氷楔形成縁辺域における氷楔破壊発生の年々変動ースバルバールでの12年間の観測総括ー

Interannual variability of ice-wedge cracking at a marginal ice-wedge site: A summary of 12-year monitoring in Svalbard

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Lowlands of Svalbard, a High Arctic archipelago, lie at a marginal periglacial condition (mean annual temperature ca.−4˚C) for ice-wedge polygons. Such a marginal condition, where ice-wedge cracking is highly susceptible to inter-annual and long-term climate changes, favors evaluation of thresholds for the activity. This study presents the results of multi-instrumental observations of ice-wedge dynamics over 12 years (2005–2017) at a low-centered polygonal field in Svalbard. Three trough-rampart systems (TR1–3) dividing polygons were instrumented to monitor (1) horizontal and vertical displacements with extensometers, (2) micro-cracking with acceleration loggers, (3) timing of crack generation with subsurface copper wires, (4) air and ground temperatures down to the uppermost permafrost (at 2 m depth), (5) moisture content within the active layer and (6) snow condition with a time-lapse camera. Data loggers recorded these values at constant (mainly 1-hour) intervals (Fig. A). New cracks were also manually mapped in early spring.

Data analyses suggest the following conclusions on deformation of the trough-rampart systems, ground motions toward ice-wedge cracking, thermal thresholds for cracking and inter-annual variability of ice-wedge cracking. (1) During the freezing periods frost heave of the ramparts induces horizontal dilation of the ramparts and counteractive contraction of the troughs. The reverse movements occur during thawing periods. These movements are superimposed by thermal dilation of polygons and counteracting contraction of marginal troughs during summer. (2) Intermittent rapid cooling events during mid to late winter often trigger temporary extension and cracking of the troughs by thermal contraction. The winter activity starts from intensive micro-cracking (ground acceleration events), followed by rapid extension and finally by major cracking in the frozen active layer (Fig. B). Significant cracking occurred eight out of the twelve winters, though the occurrences were spatially variable. (3) A common threshold for initiation of thermal contraction cracking is given by a combination of ground surface cooling below −16˚C and a thermal gradient steeper than −8˚C/m; major cracking reaching permafrost occurs with a combination of surface cooling below −20˚C and a thermal gradient steeper than −10˚C/m. These thresholds indicate that cracking is intensified by both a brittle frozen layer and rapid cooling. The results apply to fine-grained soils with minimum snow and vegetation covers. To define more widely applicable thresholds for ice-wedge cracking requires data from a variety of permafrost and substrate conditions. (4) Even in overall warm winter, short cold spells can produce effective ice-wedge cracking. This supports active ice-wedge cracking in Svalbard, which lies at a marginal condition and experiences long-term warming.

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