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Taphonomic research in permafrost regions: a survey of past and present studies in the former Soviet Union

Vereshchagin, N.K. & S.V. Tomirdiaro, S.V., 1999 - Taphonomic research in permafrost regions: a survey of past and present studies in the former Soviet Union – in: Haynes, G., Klimowicz, J. & Reumer, J.W.F. (eds.) – MAMMOTHS AND THE MAMMOTH FAUNA: STUDIES OF AN EXTINCT ECOSYSTEM – DEINSEA 6: 187-198 [ISSN 0923-9308]. Published 17 May 1999.

Russian scientists have proposed critical explanations and mechanisms for the unique preservation of Pleistocene mammal remains (bones and particularly their soft tissues) in the permafrost of northeastern Siberia during Würm-Valdai-Wisconsin. The nineteenth century ideas concerning underground ice in the permafrost of Siberia and buried glaciers were refuted completely by the middle of the twentieth century. Instead a hypothesis was developed for syngenetic and epigenetic formation of underground ice veins. Extreme physical (ecological) processes in the permafrost created unique taphonomic responses, because the conditions of death of the animals and the burial of faunal remains were sharply different from those in other landscapes of the Northern Hemisphere. Recent taphonomic views of paleofaunal researchers regarding concrete events and the causes of death of animals and the preservation of their remains in the Quaternary permafrost of 'Arctida' and the Arctic as a whole are considered.

Taphonomisch onderzoek in gebieden met permafrost: een overzicht over het onderzoek in de voormalige Sovjet Unie – Russische wetenschappers hebben voorstellen gedaan om te komen tot een verklaring van de bijzondere conservering van Pleistocene zoogdierresten (botten en zacht weefselmateriaal) in de permafrost van noordoostelijk Siberië tijdens de laatste ijstijd. De oorspronkelijke 19e eeuwse gedachten over ondergronds ijs en begraven gletschers waren halverwege de 20e eeuw achterhaald. Een hypothese over de vorming van ijs'aders' kwam ervoor in de plaats. Extreme fysische processen in de permafrost leidden tot eigen taphonomische processen, omdat de omstandigheden rond de dood van de dieren en de stoffelijke resten sterk verschilden van de omstandigheden in andere streken van het noordelijk halfrond. Nieuwe taphonomische inzichten over concrete gebeurtenissen, de doodsoorzaken van de dieren, en de bewaaromstandigheden van hun resten in de noordelijke streken met (Kwartaire) permafrost worden in dit artikel besproken.

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Keywords: taphonomy, Pleistocene, permafrost, mammoth fauna

INTRODUCTION

Complete and fragmentary carcasses, abundant bones of strange animals, particularly of mammoth, rhinoceros, and bison, found in the permafrost region of Siberia, have always aroused the interest of indigenous people as well as of scholars and travelers from around the world. Laymen and experts from early times attempted to provide explanations for those discoveries, that is to gain an insight into fossil animal paleoecology and permafrost taphonomy, but they had no basic knowledge in these fields. Their naive interpretations, frequently criticized, have now become a part of the history of science. In reality the taphonomy of the permafrost is extremely complicated and unique; it differs greatly from that of other landscapes. A stratigrapher examining organic material (be it a carcass, bone, beetle, or pollen grain) that seems to provide unequivocal dating of the layer, horizon, or formation may arrive at erroneous conclusions unless a taphonomic assessment can be made of the *in situ* status of the sample. After burial in the permafrost the organic remains could have shifted vertically within a wide range owing to their physical properties and the features of the permafrost environment. Thus, for instance, the carcass of a mammoth that had fallen into an 'ice well' at a depth of 10-20 m cannot be used for dating the layer or horizon in which it was discovered, however thoroughly we study the geological age of the animal or its skin, flesh, bone, or food remains in its stomach and intestine. It is now known that in frozen ground bones and pieces of wood are sometimes shifted vertically (!) by 10-15 m along the boundary of the frozen ground and ice veins. A reasonable explanation of the causes and patterns of formation of the 'cemeteries' and discovery of fossil remains of animals in the permafrost zone became possible owing to a thorough study of: (1) the physical (paleoecological) environments in this particular zone in the Pleistocene; (2) the biology and ecology of animal species and the types of their death; and (3) the conditions and time of burial of the carcasses and skeletons in the sediments studied. Knowledge in this area was accumulated over the past fifty years as a result of long-term and devoted research conducted by a number of scientific teams in the former Soviet Union - specialists in permafrost study, paleogeography, stratigraphy, and paleontology. Owing to these taphonomic studies of the permafrost zone it has now become possible to obtain more accurate stratigraphic data for Quaternary deposits in northeastern Siberia. This makes the search for new fossil samples of animal carcasses more promising. Taphonomy, a branch of ecology first developed by Dr. I.A. Efremov (1950), has acquired a new energy and substance.

THE HISTORY OF RESEARCH

We begin with a brief historical review of the evolution of taphonomic ideas proposed by Arctic researchers studying mammal remains in frozen grounds. The first unique taphonomic ideas were developed by Arctic travellers as early as the nineteenth century. Quite remarkable were the ideas of the Russian Academician Middendorf (1869) who described thick layers of burials, 'cemeteries' of tree trunks, whale carcasses, carcasses of pinnipeds and fishes in the muddy shallow coastal areas of the Sea of Okhotsk and in giant logjams in the rivers of the Taimir peninsula. The fossil-specimen-collectors Bunge (1895), paleozoologist Chersky (1891), Maidel (1894) and Toll (1897) traveled through the north of Yakutia and tried to explain the remains of fossil animals in ice covered grounds. Already at that time it was evident to these scientists that mammoths had inhabited the areas where their carcasses were discovered, since the long lasting preservation of their soft tissues would not have been possible without permafrost and a fast freezing of the soft tissues.

In the beginning of the twentieth century the first protocol records appeared concerning the excavations of the Berezovka mammoth. The authors of the excavations, Herz (1902) and Pfizenmayer (1926), conjectured that the death and burial of this mammoth could have occurred in the ice crevice where the animal fell and broke its pelvic bones. After excavating mammoths, the geologist Vollosovich (1909, 1914) became convinced that in one case an old female mammoth was bogged and died on the muddy edge of the Sanga Yuryakh River, where it was covered by deposits, whereas the adult male of the Liakhovski Island died under a soliflux landslide that fell from the hill situated close to it. The geologist Ermolaev (1932) described in the monograph of the Liakhovski Island the facies of thermokarst lake bottoms permanently containing abundant remains of the mammoth fauna. Ermolaev believed this

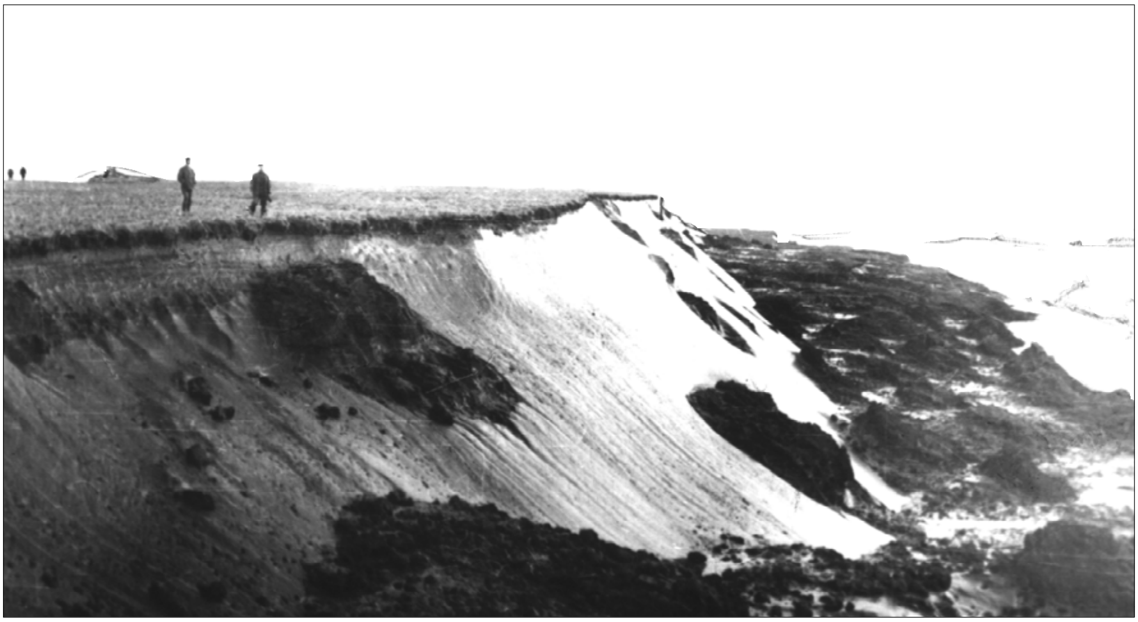

Figure 1 Precipice of the shore of the Dmitrii Laptev Strait. Visible are exposures of ice veins; walls of underground ice and oblique sections of ground columns (pressed by ice) containing mammal bones. [Photograph: S.V. Tomirdiaro, 1980]

to be the result of washing and redeposition of the primary *in situ* burials of bone remains in slopewash diluvium and lake-river and eolian deposits of the Arctic land. Similar information on facies and stratigraphy was published later by Kaialainen & Kulikov (1965) who studied the Yana and Indigirka lowland of Yakutia. In the 1940's to 1950's a stimulus for taphonomic ideas appeared as a result of new ideas about theories of permafrost, stratigraphic studies of ice thickness, the development of the radiocarbon method and geochronology, and new discoveries of carcasses and skeletons of fossil animals. The geologist Gusev (1956) described the 'mammoth horizon' in the upper part of the Quaternary system of Siberia containing numerous remains of the mammoth fauna. He also described unusual traps for mammoths in gullies of subsoil ice, ice veins, and underground ice in general, where mammoth carcasses were preserved for millennia in the form of complete frozen carcasses. It appears that the Adams mammoth (found 1799) had fallen in such a trap - a sinkhole, common on the Bykovsky Peninsula plateau east of the Lena River mouth. This also may have been the case with the mammoth on the bank of the Alazeya River that was noted in the diary of lieutenant Sarychev (1952), travelling in 1787. More new discoveries will probably be made of complete carcasses of different animals in areas of such sinkholes and gullies. The expedition to the Taimir Peninsula established that the Taimir mammoth discovered by geologists in 1947 initially lay in the permafrost of the 2nd terrace, from where it had fallen and was later discovered in the 1st terrace (Popov 1950, Portenko *et al.* 1951). In his other publication about the site, the geologist Popov (1953) noted that the carcasses of mammoths that died in the alluvial plains of Siberia had a small chance to be partly preserved lying on their side in ground pressed on the margins of permafrost areas in the Baijekhar relief (i.e. relief formed as a result of melting of ice veins by apices of 'ground columns'). Discussion with Grigoriev concerning the mammoth 'cemetery' on the Berelekh River in Yakutia led to a study of this phenomenon conducted by Vereshchagin, although 20 years later.

Studying the site of discovery of the Berezovka mammoth, the geologist Biske (1959) actually substantiated the view of Tolmachov (1929) that the animal had fallen from the cliff and was buried in a landslide of the bank in a block of ground. In this case one essential taphonomic detail was not explained: whether the break of the pelvis occurred during the animal's lifetime or after its death. If it had occurred during its lifetime the entire pelvic area would have appeared as an internal bruise. However, this is not indicated in the records of the excavation. It is worthy of note that the scientific development of a taphonomic typology of burials (locations) of large mammals in the permafrost is complicated owing to the rigorous ecological conditions of the Late Pleistocene of northeastern Asia. Usage of the actualistic principle and method, favored by paleontologists (in other words, the drawing of analogies between the burial of animals in the permafrost during the Pleistocene and during the present time) is therefore not always justified. The same reason excludes the possibility of taphonomic experiments. An explicitly actualistic approach is suitable only for interglacials, but not for glaciation epochs.

PERMAFROST FORMATION AND ITS IMPLICATIONS FOR TAPHONOMY

An elaboration of the bases of permafrost taphonomy was favoured by the geological and paleogeographical studies of the scientific institutions of St. Petersburg, Moscow, Novosibirsk, Yakutsk, and Magadan. In the 1940's and 1950's the ideas of the last century concerning underground ice in northeastern Siberia and buried glaciers were refuted completely. A hypothesis of syngenetic and epigenetic formation of ice veins was proposed. Velichko (1973, 1981a,b) offered a substantial characterization of natural processes in the Pleistocene. Velichko followed the consequences of permafrost processes in Quaternary rocks (primarily in loesses) occurring over the vast areas of northern Eurasia and elaborated the idea of the existence of a permafrost hyperzone in the Late Pleistocene extending from the eastern Atlantic up to the western Pacific. Apart from collecting valuable paleontological samples in the north of Siberia (usually identified by Vereshchagin), the geologists Miroshnikov, Kiselev, Biske, Troitsky (Troitsky 1966), Volkov, Vaskovsky, Arkhipov, Lavrushin, Romanovsky (Romanovskii 1961, Sadovskii 1961), and many others published valuable works showing stratotypical sections - exposures, notable for their unusual permafrost 'benchmarks'. About 30 such 'benchmarks' are now known for the north of Yakutia and the Magadan Region. In the 1960's and 1970's paleozoological and biostratigraphic studies in northeastern Siberia were conducted by Vangengeim (1961, 1976) and Sher (1971) under the guidance of Gromov (1948), the dean of Quaternary studies. Taphonomic interpretations can be found in the works by Sher, who discovered an early Pleistocene mammal fauna in the Krestovka River, a tributary of the Kolyma River. Recovered in marshy loamy soil of that area were remains of archaic predators, as well as beaver, *Trogontherium*, wide-fronted elk, *Soergelia*, and muskox. One should note the work by David Hopkins and John Matthews (Hopkins *et al.* 1982) on the huge fluctuations in the late Pleistocene level of the world's oceans and climate and their effect on the plant and animal world of northeastern Siberia and Alaska. This became an impetus for the development and refining of stratigraphic and taphonomic ideas concerning the permafrost of northern Siberia. Layers and horizons were denoted as formations using local Siberian terminology, separately for the Yana-Indigirka and Kolyma-Anui lowlands. Of particular interest for paleozoologists is the 'edoma' [pronounced yeh-do-mah] formation (ground affected by differential erosion). This is actually a loess layer, as a rule containing the largest amount of remains of Late Pleistocene animals. It is now divided by Tomirdiaro & Chernenky (1987) into three horizons: Zyryanian (Q 2 III), Karginian (Q 3 III), and Sartanian (Q 4 III).

Regarding Central Yakutia and the Aldan lowlands, a detailed characterization of the exposures in a number of the Aldan River terraces was published by Rusanov (1968). Burial of bone and plant remains has occurred there since the Pliocene in the terraces of lacustrine-riverine and riverine sands, pebbles, moraines, loesses, and in Holocene sandy loams and loamy soils. Fragments of animal bones, horns, and teeth scattered in the layer were described by Rusanov. These were parts of skeletons and teeth that were washed many times and redeposited in the river bed and beach facies of ancient currents in waterbodies of a different type. A remarkable taphonomic discovery of Rusanov was the fossil beaver dam buried in the thickness of brown loess of the Aldan River 50 m terrace. Wood of poplar tree, willow, and larch from this 'dam' dated to 12,000 yBP, indicating powerful rearrangements in the hydronet and relief of the region during the Holocene. The find also provided new evidence about the ecology of the beaver, especially the remarkable flexibility of the animal inhabiting rigorous conditions of waterbodies among frozen grounds.

The specialist in the permafrost of the Magadan Region, Tomirdiaro (1972, 1978, 1980, 1996; Tomirdiaro & Chernenkii 1987), described in a series of books the peculiarities of permafrost processes during the for-

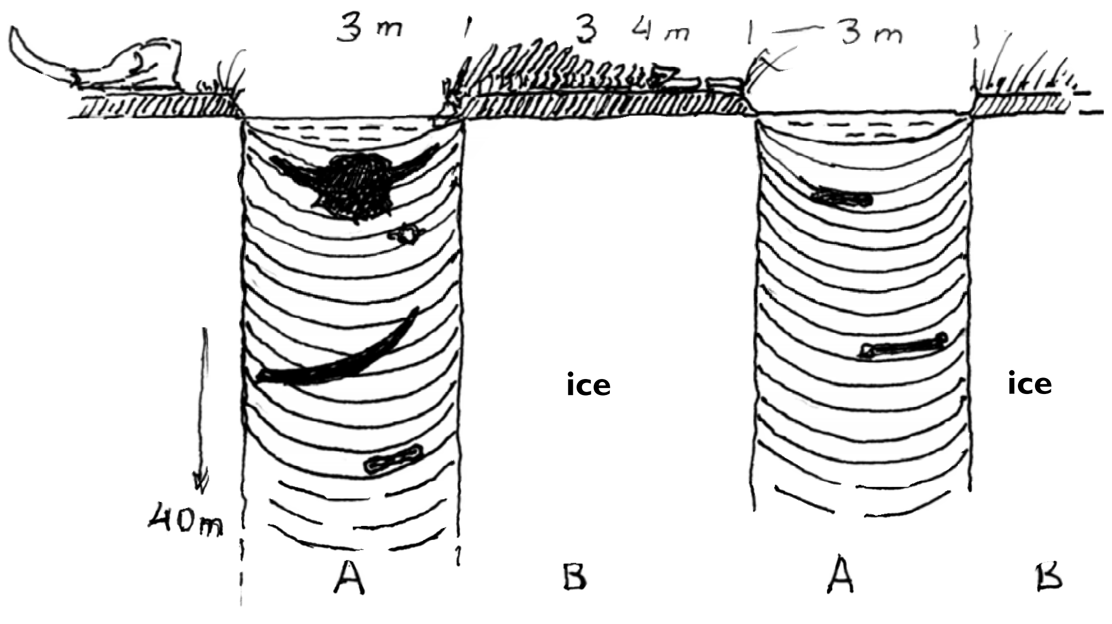

Figure 2 Vertical section of relict permafrost layer of Siberian Arctida in the north of Yakutia. The permafrost layer was to a large extent eroded by the sea in the Holocene. Accumulation and growth of the ground columns (A) occurred in the Pleistocene owing to fall-out of eolian dust. At the same time ice veins - ice walls (B) were growing as a result of water flowing into the winter clefts of permafrost polygons and condensation of hoar-frost in them. Bones and skeletons of dead animals of the Pleistocene were 'caught' into these tiny lakes and conserved in the under lake deposits with their subsequent freezing.

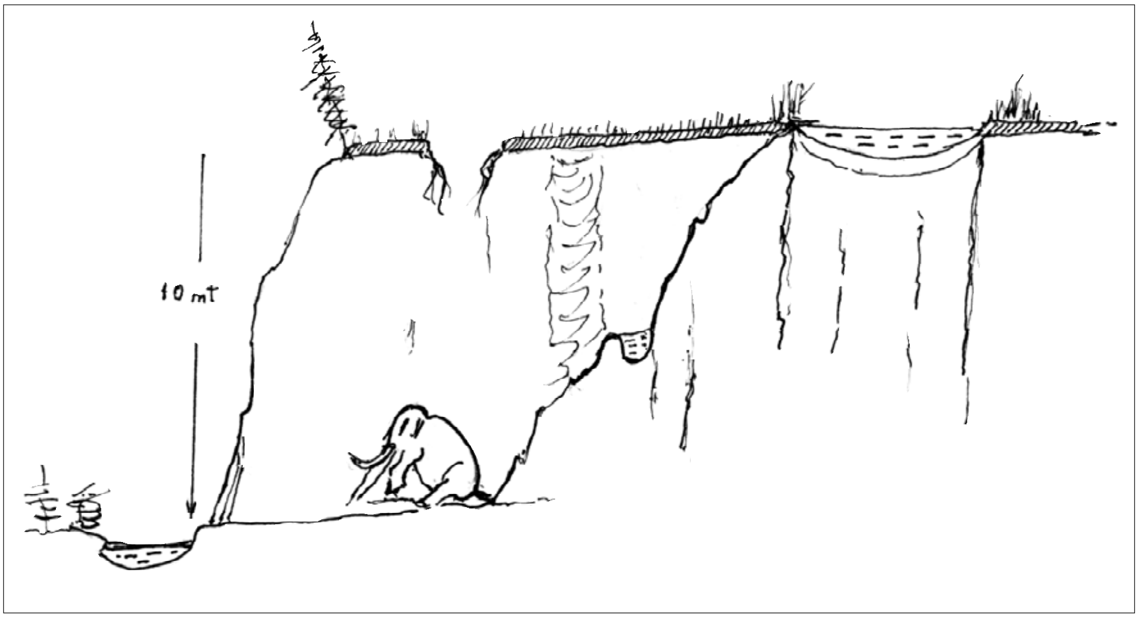

Figure 3 Vertical section of the permafrost layer in northern Yakutia in the areas of formation of natural traps on the pathways of large animals. Gullies, crevices, and sinkholes are formed in the permafrost owing to the streams beneath the turf layer.

mation and evolution of the permafrosts of Northern Yakutia. He established the leading role of an eolian factor in the formation of the loesses of Yakutia, particularly in the Sartanian epoch (Q 3 III) and discovered a specific loess-ice formation that was a part of the ice-covered subcontinent called Arctida, adjacent to Beringia. In the Late Pleistocene Arctida occupied up to one fifth of the recent Arctic Basin and was eroded by the Ocean almost completely in the Holocene. Tomirdiaro believes that the major portion of scattered bone remains of mammals were buried in the Zyryanian epoch (Q 2 III) in small thermo-karst lakes and in their bottom melted areas, and later became a part of the frozen layers of ground 'columns' pressed between ice veins (Figs. 1 & 2). Stratigraphic schemes of this researcher provide potentially productive sources for taphonomic conjectures. New discoveries of frozen carcasses of horse, bison, rhinoceros, and adult and juvenile mammoth during the 1960's through 1980's were a stimulus to the taphonomic studies and understanding of physical processes. These discoveries were published, and a part of them jointly with American scientists (see, for example, Vereshchagin & Mikhelson 1981). The Yakutian paleontologist and geographer Peter Lazarev (1980) published a brief taphonomic review of the discoveries of localities of carcasses and skeletons of mammoth, rhinoceros, horse, and bison, based on materials of the last few decades. He assumed that there existed chronological stages of formation of burials: from 50,000 to 30,000 years ago and from 12,000 to 10,000 years ago, apparently considering epochs of warming and strengthening of erosion in the Karginian and Early Holocene time. Lazarev separated several death types of animals and their burial in Yakutia: (1) deaths of large animals in thermokarst traps such as sinkholes (Fig. 3); (2) bones in mud flow coming out of thermokarst sinkholes; (3) bones in marshy ground or flowing sand, forming on lakes covered by moss; and (4) burial of separate bones in loess deposits on slopes and on river bottoms.

Vereshchagin and colleagues (Vereshchagin 1961, 1971, 1972, 1974, 1975, 1977a,b, 1981, 1982, 1988; Vereshchagin & Baryshnikov 1982, 1984; Vereshchagin & Nikolaev 1982; Vereshchagin & Ukraintseva 1985) published a series of works on the study of the Berelekh 'mammoth cemetery'. Geological sections and geological dates were discussed. The important role of water in the mass death of animals and in the formation of large burials is noted. There is a considerable similarity in the age structure of the mammoths in Berelekh and the Desna palaeolithic sites of the Russian Plain. Two cycles in the death of mammoth and their burials are noted: 45,000-35,000, and 13,000-9,000 years ago, which could have been associated with the warming periods and erosion cycles. Types of death and formation of burials of mammoths are shown in illustrations in the journals 'Polar Record' and 'Smithsonian', and became available widely in the world literature. It was shown with reference to the study of the Berelekh 'mammoth cemetery' that the typical mass death of migrating herds of mammoths occurred during passages over fragile ice of waterbodies (particularly rivers and lakes; Fig. 4). The importance of this factor for the species that gradually became extinct in the end of the Pleistocene and beginning of the Holocene was noted. Bones and tusks of mammoths buried in different grounds acquired specific colouration and quality. For example, a tusk from frozen loess is usually coloured by the azovskit mineral in an alkaline environment; the same tusk is of natural colour from a neutral environment; whereas a tusk from marshy peat deposits is blue from vivianite in an acid environment.

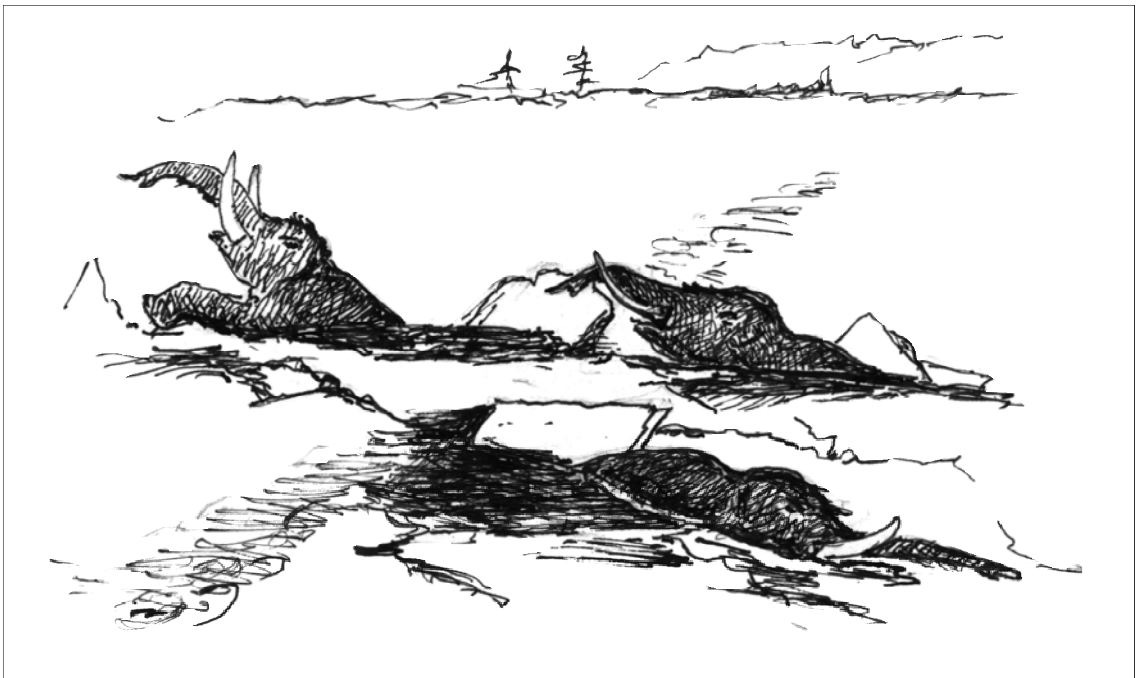

Figure 4 Death of mammoths in spring and autumn was common in the Pleistocene when the animals passed over the fragile ice of lakes and rivers. Carcasses of drowned animals were accumulated and carried by the current into bays and creeks, former river beds where they settled forming mass 'cemeteries'. [drawing by N.K.Vereshchagin]

Table 1 Types of taphonomic traps and formation of burials in the landscapes of mammoth meadow steppe and tundra steppe.

Burial Areas (tapholoci) and traps	**DEATH FACTORS**				
	Biological			**Physical**	
	Ageing	*Predators & Diseases*	*Hunting by Primitive Man*	*Weather: Snow Storms, Thaws*	*Floods: other consequences of climatic change*
Glacial Periods - Zyryanian & Sartanian Time (WI - WII)					
1. Newly formed thermokarst lakes	+	+	–	+	+
2. River beds & river banks	+	+	–	+	+
Interglacials and the Holocene					
2. River beds & river banks	+	+	+	+	+
2. Oxbow lakes in river flood plains & valleys	+	+	+	+	+
1. Thermokarst lakes	+	+	–	+	+
3. Gullies & sinkholes in walls formed by ice veins	+	–	–	+	–
3. Landslides (solifluxes) & mud flows	+	–	–	+	+
3. Peat bogs, flowing sand & flowing peat	+	+	+	+	+
1. Deluvium of slopes	+	+	+	+	+

1. Dispersed bones and bone fragments.
2. Mass "cemetaries" (skeletons, parts of carcasses, separate bones).
3. Complete carcasses and skeletons.

Probability of discovery of faunistic remains by modern man is not shown; it depends on many factors of secondary importance

Our series of slides and films on the study of fossil mammal localities in the permafrost of Siberia were demonstrated many times at international conferences on archeozoology in Moscow, Tallinn, London, Osaka, Washington, Springfield (Illinois) in the 1970's through 1990's. Our studies and views are summarized in the conclusive table of types of burials in tapholoci and specific biophysical locations of bone and other remains in the permafrost (Table 1).

CONCLUSIONS

In the middle of the twentieth century a rational interpretation was provided for the enigmatic phenomenon of the Arctic zone, i.e. the concentrated mass and dispersed 'cemeteries' of bones and complete skeletons and carcasses of Pleistocene mammals. This became possible owing to the study of frozen grounds, underground ice veins, and paleoecology of species of mammoth fauna. During the Late Pleistocene the mammoth fauna lived under the extreme ecological conditions of the permafrost zone, which determined the unique nature of the taphonomic events, the death and burial of animal remains in the sediments. The majority of the individuals whose remains were buried in the Arctic area died as a result of ageing and natural elimination of the population during migrations (drowning at the time of passing over the fragile ice of rivers and lakes, or in mud flows and peculiar ice traps: ravines and wells in the frozen ground). These processes (see Table 1) were particularly intensive in the epochs of warming periods during the Würm and in the beginning of the Holocene .

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