PERMAFROST - Seventh International Conference (Proceedings),
Yellowknife (Canada), Collection Nordicana No 55, 1998

OBSERVATIONS OF PERMAFROST-LANDSCAPE DYNAMICS RELATED TO ANTHROPOGENIC DISTURBANCES, YUKECHI STUDY SITE, CENTRAL YAKUTIA

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Abstract

This paper presents results of field observations of permafrost-landscape dynamics in central Yakutia on the Yukechi site, situated 50 km southeast of Yakutsk on the right bank of the Lena River. The analysis emphasizes the rate of surface subsidence, rate of evolution of young thermokarst topography, and characteristic features of the recovery of the ground thermal regime after forest cutting and forest fires.

The Yukechi location is a typical alas landscape of central Yakutia. The purpose of the observations is to study the rate of disturbance and recovery of landscapes in order to assess their resistance to anthropogenic effects and climatic change. Quantitative data on subsidence rates of disturbed sites were obtained for each initial form of thermokarst relief during the five-year observation period. Ground temperatures were measured in the main post-disturbance vegetation successions.

This study is relevant to environmental control and rational landscape management in permafrost regions.

Introduction

Systematic observations of ground temperatures, depth of seasonal thaw, surface subsidence of disturbed land (abandoned ploughed field, burned out or cut-down forest) have been carried out at the Yukechi site since 1992. It is a landscape typical of central Yakutia with thick, ice-rich Quaternary deposits and widely distributed alasses. The surface dips slightly to the north-west and altitudes are 200-220 m a.s.l. The Yukechi location belongs to the south-western marginal part of the Abalakh erosion-constructional plain with a prevailing alas relief.

The upper horizons of Quaternary sediments are dominated by sandy and clayey loams, sometimes with interlayers of fine-grained silty sand. These soils have unique saline and mineralogical-petrographic compositions in alas basins due to specific features of sedimentation during the thermokarst development. Wedge ice is ubiquitous in terrain between the alasses. It occurs at a depth of 2-2.5 m; the upper parts of the ice wedges are between 1-1.5 m and 2.5-3 m wide. Soil blocks in between the ice wedges do not exceed 5-6 m in diameter in plan. The depth of seasonal thaw varies between 1.2-2.5 m depending on landscape conditions.

Data sources and methods

To study the dynamics of thaw subsidence during initial stages of thermokarst, twelve observation sites were established in the Yukechi location for the purpose of surveying the dynamics of the inter-alas surfaces (Figure 1). Within these sites, there are 125 permanent marker points for determining relative elevations, including three datum points installed to depths of 4 m. Of these, leveling has been carried out at 33 points since 1992 and on the rest of the points since 1993-94. Surveys were undertaken every year in August-September, i.e., at the end of the ground thawing season. Measurements were made using an NS4 level with a mean-square error within 3 mm. This report presents data for the 1992-1996 period.

There are survey points on the following major topographic forms between the alasses:

(1) Undisturbed, even surfaces between alasses.

(2) Primary thaw depressions (sites 3A, 4A, 7, 8, 9, 11), with relative depths up to 1-1.5 m.

(3) Thaw depressions with microlakes (sites 2, 3, 4), with relative depths up to 2-2.5 m.

(4) Linear depressions (site 6), with relative depths up to 2-2.5 m.

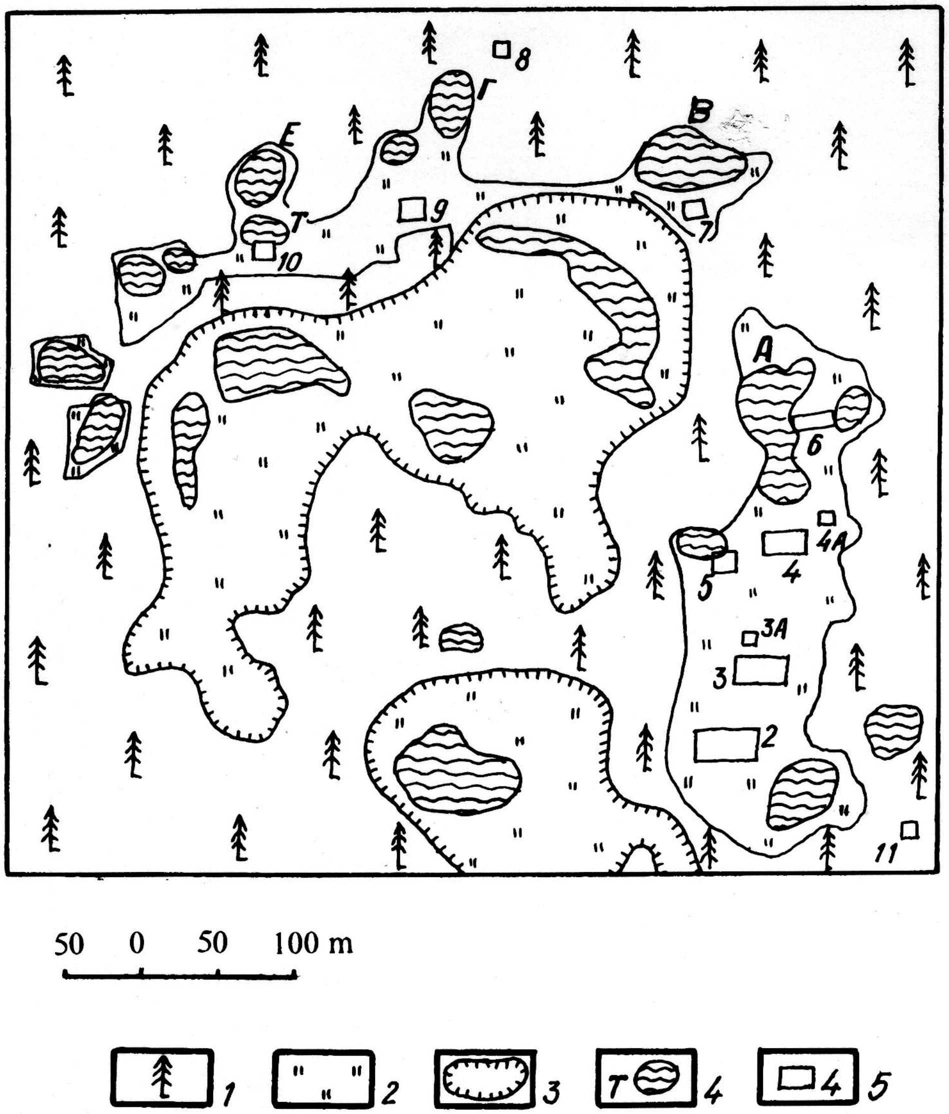

Figure 1. Schematic map of the Yukechi location.
1: forested inter-alas terrain; 2: meadows; 3: alas basins; 4: numbered thermokarst lakes; 5: numbered observation sites.

(5) Thaw depressions with incipient thermokarst lakes (sites 5, 10).

Sites 8 and 11 are situated in forest, sites 5 and 10 are at the forest-meadow border, and the rest of the sites are in meadow terrain between the alasses.

Most thaw depressions (sites 3A, 4A, 6, 7, 8, 9, 11) were completely dry at the time of observation. Two thaw depressions (sites 2, 3) had small ponds with diameters of 5-7 m and water depths of 0.5-0.8 m. Incipient thermokarst lakes (sites 5, 10) had diameters of 20-25 m and water depths of 1.5-2 m.

To study the recovery of the ground thermal regime, 10-20 m deep holes were drilled in different successions: undisturbed larch forest, 50-year old larch forest (regeneration after fire), 25-year old larch forest (regeneration after clear cutting), and meadow terrain between alasses. Temperature measurements were made with thermistor strings. In most boreholes, sensors were placed with backfilling after drilling. Measurements were made once a year, in late August-early September.

Results

Surface Subsidence Between Alasses

Survey results have shown that yearly and total (several years) values of surface subsidence (heaving) differ significantly within each site and from site to site. In addition, the amount of surface subsidence at a given point, or marker, varies greatly from year to year.

Over the observation period, maximum subsidence took place in areas with incipient thermokarst lakes (sites 5, 10) where a warming effect on the permafrost was much higher in comparison to other varieties of

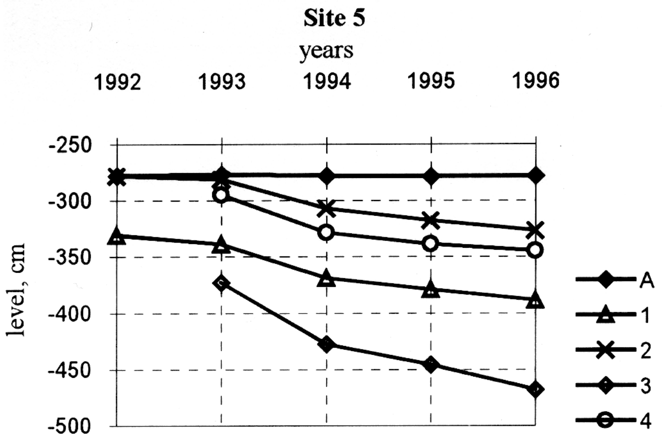

Figure 2. Surface subsidence of survey points within site 5.
A: undisturbed inter-alas terrain; 1 and 2: polygon centers at the water edge; 3: polygon center, below the water edge since 1994; 4: interpolygonal trough at 5 m from the water edge.

thaw depression. Maximum surface subsidence of 9 to 30 cm/a is recorded for site 5 which is situated at the lakeside (Figure 2). In 1993, point 3 was at the water edge and in 1994 and 1995 it was already under water. In the summer of 1995, the water depth reached 0.5 m. At this point, maximum subsidence was 55 cm in 1993-94. The rate of surface subsidence near a thermokarst lake (site 10) is somewhat less, 12-15 cm/a.

Within thaw depressions (sites 2, 3, 4), almost all points show surface subsidence to some degree (Figure 3). Maximum subsidence was 27-30 cm (sites 2, 3) for the entire observation period (1992-1996) and 26 cm (site 2) and 23 cm (site 3) per year. Within a thaw depression, some areas subside more than others, with greater subsidence not necessarily being confined to the center of the depressions. For example, within three years, point B (site 4) at the border between undisturbed inter-alas terrain and the upper part of the thaw depression slope, subsided by 26 cm compared to only 16 cm at point 1 in the central, deepest part of the depression. At sites 2 and 3, maximum surface subsidence occurred in 1993, and at site 4, in 1994. The amount of precipitation during 1993 was much below a long-term norm, but close to the norm in 1994. It follows that no direct relation exists between the rate of surface subsidence and the amount of annual precipitation. From the available data, the average rate of subsidence of the bottoms of thaw depressions with small ponds is estimated at 5-7 cm/a for the entire observation period.

The largest scatter of surface subsidence values is found for primary thaw depressions. Maximum annual and total (several years) subsidence values are observed at sites 3A and 9 (meadow terrain between alasses). There, annual subsidence of individual points was as much as 18-22 cm, but total (several years) subsidence was not high due to quite uneven settlement of the same points from year to year (Figure 4). For example, the surface at point K 1 (site 3A) subsided by 18 cm in 1993, by 7 cm in 1994, but remained unchanged in 1995. The surface of a primary thaw depression in a meadow terrain between alasses (site 4A) was even uplifted by a few cm within three years due to winter heave of soils. The surface levels of primary thaw depressions in forested interalass terrain (sites 8, 11) are regarded as relatively stable since total (several years) subsidence values there did not exceed 1-2 cm (Figure 5).

The surface of the linear depression (site 6) that connects two different-level thermokarst lakes subsided unevenly, like the other sites. Maximum subsidence (up to 18 cm within two years) occurred in its central part, whereas minimum (only 5 cm within three years) took place in the upper part of the depression. The bottom of the depression remained at the same level over the entire observation period.

Survey markers in undisturbed terrain between the alasses failed to reveal any significant changes of the surface levels over the observation period. The

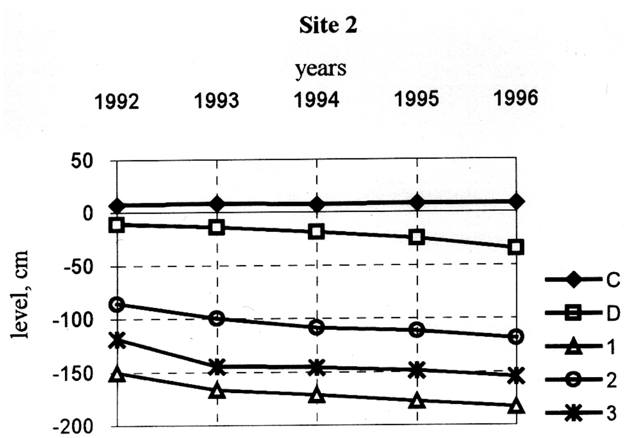

Figure 3. Surface subsidence of survey points within site 2.
C: undisturbed inter-alas terrain; D: incipient thaw depression; 1-3: centers of polygons within thaw depression.

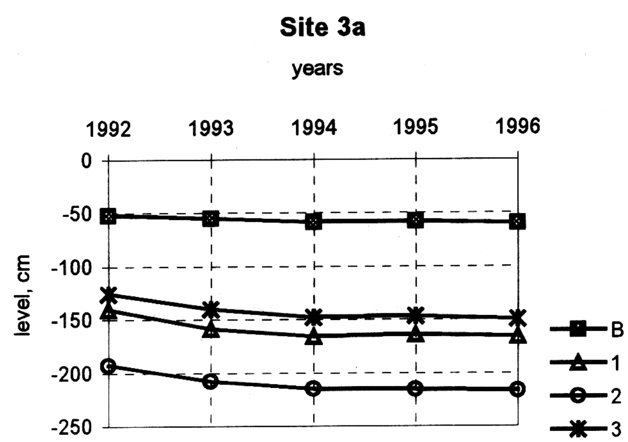

Figure 4. Surface subsidence of survey points within site 3a.
B: inter-alas terrain; 1 and 3: centers of polygons within thaw depression; 2: interpolygonal trough.

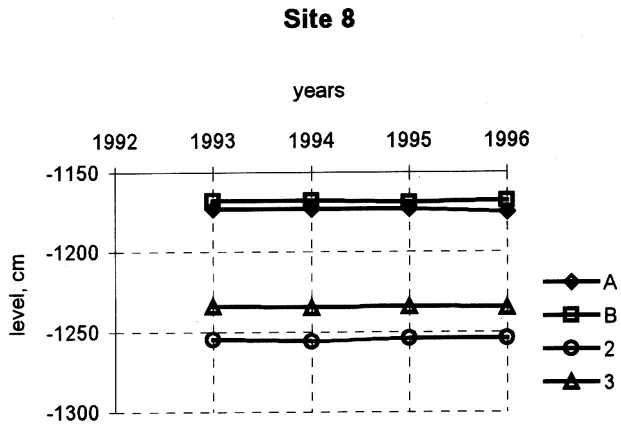

Figure 5. Surface subsidence of survey points within site 8.
A and B: forested inter-alas terrain; 2 and 3: centers of thaw depression.

observed permafrost temperatures in the undisturbed inter-alas area with the meadow vegetation type located near sites 2, 3, 3a, and 5 are shown on Figure 6.

In summary, during 1992-1996, the rate of surface settlement was up to 2-3 cm/a in disturbed interalas terrain with incipient subsidence polygons (no settlement was observed in controlled undisturbed interalas terrain); 1-3 cm/a in small, dry thermokarst depressions with a relative depth up to 0.5 m; 5-7 cm/a in thermokarst depressions with a depth of 2-2.5 cm and small ponds. Maximum subsidence, up to 30 cm/a, was observed adjacent to small thermokarst lakes. In dry thermokarst depressions, the rate of surface subsidence was high in 1992-1993, but slowed down during the last 2-3 years.

Incipient Thermokarst Lake Development

Filling in of thaw depressions is mainly dependent on the annual amount of precipitation. The latter parameter has been below the long-term norm in central Yakutia from the mid-1980's up to the present. Therefore, the above-mentioned rates of thaw subsidence should be considered as corresponding to intrasecular cycles with insufficient precipitation.

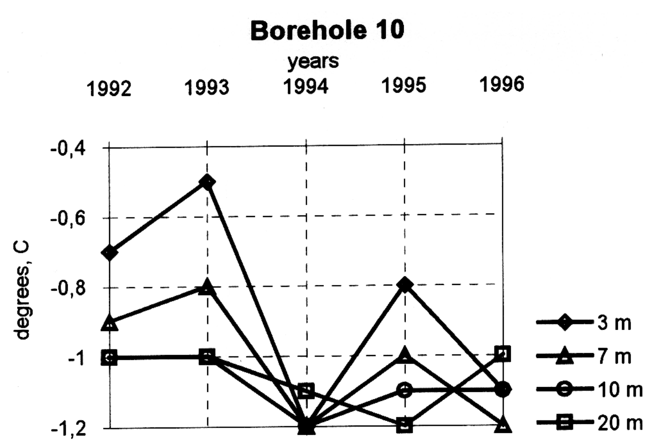

Figure 6. Variability of permafrost ground temperatures near sites 2, 3a and 5

To gain information on the dynamics of thermokarst formation in the study area during the past, the authors have analyzed the available aerial photos taken in 1946, 1954, 1971, 1987 and 1992. Unfortunately, a lack of photos prior to 1946 makes it impossible to assess the development of a thermokarst process during the first few years after disturbance. In addition, the small scale and unsatisfactory quality of most of the photos make it difficult to decipher some details of the studied phenomenon, in particular subsidence-polygonal microrelief and primary areal subsidence of small diameter.

Thermokarst lake B (site 7) is now full of water; the lake basin has clearly defined edges. In 1946, a thaw depression with small ponds at the edge of a ploughed field existed there; by 1954 it had changed into an incipient thermokarst lake; by 1971 it had deepened greatly to form a lake basin with clearly defined edges; between 1971-1995 the lake grew significantly in size.

Site 5 is at the border between a forest and a former ploughed field. A thaw depression with small ponds, which formed in 1946, existed unchanged for a long time. A 1987 photo evidences its transition into an incipient thermokarst lake. At present, the lake has not yet reached the stage of a lake basin with clearly defined edges, and occupies only part of the thaw depression bottom. Leveling surveys reveal significant surface subsidence, from 9 cm/a to 30 cm/a (maximum 55 cm/a) at the lakeside.

Sites 2 and 3, which are situated in the central part of an extensive abandoned ploughed field, were thaw depressions with small ponds in 1946. They remain at this stage now, although they have expanded considerably over the last 50 years.

Site 9, which existed as a primary thaw depression in 1946, remains unchanged after 50 years. Sites 8 and 11, which are situated in the forest, show no changes in their outlines from 1946 to 1995, remaining at the stage of primary thaw depression.

The duration of initial thermokarst stages at the Yukechi site can be determined, as the onset of human-induced disturbance is known (1931-1933). Within 15 years of the onset of anthropogenic disturbances, the areas of former ploughed fields where sites 2, 3, 5 and lake B (site 7) are situated, experienced the following stages: forest clearing, polygonal microrelief, primary thaw depression, thaw depression with small ponds.

The duration of the stage of thaw depression with small ponds was about 10 years in future lake B area (site 7), about 25 years in the site 5 area, whereas the areas of sites 2 and 3 still remain at this stage after about 50 years. The time since primary thaw subsidence in the vicinity of site 9 is at least 50 years, whereas that of primary thaw depressions in the forest (sites 8 and 11) may be well in excess of 50 years, because their origin has no relation to forest clearing. In the 1954 aerial photo, lake B appears as a small incipient thermokarst lake; in the 1971 photo, it is already a lake basin with clearly defined edges, i.e., the incipient lake stage lasted for less than 17 years. Here, the young thermokarst stages lasted for less than 40 years, from forest clearing to the thermokarst lake stage.

The youngest and most rapidly developing thermokarst forms are found at the borders of the forest and former ploughed field because these are at the base of local dips of the interalas surfaces, where surface and ground water accumulates due to significant differences in the depth of seasonal thaw beneath the forest and ploughed fields.

Ground Temperature of Recovered Areas

In the study area, the mean annual ground temperature at a depth of 15-20 m (-2.1°C) beneath undisturbed larch forest (130-150 year old), can be taken as a reference value. The greatest change of average annual ground temperature is found in these interalas terrain where forest communities have been completely replaced by meadow. The average ground temperature of meadow terrain between alasses in the study area is -1°C.

The ground temperature of a 25 year old larch forest (regeneration after clear-cutting) is -1.8°C, whereas that of a 50 year old larch forest (regeneration after fire) is -2.5°C. The difference in the ground temperature is due to the thick stand of trees in the after-fire forest. As the stand thins, cooling to the initial ground temperature takes place. For example, 80-90 year old forests regenerated after partial cutting have a ground temperature of -2°C.

The results obtained indicate that average annual ground temperatures of undisturbed larch forests increase during the first two or three decades after anthropogenic effects (cutting, fire) and then start to decrease with forest regeneration. With time, a short-term phase of minimum temperatures sets in that corresponds to a thick, short and medium stand of the trees. Then an increase to the initial (prior to anthropogenic effects) ground temperatures occurs as a normal, primary stand of the trees develops. A similar pattern was previously noted by the authors in the recovery successions with beech trees in the Umaibit location, 90 km southwest of Yakutsk, on left bank of the Lena River.

Conclusion

The data obtained on the rate of surface subsidence, the rate of evolution of thermokarst topography, change in ground temperature during forest regeneration provide a basis for monitoring the permafrost landscapes of central Yakutia in the coming decades. This is particularly important for solving problems that arise from a predicted global climate warming. Intensive thermokarst development can serve as an indication of the predicted warming and a guide to possible ways that modern permafrost landscapes may be transformed.