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SHORT NOTES

ORIENTATION OF SOIL STRIPES CAUSED BY NEEDLE ICE

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Abstract. Orientation of striping caused by needle ice has been ascribed in the past to (1) wind direction during soil freezing, and (2) azimuth of the sun during thawing. Recent evidence supports the latter concept.

Résumé. *Orientation des rubannements du sol causes par la glace en aiguille.* L'orientation des rayures causées par la glace en aiguilles a été attribuée dans le passé (1) à la direction du vent pendant le gel du sol et (2) à l'azimut du soleil pendant la fusion. Des observations récentes confirment cette seconde théorie.

Zusammenfassung. *Orientierung von Streifenböden, verursacht durch Nadeleis.* Die Orientierung von Streifenbildung, verursacht durch Nadeleis, wurde bisher (1) der Windrichtung während des Bodengefrierens und (2) dem Sonnenazimuth während des Tauens zugeschrieben. Neuere Erkenntnisse unterstützen die zweite Annahme.

Introduction

In a recent paper in this journal Schubert (1973) discussed the origin of ground striped (striated) by needle ice in the Venezuelan Andes. Schubert has concluded, in agreement with Troll (1944), that the stripes are aligned parallel to night-time winds when the needle ice grew. No mechanism has yet been offered to explain this phenomenon. Lliboutry (1954, 1955) has proposed a second theory, again without elaboration, that the stripes are a *penitente* feature, resulting from differential day-time melt. Most writers (e.g. Tricart, 1963) have accepted Troll's wind-stripe origin.

The present writers have witnessed the formation of needle-ice striped ground over a 15 year period from sea-level to alpine sites of 2 000 m in south-western British Columbia, Canada, and at a range of altitudes in New Zealand (Mackay and Mathews, 1974). Experiments have also been carried out on the control and on artificial orientation of striping. These observations support Lliboutry's *penitente* concept and show that the stripes grow in the day-time during thaw, and not in the night-time as a result of freezing when under the influence of wind. Outcalt (unpublished) has confirmed many of the observations of the writers in south-western British Columbia.

Washburn (1973, p. 81) in commenting on the two opposing theories suggests "that the wind hypothesis requires further research before being eliminated, even though the sun hypothesis can be demonstrated in places and may well be the general explanation". It is the purpose of this note to examine the direction of the striated ground in the Venezuelan Andes in terms of a day-time thaw origin, and to compare these with our own observations.

Time of needle-ice stripe development

Needle ice tends to grow at night under clear-sky radiation cooling (Outcalt, unpublished). When the clear skies and thawing conditions occur on the following morning, the needle ice with its superincumbent load collapses and stripes can be seen to have formed. A repetition of several freeze–thaw days, under clear-sky conditions, leads to progressively better stripes. In general, the stripes parallel the sun's shadows at the time when the needle ice columns collapse. Striped ground tends to form in the mid to late morning in south-western British Columbia, Canada (Fig. 1). During the winter season, the orientation will veer or back from month to month, depending upon whether the hours of daylight are getting shorter or longer. Somewhat similar observations on the thaw origin of striped ground due to ice needles have been made by Hastenrath and Wilkinson (1973, p. 159) in the mountains of Lesotho, southern Africa, at about lat. 29° S.:

> "The sunshine of the morning hours melts the ice needles and the fine material sinks back to the surface. A marked stripe-like arrangement of the fine material is generally observed with an approximate ENE–WSW direction (pl. 1). The exact orientation is very sensitive to obstructions of the horizon, in such a way that stripes point in the direction of local sunrise."

Fig. 1. Needle-ice columns melting in the early morning sun at an altitude of 1 750 m, Garibaldi Park, south-western British Columbia, Canada. Note the shadows of the sun in line with the stripes, and the collapsing ice needles. At this site, very little soil has been uplifted by the needles.

In view of the similar observations made by Hastenrath and Wilkinson in southern Africa, and the writers in south-western British Columbia, Canada, and in New Zealand, it may be of interest to compare the stripe directions for Venezuela as given by Schubert (1973) with the sun's position expressed in terms of the sun's apparent time for the corresponding stripe direction. The stripe directions are expressed in terms of the bearing from true north. For the Venezuela locations (lat. 8° 30′ N. to 9° N.) the stripe directions and sun's apparent times were: 8 December 1971, 126° to 130° at 09.00 to 09.30 h; 12 December 1971, 120° to 130° at 08.00 to 09.30 h; and 26 February 1972, 100° to 105° at 06.30 to 08.00 h. Clearly, the Venezuelan stripes parallel a morning sun position and, as the altitude of the sun increases from December to February, the stripes form earlier.

Wind and stripe direction

The observations of the writers have shown that the nights when needle ice has grown have usually been calm, because such conditions are typical of clear-sky radiation cooling where the field observations have been carried out. Both Troll (1944) and Schubert (1973) have stressed the role of night-time winds. On 1 May 1934 Troll observed striping on Mount Kenya, on the Equator, to have a bearing of 120° on a slightly inclined overgrown surface (Troll, 1944, fig. 21). Troll attributed the stripes to north-west–south-east winds. The Venezuelan data, as reported by Schubert (1973), were: on 8 December 1971, the wind velocity was 2.1 m/s in the stripe direction; on 12 December 1971, the wind was 1.6 m/s and at an angle of 35° to the stripes; on 26 February 1973, the wind blew at 3.7 m/s and was inclined 80° to the stripes, or nearly at right-angles. Thus the three Venezuelan examples do not show a close agreement between wind and stripe direction.

Neither Troll nor Schubert have given a physical interpretation of why wind would or could induce parallelism in needle-ice columns which grow by the upward movement of soil water with freezing at the base of the soil columns. Inasmuch as dead air is trapped beneath the needle-ice soil cap and the ground surface, why should a gentle wind, blowing only a few meters per second, affect the growth of ice columns where ice segregation is beneath the columns at the ground surface, or even below the ground surface in tiered ice columns?

Field experiments

On mornings when needle-ice striped ground has formed, artificial shading of the ground has prevented the formation of striped ground. Inasmuch as the shading occurred *after* the needle ice had grown, night-time freezing and wind action are automatically excluded. In a somewhat similar manner, Hastenrath and Wilkinson (1973, p. 159) have reported that the stripe orientations in the mountains of

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Lesotho are very sensitive to the shading by local obstructions of the horizon so that the stripes point in the direction of the local sunrise.

In one Vancouver, British Columbia, site, well shaded by evergreen trees in the winter months, stripes fail to develop on thawing of needle ice; in spring, however, when the same site is illuminated by the morning sun, then higher in the sky, stripes develop parallel to the sun's azimuth. During the winter period, moreover, stripes in a very different direction have been produced artificially by thawing with a heat lamp and the stripes were oriented parallel to the rays of the lamp.

Conclusion

Needle-ice striped ground can be shown to result as a thaw phenomenon by direct observation, by controlled and natural shading which prevents stripe growth, and by experiments with a heat lamp to cause striping. The Venezuelan data given by Schubert (1973) appear to have orientations compatible with the thaw theory of origin.

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