S. P. Kachurin *
Moscow

THERMOKARST WITHIN THE TERRITORY OF THE U.S.S.R.

Abstract

Thermokarst is a widespread natural phenomenon in permafrost regions; outside these areas there is no thermokarst.

The presence of ground-ice near the surface is necessary for the development of thermokarst. The main cause of its origin lies in changes of the heat exchange conditions in the upper layers of deposits, leading to the melting of the ground-ice.

Alterations in the heat exchange conditions within the layer of seasonal thermal fluctuations (i. e. in a layer up to 15—20 m depth) depend, in different geographical regions on many reasons, and not climatic changes alone.

Thermokarst is not a variety of karst, but an entirely independent natural phenomenon.

Different types of thermokarst formations correspond to different genetic types of ground-ice; nevertheless in many cases the forms produced are similar in appearance.

The process of thermokarst development is influenced by the geological structure, the facial differences of the deposits and the geomorphic conditions prevailing in any particular area.

The similarity of thermokarst settling features causes difficulties in ascertaining the genesis of the individual forms as well as in their classification. Thus, in studying the thermokarst phenomenon it is necessary to apply various methods of both field and laboratory investigations.

Like many other geologo-geographical phenomena thermokarst is usually zonal.

On the basis on data derived from the literature three main zones of thermokarst development may be roughly distinguished in the territory of the USSR, though no clear boundary can be drawn between these zones.

The history of thermokarst development is closely related to the aggradation of permafrost during the Quaternary period and, in a still larger measure, to the process of its degradation.

The historical period of the increasing influence of human activities upon the natural conditions of the environment is especially significant and promotes a further development of the phenomenon.

Thermokarst affects, in its turn, the economical and industrial activities of men thereby compelling us to undertake appropriate measures in order to control the disastrous effects of this phenomenon.

Thermokarst is a characteristic and widespread natural phenomenon peculiar to various regions of permafrost areas. Outside these regions, thermokarst does not develop, although traces of it are found in the form of hilly-sink relief, saucer-like depressions, and specific lacustrine topography.

A necessary condition for the development of thermokarst is the presence of subterranean (fossil) ice in the upper layers of perennially frozen grounds. The larger the quantity of subterranean ice, the more are the thermokarst forms extensively developed.

Changes in the thermal regime of the soil and the underlying rocks

* Institute of Permafrost Studies V. A. Obruchev, Moscow.

accompanied by high temperatures are the chief reason for the development of thermokarst. This induces to melting of frozen rocks and ice. Changes in the heat exchange between the soil and the atmosphere as well as between the soil and the underlying rocks in a layer with seasonal temperature variations (down to 15—20 m) in different geographical regions depend upon many causes and are not always connected with climatic changes. Numerous cases are known of thermokarst developing in an unchanging climate.

Thermokarst is not a variety of karst and, genetically, it totally differs from the latter and represents an absolutely independent specific phenomenon of nature. It should be recalled that underlying the development of karst, is a chemical process — the dissolution and leaching of solid rocks like limestone, dolomites, and gypsum, which process occurs under any climatic conditions, but is most widespread in regions with a warm and humid climate. Underlying the development of thermokarst is a physical (thermal) process — the melting of subterranean ice inducing subsequent subsidence of the overlying layers of soil and loose rocks. This phenomenon is peculiar to regions with a cold climate.

Thermokarst relief forms are outwardly similar to karst forms. They depend upon a number of conditions, among which the most important are the forms of ice insertion within the frozen rocks. Different types of thermokarst formations correspond to different genetic types of subterranean ice and to the forms of its insertion and occurrence during thawing. It often happens that similar sagging relief forms arise during the melting of genetically different ice. This complicates a determination of the genesis of various forms of thermokarst formations. In field studies of thermokarst, a whole range of methods has to be applied, among which especially an analysis of the texture of the frozen rocks and the ice formations. In these investigations, much attention should be devoted to geological, physico-geographical and geophysical conditions.

Thermokarst development should be most intense under the following natural conditions: (1) in connection with rises in the mean annual temperature of the soil; (2) in connection with an increased amplitude of temperature. A combination of these processes leads to a maximum growth in the depth of the seasonally thawed layer (see fig. 1).

Thermokarst development is highly dependent on the geological structure, the facies composition of the rocks in which it occurs, the degree to which they are saturated with ice, the local topography, the soil and vegetative covers, the conditions of snow accumulation, the drainage of surface waters, and other conditions. In some cases, the development of thermokarst is greatly influenced by human activities, for example,

by the ploughing up of virgin lands, and by the felling of trees, by forest fires, by the building of different constructions, particularly with heat--generating plants, by the digging of ditches, and such like. Under the influence of human activities, the development of this process may proceed very intensively, even at a catastrophic rate.

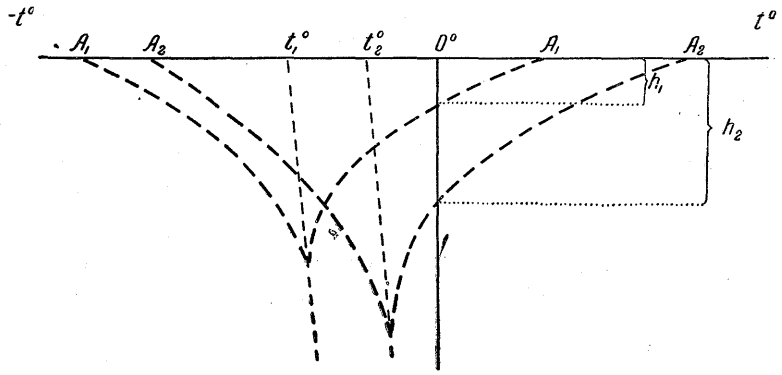

Fig. 1. Interrelationship between variations in the mean annual temperature ($t°_1$ and $t°_2$), the temperature amplitude (A_1 and A_2) and the depth of soil thawing (h_1 and h_2); the latter quantity increases with rising mean annual temperature and temperature amplitude

The production of thermokarst can result from a definite relationship between the depth of occurrence of ice and the depth of seasonal thawing of the soil and rocks. Subterranean ice begins to thaw when these depths are equal; this is followed by a sagging of the soil layer and the subsequent development of thermokarst forms.

One must also be aware of the fact that, depending upon the grain-size composition of the rocks, as well as the salt and mineral composition of the water, water percolation from thawing layers passes first through frozen layers with a slight negative temperature (for instance, Jurassic clays at minus 0,3° C). A contributive factor is the existence of unfrozen water deep within perennially frozen rocks, the quantity of the water depending upon a number of conditions.

The development of thermokarst relief forms takes place within definite limits. Interruption or stabilization of the process sets in under the following conditions: (a) total thawing of the subterranean ice; (b) drying up of a basin of thermokarst origin before all the ice has melted; (c) filling in of a depression with loose rocks.

In all such cases, the conditions of heat exchange in the rocks undergo a change.

On the basis of an analysis of extensive material obtained by different investigators in various regions of permafrost, a rough classification of thermokarst forms has been outlined. The basic principle of classification is a genetic principle, based on the study of types of subterranean ice together with combination of other elements of the geologico-geographical environment, upon which the development of thermokarst depends.

Notwithstanding the diversity of types of recent forms of thermokarst formations, it appears possible to distinguish two principal categories of forms: (a) thermokarst forms in the proper sense, and (b) thermokarst forms of mixed origin.

Each of these categories is subdivided into a number of types of thermokarst formations in accordance with the types of subterranean ice and other conditions. For the first category, the type of ice formation is of basic importance, while all the other conditions only contribute to the development of the process and to some of its particulars. As regards the second category of forms — though it also depends on the types of ice insertions — of great and equal importance in their development are other processes, under the influence of which thermokarst develops, such as solifluction, suffusion, erosion, karst and others.

The first category includes the following forms of thermokarst: polygons, which arise at the site of thawing of repeated ice veins; it shows the following varieties: polygonal-grid, polygonal-cell, merged polygons; flat-bottom sink types in areas with vein- and other segregation ice; hilly--sink types that develop in areas with ice of injection and infiltration origin; hollow types that form during the melting of covered (ancient-glacial or recent) ice; subterranean cavities left by thawing ice of different origin; and, finally, forms of thermoplanation, thermo-abrasion, and thermo--erosion that develop during thawing of grounds of different genesis.

The second category includes several form types: thermokarst-solifluction types that develop on rocks with a high content of dispersed ice that easily move upon thawing; thermokarst-suffusion types appearing in areas with ice-containing grounds underlain by rocks that readily percolate and leach (for example, loessial); thermokarst-erosion types that form in areas with readily eroding ice-containing rocks; and, finally, thermokarst-karst types that are developed on areas of ice-containing rocks overlying rocks subjected to the process of karst formation.

The qualifying term *thermokarst* indicates that all these types develop under the process of thawing of subterranean ice in rocks of different origin.

To each of these form types corresponds a set of conditions, the combination of which determines the various forms of thermokarst formations.

This classification of thermokarst forms does not, of course, exhaust all the possible types of such forms. Their number will probably increase with the advance of studies: but the major ones can be regarded having been taken into consideration.

Despite the comparatively great diversity of thermokarst forms and their varied-territorial distribution, it seems possible (as a first approximation) to divide the area of permafrost into thermokarst zones. The author regards as its most outstanding feature the genetic type of thermokarst formation, whose extent is determined by that of the types of subterranean ice. The second characteristic of zonation is the predominant trend of the process in the frozen rocks under present climatic conditions: either moderation (degradation) of the severity of the thermal regime of the rocks, a stable condition, or increase of the severity of the regime.

On the basis of these principal features, the region of permafrost may be divided into three independent zones whose boundaries, however, are not clearly defined. Arbitrarily, these zones may be designated as: southern, middle and northern.

The southern zone is located along the southern boundary of the permafrost region and is distinguished by a highly unstable thermal regime of the upper rock layers, by signs of degradation of the perennially frozen rocks and by extensive thermokarst of nearly all types, with the exception of polygonal forms (which occur here as relict forms). Here, the development of thermokarst takes place under conditions of interrupted heat exchange in the soil.

The northern zone, which is located along the northern shoreline of Eurasia, is characterized by a stable rigorous thermal regime of the rocks, the absence of signs of large-scale degradation of the frozen grounds, and at the same time by a very intensive spread of thermokarst formations at the expense of the thawing of vein and other ice segregations. The development of thermokarst is here mainly due to the influence of severe disturbances of the open surface frost-cracks, to solifluction, and other processes, including the effects of stationary masses of surface water. This is a paradoxical situation for thermokarst develops intensively in a rigorous climate and in the absence of degradation of frozen ground. This fact finds its explanation in the large-scale extent of subsurface ice, by the abundance of surface water and excessive humidity of the soil.

The third (middle) zone is intermediate and characterized by mixed conditions in the development of layers of frozen rocks and ice, and, accordingly, by a mixed composition of forms of thermokarst formations, in part peculiar to the northern zone, and, in part, to the southern one.

Within these zones are regions and sub-regions with similar principal

features of thermokarst development but with different supplementary features and details.

The history of the development of thermokarst in the present-day permafrost region is, to a great extent, connected with the conditions of the post-glacial period. The beginning of thawing of subterranean ice and the large-scale development of thermokarst coincides with the beginning of a warmer climate in the Atlantic period, under the influence of which thermokarst development extended throughout the entire region of permanently frozen rocks. During the sub-Atlantic period (in Europe) occurred a slight cooling that inhibited the development of thermokarst. During the present period appeared a new wave of warm climate, under the effects of which thermokarst development is greatly expanding mainly in the southern zone. Human activities also contribute to the development of thermokarst.

Thermokarst exercises a very great influence on the activities of man. It is quite clear that the widespread development of thermokarst hampers human activities. In many cases, it complicates the construction of buildings, roads and various other enterprises. No less is its influence on the development of agriculture. It therefore becomes necessary to work out special measures to inhibit the development of thermokarst under any conditions. Thermokarst is associated by a range of various other processes which in turn depend on numerous conditions of general and local importance. The study of this phenomenon and its associated processes is important from both the theoretical and the practical view-point; therefore, it may constitute a special problem for a multi-purpose study of northern countries. Only the participation of a large number of investigators of various profiles can give a profound explanation of the development of this natural phenomenon under diverse conditions, and, thereby contribute to a better solution of the problems connected with effects on human activities.

References cited

Baranov, I. Y. 1958 — Reliktovyj termokarst v Predbaikale (Relict thermokarst in the Antibaikal region). *Materialy k osnovam ucheniya o merzlykh zonakh zemnoj kory*, vyp. 4, Moskva.

Black, R. F. 1954 — Permafrost — a review. *Bull. Geol. Soc. Amer.*, vol. 65.

Black, R. F., Barksdale, W. L. 1949 — Oriented lakes of northern Alaska. *Jour. Geol.*, vol. 57.

Bunge, A. 1884 — Naturhistorische Beobachtungen und Fahrten im Lena Delta. Aus Briefen an den Akad. L. v. Schrenk. *Bull. Akad. imp. Sci. St-Pétersbourg*, t. 29.

Ermolaev, M. M. 1932 — Geologicheskij i geomorfologicheskij ocherk ostrova B. Lyakhovskogo, v. kn. Polyarnaya geofizicheskaya stanciya na ostrovie B. Lyakhovskom (summary: Geological and morphological sketch of the Bolshoy Liakhovski Island). *Trudy Sovieta po izucheniyou proizvodit. sil.*, ser. Yakutskaya, vyp. 8.

Gallwitz, G. 1949 — Eiskeile und glaziale Sedimentation. Berlin.

Grigoriev, A. A. 1956 — Subarktika (Subarctic). Moskva.

Gusev, A. I. 1938 — Tetragonalnye grunty v arkticheskoj tundre (Tetragonal polygons in the arctic tundra). *Izv. Gosudarstv. Geogr. Obshchestva*, t. 70. Leningrad.

Hopkins, D. M. 1949 — Thaw lakes and thaw sinks in the Imuruk Lake area, Seward Peninsula, Alaska. *Jour. Geol.*, vol. 57.

Jong, W. J. 1960 — Thermokarst en kryokarst als pseudokarst-verschijnsch. *Geogr. Tijdschrift*, Jhg. 13.

Kachurin, S. P. 1959a — Termokarst v predelakh SSSR (Thermokarst within the territory of the U.S.S.R.). *Materialy po obshchemu merzlotovedeniyou VII Mejduvedomstvennogo Soveshchaniya po merzlotovedeniyou 1956*, Moskva.

Kachurin, S. P. 1959b — Kriogennye fiziko-geologicheskije yavleniya v rajonakh s mnogoletnemerzlymi porodami, in: Osnovy geokriologii, merzlotovedeniya (Cryogenic phenomena in the permafrost area). Moskva.

Kudryavcev, V. A. 1958 — O termokarste (On the thermokarst). *Voprosy fiz. geogr. Polyarnykh stran*, vyp. 1, Moskva.

Leffingwell, K. 1919 — The Canning River region, northern Alaska. *U. S. Geol. Survey, Prof. Paper*, no 109.

Popov, A. I. 1955 — Proiskhojdenie i razvitie moshchnogo iskopaemogo lda (Origin and development of thick fossil ice). *Materialy k osnovam ucheniya o merzlykh zonakh zemnoj kory*, vyp. 2.

Popov, A. I. 1956 — Le thermokarst. *Biuletyn Peryglacjalny*, nr 4.

Soergel, W. 1936 — Diluviale Eiskeile. *Ztschr. d. Deutsch. Geol. Ges.*, Bd. 88.

Steche, H. 1933 — Beiträge zur Frage der Strukturböden. *Bericht Verh. Sächs. Akad. Wiss. Leipzig*, Math.-Phys. Kl., Bd. 85.

Washburn, A. L. 1956 — Classification of patterned ground and review of suggested origins. *Bull. Geol. Soc. Amer.*, vol. 67.

Pl. 1. Powerful ice veins above forty metres long in the bank of the river in the north of Siberia