Provenance of Zircon in McMurdo Sound Antarctica

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BRIEF. This study analyzes the ages of zircon minerals found in the ANDRILL core in order to track past ice flow.

ABSTRACT. Antarctica has been losing ice faster than it can be replenished for a long time, and the faster this happens, the more sea levels will rise. Researching how ice flows in Antarctica can aid in drawing predictions of future sea level rise, atmospheric patterns, and ocean currents. A section of one of the ANDRILL sedimentary cores collected from the sea floor offshore of Antarctica was used for this study. The debris in this core was deposited by the Antarctic ice sheet advancing and retreating over millions of years. By isolating zircon minerals from five samples of the core and collecting their Uranium and Lead isotope data via laser ablation inductively coupled plasma mass spectrometry, a crystallization age was found for each mineral. By dating the zircon grains from each sample, we can see if the debris in the core came from the same source or if it changed over time, which we can interpret as indicating if the ice flow changed. Because we found similar ages of the zircon grains in each sample, we can interpret that the Antarctic Ice Sheet has been flowing in the same way for the history shown in the samples. By adding this information to that obtained by other Antarctic geologists, we can model how Antarctica will melt in the face of present and future global warming.

INTRODUCTION.

Antarctica has the largest ice sheet on the planet, and it is the largest potential impactor on sea level change. The ice and the land beneath it carry millions of years' worth of geological information. Although scientists know that Antarctica's ice sheet has changed size and shape significantly in the past, there is a lack of knowledge about the changes in the patterns of ice flow *(1)*. Better understanding of how Antarctica's ice cover changed over millions of years provides a picture of possibilities for how it will change in the future, and how these changes will impact sea levels, ocean currents, and atmospheric patterns *(2-4)*.

This study analyzes whether the Ross ice shelf's (Figure 1) ice flow pattern has changed by examining the sediment it deposits. The Ross Ice Shelf is the largest ice shelf in Antarctica, and it drains portions of both the East and West Antarctic Ice Sheets. Due to the increased urgency of the problems caused by global warming in the past few decades, more scientists are studying Antarctic provenance *(5,6)*. Provenance analyses aim to pinpoint where the sediment in an area came from and how old the sediment is. By assessing whether the provenance changed over time, we can see if the ice sheet flowed with the same patterns each time the ice sheet grew and retreated.

We studied a core sample from McMurdo Sound Antarctica gathered by the Antarctic Geological Drilling Program (ANDRILL) marked by the white arrow in Figure 1. ANDRILL is a drilling project that drilled two cores near Ross Island, Antarctica. This study analyzes five different 8-10 cm sections of glacial till, or the sediment deposited by the melting ice sheet, from the ANDRILL 1B core.

One of the more commonly used methods of analyzing sediment core samples is isotopic dating. Of the minerals used to date sediment, zircon ($ZrSiO$) is one of the most efficient, and was consequently used in this study *(3, 7, 8)*. Zircon is a mineral found in igneous and metamorphic rocks whose isotope ratios are indicative of the crystallization period of the zircon. Zircon is used as a provenance indicator because it is a very robust mineral, highly resistant to weathering and heat, and reliably preserves uranium and lead isotopes for millions of years. Because zircon grow in rings, like an onion, it is ideal to extract the age from their center, as it contains the original crystallization age *(3)*.

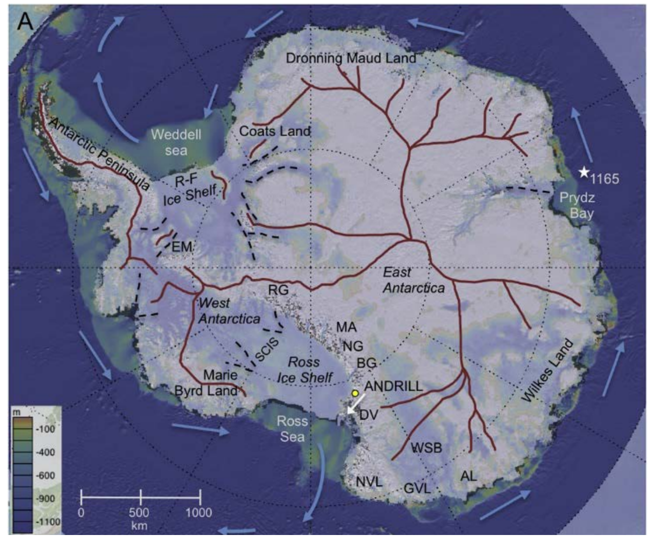

Figure 1. Map of Antarctica showing the location of the ANDRILL core (*3*).

Our goal was to use zircon to determine the source of glacial sediments, and then to use the origin data to better characterize past ice flow. For example, by studying the source of ice-rafted debris carried by icebergs, Williams et al. were able to reconstruct iceberg and ocean circulation patterns for the time period of 3.5 to 19 million years (Ma) *(9)*. Farmer et al. examined glacial till from the last glacial maximum in the Ross Sea area and were able to distinguish differences in sediment that came from either the East Antarctic Ice Sheet (EAIS) or the West Antarctic Ice Sheet (WAIS) *(4)*. Via isotopic dating of our five samples, we were able to identify similarities and differences between the samples. This information can be the basis of interpretations surrounding Antarctic ice sheet stability and predictions of future ice melt.

MATERIALS AND METHODS.

In 2006 and 2007 ANDRILL dug two cores (1B and 2A) in McMurdo Sound, Antarctica. Five samples were obtained from the ANDRILL 1B core that represent five different tills with different ages. Each 8-10 cm core sample is representative of a different depth below the sea floor (32.75-32.85 m, 61.68-61.76 m, 81.55-81.65 m, 103.58-103.66 m, and 108.11-108.19 m), which can be seen in Figure 2.

To isolate the zircon from the samples, several steps to sequentially eliminate non-zircon minerals based on size, magnetism, density, and morphology were taken. First, the five samples were sieved individually to isolate the 63-250 micrometer grain sizes, the typical size of zircon *(11)*. Next, a strong hand magnet was passed over the sample; because zircon is not magnetic, anything that attached to the magnet was discarded *(12)*. After the hand-magnet separation, the samples were separated by density using lithium heteropolytungstate (LST) *(13)*. Separation with LST removes minerals that are less dense than

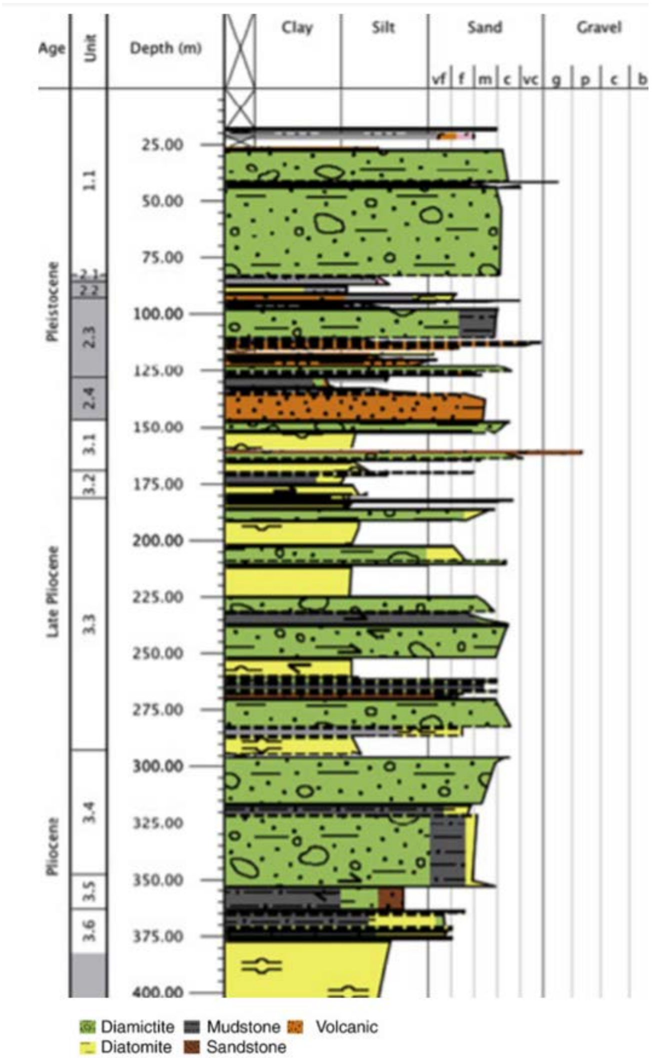

Figure 2. Lithological description of the ANDRILL 1B core *(adapted from 10).*

2.8 g/cm^3 from the sample. The dense fraction of the sample was magnetically separated with a Frantz machine. The magnetic separating machine uses stepwise increases in magnetic strength (0.6, 0.9, 1.2, and 1.6 amps) to ensure that nonmagnetic grains like zircon are not dragged to the magnet with other materials.

After removing the magnetic minerals, the non-magnetic fraction was examined under a microscope and the zircon minerals were hand-picked. Zircon is identifiable by its long thin shape with pointed tips. After each was found, it was placed onto a piece of tape, which was then attached to a mold, into which an epoxy was poured. After the epoxy hardened, the resulting puck holding the zircon grains could be pulled away from the tape and polished in order to expose the center of as many of the grains as possible.

After carbon coating each polished epoxy puck in order to make them conductive, they were examined using a scanning electron microscope (SEM) to ensure the grains were not apatite, a mineral similar in shape to zircon that would interfere with results. Once the zircon grains were identified, images numbering each grain were taken to more easily track the data in the next steps.

Uranium (U) and lead (Pb) isotope data were collected using a laser ablation inductively coupled plasma mass spectrometer, and the data were converted into approximate ages of each zircon grain using the Glitter software package. If the ages are less than one billion years old,

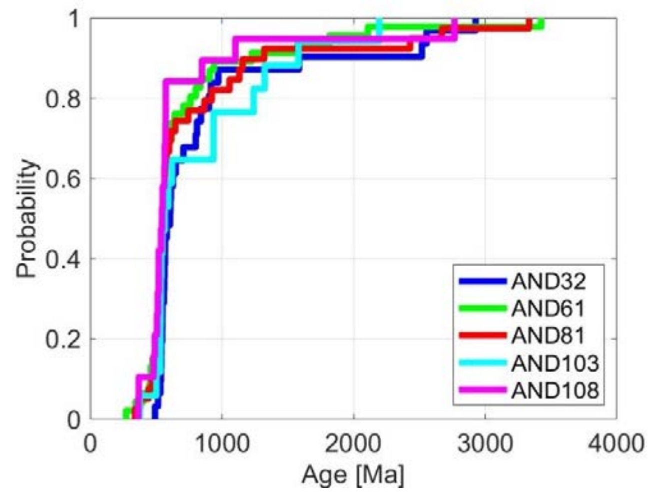

Figure 3: Cumulative distribution function showing the percentage of grains from each sample from each depth

the age from the $^{235}U/^{206}Pb$ isotope ratio is used. If they are greater than one billion years old, the age from the $^{206}Pb/^{207}Pb$ ratio is used. These ages were graphed as histograms and the age populations were compared using a Kolmogorov-Smirnov test (K-S test). If the p-value of the K-S test on any two samples was less than 0.05, then the age population in those two samples were considered statistically different.

RESULTS.

We retrieved 152 zircon grains from which we were able to get U-Pb isotope data. The most zircon grains found in any one sample was 46, and the least was 17.

The cumulative distribution function (Figure 3) shows the probability that any one grain of zircon found from any sample will be a certain age, which is useful for comparing samples of different sizes. The more vertical a sample's function is at any age, the higher probability that any zircon grain from that sample will be the age that corresponds with the vertical function. For instance, because AND108 is vertical from approximately 0.1-0.85 at 500 Ma, there is a 75% probability that any zircon grain from that depth is 500 Ma. Because every sample creates a similar shape on the graph, the samples have similar provenances. It is also notable that each of the samples are overwhelmingly vertical at approximately 500 Ma, showing that every sample contains a majority of zircon grains from 500 Ma.

We conducted a Kolmogorov-Smirnov (K-S) test to assess if any two samples are statistically significantly different. The results of the K-S tests for all the possible comparisons are shown in Table 1. K-S values greater than 0.05 indicate that the samples are not statistically different, while values less than 0.05 are statistically different.

DISCUSSION.

The K-S tests indicate that AND32 may be a statistically different zircon population because when compared to the other samples its K-S values are below 0.05. Sample AND32 has a K-S test value less than 0.05 when compared to samples AND61, AND81 and AND108. This result could indicate that a change in provenance occurred between the time periods represented by sample AND61 and AND32, however because we only recovered 31 zircon grains from AND32, this low K-S value could be due to the small sample size. AND32 differs from the other samples mostly in that it has no zircon aged 273-491 Ma. If AND32 had one zircon aged between those years, it would statistically match the other tills. All of our five samples have less than 120 zircon which would be ideal for a K-S test. Thus, these data are indicative of

Table 1. Results for the K-S test comparing the five different zircon populations with each other. Samples with significantly different ages are in bold.

Sample	AND61	AND81	AND103	AND108
AND32	**0.0381**	**0.0450**	0.4094	**0.0398**
AND61	--	0.7966	0.4718	0.5313
AND81	--	--	0.3164	0.6288
AND103	--	--	--	0.2857

the sediment provenance, but we cannot draw valid statistical conclusions from them.

Because the K-S test shows that samples AND61, AND81, AND103, and AND108 are not statistically different, it is likely that as the ice advanced and retreated over the ANDRILL site, it did so with the same ice flow patterns and that the provenance of the glacial till in each sample is likely the same. These four samples represent tills ages 908-1,014 thousand years (ka) to 1,014-1,633 ka, and these results suggest that the ice flow patterns have not changed in that time. We can also infer that glacial erosion was minimal between these samples because the zircon ages do not change over time. Because it has remained stable for so long, we can assume that this pattern of ice melt will remain the same in the future.

The data generated can also be used to identify the specific sources of the sediment being deposited in the 1B core, as did Giorgetti et. al. by examining clay and heavy mineral assemblages, which indicated that the sediment flowed from the Transantarctic Mountains *(14)*. Alternatively, rock magnetic and electron microscopy signatures of magnetic minerals can be used similarly to zircon in order to trace provenance *(15)*. West Antarctica is geologically much younger than East Antarctica, and its zircon typically dates to the Mesozoic age (252-66 Ma). Because there was no zircon deposited from the Mesozoic age, we can infer that no ice from the WAIS flowed into site 2B *(3)*.

These findings can be used to create and update models of future Antarctic ice flow. Such models are able to predict how Antarctic ice will melt in the next hundreds of years and have indicated that the melting of the West Antarctic Ice Sheet will contribute up to six meters of sea level rise, enough to devastate New York City and the entire state of Florida *(16,17)*. Although the EAIS has the capacity to contribute 54 meters to sea level rise, our data and that of other scientists, through several alternative methods indicate that this is improbable. Via tracking ^{10}Be and ^{26}Al isotopes in quartz, Shakun et. al. concluded that in the past eight million years, the EAIS has not shrunk far beyond its current size *(18)*. Our data are consistent with this interpretation because our data suggest that the EAIS has been flowing in the same way for the past approximately one million years. In agreement with our data, many ice sheet models also indicate that the East Antarctic Ice Sheet (EAIS) will contribute very little to sea level rise due to its relative stability *(16,17)*.

Some other studies have shown changes in the provenance of the ANDRILL 1B core over time. By analyzing granule- to cobble-sized clasts as opposed to the significantly smaller zircon grains, Talarico et al. found changes in cobbles as far down as 575 meters below the surface *(18)*. This implies that the Ross Ice Sheet has changed flow patterns over time, even within the 32.75-108.19 meters investigated in this study. However, looking at just cobble-sized material is a less reliable method because of biases in what rock types survive glacial transport. Zircon are resistant minerals that survive glacial transport and provide a more statistically robust method than cobble provenance methods. Monien et. al. shows the lithology in ANDRILL core 1B cycles between diamictite, diatomite, mudstone, sandstone, and volcanic rock *(19)*. This study focused on the provenance of the tills, but we could learn more about the Antarctic environment by examining the provenance of other lithologies in the ANDRILL cores.

By analyzing five samples from the ANDRILL core we were able to make several inferences about Antarctica's ice flow patterns around this site, regardless of sample size. These inferences about the past are useful in making predictions about Antarctica's ice flow in the future and are consistent with the prediction that the EAIS will remain stable and contribute minimal ice melt toward sea level rise.

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