Pan-African age of the Gamburtsev Mountains?

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Summary The Gamburtsev Mountains are the Earth's most enigmatic mountain range, situated in the middle of Antarctica underneath the thick East Antarctic Ice Sheet. Here we present an indirect geochemical approach to learn about the composition and history of the Gamburtsev Mountains by studying ODP Site 1166 sediments from Prydz Bay. We have made $^{40}Ar/^{39}Ar$ analyses of individual hornblende grains, laser ablation U-Pb analyses of individual zircon grains, and Nd isotope analyses of bulk sediments from downcore samples. Zircon U-Pb ages of samples with Eocene depositional ages (deposited by braided river systems prior to the build-up of the East Antarctic Ice Sheet) show a prominent population peak at 500-550 Ma, reflecting the pan-African orogeny, which resulted in the final amalgamation of Gondwana. Additionally a second tectono-thermal event is revealed at 850-1050 Ma, in agreement with published U-Pb zircon data on outcrop samples from the Prydz Bay area. Hornblende grains from the same samples have a clear pan-African age cluster around 500 Ma. This age structure is found in modern diamicts around the Prydz Bay area and in Pliocene to Pleistocene diamicts at Site 1166. Neodymium isotopes at Site 1166 show a negative shift from values averaging ε_{Nd} = –14.9 for alluvial and shallow marine sandstones of Oligocene to Eocene age to values around ε_{Nd} = –17.5 for Pliocene to Pleistocene diamicts. We suggest that our results exclude the likelihood that the Gamburtsev Mountains are a young (<500 Ma) volcanic orogen. From the current dataset we tentatively conclude a pan-African origin of the Gamburtsev Mountains.

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Introduction

Antarctica is about the size of the United States and Mexico combined, yet it is largely hidden from direct observations due to its 98% ice cover. Hence most of our knowledge of the geology and the tectono-metamorphic history of the interior of the continent comes from geophysical observations. One of the most puzzling features of Antarctica is the Gamburtsev Mountains, a subglacial mountain range situated in the middle of East Antarctica that extends 1200-1300 kilometer across with an estimated pre-ice elevation of more than 2500 meters (Fig. 1; DeConto and Pollard, 2003). Some models of ice sheet growth suggest that this is where the East Antarctic Ice Sheet (EAIS) first developed (e.g., Huybrechts, 1993). Today the Gamburtsev Mountains are part of the drainage system of the Lambert Glacier, the largest single ice stream flowing from the interior of the Antarctic Plateau, draining about 20 % of the EAIS. Our knowledge about the Gamburtsev Mountains is very poor, however, and a large number of international research projects strive to resolve the nature of these subglacial mountains in the context of the International Polar Year (e.g., GigaGAP, GAMBIT, GAMSEIS, Gamburtsev Subglacial Mountain Drilling – GSMD; http://www.ipy.org). Unless drilling through the EAIS will recover direct samples, a promising approach to "sample" the Gamburtsev Mountains is to examine sediment from a drainage system originating in the Gamburtsev Mountains, and deposited in a downstream marine setting prior to Antarctic glaciation. We assume that the tectonic depression of the Lambert Graben, which is at least 120 million year old, would have been a preferred drainage pathway in pre-glacial times (e.g., Jamieson et al., 2005).

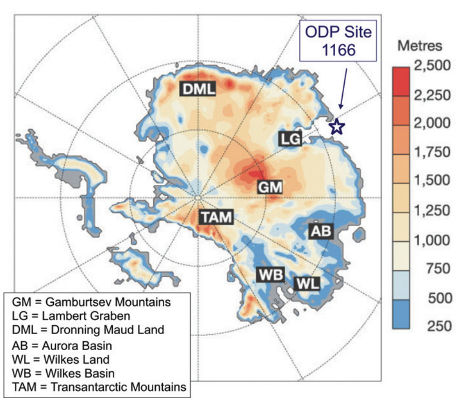

Figure 1. Early Cenozoic ice-free Antarctic topography in meters above sea level from DeConto and Pollard (2003). Location of ODP Site 1166 downstream the drainage system of the Gamburtsev Mountains is indicated by the blue star.

Samples and methods

We identified ODP Leg 188 Site 1166 in Prydz Bay as a promising location for determining the composition of the Gamburtsev Mountains Site 1166 is located on the Prydz Bay continental shelf (Fig. 1), on the southwestern flank of Four Ladies Bank, and comprises a diverse suite of strata that from the bottom up include pre-glacial, early glacial, and glacial sediments. Figure 2 shows the five lithostratigraphic

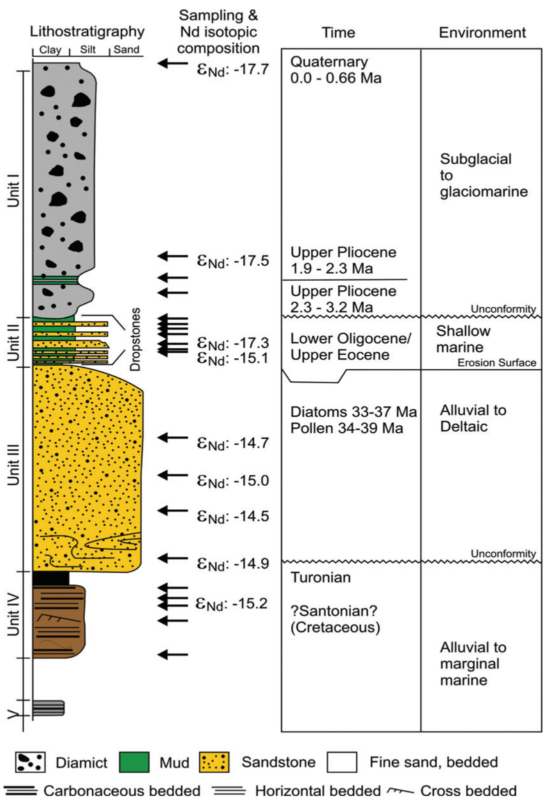

Figure 2. Summary diagram of Site 1166 modified from Cooper and O'Brien (2004). Arrows mark locations of samples used in this study. Next to the arrows, Nd isotopic compositions of bulk samples are reported expressed in epsilon units (= deviation of a measured $^{143}Nd/^{144}Nd$ from a chondritic value in parts per 10,000).

units recovered at Site 1166, together with age constraints based on diatom biostratigraphy and palynology and an interpretation of the paleo-environment as summarized in Cooper and O'Brien (2004). Unit III consists of poorly sorted sands with a silty clay matrix of early to late Eocene age. This unit has been interpreted as subaerial alluvial plain. With the caveat that we assume that the Gamburtsev Mountains were an elevated mountain belt in the Eocene, and that the pre-Oligocene riverine drainage system was transporting erosional products from the mountain belt into the Lambert Graben and Prydz Bay, we suggest that the sediments of Unit III very likely comprise material being eroded off the Gamburtsev Mountains. However, as indicated in Figure 2, we sampled all different stratigraphic layers for geochemical analyses to be able to see potential transitions from a pre-glacial composition of the sediments, potentially probing the Gamburtsev Mountains, to the glacially eroded sediment of Unit I.

Samples were disaggregated in de-ionized water and washed through a 63 micron sieve. The detrital component of the <63 micron fraction was used for Nd isotopic analyses on the L-DEO AXIOM MC-ICP-MS after removal of authigenic material by sequential leaching and separation of Nd on a two-step column procedure (see van de Flierdt et al. (in press) for analytical details). The >63 micron fraction was sieved at 250 microns to pick hornblende grains. Samples and monitor standards were co-irradiated in the Cd-lined in-core facility (CLICIT) at the Oregon State reactor and single-step laser fusion $^{40}Ar/^{39}Ar$ analyses for individual grains were processed at the L-DEO Ar geochronology lab using a CO_2 laser for fusion (see Roy et al., submitted, for analytical details). Zircons were separated from the 63-250 micron fraction using heavy liquids and a Frantz isodynamic separator. U-Pb geochronology of zircons was conducted by laser ablation MC-ICP-MS at the Arizona LaserChron Center. The analyses involve ablation of zircon with a New Wave/Lambda Physik DUV193 Excimer laser (operating at a wavelength of 193 nm) using a spot diameter of 35 microns. Details of analysis procedures and estimates of uncertainty are given at http://www.geo.arizona.edu/alc/detrital%20zircon%20methods.htm.

Results and discussion

A summary of the detrital Nd isotopic compositions at Site 1166 is shown in Figure 2. Samples of Cretaceous, Eocene, and lower Oligocene/upper Eocene sand layers show a Nd isotopic composition averaging $\varepsilon_{Nd} = -14.9$. Moving up in the sediment column, a slight shift in provenance seems to have happened during the lower Oligocene/upper Eocene. One shallow marine clay layer, as well as one glacio-marine diamict, and a core top sample show Nd isotopic compositions of $\varepsilon_{Nd} = -17.7$ and -17.5. Although this shift in the Nd isotopic composition around the lower Oligocene/upper Eocene seems to be a robust feature, we are unable to derive any major interpretation from the data until we have Sm and Nd concentrations to calculate model ages. From preliminary results for downcore samples at a nearby glacial till location, the 2.5 epsilon unit shift seems to reflect different sources in the Prydz Bay area, which however are not vastly different in age (ca. 1.9 to 2.2 Ga old continental crust). $^{40}Ar/^{39}Ar$ hornblende ages are presented in Figure 3 as stacked histograms, each representing a different lithostratigraphic unit at Site 1166 (see Fig. 2). All three units show the same prominent peak at about 500 million years. This extensive pan-African provenance is consistent with the results of the survey by Roy et al. (submitted) for glacio-marine core-top samples, with the results obtained by Hemming et al. (2007) for glacial tills from Prydz Bay, as well as with the review of evidence for pan-African metamorphism in Gondwana (Veever, 2004). We consider that these data provide an important insight into the composition of the Gamburtsev Mountains. $^{40}Ar/^{39}Ar$ hornblende ages are the result of the last major tectono-metamorphic event of the source region of the sediments, and therefore we can say with confidence that the source region of Site 1166 has not experience a thermal event in excess of 450°C since 500 Ma. If our assumption is correct that the riverine erosion products of the Gamburtsev Mountains were indeed delivered to Prydz Bay prior to glaciation on Antarctica, this would mean that the Gamburtsev Mountains are most likely of pan-African age.

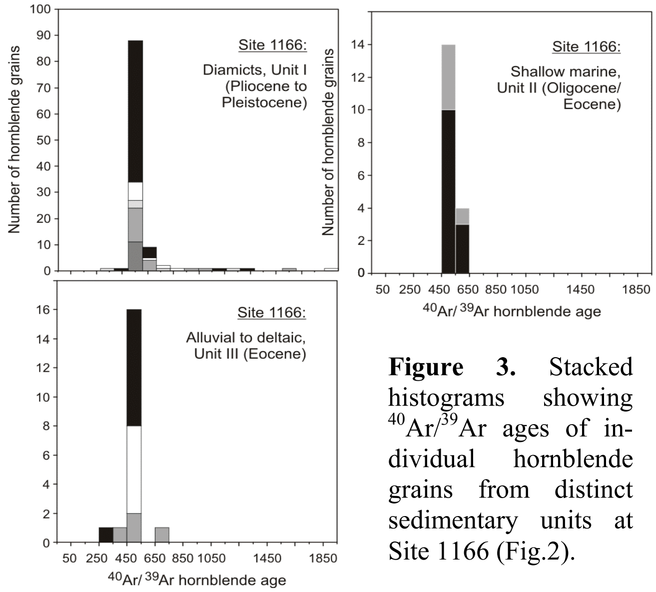

Figure 3. Stacked histograms showing $^{40}Ar/^{39}Ar$ ages of individual hornblende grains from distinct sedimentary units at Site 1166 (Fig.2).

To "see through" the metamorphic ages, we performed U-Pb ages on individual zircon minerals from three samples within Unit III (Figs. 2 and 4). The age probability plots were produced with the normalized probability plot routine provided on the Arizona LaserChon website, and the Site 1166 samples (red, green, blue) are shown in comparison to data for the Rayner Province (purple) and the Prydz-Denman-Darling orogen (black) (Fitzsimons, 2000). Zircons from all three samples from Site 1166 show a U-Pb age population peak at around 500-550 Ma, with a subordinate peak at about 850-1050 Ma (Fig. 4). Older zircon grains are very sparse.

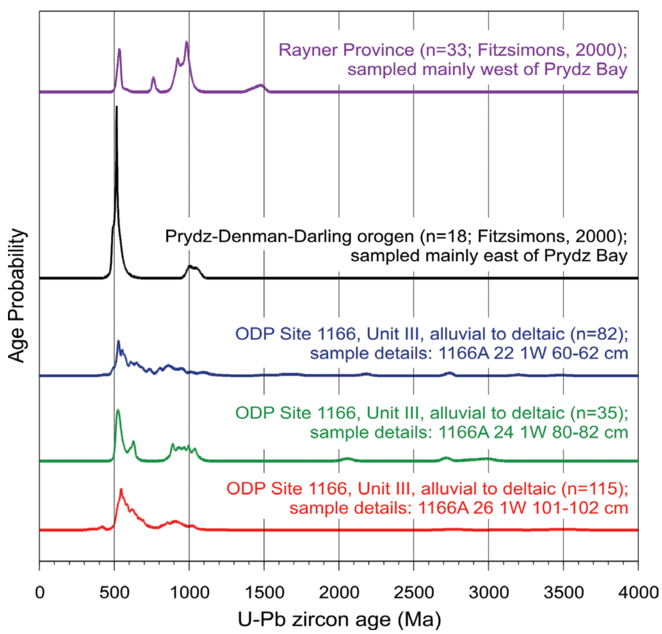

Figure 4. Stacked probability plots of U-Pb zircon ages for the Eocene alluvial to deltaic sequence at Site 1166 (red, green, blue) in comparison to U-Pb zircon ages from the Rayner Province and the Prydz-Denman-Darling orogen (black and purple; Fitzsimons, 2000b)

Based on our geochemical data, and assuming that the sampled fluvial sediments at Site 1166 have a source from the Gamburtsev Mountains, we suggest that the possibility that the Gamburtsev Mountains are a young volcanic orogen can be excluded. This interpretation is in agreement with several lines of evidence, including: (1) the general view that there is no evidence for post Gondwana-break-up tectonic activity in the interior of the East Antarctic craton (e.g., Fitzsimons, 2000a), (2) reported features indicating that the Gamburtsev Mountains may have been in place as nucleation site for the Carboniferous-Permian glaciation (Veevers, 1994), and (3) surface wave tomography indicating more than 250 km deep continental roots underneath East Antarctica (Morelli and Danesi, 2004). Our proposed age of ~500 Ma for the crust that composes the Gamburtsev Mountains is not inconsistent with a suggested mid-Carboniferous origin due to shortening of an intracratonic basin in response to long-distance stress from the Variscan collision (Veevers, 1994) or with a suggested Carboniferous initiation of rifting in the Lambert Graben associated with the rise of the Gamburtsev Mountains (Lisker et al., 2003). However, we are left with the puzzling question why the Gamburtsev Mountains are still such a huge mountain range if they were formed so long ago. We hope that the answer to this question might be found through the geophysical efforts during the IPY, revealing the architecture of the lithosphere underneath this enigmatic mountain range.

Summary

We present new data on downcore sediments from ODP Site 1166 (Prydz Bay), taken in order to identify the age of the crust that makes up the Gamburtsev Mountains. Combined U-Pb dating of zircons, $^{40}Ar/^{39}Ar$ dating of hornblendes, and bulk Nd isotopic compositions reveal no major provenance change from pre-glacial erosional deposits (alluvial and deltaic sands) to glacial deposits (diamicts). Assuming that the alluvial and deltaic samples at Site 1166 with an Eocene depositional age comprise a significant fraction of material eroded from the Gamburtsev Mountains, the predominant pan-African age in U-Pb dated zircons indicates an age of ~500 Ma for the crust that makes up the Gamburtsev Mountains. Potential tectonic scenarios for a pan-African origin and the uplift history of the Gamburtsev Mountains, taking into account the remarkable present day elevation, remain to be identified.

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