

Integrated tephrochronology of the West Antarctic region: Implications for a potential tephra record in the West Antarctic Ice Sheet (WAIS) Divide ice core

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Summary Mount Berlin and Mt. Takahe, two West Antarctica volcanic centers have produced a number of explosive, ashfall generating eruptions over the past 500,000 yrs. These eruptions dispersed volcanic ash over large areas of the West Antarctic ice sheet. Evidence of these eruptions is observed at two blue ice sites (Mt. Waesche and Mt. Moulton) as well as in the Siple Dome and Byrd (Palais et al., 1988) ice cores. Geochemical correlations between tephra sampled at the source volcanoes, at blue ice sites, and in the Siple Dome ice core suggest that at least some of the eruptions covered large areas of the ice sheet with a volcanic ash, and $^{40}\text{Ar}/^{39}\text{Ar}$ dating of volcanic material provides precise timing when these events occurred. Volcanic ash from some of these events expected to be found in the WAIS Divide ice core, providing chronology and inter-site correlation.

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Introduction

Ice cores collected in polar regions offer unique records of past climate and volcanism. Deep ice cores collected in Antarctica provide climate records for as much as 100,000–400,000 years of earth's history at annual to decadal to multi-decadal resolution. However, deciphering the chronology of ice cores, particularly the age of ice at a given depth, can be difficult in areas of low accumulation, and particularly in the deeper parts of cores. The interpretation of the global climate record is critically dependent on having some idea of chronology for lower parts of ice cores, or at least being able to correlate these records to climate records from other environments.

In addition to being a climate archives, ice cores also capture volcanic particles (tephra) and aerosols, produced during major explosive eruptions. Tephra layers in ice cores can provide important time-stratigraphic information if geochemically tied to a known, dated eruption, or used as cross-correlated time horizons between ice cores. Tephra examined in West Antarctica are dominated by local source volcanoes, although some record of non-Antarctic volcanism is also present.

Source Volcanoes: Mt. Berlin and Mt. Takahe

A number of volcanoes protrude through the West Antarctic Ice Sheet (LeMasurier and Thomson, 1990) (Fig. 1). Of these, Mt. Takahe and Mt. Berlin have been the most active ash-producers over the last 500,000 years. Mt. Takahe, a flat-topped stratovolcano, has produced a number of recent trachytic eruptions, including events at 8.2 ± 5.4 ka, 93.3 ± 7.8 ka and 102 ± 7.4 ka (Wilch et al., 1999). Mt. Berlin has also erupted a number of times over the last 100,000 years, including young events sampled in the crater region of Mt. Berlin at 10.3 ± 5.3 , 18.2 ± 5.8 , 25.5 ± 2.0 (Wilch et al., 1999). The explosive eruptions from these volcanoes, particularly Mt. Berlin, could have reach heights of 30 km (Wilch, 1997). A number of eruptions from Mt. Berlin have been recognized in an englacial tephra section at Mt. Moulton (discussed below). These explosive eruptions are typically of peralkaline trachytic composition, but distinct chemical differences have been observed between the two volcanoes, and as well as between different eruptions from the same volcano.

Discussion

The explosivity and apparently large area covered by deposits from some of the eruption mentioned above suggest that some may be present in the WAIS Divide ice core. Deposits resulting from some of these explosive eruptions have been found in outcrop on the source volcanoes (Wilch et al., 1999). However outcrop exposures of many of the deposits are likely to be absent due to erosion or coverage by subsequent eruptions. A more complete



Figure 1. Map of West Antarctica showing location of volcanoes Mt. Takahe and Mt. Berlin, blue ice site at Mt. Waesche, and location of WAIS Divide, Byrd and Siple Dome ice cores

However outcrop exposures of many of the deposits are likely to be absent due to erosion or coverage by subsequent eruptions. A more complete

record of the explosive eruptions is preserved as tephra layers in ice than is represented by near-source rock outcrops. Three sites in West Antarctic containing significant tephra records are known. These include the Mt. Moulton and Mt. Waesche blue ice deposits, and the Siple Dome ice core. The details of these sites are presented below, followed by a discussion of the potential tephra record that may be expected in the WAIS Divide ice core.

Mt. Moulton

A site on the shoulder of the ice-filled summit crater of Mt. Moulton, located at an elevation of 2800 meters in West



Figure 2. Photograph of englacial tephra layer at Mt. Moulton site with Mt. Berlin in background.

Antarctica, exhibits a long section of exposed blue ice and intercalated tephra layers. Many of the tephra layers are thick (up to 10 cm) and coarse (pumice up to 3 cm) (Fig. 2). A total of 48 visible tephra layers are observed. Detailed dip measurements and GPS mapping reveals a simple geometry of parallel tephra layers all exhibiting consistent dips (Fig. 3). The simple stratigraphy of the tephra layers suggests that although the local ice is thinned, based on the boudinaged appearance of the thicker tephra layers, it is otherwise undeformed. Most of the Mt. Moulton tephra layers are trachytic, and are thought to be derived from Mt. Berlin, located only 30 km away from the blue ice site (Fig. 2). Eight of the tephra layers at the Mt. Moulton site have been directly dated using ⁴⁰Ar/³⁹Ar geochronology of potassic feldspar phenocrysts, to (in stratigraphic order from top to base of the blue ice section) 10.5±2.5; 24.7±1.5; 92.1±0.9; 104.9±0.6; 118.1±1.3; 135.6±0.9; 225.7±11.6; and 495.6±9.7 ka.

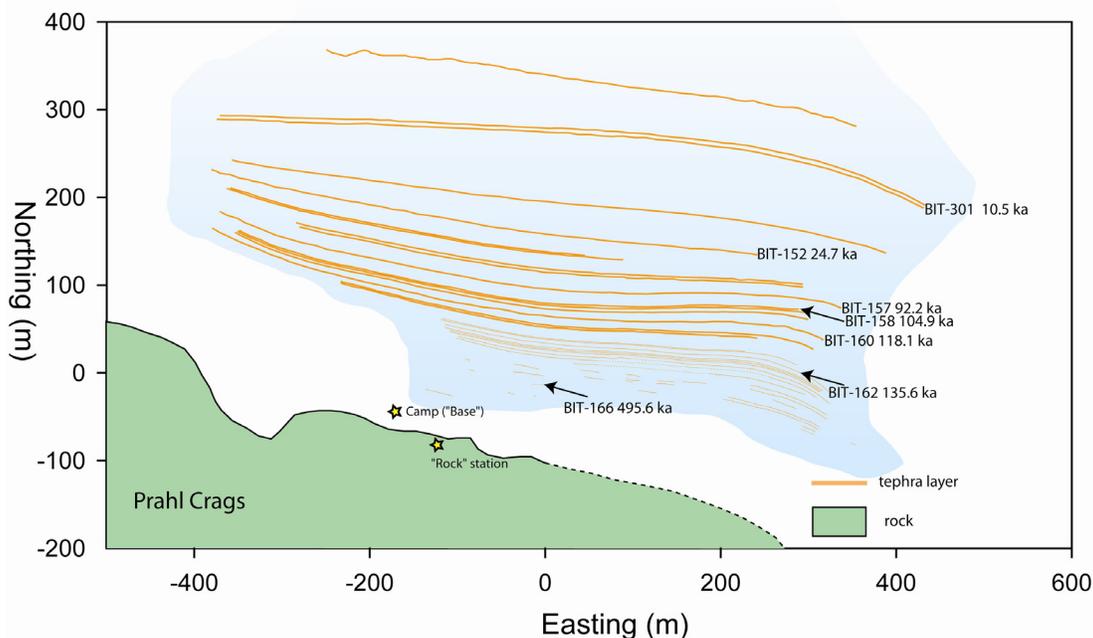


Figure 3. GPS-produced map of tephra layers at the Mt. Moulton site showing tephra ages.

Mt. Waesche

In contrast to Mt. Moulton, the Mt. Waesche site, located at between 1900-2000 meters elevation in a blue ice field on the south side of the volcano, displays a complex, deformed stratigraphy. The tephra layers at Mt. Waesche are dominantly either coarse and basanitic, probably of local derivation, or fine and trachytic, mainly derived from Mt. Berlin or Mt. Takahe. One of the stratigraphically highest tephra layers at Mt. Waesche is geochemically correlated to the 8.2±5.4 ka from Mt. Takahe.

Three tephra layers at Mt. Waesche have been geochemically correlated with layers found at Mt. Moulton. The correlative layers have ages of between 15 and 27 ka, 27 ± 2 ka, and between 106 and 119 ka, consistent with apparent stratigraphic order. A single tephra layer at Mt. Waesche has been directly dated using $^{40}\text{Ar}/^{39}\text{Ar}$, and yields an apparent age of 117 ± 7 ka. Although there are tephra layers that seem stratigraphically below the 117 ± 7 ka layer, they appear to represent an overturned repetition of some part of the upper section. Hence, there is no evidence for ice significantly older than 117 ka at Mt. Waesche.

Siple Dome

A total of 36 tephra-bearing layers have been recognized in the Siple Dome A ice core (Fig. 4). Despite the very fine grain size of these tephra layers (mostly less than 20 microns (Fig. 5) geochemical characterization of all 36 layers was carried out by electron microprobe. The uniform geochemical composition and grain size of individual tephra layers within this core suggest that they are primary deposits from explosive volcanic eruptions, and therefore represent time-stratigraphic markers in the ice core. The source volcanoes for these tephra layers are largely found within the Antarctic plate, although some South American and possibly a New Zealand volcano are also represented. Statistical geochemical correlations have been made between 12 of the tephra layers and source volcanic eruption. Ten of the tephra layers are correlated to known tephra layers found at Mt. Moulton or Mt. Berlin. One correlation is also made to an eruption from Mt. Takahe, which took place at 8.2 ± 5.4 ka. This tephra layer has also been recognized in the Byrd Core (Palais et al., 1988). One tephra layer is correlated to Mt. Hudson, located in South America. The existing ice core chronology agrees well with independently determined chronologies for the source eruptions.

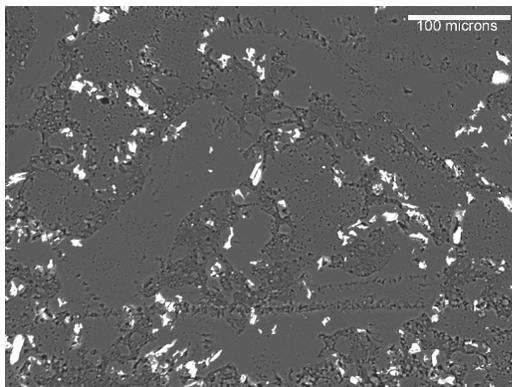


Figure 5. Backscattered electron image of tephra layer from the Siple Dome ice core. Bright areas represent tephra particles and dark areas are mounting epoxy.

The lowest tephra layer in the ice core, located at 986.21 m depth, is correlated to a source eruption with an age of 118.1 ± 1.3 ka, providing a chronological pinning point for the lower ice. Furthermore, an episode of anomalously high volcanic activity in the ice in the SDM-A core between 18,000 and 35,000 was observed in this study and also by Gow and Meese (in review). This episode, which has also been recognized in the Byrd ice core (Gow and Williamson, 1971), is here tied to eruptive activity of the Mt. Berlin volcano.

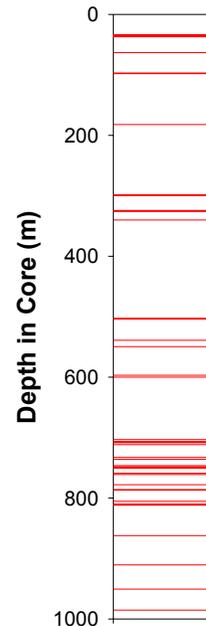


Figure 4. Depiction of the depth of tephra layers within the Siple Dome ice core. Each red bar represents a tephra layers.

WAIS Divide

The WAIS Divide ice core is located in central West Antarctica (Fig. 1), in reasonably close proximity two the two main West Antarctic tephra-producing volcanoes, Mt. Takahe and Mt. Berlin, and is therefore likely to contain a number of known tephra layers from the two volcanoes. However, the presence of ash from a given eruption in an ice core can depend on two factors. First, the wind direction at the time of substantial eruption must be favorable to transport the tephra towards the deposition site. Second, if the tephra is deposited at the site, it must be locally preserved in such a way as to be present in the core. In the case of the Siple Dome ice cores, a tephra layer that was found in the Siple B core was not present in the Siple A core, although the two cores were only 10 m apart (Dunbar et al., 2003). This tephra distribution is likely to have resulted from non-uniform preservation of tephra on the local snow.

The youngest widespread tephra layer from a West Antarctic volcano is the 8.2 ka eruption from Mt. Takahe. This widespread tephra layer is found in the Byrd ice core (Palais et al., 1988), the Siple Dome ice core, and at Mt. Waesche. The WAIS Divide site is closer to Mt. Takahe than any of these other sites (350 km away as opposed to 430, 950 and 380 km, respectively), and therefore likely to have received a substantial deposit of tephra, given a favorable wind direction at the time of deposition. The presence of the tephra in the Byrd ice core suggests that the wind direction was at least somewhat favorable for deposition at the WAIS Divide site. The Mt. Takahe ash layer in the Siple Dome core was one of the 8 visible layers in the core, and contained abundant glass shards (Fig. 5). At Mt. Waesche, the layer was thick enough to be visible on a blue ice surface, suggesting that this was a major eruption.

In lower part of the WAIS Divide core, Mt. Berlin is likely to dominate the tephra record. Of the numerous eruptions from Mt. Berlin that occurred between 100,000 yrs ago and present, a number are present at Mt. Waesche, Mt. Moulton and in the Siple Dome sites. At least some of these tephra layers expected to reach the WAIS Divide site. The most promising targets are those that have been identified both at either Mt. Berlin or Mt. Moulton and in the Siple Dome ice core, because the two sites are in different directions from the source volcano, suggesting that the area of deposition was relatively broad. This includes a total of 9 tephra layers, ranging in age from $<10.5 \pm 2.5$ to $>92.1 \pm 0.9$ ka. Discovery of these layers in the WAIS Divide core could provide a number of useful cross-correlated time-stratigraphic markers linking the climate records.

Based on the accumulation rate and the ice thickness, the age of the deepest WAIS Divide is expected to be at least 100,000 years. There are a number of tephra layers that may be found in the deepest part of the core. These include the 92.1 ± 0.9 ; 104.9 ± 0.6 ; 118.1 ± 1.3 ka tephra layers erupted from Mt. Berlin and found at Mt. Moulton. Two other possibilities include the 93.3 ± 7.8 ka and 102 ± 7.4 ka eruptions from Mt. Takahe. Ideally, more than one of these tephra layers will be present in the WAIS Divide core, providing a robust chronology for the oldest ice in this important climate record.

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