available age data allow a relatively well-constrained age model to be constructed for the upper 700 m of the drill core. Available diatom biostratigraphic constraints and <sup>40</sup>Ar/<sup>39</sup>Ar ages allow a unique correlation of ~70% of the AND-1B magnetic polarity stratigraphy with the Geomagnetic Polarity Time Scale (GPTS). Unique correlation is not possible in several coarse diamictite intervals with closely spaced glacial surfaces of erosion and sparse microflora. However, the age model indicates relatively rapid (up to 1m / k.y.) and continuous accumulation of intervening finer grained diatomaceous intervals punctuated by several half to million year hiatuses representing more than half of the last 7 m.y. in the AND-1B record. The mid-late Pleistocene is represented by superimposed diamictite units separated from upper Pliocene alternating diamictites / diatomites by a ~ 1 m.y. hiatus coincident with a regionally correlated seismic reflection surface. A c. 100 m thick diatomite represents a significant portion of the early Pliocene record in the AND-1B drillcore. Strata below ~620 m are late Miocene in age, however biostratigraphic constraints are absent below 586 m and correlation with the GPTS is relatively unconstrained.

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### Introduction

In the austral summer of 2006/07, the ANDRILL project recovered a 1284.87 m drillcore from beneath the floating McMurdo Ice Shelf. The drill site lies in c. 950 m of water in an overdeepened moat basin surrounding the combined volcanic load of Ross Island. The rig was sited on the ice shelf surface close to the Williams Field Aerodrome (~5km E of Scott Base). Drilling utilized a diamond drilling system with sea riser and recovery was >98%. The site chosen lies in the path of the advancing McMurdo/Ross Ice Shelf but at a depth that is least likely to have seen erosion of the record from ice grounding. The upper part of the sedimentary succession is intimately linked to the nearby Ross Island volcanoes, which provided accommodation space through the Plio-Pleistocene and also delivered volcanic material to the site and hence provide opportunities for dating the record. Drilling recovered a stratigraphic succession of alternating diamictites, diatomites and volcanoclastic sediments. Preliminary chronostratigraphic data enable an age model to be constructed for the upper 700 m (upper Miocene – Pleistocene) of the cored succession.

### Chronostratigraphic data

#### *Diatom Biostratigraphy*

The upper 586 m of the AND-1B drill core contains a varied and rich Plio-Pleistocene diatom flora. Abundances and preservation vary markedly with facies changes in the core and occurrences are often truncated or interrupted by rapidly changing facies and frequent hiatuses. Above 150 m, diatom occurrences are restricted to thin stratigraphic intervals containing mixed assemblages indicating potential reworking. Potential age diagnostic species include *A. actinophilus*, *T. gracilis*, *T. antarctica*, *T. elliptipora*, *A. ingens*, *R. leventerae* and *T. fasciculata* indicating a latest Pliocene through mid-Pleistocene age. Between 150 and 586 m, diatom abundances are higher, preservation is good and reworking is limited. Thick diatomaceous intervals include *T. kolbei*, *R. diploneides*, *T. inura*, *T. tetraoestruppii* var. *reimerii*, *A.*

*fasciculatus*, *A. maccollumii*, *T. vulnifica*, *F. praeinterfrigidaria*, *F. Barronii*, *T. striata*, *T. complicata*, *R. diploneides*, *T. oestrupii*, and *T. torokina* indicating an early – late Pliocene age range for this interval.

### **Magnetostratigraphy**

Characteristic remanence directions were identified at meter resolution between 32 m and 242 m and at 2-5 m resolution between 240 and 700 m in the AND-1B drill core. Samples were analyzed post drilling using cryogenic magnetometers and a combination of alternating field and thermal demagnetization methods depending on demagnetisation behaviour in a suite of ~10 m spaced pilot samples. The resulting inclination data define a series of eight normal polarity magnetozones (N1 – N8) alternating with seven reversed polarity magnetozones (R1-R7) for the upper 700 m of the drill core (Figure 1). Coarse lithofacies and poor recovery prevented sampling or the isolation of characteristic remanence directions from vector component plots for several relatively thin stratigraphic intervals shaded in grey on the polarity log in Figure 1. The punctuated nature of the record limits correlation with the Geomagnetic Polarity Time Scale (GPTS), however, biostratigraphic and radiometric constraints allow unique correlation for a significant proportion of the upper 700 m of the drill core (Figure 1).

### **<sup>40</sup>Ar/<sup>39</sup>Ar**

<sup>40</sup>Ar/<sup>39</sup>Ar analyses of volcanic material from the upper 700 m of the AND-1B drill core provide ages for three stratigraphic intervals. At 85.53-85.85 m, an isochron age of  $1.014 \pm 0.004$  Ma was obtained for euhedral sanidine phenocrysts separated from a felsic tephra. At 112.51-112.62 m and 136.21-136.27 m, purified glass samples from basaltic tephtras, yielded isochron ages of  $1.65 \pm 0.03$  Ma and  $1.67 \pm 0.03$  Ma, respectively. Incremental heating of a whole rock sample from a basaltic lava flow at 648.37-648.43 m yielded a plateau age of  $6.48 \pm 0.13$  Ma.

### **<sup>87</sup>Sr/<sup>86</sup>Sr**

Strontium ratios were determined from calcareous macrofossils and microfossils from the upper 500 m of the AND-1B core. Most of the macrofossils are taxonomically indeterminate fragments of bivalves and/or barnacles and yielded ages ranging between ~5 and ~20 Ma from comparison with the Strontium Look-up Table (version 4:08/04) described in McArthur et al. (2001). As well as being significantly older than the age predicted by <sup>40</sup>Ar/<sup>39</sup>Ar and diatom biostratigraphy, there is no stratigraphic order to the inferred ages. Thus we could only assume possible contamination and/or reworking of older material, consequently the data were not included in the age model for the drill core. However, an age of  $1.52 \pm 0.06$  Ma was obtained for a foraminifera concentrate at 91.6 m, which is more consistent with the resulting age model.

### **Glacial surfaces of erosion**

Some 40 glacial surfaces of erosion were identified in the upper 700 m of the AND-1B core during the initial core characterization. These surfaces record a period of glacial advance that resulted in erosion of underlying strata, and hence potentially represent hiatuses in the succession. The glacial surfaces of erosion are identified on the basis of a sharp, or occasionally amalgamated, contact between diamictite overlying facies and often, though not always, sheared and deformed finer grained underlying facies.

## **Construction of the age model**

Diatom first and last occurrences (D) are plotted on Figure 1 according to a constrained optimisation model for southern ocean diatom biochronology and published age ranges as summarized by Cody et al. (in press). Left-facing arrows represent first occurrences and right facing arrow represent last occurrences, respectively. Fine vertical dashed lines represent potential error in identification in the occurrences in the AND-1B core either from possible reworking or sporadic occurrences. Yellow boxes represent age and depth range of diatom assemblages zones (DUA) from diatomaceous intervals in the core. Age ranges for assemblage zones are derived from published data summarized in Cody et al. (in press). Argon ages (A) are plotted as red dots with error bars on Figure 1 - only A4 has a significant error. The Strontium age on foraminifera from 91.56-91.61 m is plotted as a beige dot with error bars. Lines Ri, Rj and Rk represent seismic reflection horizons identified in seismic reflection data. Potential unconformities in accumulation are shown on Figure 1 where glacial surfaces of erosion were identified by physical criteria observed in the drillcore.

Correlation of the magnetozones identified in the AND-1B core with the GPTS (Ogg and Smith, 2004) is constrained as follows: 1) Line of correlation is pinned to <sup>40</sup>Ar/<sup>39</sup>Ar ages within errors and matching polarity; 2) line of correlation is constrained by age range of diatom assemblage zones and matching polarity; 3) line of correlation passes younger than individual first occurrences and older than individual last occurrences where these are consistent with diatom assemblage zones; 4) Solid line of correlation is drawn where a 1:1 match of polarity stratigraphy with the GPTS is defined, recognized polarity reversals are marked with a +; 5) a dashed line of correlation represents upward or downward continuation to the nearest unconformity within polarity constraints but where other constraints do not preclude alternative polarity correlations; 6) No line of correlation is given for intervals with multiple unconformities and limited constraints.

## **Preliminary chronostratigraphy of the AND-1B record**

The available age data allow a relatively well-constrained age model to be constructed for the upper 700 m of the AND-1B drill core. Available diatom biostratigraphic constraints and  $^{40}\text{Ar}/^{39}\text{Ar}$  ages allow a unique correlation of ~70% of the AND-1B magnetic polarity stratigraphy with the GPTS (Ogg & Smith, 2004). Unique correlation is not possible in several coarse diamictite intervals with closely spaced glacial surfaces of erosion and sparse microflora. The age model indicates relatively rapid (up to 1 m / k.y.) and continuous accumulation of intervening finer grained diatomaceous intervals punctuated by several half to million year hiatuses, representing more than half of the last 7 m.y. of the AND-1B record.

### ***The Pleistocene record (0 – 150 m)***

A significant hiatus (1.7-2.4 m.y.) co-incident with the Rk seismic reflector separates an overlying Pleistocene succession dominated by diamictite from an underlying Pliocene succession of alternating diamictites and diatomites. The hiatus coincides with a closely spaced pair of glacial erosion surfaces identified at 150.23 and 150.73 m and represents ~ 1 m.y. Two  $^{40}\text{Ar}/^{39}\text{Ar}$  ages on basaltic tephra constrain the interval between 112 m and 136 m to the lowermost Pleistocene and indicate relatively rapid accumulation (~5m /k.y.). A series of glacial surfaces of erosion between 93 m and 109.42 m account for much of the early Pleistocene (Chron C1r.3r) followed by a less rapidly accumulated interval of normal polarity between 80.03 m and 84.97 m (N2), which immediately overlies the felsic tephra ( $1.014 \pm 0.004$  Ma / 85.53-85.85 m) and is correlated with Chron C1r.1n (Jaramillo). Accumulation rates of the diamictite interval above 72.84 m is 0.5 m / k.y. or less, but poor recovery in the upper 30 m and sparse age data in the upper 50 m prevent any better constraint on the upper Pleistocene.

### ***The upper Pliocene record (150 - ~350m)***

Between 150 m and ~350 m, correlation of the AND-1B magnetic polarity record with the GPTS is constrained by several first and last occurrences of diatom species as well as diatom assemblage zones generally represented by diatomite intervals punctuated by diamictite intervals with poorly represented diatom flora. Although the combined diatom flora suggests that this interval of the core correlates with the mostly normal Chron C2An (Gauss), the AND-1B polarity record is dominated by reversed polarity and represented by a R-N-R polarity pattern. The intervals between 150 m and 210.56 m and about 300 m are relatively well constrained and correlated with the Chron C2An.1n / Chron C2r.2r (Gauss / Matuyama) boundary and Chron C2An.2r (Mammoth), respectively. While unambiguous correlation is not possible for the rest of the upper Pliocene interval of the core, an average accumulation rate of 0.2 m / k.y. with Milankovitch order cyclicity in diatomite / diamictite alternations is suggested. The Rj seismic reflector (3.2-3.3 Ma) appears to correlate with a lithologically distinct diamictite – diatomite transition with no hiatus indicated.

### ***The lower Pliocene record (~350 - ~620m)***

A succession of disconformities between 346.03 m and 586.45 m contain the lower- upper-Pliocene boundary with a 0.5 – 1 m.y. hiatus distributed on one or more of the glacial surfaces of erosion. Between 363.37 m and 620 m, diatom flora constrain correlation of this interval of the AND-1B record with chrons C3n.1n (Cochiti) to C3n.r (one of the short reversed subchrons within the Gilbert) of the GPTS and a unique correlation is possible. An average accumulation rate of 0.5 m / k.y. is indicated for both the mostly diatomaceous intervals as well as the alternating diatomite / diamictite intervals. The exception is the lower part of diatomaceous lithological unit 4.1, where a much slower accumulation rate (~0.1 m / k.y.) is indicated. This interval corresponds with seismic reflection horizon Ri.

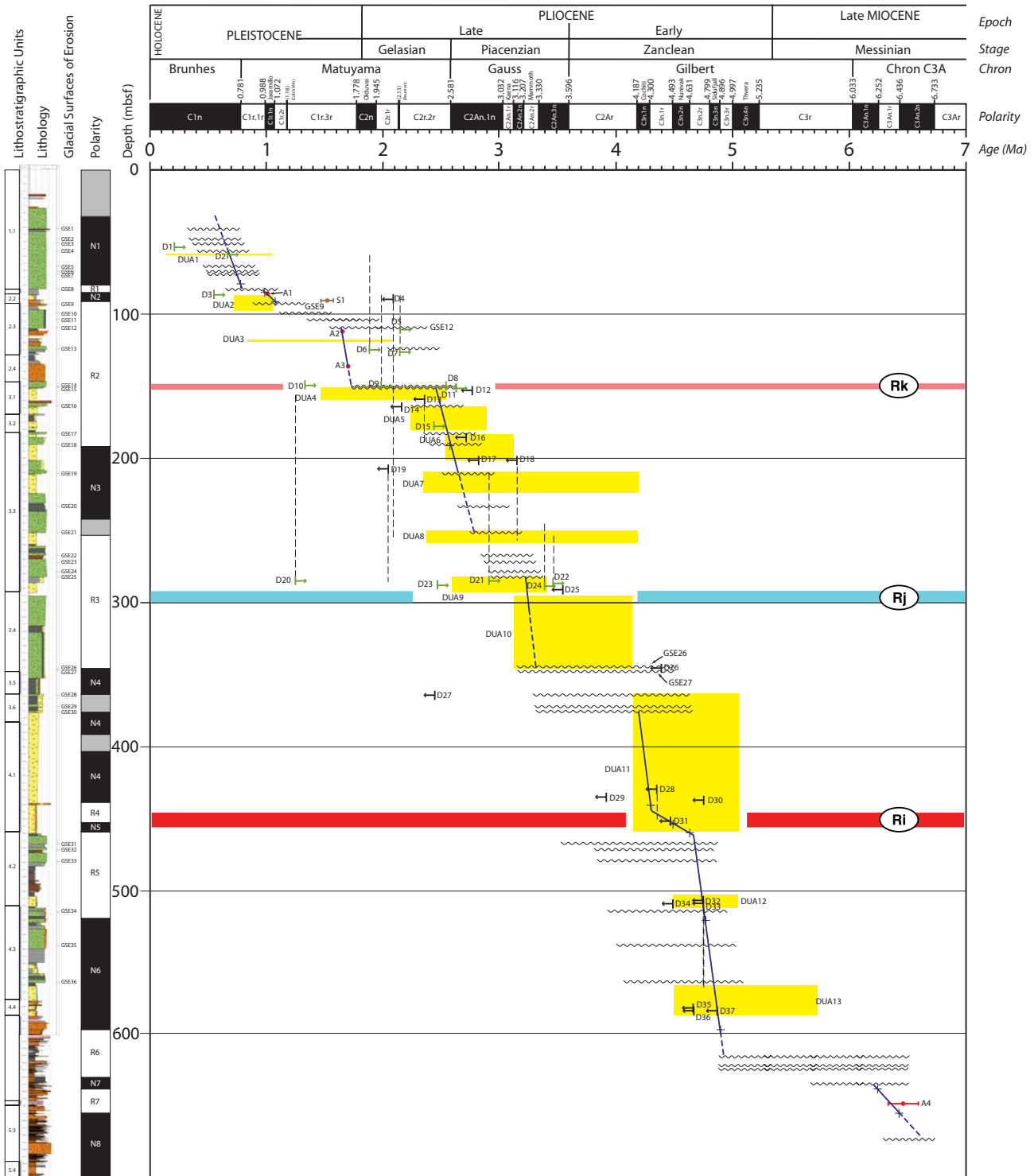
### ***The Miocene record (>~620m)***

Below ~ 620 m, an  $^{40}\text{Ar}/^{39}\text{Ar}$  age ( $6.48 \pm 0.13$  Ma) on the basaltic lava flow at 648.37-648.43 m indicates a late Miocene age for this interval of the core and a correlation with Chron C3A is implied, with a ~1 m.y. hiatus indicated distributed among several disconformities between 615 and 635 m.

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**Figure 1.** Preliminary age model for the upper 700 m of the AND-1B drill core. The age model is based on diatom biostratigraphy (D = individual first and last occurrence datums, DUA = Diatom assemblage zones),  $^{40}\text{Ar}/^{39}\text{Ar}$  ages (A) on tephric material,  $^{87}\text{Sr}/^{86}\text{Sr}$  (S) analyses of foraminifera and magnetostratigraphy. Disconformities represent glacial surfaces of erosion. Ri, Rj, and Rk are seismic reflection horizons identified by the seismic reflection data. Line of correlation to the Geomagnetic Polarity Time Scale (Ogg & Smith, 2004) is shown as solid with polarity reversal tie-points marked with a + where other constraints allow a unique correlation and is dashed where continuity of accumulation is inferred. No line of correlation is given for intervals with multiple disconformities and limited constraints.