$a/3<11\bar{2}0>$ basal dislocations can be seen to originate at grain boundary facets (some are labeled F_1–F_8), most of which have completely traversed the grains. Dislocation pile-ups can also be observed. A good example is evident at "X." This particular pile-up relaxed considerably during the annealing process.

Our studies help to elucidate the fundamental mechanisms responsible for the mechanical behavior of ice. For example, the model used to explain the "brittle-to-ductile transition" in ice (Currier and Schulson 1982; Schulson, Lim, and Lee 1984) is based on dislocation pile-ups. The observed pile-up relaxation can also explain the reverse strain that has been observed on partial unloading during creep (Ignat and Frost 1987).

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Geochemical composition and stratigraphy of tephra layers in antarctic blue ice: Insights into glacial tephrochronology

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The blue ice areas along the Transantarctic Mountains where meteorites are collected also contain "dust bands" exposed in stratigraphic section at the ice surface, many of which are volcanic ashes (tephra) (Koeberl 1988; Marvin 1988). Although these "dust bands" have been noted by previous workers, the englacial stratigraphy or particle geochemistry had never been rigorously examined. Approximately 50 of these layers from a number of different blue ice areas along the Transantarctic Mountains of southern Victoria Land were sampled during the 1994–1995 field season and most are revealed to be tephra, although some layers contain terrestrial windblown(?) debris (table). The layers range from thin, faint laminae to distinct bands up to 50 centimeters thick. The bands dip from near-horizontal to near-vertical, depending on the geometry of local ice flow.

Detailed global positioning system (GPS) mapping reveals that a complex but coherent stratigraphic sequence is defined by the tephra. Individual tephra and dust layers can be traced for up to 10 kilometers, and further tracing was inhibited only by snow cover, not by disappearance of the layer within the ice (figure 1). The same sequence of tephra and dust layers can be recognized throughout a single geographic area, irrespective of local ice-flow conditions. Their consistent orientation, coherent stratigraphy, and the nature of their contacts with adjacent ice indicate that the tephra and dust layers were deposited as stratigraphic layers rather than having been emplaced by shear at the base of the ice sheet. The lower contact with the ice is invariably sharp and is interpreted to be the depositional surface; whereas the upper contact is diffuse, apparently because of mixing with later snow. No significant shearing or brittle deformation of the dust and tephra section was observed.

Petrographic observations show that most of the layers are composed of volcanic glass shards and crystals. In many samples, the glass and crystals appear to be fresh and unabraded, and very delicate volcanic glass textures, such as finely vesicularity and bubble wall fragments, are preserved. The average size of particles within the layers ranges between less than 2 to approximately 100 micrometers (μm) and are well-sorted. Within individual tephra layers, glass color and bubble morphology are consistent. The glass color ranges from brown to light green. The glass contains variable amounts of microlites, the browner mafic glass tending to be more microlite-rich than the greener silicic glass. Bubbles in the brown glass tend to be small (approximately 10–20 μm) and round, whereas stretched vesicles are more typical in the greenish glass. Other layers are composed of terrestrial rock fragments and/or rock fragments mixed with tephra. Petrographically, these layers are distinctive from the purer tephra layers because of the presence of rook fragments and the greater range of grain sizes within an individual layer.

Tephra in bare ice areas along the Transantarctic Mountains, sampled during the 1994–1995 field season. Locations and preliminary compositions are given.

Location[a]	Composition	Status
Allan Hills (76°43'S 159°40'E)	Basanitic, trachytic phonolitic	Sampled and mapped in detail
Carapace Nunatak (77°10'S 159°47'E)	Basanitic to trachytic	Selected units sampled, preliminary mapping done
"Meteorite City" (76°15'S 156°32'E	Mafic and/or debris	Two units sampled
"Far Northern Icefield" (76°05'S 156°10'E)	Mafic or debris	One unit sampled
"Far Western Icefield" (76°59'S 156°56'E)	Mafic to silicic	Two units sampled
Reckling Moraine (76°13'S 158°29'E)	Silicic and debris	Four units sampled
Elephant Moraine (76°20'S 157°15'E)	Debris(?)	Two units sampled
Horseshoe Peak area (77°37'S 160°E)	Basanitic	Three units sampled
Depot Nunatak (77°45'S 159°58'E)	Mafic and/or debris	Two units sampled
Angino Bluff (78°13'S 158°45'E)	Mafic	One unit sampled
Mount Metschel (78°16'S 159°09'E)	Mafic and silicic	Two units sampled
Alligator Peak (78°26'S 158°48'E)	Mafic and silicic	Three units sampled
Warren Range (78°32'S 158°16'E)	Mafic	One unit sampled

[a] Designations in quotation marks are not official names, but the features are distinct geographical units.

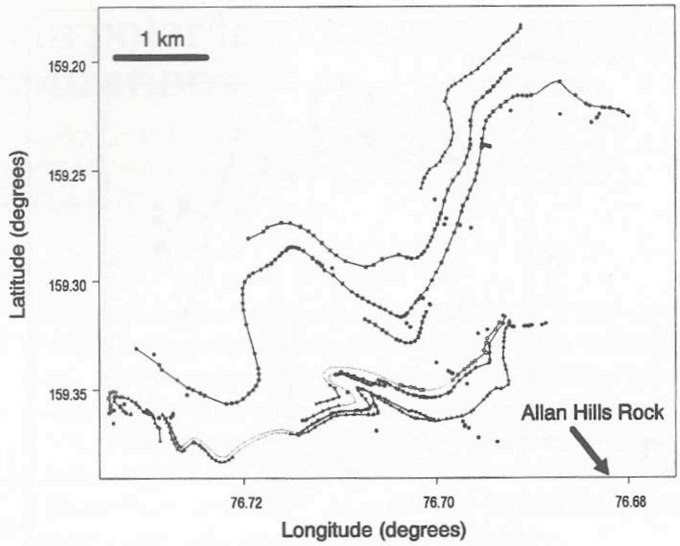

Figure 1. Map of tephra layers in blue ice at Allan Hills as determined by differential GPS mapping. Solid lines connecting points indicate definite correlations, and dotted lines indicate correlations suggested by mapping and petrographical observations. Symbols with no connecting lines are tephra units for which detailed mapping was not carried out but which run parallel to mapped units.

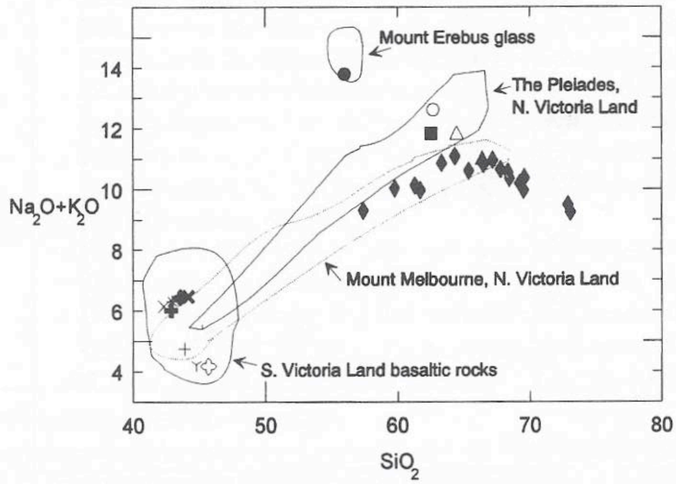

Figure 2. Total alkali (Na_2O+K_2O)/silica (SiO_2) diagram of average tephra compositions (n=4–15). Tephras were collected at Allan Hills and other localities. Compositions determined by electron microprobe analysis. Chemical composition fields of a number of different possible sources are shown.

Major and trace element composition of individual tephra shards was determined using the electron and ion microprobe. These analyses allow the chemical homogeneity of tephra layers to be assessed and allow detailed chemical fingerprinting to tie tephra layers to source volcanoes. The composition of tephras includes basanite, trachyte, phonolite, and rhyolite (figure 2). Individual glass shards appear to be chemically homogeneous with respect to major and trace elements. Within individual tephra layers, the glass compositions are extremely homogeneous, with the exception of one tephra unit, which ranges from 57 to 70 weight percent silica (SiO_2) (figure 2). Examination of the major and trace elements trends exhibited by 20 analyzed glass fragments suggests, however, that this unit was erupted from a zoned magma chamber, rather than representing shards from a number of unrelated eruptions. Although the major element geochemistry of glass shards can help distinguish between magma types, trace element compositions of the tephra units, as determined by ion microprobe, yield a more distinctive chemical signature (figure 3*A*). This is particularly important for basanitic tephra units, which can be virtually indistinguishable based on major element chemistry (figure 3*B*). Trace element determinations will be used to refine the correlations to source volcanoes made using major elements.

Preliminary chemical correlations of tephra layers with their source volcanoes have been made, and layers are thought to have been derived from Mount Erebus (Kyle, Moore, and Thirlwall 1992; Dunbar, Cashman, and Dupre 1994) (in southern Victoria Land) and from Mount Melbourne (Worner et al. 1989) and The Pleiades (Kyle 1990) (both in northern Victoria Land) and basanitic centers in the southern McMurdo Sound

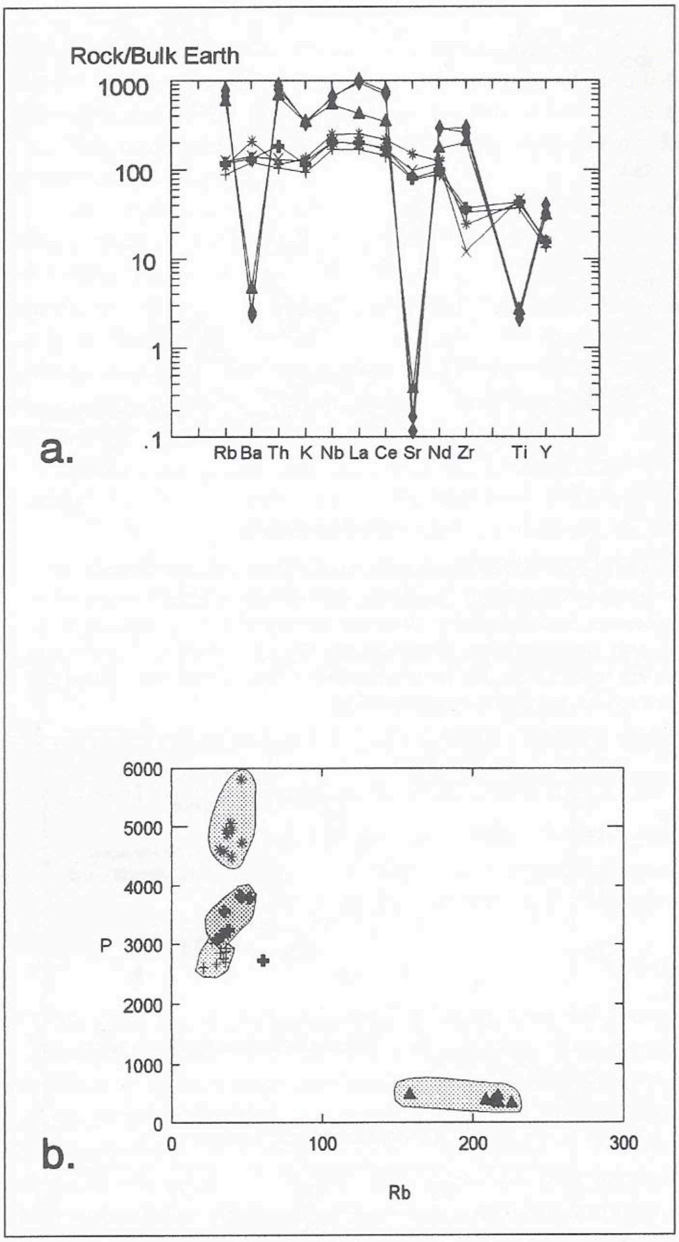

Figure 3. *A.* Representative ion microprobe analyses of individual glass shards from tephra units in blue ice from Allan Hills. Spider diagram for six different tephra units (two separate analyses of a single tephra unit are shown). *B.* Phosphorus (P) vs. rubidium (Rb) plot for four different tephras, showing the ability of trace elements to distinguish between compositions that are indistinguishable based on major element compositions.

area (figure 2). Because of their ease of access and sampling, blue ice areas offer an alternative to deep ice cores for the reconstruction of regional and possibly global volcanic records. Argon-40/argon-39 dating of large tephra samples, which can be readily collected from blue ice areas, offers a means of establishing a chronology that may extend back to 300,000 years ago or more. Furthermore, dated layers found in blue ice areas may be geochemically correlated with tephra in deep ice cores, enabling a reliable chronology to be established.

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