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CORRELATION OF A 3,200 YEAR OLD TEPHRA IN ICE CORES FROM VOSTOK AND SOUTH POLE STATIONS, ANTARCTICA

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Abstract. Tephra layers in two Antarctic ice cores are correlated on the basis of their chemical compositions and estimated ages. We believe the tephra was produced about 3,200 years ago from a major explosive eruption of Candlemas Island in the South Sandwich Islands. This is the first time that tephra layers have been correlated between two widely separated ice cores and demonstrates that tephra layers may serve as stratigraphic markers for correlating, and perhaps in some cases, dating Antarctic ice cores.

Introduction

Studies of ice core samples from Greenland and Antarctica provide detailed information about past climate and the chemical composition of the atmosphere, for at least the last 150,000 years (Dansgaard et al., 1981, 1982; Lorius et al., 1979, 1985; Oeschger, 1985). The preservation of volcanic deposits (both soluble acids and insoluble volcanic ash particles) from both local and distant volcanic sources in Antarctic and Greenland ice (Hammer et al., 1981; Kyle et al., 1982, 1984 ; Hammer, 1984; Palais, 1985; De Angelis et al., 1985; Delmas et al., 1985) is of particular interest.

Eruptions from Antarctic volcanoes in the McMurdo Volcanic Group and Marie Byrd Land (Keys et al., 1977; Kyle et al., 1981) and volcanoes in the South Sandwich Islands (Nishio et al., 1984 a,b) are recorded principally as visible tephra (volcanic ash) layers in the ice cores, whereas eruptions originating from volcanoes in the more distant regions of Indonesia, South America, and New Zealand have produced only layers of elevated acidity (e.g. H_2SO_4), recognized by detailed analyses of the chemical composition of the ice (Delmas et al., 1985).

In Greenland, eruptions of nearby Icelandic volcanoes have produced well-defined layers of elevated acidity, identified by increases in the D.C. electrical conductivity of the ice, but no insoluble volcanic ash particles have ever been identified (Hammer et al., 1981; Hammer, 1984). The only well confirmed evidence to date, for long-distance (> several thousand kilometers) transport of volcanic ash particles to the polar ice sheets, in either hemisphere, is the study by De Angelis et al. (1985), in which volcanic ash particles originating in the 1982 eruption of El Chichon, Mexico, were found in surface snow of the Greenland ice sheet. Further evidence that tephra can be transported far from source, and is therefore useful for correlation purposes, is the study by Kyle and Seward (1984), in which tephra from New Zealand was identified in deep-sea piston cores from the South Pacific sector of the Southern Ocean near the Balleny Islands.

In this paper we report the first correlation of tephra layers between two ice cores in Antarctica. The visible tephra layers in ice cores from Vostok Station (78° 28' S, 106° 48' E) and South Pole Station (90° S), have been correlated on the basis of their chemical composition and estimated age. We believe that the tephra originated in a major explosive eruption from Candlemas Island in the South Sandwich Islands about 3,200 years ago.

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Sampling and Analysis

Ice samples containing the two tephra layers were melted and filtered onto Nuclepore™ (0.4 μm diameter pore size) filters in a Class 100 clean room. A section from each filter was examined by scanning electron microscope (SEM) and energy-dispersive x-ray analysis (EDAX). A polished microprobe section of each sample was prepared by washing the particles off of the filter and mounting them in epoxy.

The energy-dispersive x-ray analyses use "ZAF" corrections to calculate oxide percents (normalized to 100%), from element peak intensities and theoretical standards. The accuracy of the analyses was checked against glass and mineral standards and the precision of the analyses was determined by repeated analyses of these same standards. The microprobe analyses were corrected using the Bence-Albee matrix correction procedure (Bence and Albee, 1968) and glass standards were used to check analytical precision and accuracy The microprobe analyses are more precise than the EDAX analyses, as can be seen by comparing the standard deviations of the analyses (Table 1).

Results

Vostok Tephra

The Vostok tephra is the informal name proposed by Kyle et al.(1982) for a 0.05 m thick, diffuse tephra layer found at 100.8 m in an ice core drilled in 1979 at Vostok Station in East Antarctica (Figure 1). The depth/age relationship (Parker et al., 1982) for the Vostok core suggests an age of about 3,200 a B.P. The Vostok tephra is composed of 55 % lithic material (mainly well-rounded, brown, cryptocrystalline glass), 40 % clear glass shards and 5 % crystals (mainly feldspar) (Figure 2 c,d).

Kyle et al.(1984) considered three possible source regions (the South Shetland Islands, the South Sandwich Islands and the Southern Andes) for the Vostok tephra and concluded that the South Sandwich Islands were the most likely source. Rocks from the South Shetland Islands and the Southern Andes have higher total alkali content and lower iron contents, respectively, than the Vostok tephra. The Vostok tephra (Table 1, sample 3,4) is most similar in composition to an aphyric andesite from the northern part of Candlemas Island in the South Sandwich Islands, which is one of the youngest of the South Sandwich Islands (Table 1, sample 5)(Baker, 1978; Tomblin, 1979). Lavas from Candlemas Island are exceptionally low in potash (K_2O), a characteristic feature of the Vostok tephra.

Grain size analyses of the Vostok tephra indicate initial deposition of coarse particles (mean diameter of about 45 μm) followed by deposition of much finer particles (mean of about 7 μm), composing the bulk of the tephra (Figure 3) The mass concentration of tephra in melt water samples gradually increases from a background of about 1 μg/ml to a peak of about 14 μg/ml. The original thickness of the tephra is unknown as the diffuse nature of the Vostok tephra in the core makes it difficult to calculate a mass accumulation rate (mg/cm^2/ 1000a), as is done in deep sea cores.

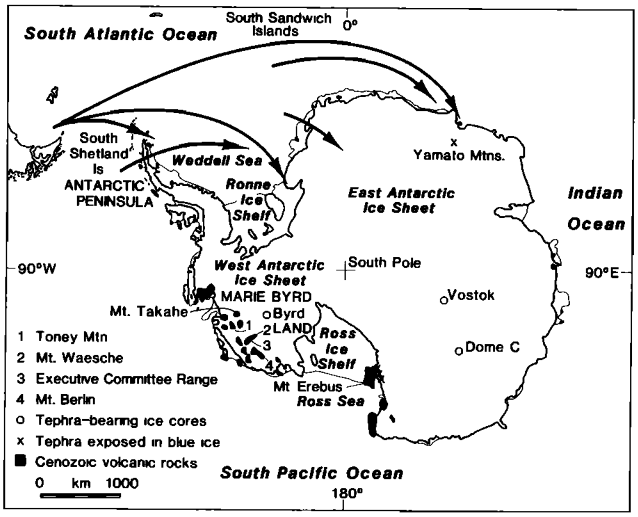

Fig. 1. Map of Antarctica showing core locations and probable paths of atmospheric transport from the South Sandwich Islands to the Antarctic ice sheet.

South Pole Tephra

In 1983/84 a 361 m ice core was drilled at the South Pole with a distinct tephra layer (3mm thick) at 303.44 m. The tephra is composed primarily of vesicular glass shards and lithic material with a small percentage of crystals, including quartz, pyroxene and plagioclase of intermediate composition (Figure 2 a,b). Major element analyses of the glass shards in the South Pole tephra (Table 1, analyses 1,2) compare well

Table 1. Major element analyses (wt. %) of tephra from the South Pole and Vostok cores, and a rock from the South Sandwich Islands.

	1	2	3	4	5
n	5	11	9	37	
SiO2	59.98(1.21)†	60.1(3.02)	60.56(0.42)	59.73(1.79)	60.9
TiO2	0.78(0.9)	0.3(0.22)	0.74(0.07)	0.90(0.16)	0.95
Al2O3	16.03(0.94)	17.6(3.40)	14.92(0.82)	14.84(0.66)	14.8
FeO*	7.37(1.14)	9.0(3.79)	9.15(0.57)	10.25(1.23)	8.34
MnO	0.16(0.8)	0	0.23(0.04)	0.15(0.12)	0 11
MgO	1.71(0.28)	3.5(1.91)	2.39(0.34)	2.44(0.48)	2.35
CaO	6.79(0.42)	5.5(1.35)	6.72(0.26)	6.64(0.76)	6.09
Na2O	5.94(0.83)	3.6(0.89)	3.31(0.38)	4.46(0.57)	3.67
K2O	0.39(0.09)	0.1(0.15)	0.44(0.05)	0.63(0.19)	0.39
P2O5	0.08(0.09)	0.3(0.13)	n.d.	n.d.	0.12
Total	99.23	100	98.46	100.04	97.72

Key:

* FeO, total Fe as FeO;
† one standard deviatio n.d. indicates not detected; n is number of samples.
1. South Pole Tephra- Electron microprobe analyses, Univ. of Rhode Island,(Analyst, J. Palais).
2. South Pole Tephra-Energy-dispersive x-ray analysis, Ohio State Univ.(Analyst, T. Leonardi).
3. Vostok Tephra- Electron microprobe analysis, Los Alamos NationalLaboratory (Analyst, J. Palais)(Kyle et al., 1984).
4. Vostok Tephra- Energy dispersive x-ray analysis, Arizona State University(Analyst, E. Thomas)(Kyle et al., 1984).
5. Candlemas Island-Aphyric andesite, Cauldron Lake lava, northern Candlemas Island. Wet chemical analysis (Tomblin, 1979).

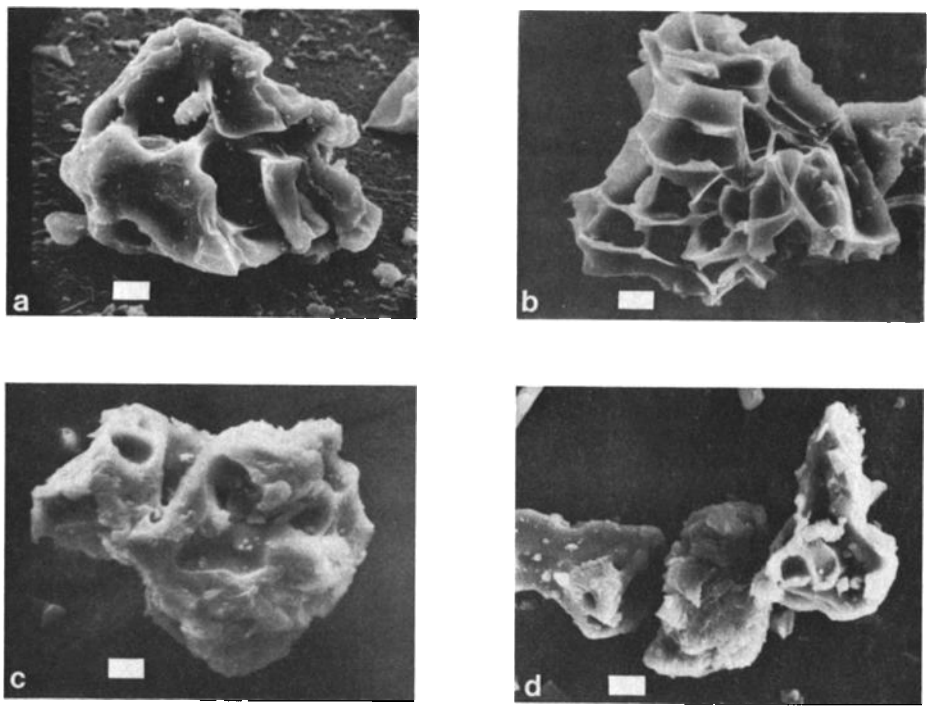

Fig. 2. Scanning electron micrographs of tephra from the South Pole and Vostok ice cores. a) South Pole tephra blocky, moderately vesicular, partially altered shard with shallow spherical vesicles. Fine adhering dust. 2400 x; 1 cm=4 µm. b) South Pole tephra highly vesicular, fresh shard with delicate square to rectangular vesicles. 2400x; 1 cm=4 µm. c) Vostok tephra subrounded, blocky, moderately vesicular shard, partially altered, with shallow spherical vesicles. Fine adhering dust. Compare with a).1110 x; 1 cm= 9 µm d) Vostok tephra blocky shards with fine adhering dust, few vesicles.1110 x; 1cm = 9 µm.

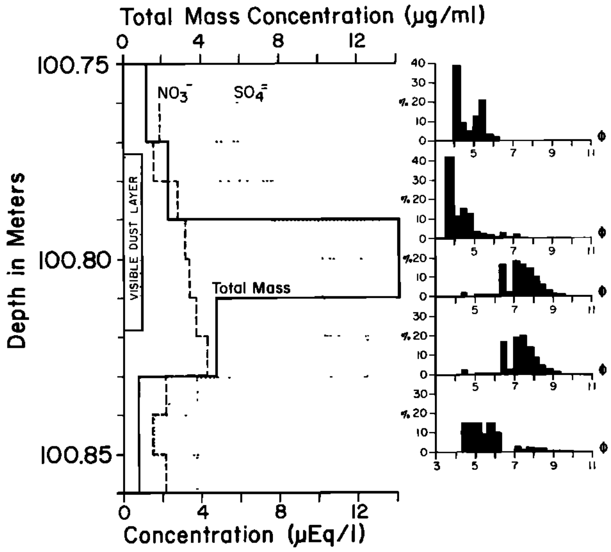

Fig. 3. Depth variation of mass concentration of tephra in a 0.10 m section of the Vostok core. Histograms show the grain size distribution of tephra in the samples that were analyzed for mass concentration. Sulfate and nitrate data from Kyle et al.(1982).

with those of the Vostok tephra (Table 1, analyses 3,4), which suggests that they might be from the same eruption. This is further supported by the estimated age of the ice enclosing these layers, as discussed below.

Depth-Age Relationships

There is no absolute dating of either the South Pole or Vostok cores, but two lines of evidence suggest that the tephra layers (Vostok tephra-100m; South Pole tephra-300m) are coeval. First, a rough estimate of the age of these two layers is made by assuming a similar depth-density profile for the two locations and accumulation rates which differ by a factor of about three (Vostok 2.0-2.5 $g/cm^2/a$ (Young et al., 1982; Lorius et al., 1985); South Pole 7-9 $g/cm^2/a$ (Jouzel et al., 1983)). Secondly, our estimated depth-age profile for the South Pole core (Figure 4), based on depth-age estimates of Schwander (1984), Mosley-Thompson (1980) and Kuivinen et al. (1982), suggests an age of 3,250 a B.P. at 300 m in the South Pole core. This compares well with the estimated age (3,200 a B.P.) for the Vostok tephra (Parker et al., 1982).

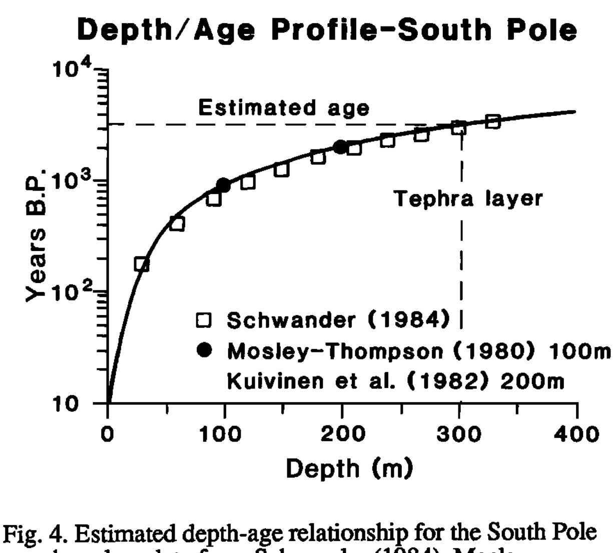

Fig. 4. Estimated depth-age relationship for the South Pole core based on data from Schwander (1984), Mosley-Thompson (1980) and Kuivinen et al (1982).

Discussion

Tephra similar in composition to that in the Vostok and South Pole cores also occurs in layers at the surface in blue ice areas (the Meteorite Ice Field) of the Yamato Mountains , Queen Maud Land, East Antarctica (Figure 1) (Nishio et al., 1984; Katsushima et al., 1984). Although the ages of the tephra layers in the Yamato Mountains are not well constrained, they are of the correct order of magnitude to be correlative with the Vostok and South Pole tephras. ^{36}Cl analyses of ice associated with these tephra layers, suggest that the age of the ice in the Meteorite Ice Field of the Yamato Mountains is less than one ^{36}Cl half-life (3×10^5 a) (Nishiizumi et al., 1979). The ^{14}C terrestrial age of chondrite Yamato 75102, collected near tephra layer C-32, indicates an age of $3.0 \pm 1.2 \times 10^3$ a (Nishio, personal communication, 1985). The terrestrial ages of four other Yamato meteorites are believed to be in the range of 3,000-22,000 a. Calculation of flow lines in the Meteorite Ice Fields gives an age for the ice upstream of Motoi Nunatak, near tephra layer C-32, in the range from one to several thousand years old (Nishio et al., 1984).

Tephra layers in piston cores from the South Atlantic Ocean (Ninkovich et al.,1964; Federman et al., 1982) were believed to be erupted from the South Sandwich Islands within the last 30,000 years. Based on a sedimentation rate of 8 cm/1000 a, a tephra layer at 0.20 m in core V 14-56 would be 2,500 years old (Federman et al., 1982). This is probably a minimum estimate, however, since erosion by Antarctic Bottom Water may have removed some of the sediments in the core (Ledbetter and Ciesielski, 1986). The tephra has a similar composition and age to the tephra layers from Vostok, South Pole and from the Yamato Mountains and may correlate with them.

Conclusions

These analyses and inferences are consistent with the conclusion that the tephra layers in the South Pole and Vostok cores are coeval and represent deposition from a major explosive volcanic eruption in the South Sandwich Islands (probably from Candlemas Island) about 3,200a B.P. For the first time tephra layers from two widely separated ice cores have been correlated, which reinforces the utility of tephrochronolgy for ice core studies. This tephra layer provides an excellent stratigraphic marker for Antarctic ice cores and should be sought at other locations. Furthermore, a detailed study of the dispersal of this tephra layer may provide information on the transport of atmospheric particles in this part of the southern hemisphere. The occurrence of an apparently widely dispersed tephra layer in East Antarctica, possibly originating from the South Sandwich Islands, is consistent with the paths of atmospheric transport proposed by Alt et al. (1959), Carleton (1981) and Thompson and Mosley-Thompson (1982).

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