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Foliation on Tyndall Glacier, southern Patagonia

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Abstract

The foliation pattern is described along a transverse profile on the ablation area of Tyndall Glacier, the Southern Patagonia Icefield. One to three sets of foliation planes are observed at each site on the ice surface. Foliation consists of alternating layers of relatively bubble-free ice and bubbly ice. Foliation is generally folded and sometimes faulted, which indicates a complex strain regime. At the medial moraine the foliation is strongest and only one set of foliation planes is observed. This foliation at the medial moraine is parallel to glacier flow and is clearly seen from aerial photographs, suggesting a similar origin to flow stripes observed on satellite imagery of Antarctic glaciers.

1. Introduction

Foliation is defined by Paterson (1981, p. 218) as "a planar or layered structure that develops in glacier ice during flow". It is therefore a secondary structure developed by deformation of pre-existing structures such as sedimentary layers, crevasses, ice lenses and debris bands. It is normally found in the ablation area of both temperate and cold glaciers.

Foliation layers differ in ice texture. Allen *et al.* (1960) found for a temperate glacier that the textures were coarse-bubbly, coarse-clear (blue ice), and fine-bubbly (white ice). The color contrast of the foliation layers makes them clearly seen on the ice surface, sometimes even from aerial photographs. In the lower ablation area of a glacier the foliation planes are usually arc-shaped with a convex curvature downstream, known as "nested spoons".

Foliation is determined by the cumulative strain that the ice has experienced rather than contemporary strain rate of the ice. Milnes and Hambrey (1976) found a good correlation between the foliation pattern on a Swiss glacier with total strain estimated semi-graphically from the velocity field. Hudleston and Hooke (1980) used a numerical model of ice flow and were able to explain many characteristics of the foliation pattern on a glacier.

2. Measurement and foliation pattern

The strike and dip of foliation layers were measured with a compass at stations T1 to T11 along the transverse profile of Tyndall Glacier (Fig. 1). Distances, elevations and velocities of these stations were surveyed by Kadota *et al.* (1992). A profile of the ice thickness is shown in a separate report (Casassa, 1992).

In general three sets of foliation planes were observed at each site, as well as one set of crevasses. Foliation planes were sometimes folded and faulted. The two most prominent foliation planes and the crevasses were plotted in Fig. 1, as well as ice velocities. From visual inspection, the texture of the ice was found to consist of interleaved layers of blue and white ice as described by Allen *et al.* (1960). Close to the glacier margin and also at station T8 coarse ice with few bubbles was found to be interleaved with fine-bubbly ice.

Foliation was weak at the margin and became stronger toward the center of the glacier. The primary (*i.e.* most prominent) foliation followed closely the general flow direction of the glacier and had an up-glacier dip.

At the medial moraine the secondary foliation disappeared. Here the primary foliation was very

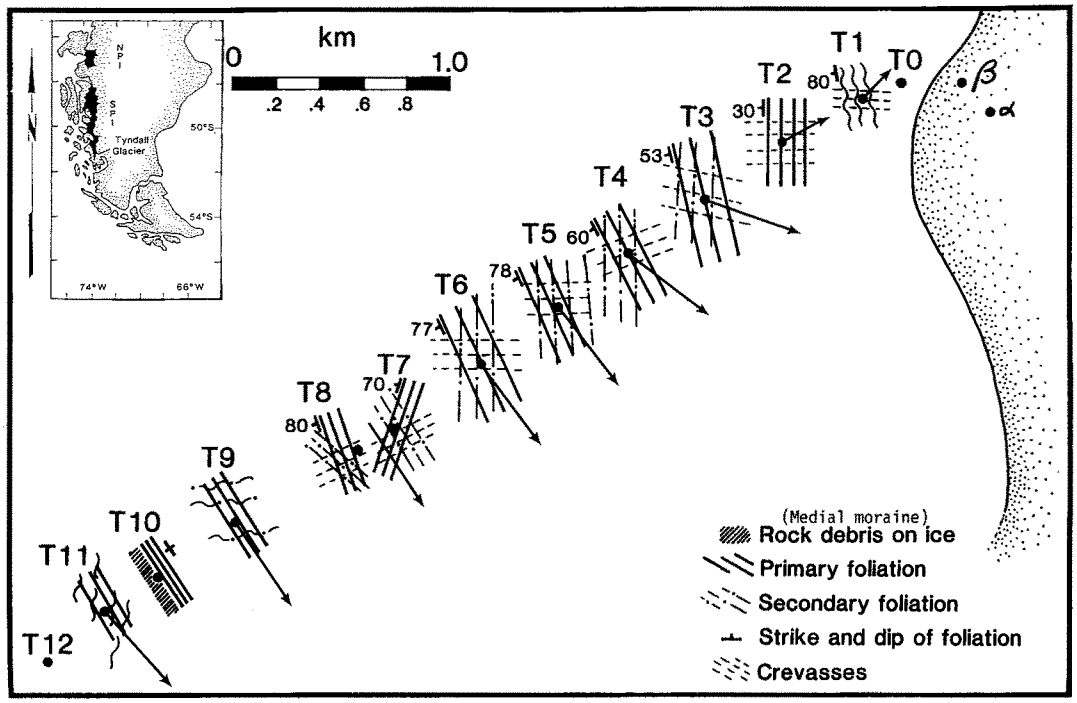

Fig. 1. Schematic diagram of foliation and crevasses on Tyndall Glacier. The wiggly lines represent folded foliation planes. The numbers indicate dip in degrees. Vertical dip is indicated by a cross at T10. The arrows indicate ice velocity, which was measured by Kadota *et al.* (1992) from stations T1 to T6. Beyond station T6 the velocity vectors correspond to those measured in 1985 by Naruse *et al.* (1987). Velocity increases from about 0.1 m/d at T1 to 1.9 m/d at T11. The length of the vectors is not proportional to the velocity magnitude.

prominent and continuous. The dip at the medial moraine was vertical and the width ranged from 0.1 m to 3 m. Secondary foliation appeared again at each side of the medial moraine.

Crevasses had a width of 0.2 to 1 m and were quite regularly spaced from T1 to T8. No crevasses were found at the center of the glacier, which is expected in the ablation area of a glacier. However, the crevasse pattern from T1 to T8 becomes perpendicular toward the center of the glacier, which suggests shear stress and extending flow. This pattern, which is typical of the accumulation area of a glacier suggests a longitudinally convex bed in this part of Tyndall Glacier.

3. Discussion

The occurrence of three sets of foliation planes suggests different origins and a complex pattern of strain on the glacier. The complexity of the cumulative strain is also suggested by the folding and faulting of many of the foliation planes. The absence of the arc-shaped foliation on this part of Tyndall Glacier might be due to absence of transverse crevassing in the upstream zone. Hambrey *et al.* (1980) believe that the arc-shaped foliation on alpine glaciers develops as crevasse traces.

The pattern of the primary foliation agrees with the pattern mapped by Naruse *et al.* (1987) from aerial photographs. However, Naruse *et al.* could not map any foliation from stations T2 to T8 because of the limited resolution of the aerial photographs. Merging both the ground and aerial photograph data sets provides the best representation of the glacier structure.

The prominent single foliation found at the medial moraine suggests a similar origin to flow stripes

that appear on satellite imagery of Antarctic glaciers (Crabtree and Doake, 1980 ; Casassa *et al.*, 1991). Flow stripes extend for several hundreds of kilometers in Antarctica and generally coincide with flow lines. The longitudinal foliation planes on the confluence area of valley glaciers are believed to occur by transverse compression (Anderton, 1973).

At station T9, which is located close to the medial moraine, the primary foliation direction is roughly parallel to the ice velocity (Fig. 1). At station T11, also close to the medial moraine, the ice velocity is nearly parallel to the foliation. The ice velocity intersects the primary foliation at high angles at all other stations in this two-dimensional diagram. At station T7 the secondary foliation is parallel to ice velocity, but this is regarded as fortuitous. The conclusion is that foliation parallels ice velocity around the medial moraine.

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