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Dendrogeomorphological research on thermokarst depressions in Western Siberia

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Introduction

Much of the discontinuous permafrost is within 1°C to 2°C below the thawing point and highly susceptible to degradation (Osterkamp, Viereck, Shur et al. 2000). Any additional energy input to the surface will result in a formation of new thermokarst; a degradation form of permafrost with karstlike surface features (Muller 1947).

An alteration of the energy balance can be caused by climatic changes like, for example, increasing mean annual air temperature and precipitation or due to natural or anthropogenic destruction of the isolating vegetation cover, which protects the soil from summer warming. The thickness and period of snow cover has an ambivalent influence on the soil temperature. On the one hand, long snow coverage in spring and early summer shelter from heating, on the other hand early snow in autumn and thick coverage in winter prevent from cooling and freezing of the active layer (Burn & Smith 1990; Osterkamp & Romanowsky 1999; Vaganov, Hughes, Kirdyanov et al. 1999; Agafonov, Strunk, Nuber 2004).

The formation of thermokarst depressions is initiated by a thawing of the ice-rich upper part of permafrost. The loss of ‘excess ice’ leads to ground settlement as well as ponding of surface water and melted ground ice. As a consequence a boggy, sometimes water filled depression is formed. Once established, radial widening starts by thermal erosion which subsequently will destroy the surrounding vegetation. Trees affected by the expansion of thermokarst depressions show an eccentric stem growth often associated with compression wood. These wood anatomical features combined with geomorphological research allow to date and reconstruct the development of thermokarst as well as the initiating factors of the thawing process.

Methods

Study Site

The study site is located in western Siberia at the left riverside of the river Synja, a small tributary of the river Ob (65°03’N, 64°40’E). The elevation is approximately 20 m a.s.l. The whole area is underlain by permafrost with an observed active layer of about 40 – 200 cm. The silty soil is covered by an 30 cm thick moss layer under a canopy predominated by Pinus sibirica. Mean annual air temperature is about –4.8°C, precipitation is about 480 mm/a. The site encompasses numerous thermokarst depressions with a range in diameter from few metres to several hundred metres.

The investigated thermokarst depression has a diameter of about 80 metres and a depth of about 2 metres. The surface of the depression consists of a 60 cm thick floating peat layer on a water body with a depth of up to 1.4 metres. Measured water temperature is 5.7°C. The soil beneath the water body is unfrozen whereas the position of the permafrost table is unknown.

There are numerous living and tilted trees on the slope of the depression whereas inside the depression dead trees are still standing in a more or less upright position. The number of dead yet still standing trees decline with distance from the bank line. The dead trees fell over and lie well preserved in the water body on the bottom of the depression. These trees can be located with probes and salvaged from the ground.

Methodological Considerations

In the course of the proceeding widening of the depression trees will be affected by the back moving slope. Considering this influence on trees (Schweingruber 1996), resulting tree growth can be classified into three phases (Fig. 1):

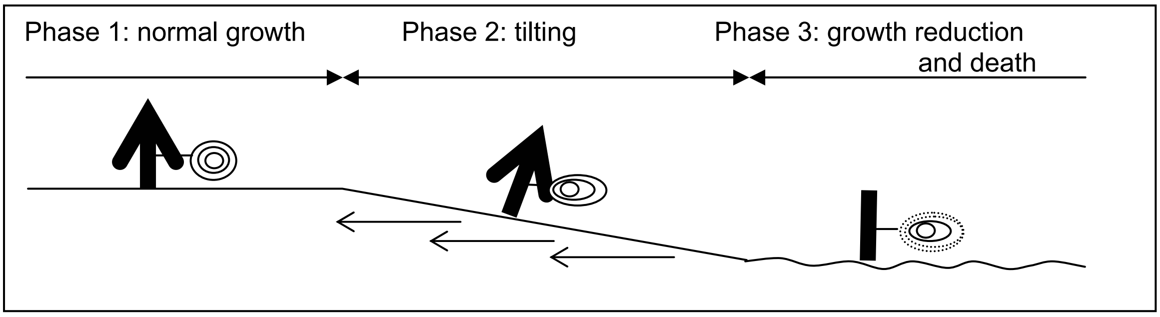

Figure 1: Influence on tree growth

Phase 1: Outside the depression trees show a normal growth with almost concentric tree rings.

Phase 2: Affected by the progressing slope, the trees become tilted and react by forming compression wood and/or eccentric tree rings.

Phase 3: Attaining the boggy depression, the roots of the tree get flooded by the stagnating water inside the depression. Drastic growth reduction starts and ends at last with the death of the tree after a few years.

Sampling

About 235 trees from inside the depression and the surrounding area were sampled. The position of each sampled tree was measured and marked in a map of the depression. Cores (n = 104) from living trees were taken in direction of tilting. Cross sections (n = 131) were cut from dead trees.

Analysing

The ring widths of sanded samples were measured with a precision of 0.01 mm with LINTAB. The discs were measured usually in two radii, the longest and the shortest one. If the disc indicates a tilting of the tree in more than one direction up to four radii were measured. The samples were crossdated with TSAP. Finally, crossdating was visually verified using standard procedures after Stokes and Smiley (1968).

Results

To reconstruct the rate of widening of the depression it is necessary to determine the average time of tilting as well as the date of death of the trees depending on their distance to the present bank line (Fig. 2).

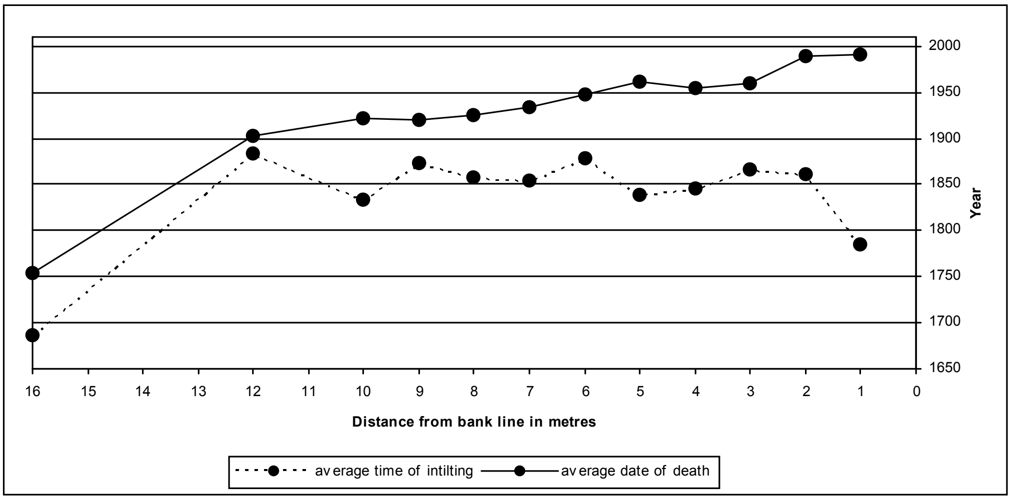

Figure 2: Average time of tilting and death depending on distance (example for the western part of the depression)

The average time of tilting does not show a more or less straight ascending graph with descending distance from the bank line as it theoretically could be expected. On the contrary, there is a concentration of tilting around the year 1850 independent from the distance, which points towards a destabilization of the whole area at that time. The average time of death shows the expected dependence on the distance. At the latest around 1900 the graph shows an acceleration of the widening rate.

The derived average rate of widening for all parts of the depression is about 2.6 – 5.3 cm/a between 1500 and 1750, rises up to 10 cm/a between 1750 and 1900 and stays stable at a high level of about 16 cm/a until today with a maximum rate of widening of 21 cm/a between 1900 and 1920. Figure 3 shows the reconstructed spatial-temporal development of the thermokarst depression since 1500 AD.

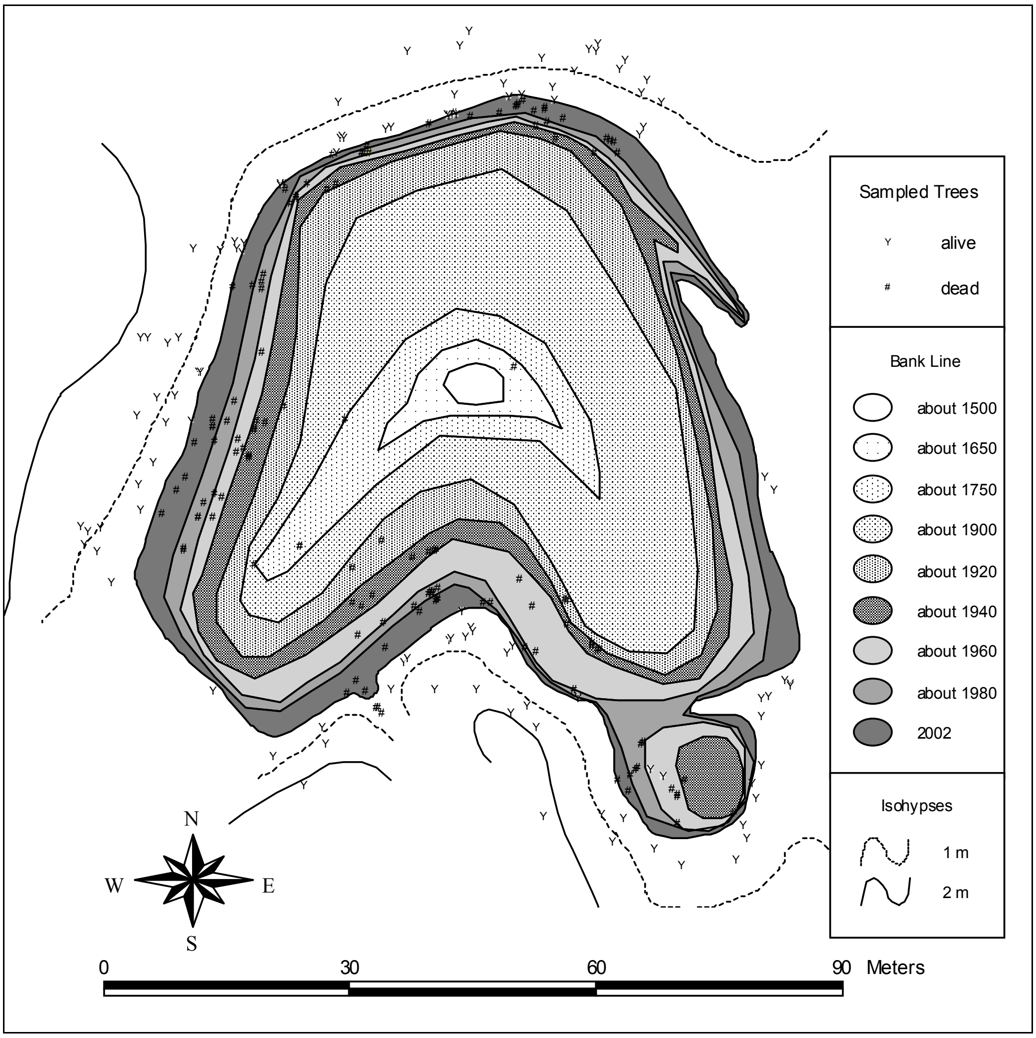

Figure 3: Spatial-temporal development of thermokarst

The bank lines for the time between 1500 and 1900 as well as at the eastern part of the depression are based on a small number of sampled trees. These lines could be verified by the salvaging and analysing of a higher number of sunken trees from the bottom of the depression.

Since we have not yet enough samples from the inner part of the depression, we cannot definitely state if this thermokarst depression is caused by climatic changes or by disturbance of the vegetation.

The number of sampled trees in relation to the different periods, supported by the discovery of charcoal, indicates an almost complete destruction of the former vegetation by a fire between 1822 and 1832. This fire seems to be the main reason for the disruption of the thermal equilibrium of permafrost followed by a destabilization of the whole area around 1850 and an accelerated widening of the thermokarst depression at the latest since 1900.

Conclusion

Dendrogeomorphological analysis of tree rings is an apt method to date thermokarst depressions and to reconstruct their process of widening. Depending on density of tree stands, a temporal resolution of the progressing widening of about 5 to 10 years for hundreds of years is possible. Sequences of aerial photographs may provide a higher temporal resolution but only for the last century. In addition to geomorphological information, tree rings provide climatological and ecological information, which help to reconstruct thermokarst development in a certain area.

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