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Talus cone activity recorded by tree-rings of Arctic dwarf shrubs: a study case from SW Spitsbergen, Norway

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Dendrochronological methods were used to determine talus cone activity in the Arctic area. Talus cones are one of the most characteristic geomorphological features of the Svalbad Archipelago. Two species of dwarf shrubs, *Salix polaris* and *Salix reticulata,* which belong to the Willow family (*Salicaceae*), were collected from two talus cones located in the SW Spitsbergen Island. These small creeping shrubs (less than 10 cm tall with stem diameters ranging from 0.5 cm to 1.1 cm) have well developed tree-rings which allow them to be used for dendrochronological research. The age of the dwarf shrubs showed the minimum time during which the cones were disturbed by mass movements. Observations and material analysis indicate that currently the talus cones are active, but their development through debris flow, creep and rock particle slide is observed only episodically. An increased rate of vegetation colonization during the 1980s indicates that geomorphic events were less active in the talus cone area during this time.

Key words: the High Arctic, talus cones, dendrochronology, dwarf shrubs

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INTRODUCTION

Talus cones are formed by rock weathering, rock fall and by a further downslope transport caused by creep, slide, debris flow or snow avalanches (Luckman, 1977; Church et al., 1979). These apron-like accumulations of coarse-grained rock particles are very common, characteristic geomorphological features of periglacial, arid and high-mountain environments (Albjär et al., 1979; Kotarba, Stromquist, 1984). Depending on the active geomorphic process, the supply of talus material may be either a continuous or a periodic process. The structure, morphology and sources of material of talus cones in the Arctic areas have been reported in many papers (Rapp, 1960; Jahn, 1967; Church et al., 1979; Akerman, 1980; 1984; Rudberg, 1986; Ballantyne, 2003). Analyses of the geomorphic processes influencing talus cone development in periglacial climatic conditions have been provided mainly on the basis of air photographs and direct field measurements or according to discontinuous records (^{14}C, lichenometric and OSL dating) on several arctic sites (Rapp, 1960; Rapp, Nyberg, 1981; Jonasson et al., 1991; Matsuoka et al., 2003; Kostrzewski et al., 2004; Hansom et al., 2008). In arctic and alpine ecosystems where trees are rare or absent, dendrochronological research is limited, although a large number of dendroecological and dendroclimatological studies have been carried out on arctic dwarf shrubs (Beschel, Webb, 1963; Warren, Wilson, 1964; Kuivinen, Lawson, 1982; Woodcock, Bardley, 1994; Shaver, 1986; Rayback, Henry, 2005; Schweingruber, Poschold, 2005; Bär et al., 2006; Au, Tardif, 2007). In this paper, the use of tundra shrubs is described as a source of dendrogeomorphological information about talus cone activity in the High Arctic.

RESEARCH AREA

The research was carried out in Wedel Jarlsberg Land in SW Spitsbergen, Svalbard (Fig. 1). Two talus cones located in the vicinity of the Polish Polar Research Station in the Horsund area were selected for detailed research (Fig. 2). Longitudinally aligned mountain massifs with elevations of ca. 500–600 m a. s. l. and coastal plains with several marine terraces dominate the landscape. The mean annual air temperature is –4.4 °C, varying from –11.3 °C in January to +4.4 °C in July (Marsz, Styszyńska, 2007). As is usual in Arctic regions, there is little precipitation – only 300–400 mm. Variations of Arctic

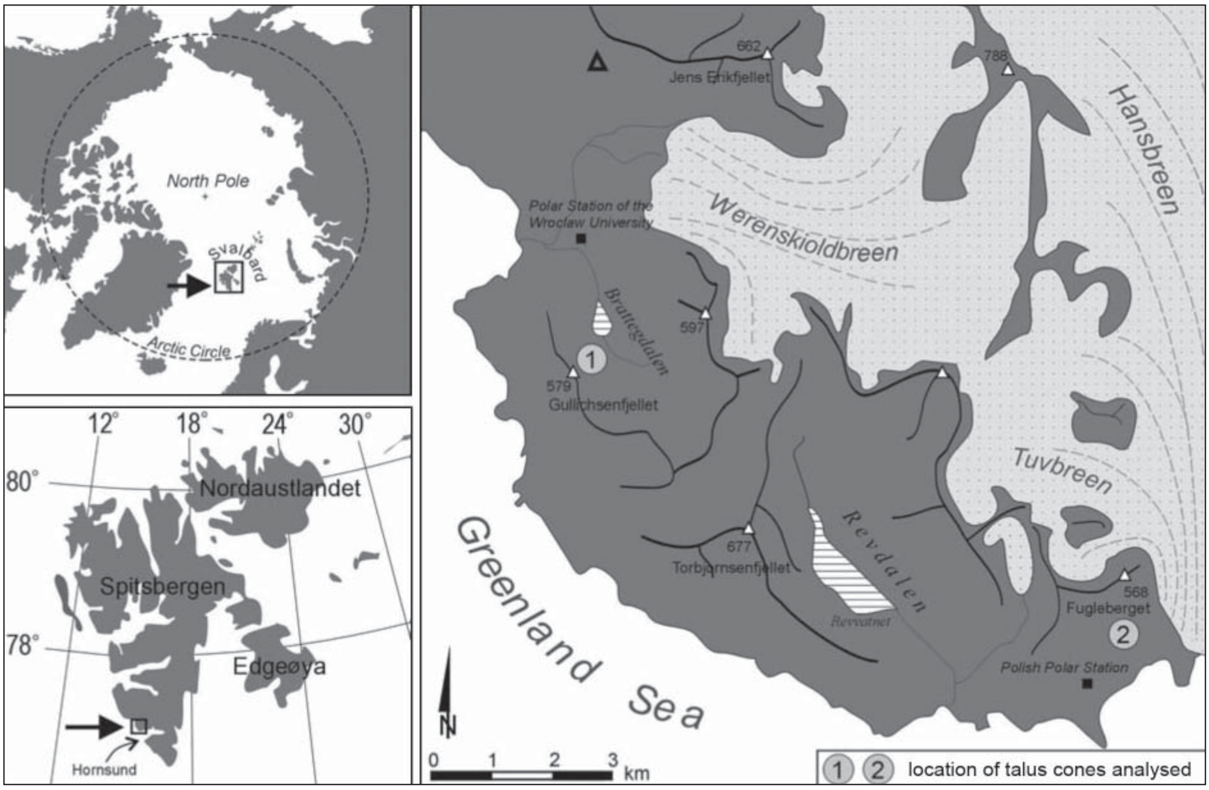

Fig. 1. Location of the study area

1 pav. Tyrimų plotas

climatic conditions, mainly relating to the topography of the area and the influence of the ocean and glaciers, geology and the thickness of snow cover, determine the development of vegetation. Tundra community vegetation is dominated by low creeping dwarf shrubs and by various species of mosses, herbs and lichens. Because of the climatic conditions, the vegetative period is short. It starts in June and lasts until around the end of August, ranging from 40 to 70 days. Tundra community is especially rich in plains (Fig. 3). On screes, moraines and block fields, the vegetation cover is generally no more than 10–15% (Påhlsson, 1985; Rønning, 1996).

MATERIALS AND METHODS

Wood material

For the dendrochronological dating of talus cone activity, two species of dwarf shrubs belonging to the Willow family (*Salicaceae*) were used. *Salix polaris* (Wahlenb.), commonly known as polar willow, and *Salix reticulata* (L.), called net-leaved willow, are deciduous, prostrate, trailing shrubs usually less than 10 cm tall. Their stem and root systems are located underground in the uppermost part of the active layer of permafrost.

Geomorphic mapping and samples collection

The study sites were selected according to the accessibility of the *Salicaceae* species and their location within talus cones. Samples were collected and field research carried out over two

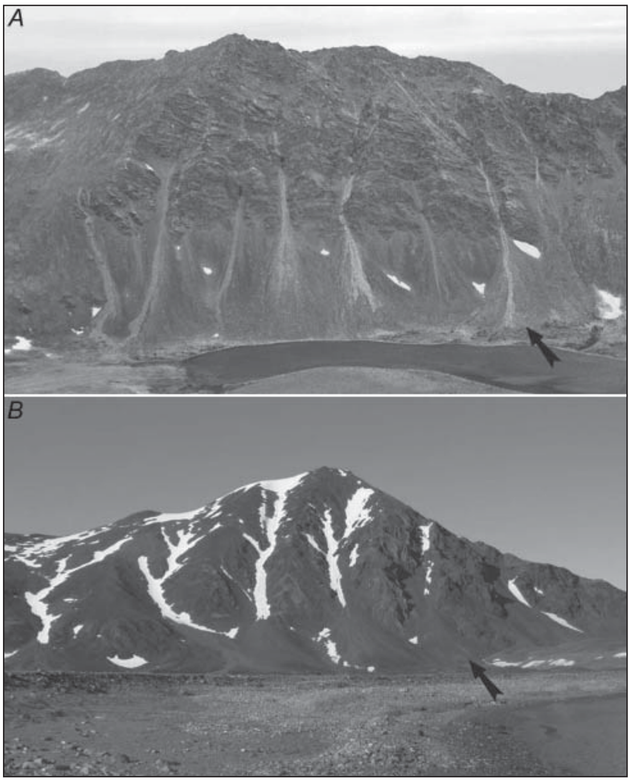

Fig. 2. *A* – Eastern slopes of Gullichsenfjellet massif (579 m a. s. l.), *B* – Fugleberget massif (568 m a. s. l.). Arrows point to talus cones studied

2 pav. *A* – Gulichsenfleleto masyvo rytinis šlaitas (579 m.v. j. l.), *B* – Fuglebergeto masyvas (568 m.v. j. l.). Rodyklės žymi tirtus deliuvio kūgius

Fig. 3. Arctic tundra in the Rev Valley to the west of the Polish Polar Research Station in Hornsund

3 pav. Arktinė tundra Revo slėnyje į vakarus nuo Lenkijos poliarinių tyrimų stoties Hornsunde

Arctic summers – 2007 and 2008. Simple geodesic methods were used for mapping the debris cones drawn to a scale of 1 : 500. Complete individuals of *S. polaris* and *S. reticulata,* including the root and branch systems, were collected in the field (Fig. 4, *A*). Each individual was documented by digital photos (Fig. 4, *B*).

Laboratory analysis of collected materials

In order to examine the oldest part of the sample, individual plants were sectioned every 4–6 cm. The samples were sectioned with a GSL1 sledge microtome, taking 15–20 μm cross-sections at 4 to 6 different locations along the length (Fig. 3, *A*). Microtome sections were prepared from the whole diameter of the selected segments (Fig. 3, *B*). The number of annual rings and tree-ring widths analyzed were measured along the longest radius of the stem, using OSM3 and PAST4 (SCIEM) programs (Fig. 4, *C*).

RESULTS

Wood anatomy characteristics

Woody plants with tree rings can be found in all climates on the Earth, but the frequency of species with clearly visible tree rings is directly related to the seasonality of climate (Schweingruber, 1996). Growth-ring boundaries in arctic *Salicaceae* have been reported at various times, especially in the case of *Salix arctica* (Pall.) (Beschel, Webb, 1963; Warren, Willson, 1964). *S. polaris* and *S. reticulata* are semi-ring-porous and have well-defined growth-rings (Owczarek, 2009) whose boundaries are delimited by one or more rows of cells (Fig. 4, *B*). The cells, rectangular in cross-section, are usually smaller in *S. reticulata* compared to *S. polaris;* the boundaries of *S. reticulata* tree-rings are therefore more visible and easier to count. Maximum stem diameters range from 0.5 cm to 1.1 cm, so annual growth-rings are very narrow. In the individual plants they ranged

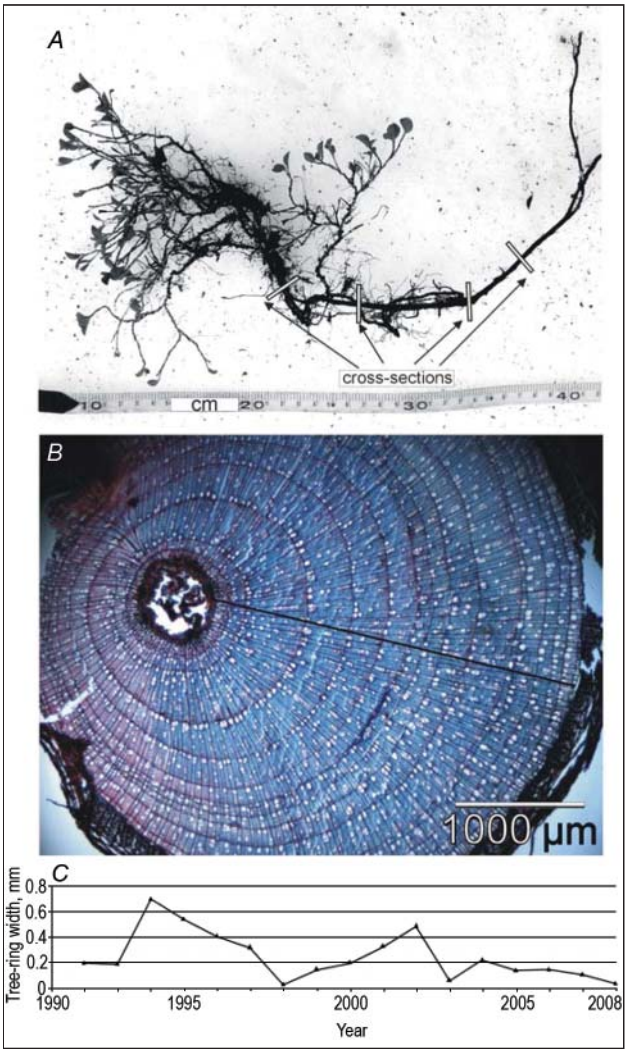

Fig. 4. *A* – individual of *Salix polaris*, white-black lines indicate cross-sections taken from the sample; *B* – example of the *Salix polaris* cross-section, black line marks the longest radial of the stem; *C* – tree-ring width diagram

4 pav. *A* – *Salix polaris* mėginys, baltos ir juodos linijos žymi tirtus pjūvius; *B* – *Salix polaris* mėginys, juoda linija žymi ilgiausią kamieno radialą; *C* – rievių pločio diagrama

from relatively wide (0.8 mm in width) to extremely narrow rings less than 0.01 mm in width, usually observed in *S. polaris* (Fig. 4, *C*). Discontinuous growth rings are very common in the species analyzed. Partially absent tree rings appear due to, for example, climatic conditions (frost year, absence of water), mechanical stress connected with periglacial processes, or partial limitation of root and stem growth space. The age of samples is used to determine the minimum age of the geomorphic form or processes (Stoffel, Bollschweiler, 2008). Reaction wood, called tension wood in angiosperms, and scars are clearly visible in the dwarf shrub species analyzed (Owczarek, 2009). These parameters, plus the geomorphological features, make it possible to reconstruct the spatial and temporal patterns of slope movements, for example, debris flow events or solifluction movements on the talus cones.

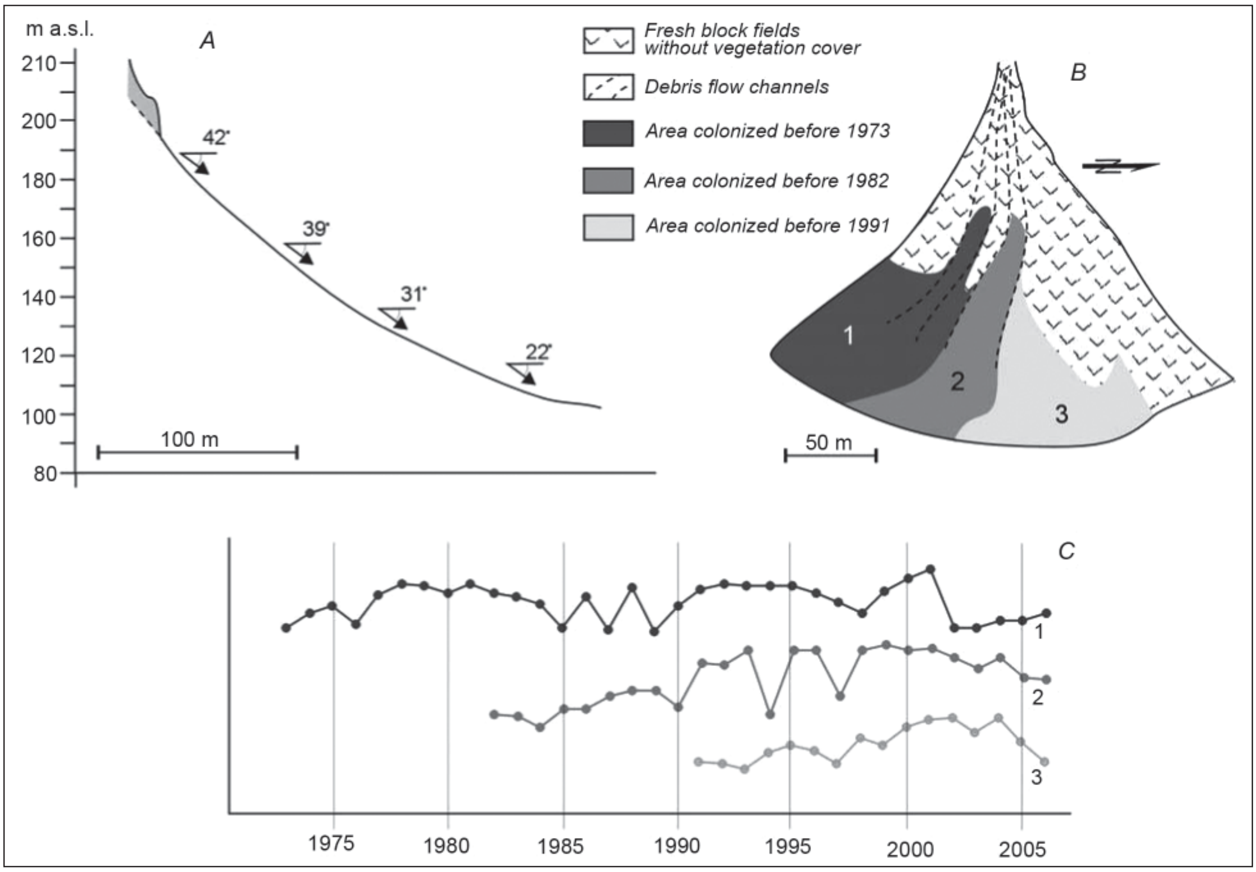

Fig. 5. The Brateggdalen talus cone: *A* – longitudinal profile, *B* – morphological sketch, *C* – tree-ring diagrams of the oldest samples of *Salicaceae* collected from the distal part of the cone

5 pav. Brategdaleno deliuvio kūgis: *A* – meridianinis profilis, *B* – morfologinis eskizas, *C* – seniausio *Salicaceae* mėginio, paimto iš distalinės kūgio dalies, rievių diagramos

Talus cones: morphology and dynamics

Brateggdalen talus cone (site 1). The eastern slope of the Gullichsenfjellet massif (579 m a. s. l.) is dominated by well-developed talus cones (Fig. 2, *A*). The massif is built from Middle Proterozoic white and green quartzites (Manecki et al., 1993). The lower parts of the cones are located on the flat Brategg valley bottom, about 90–100 m a. s. l. The cones have a distinct lower convex margin with an angular block-rich surface. The cones are situated below rock-fall chutes which are steep and narrow and have an irregular longitudinal profile.

The talus cone analyzed is 110 m in height with an average slope gradient 33° (Fig. 5, *A*). In the steep upper and middle part of the cone, two debris flow channels are observed with distinctly visible levees (Fig. 5, *B*). Irregular solifluction lobes and weakly developed debris flow tracks can be observed in the morphology of the lower part. The rock material is angular, and the grade is finer at the top and coarser in the distal part. In the marginal areas, there are blockfields. Fresh blockfields, without vegetation cover, are observed in the upper part and the north-facing side of the cone. Twelve samples of *S. reticulata* and *S. polaris* were collected from the middle and the distal parts. Tree-ring analysis indicates that the cone started being colonized by vegetation in the last century, in the early 1970s. In the first phase, the vegetation started appearing on the south-facing side of the cone (Fig. 5, *B*, *C*). At present, only the north side of the cone is active. The cone is being developed here through debris creep and slide.

Fugleberget talus cone (site 2). Five large talus cones have developed on the southern slopes of the Fugleberget massif (568 m a. s. l.). The cones are situated below narrow rock-fall chutes which refer to schist beds within a complex of Middle Proterozoic paragneisses (Fig. 2, *B*). The distal parts of the cones are located on the coastal plain and on the outer face of the Hans Glacier end moraine at 30–35 m a. s. l.

The talus cone analyzed is convex, with an average slope gradient 28° (Fig. 6, *A*). Fresh blockfields can be observed on the proximal and west-facing side of the cone. The morphology of the cone is characterized by a few weakly developed debris flow tracks (Fig. 6, *B*). Lobate debris flow accumulations and solifluction lobes, partly colonized by vegetation, can be observed in the marginal zone of the cone. The oldest samples were collected from the east-facing side of the cone (Fig. 6, *B*, *C*). *Salicaceae* were collected from non-active debris flow channels. These debris flow tracks developed

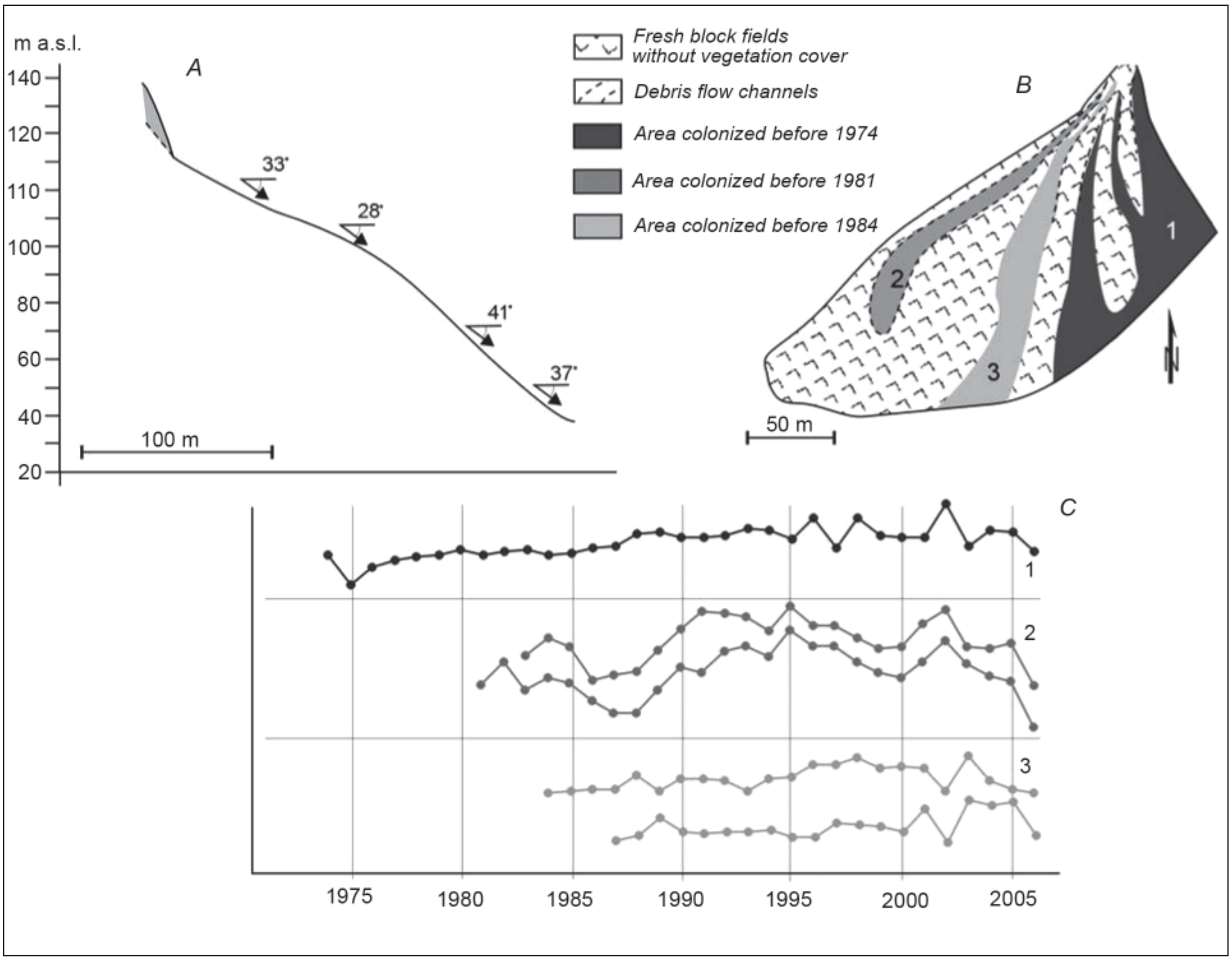

Fig. 6. The Fugleberget talus cone:
A – longitudinal profile, *B* – morphological sketch, *C* – tree-ring diagrams of the oldest samples of *Salicaceae* collected from the cone area

6 pav. Fuglebergeto deliuvio kūgis:
A – meridianinis profilis, *B* – morfologinis eskizas, *C* – seniausio *Salicaceae* mėginio, paimto iš distalinės kūgio dalies, rievių diagramos

before 1980. Dwarf shrubs started colonizing the channels in last century (in the early 1980s). From that moment they were no longer active. Fresh debris flow tracks and lobate debris slides can be observed in the eastern part of the cone (Fig. 6, B).

CONCLUSIONS

The main goal of the research was to show that dwarf shrubs are useful for talus cone analysis in the Arctic area. Talus cones are a very good indicator of geomorphic process activity in the periglacial zone. Depending on the course of the geomorphic processes, the input of the talus material can be either a continuous or a periodic process. The research demonstrates that rock material supply conditions have been varying over the last 40 years. The talus cones were active and sediment input was continuous before 1970, as shown by the age of the dwarf shrubs collected. The oldest sample was 33 years old. *Salicaceae* started colonizing the surface of the cones in the last century (in the early 1970s). This process intensified during the 1980s. Colonization of the talus cones indicates a decrease in the dynamics of geomorphic processes. An increase in mass movement activity is noticeable from the beginning of the 1990s. The small number of young individual dwarf shrubs indicates a frequent supply of fresh rock material.

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PIETVAKARIŲ ŠPICBERGENO DELIUVIO KŪGIŲ AKTYVUMAS ARKTINIŲ NYKŠTUKINIŲ KRŪMYNŲ RIEVIŲ TYRIMO DUOMENIMIS

Santrauka

Deliuvio kūgiai, būdingiausios Svalbardo archipelago arktinėse platumose geomorfologinės formos, buvo tiriami dendrochronologiniais metodais. Nykštukiniai karkliniai krūmynai (*Salicaceae*, *Salix polaris* ir *Salix reticulata*) iš dviejų kūgių, esančių pietvakarinėje Špicbergeno salos dalyje, turi gerai matomas rieves, tinkamas dendrochronologiniams tyrimams. Nykštukinių krūmynų amžius rodo minimalų amžių, kai kūgius paveikė slenkančios masės. Stebėjimai ir turima medžiaga leidžia teigti, kad deliuvio kūgiai dabar yra aktyvūs, tačiau šis aktyvumas epizodinis. Padidėjęs augmenijos kolonizacijos greitis 1980 m. rodo, kad geomorfiniai procesai tuo metu buvo mažiau aktyvūs.

Raktažodžiai: arktinės platumos, deliuvio kūgiai, dendrochronologija, nykštukiniai karkliniai krūmynai