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Mineralogical implications for the Late Pleistocene glaciation in Amery Oasis, East Antarctica, from a lake sediment core

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Abstract: The clay mineralogical composition of a 552 cm long sediment core from Lake Terrasovoje in Amery Oasis, East Antarctica, was analysed and compared with that in surface sediments from other locations in the vicinity. The lower part of the sediment core is formed by sub- and proglacial sediments with a dominance of smectite and illite, and lower amounts of kaolinite and chlorite. The upper part of the core is deposited after 12 500 cal yr BP and mainly composed of illite and kaolinite, with low amounts of smectite and chlorite, such as found in samples from rock outcrops and covering sediments throughout Amery Oasis. The clay composition in the lower section of core Lz1005 suggest that the basin of Lake Terrasovoje was filled by a 150–200 m thickened Nemesis Glacier prior to 12 500 cal yr BP rather than by local ice caps.

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Introduction

The East Antarctic Ice Sheet (EAIS) contributes *c.* 79% to the global ice volume. Changes in the extent and volume of the EAIS have a direct impact on global sea level (Denton & Hughes 2002), and affect the global heat budget by influencing the albedo and the atmospheric and oceanic circulation patterns (Ingólfsson & Hjort 1999). Predictions of the near-future EAIS evolution require a good understanding of modern climatic and environmental developments, but also of the variability of the ice sheet in the past. However, it is still under debate, whether the thickness and extent of the EAIS was much larger during the Late Pleistocene or if they were comparable to the present settings. Indications for both scenarios have been found in different coastal regions or were modelled based on relative sea level changes and paleoenvironmental information derived from the investigation of ice cores, marine and lacustrine sediment sequences or geomorphological evidence.

Amery Oasis is located at the margin of the Lambert Glacier/Amery Ice Shelf system (Fig. 1), which drains about 14% of the EAIS (Higham *et al.* 1997, Hambrey & McKelvey 2000). It has been suggested that local ice expansion onto Amery Oasis during the Last Glacial Maximum (LGM) was relatively modest, with ice extents not much different from today (cf. Adamson *et al.* 1997, Hambrey & McKelvey 2000). In contrast, marine cores from Prydz Bay indicate that the Lambert Glacier/Amery Ice Shelf system was significantly extended during the LGM and grounded half way across Prydz Bay (e.g. Domack *et al.* 1998, Whitehead *et al.* 2006 and references therein). Retreat of Lambert Glacier/Amery Ice Shelf at 14–11 ka BP (O'Brien & Harris 1996, Domack *et al.* 1998, Taylor & McMinn 2001, 2002, Verleyen *et al.* 2005) was contemporaneous with the deglaciation of several basins in Amery Oasis between 20 and 10 ka BP (Wagner *et al.* 2004, Fink *et al.* 2006).

The basin of Lake Terrasovoje is located in the northern part of Amery Oasis at 148 m a.s.l. (Fig. 1; Wagner *et al.* 2004). The outlet of the lake drains into a horseshoe-shaped basin, which is at least 100–150 m deeper than the surrounding terrace and fed by a branch of Nemesis Glacier to the north. The deglaciation of Lake Terrasovoje after the local glacial maximum occurred prior to *c.* 12 500 cal yr BP (Wagner *et al.* 2004). This was reconstructed from the study of a 552 cm long sediment sequence (core Lz1005) from the lake. The changes of the biological and biogeochemical components in the sediment sequence are chronologically well constrained (Fig. 2) and provide crucial information about the regional climatic and environmental history after the deglaciation of the lake basin (Wagner *et al.* 2004).

Clay minerals in sedimentary records can reflect sediment provenances. A comparison of the clay minerals in the Lake Terrasovoje sediments with those in surface sediments from other locations in Amery Oasis might reveal, whether the lake basin was inundated by an enlarged version of the local ice caps or cirque glaciers on the Loewe Massif, or a significantly thickened Nemesis Glacier during the local glacial maximum (Fig. 1). For this purpose, the clay fraction (< 2 µm) from core Lz1005 and from surface sediments of other basins in the region was separated by settling tubes, investigated by XRD, determined using the

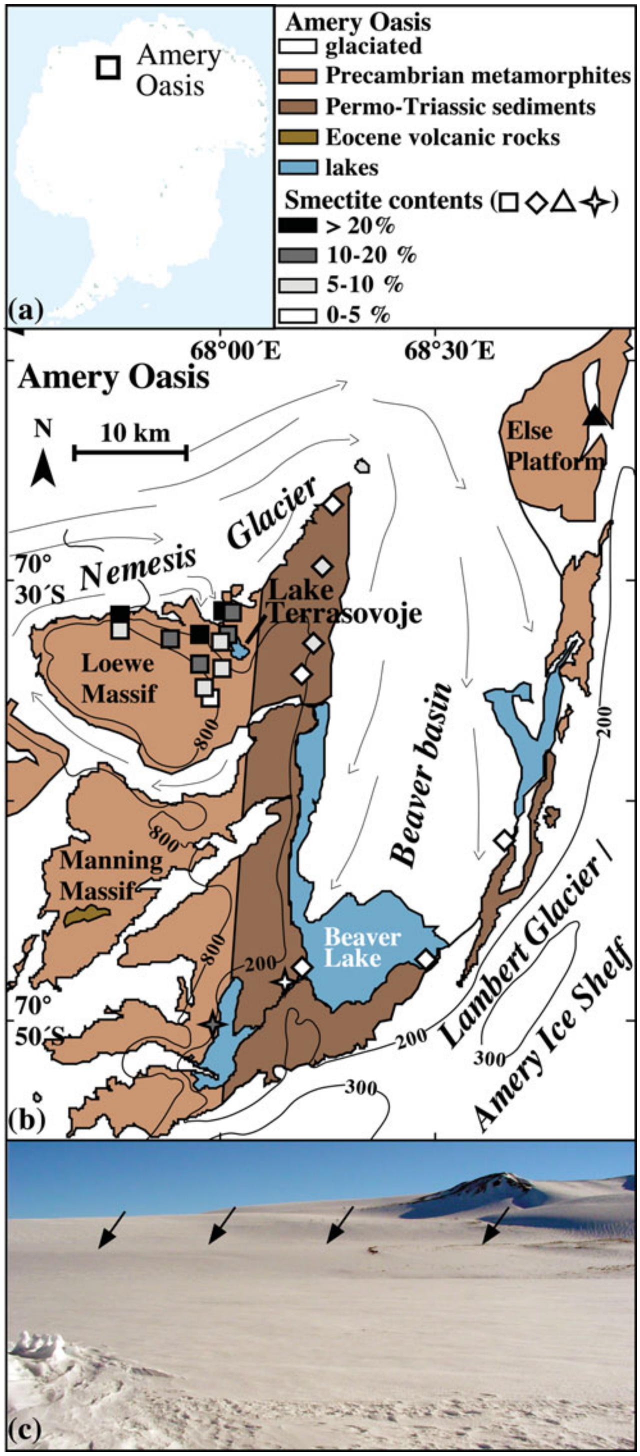

Fig. 1. a. Map of Antarctica showing the location of Amery Oasis. **b.** Simplified geological map (after Cantrill *et al.* 1995, Mikhalsky *et al.* 2001) of Amery Oasis with location of Lake Terrasovoje and moraine samples and their smectite contents (for symbols see Fig. 3). **c.** Photo of heavily snow covered Lake Terrasovoje, taken from the outlet in the north-western edge of the lake. The terrace on the southern slope of the lake is marked by black arrows and indicates a relict terminus of a glacier tongue. Photo taken by Rob Ferguson.

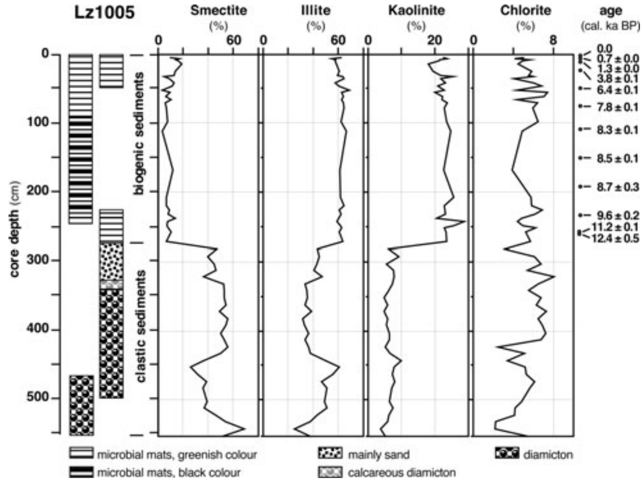

Fig. 2. Lithology, clay-mineral distribution, and radiocarbon dates (in cal. yr BP) from the sediment core Lz1005 from Lake Terrasovoje.

MacDiff programme, and compared with existing data (Ehrmann *et al.* 2003).

Results and discussion

Based on the lithology, water content, density, and biogeochemistry two major sedimentary units were distinguished in core Lz1005 from Lake Terrasovoje (Wagner *et al.* 2004).

The core section from 552–270 cm is dominated by unsorted clastic sediment with particles ranging in size

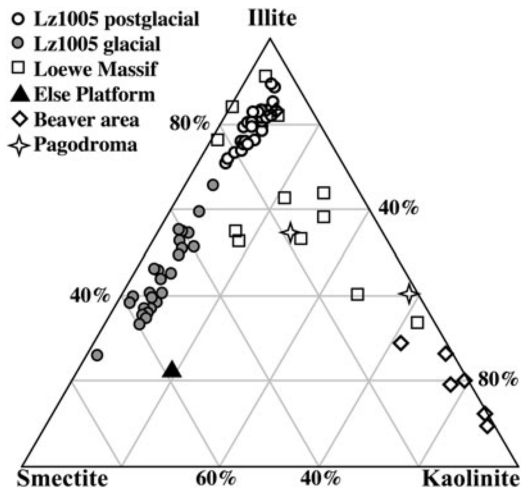

Fig. 3. Ternary diagram showing the clay-mineral composition in moraine samples from Amery Oasis and in core Lz1105 from Lake Terrasosvoje. Stars indicate clay mineral composition of formations of the Pagodroma Group (Ehrmann *et al.* 2003). For locations see Fig. 1b.

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from clay to gravel, with a higher proportion of sand between 330 and 270 cm. This section probably represents sub- and proglacial sediments, which were deposited during the final stage of the glaciation or during the deglaciation of the lake basin after the local glacial maximum (Wagner *et al.* 2004). The clay mineralogical composition of this section displays some minor variations and is dominated by smectite and illite, with lower amounts of kaolinite and chlorite (Fig. 2). Illite and, with a lower proportion, chlorite are typical clay minerals provided from the Precambrian metamorphites in East Antarctica (Ehrmann *et al.* 1992, Diekmann *et al.* 2003). The kaolinite in the Lake Terrasovoje sediments probably originates from the Permo–Triassic sediments in Amery Oasis (Webb & Fielding 1993). Smectite includes various expandable clay minerals and is normally not formed under the polar conditions existing today in the oasis. Smectite can be supplied by the Tertiary sediments of the Pagodroma Group. However, the smectite proportion in these sediments is in general less than 25% (Ehrmann *et al.* 2003). The relatively high amount of smectite between 32–69% in the sub- and proglacial sediments from Lake Terrasovoje (Fig. 2) hence indicates additional supply of this mineral, probably by long distance transport from the Eocene volcanic rocks cropping out at the nearby Manning Massif or from the hinterland of Amery Oasis (Mikhalsky *et al.* 2001).

The upper 270 cm of core Lz1005 consist of organic-rich sediments, which are mainly formed by fine laminated microbial mats. These biogenic sediments were deposited under limnic conditions after the deglaciation of the lake basin at *c.* 12 500 cal yr BP (Fig. 2; Wagner *et al.* 2004). This upper section displays minor variability in clay mineralogical composition, but can be clearly distinguished from the lower section of the core, as it is mainly composed of illite and kaolinite, with low amounts of smectite and chlorite (Fig. 2). The low proportion of chlorite in combination with conspicious amounts of smectite between 3 and 19% (Fig. 2) suggests that the minerogenic particles in this upper section of the core originate from bedrock and glacial sediments exposed in the vicinity of the lake. This assumption is supported by the clay mineral composition of samples from rock outcrops and covering sediments throughout Amery Oasis. These samples contain minor concentrations of smectite and chlorite and high amounts of illite and kaolinite, though the proportions of the various clay minerals vary depending on the spatial distribution of the different geological formations in the catchment (Fig. 1).

Interpretation

The clay mineralogical composition of the sub- and proglacial sediments of Lake Terrasovoje core with their relatively high contents of smectite implies that these sediments were neither eroded from the bedrock nor from the Tertiary and Quaternary sediments exposed in Amery Oasis today. This conclusion is supported by the clay mineral composition in moraines sampled at different locations in Amery Oasis (Fig. 1). The moraines are composed of both illite- and kaolinite-rich sediments aligned on a distinct two-member mixing line. A probable explanation for the relatively high contents of smectite and the low contents of kaolinite in the lower section of core Lz1005 is their origin from alkaline or intermediate volcanic rocks (Biscaye 1965, Heim 1990, Ehrmann *et al.* 1992, 2005). With the exception of a restricted area in the Manning Massif (Fig. 1), such rocks are not exposed in Amery Oasis today (Mikhalsky *et al.* 2001). Ehrmann *et al.* (2003) suggested that large areas of subglacial volcanic rocks occur in the western hinterland of Amery Oasis and are responsible for a relatively high amount of smectite in Tertiary sediments of the Pagodroma Group.

The only way to supply smectite from this source in the western hinterland of Amery Oasis to the Lake Terrasovoje basin was through glacial transport by the Nemesis Glacier, which today flows eastward along the northern margin of Amery Oasis. At present, a lateral tongue of Nemesis Glacier terminates 1.5 km north of and *c.* 100–150 m below Lake Terrasovoje (Adamson *et al.* 1997). In order to explain the relatively high amounts of smectite in the lower section of core Lz1005, we suggest that the Nemesis Glacier prior to 12 500 cal yr BP was significantly thicker than today and reached as far as Lake Terrasovoje. Such a glacial configuration is consistent with an increase of smectite contents in moraines on Loewe Massif with decreasing distance towards Nemesis Glacier (Fig. 1). Increased ice thickness and extent have also been suggested from model simulations by Huybrechts (2002), and would match a proposed retreat of the Nemesis Glacier from the Loewe Massif between *c.* 16 and 11 ka BP (White *et al.* 2005).

Geomorphological indication for a much thicker lateral tongue of Nemesis Glacier during the past is given by a terrace located at least 60–80 m above the present lake level at the southern rim of the Lake Terrasovoje basin (Fig. 1). This terrace most probably represents a glacier highstand during the local glacial maximum or indicates a shoreline of a proglacial lake, dammed by a thickened Nemesis Glacier. The difference between the altitude of this terrace and the terminus of Nemesis Glacier in the horseshoe shaped basin today is at least 150–200 m, which probably indicates the increased ice thickness of this glacier during the local glacial maximum.

A significantly thicker and enlarged Nemesis Glacier during the local glacial maximum, however, would not rule out that large parts of the Amery Oasis have remained ice free, which is indicated by the results of geomorphological observations (Adamson *et al.* 1997) and exposure dating (Fink *et al.* 2006).

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