MAMMOTH STEPPES AND FUTURE CLIMATE

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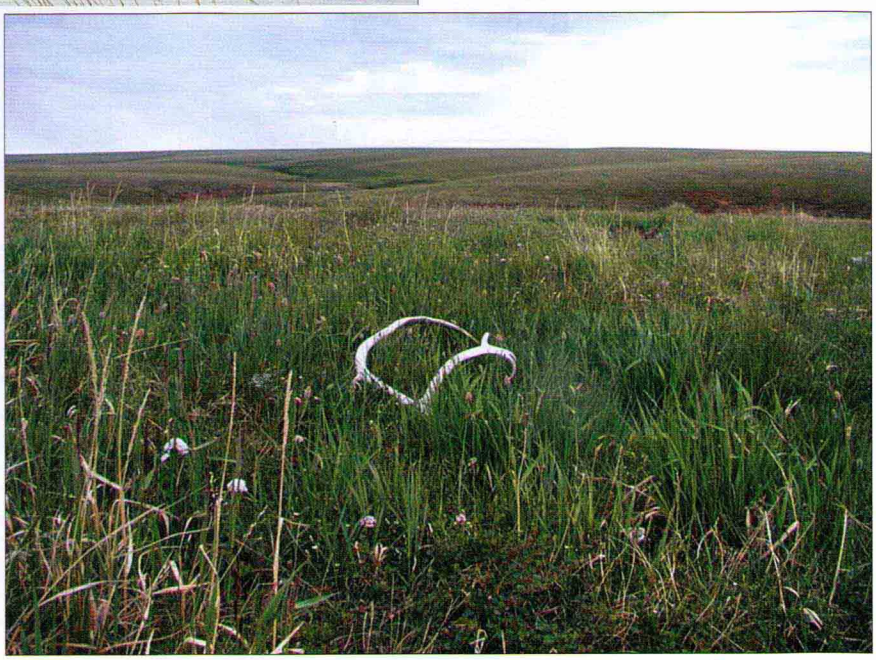
Man's appearance and his settlement across the world are closely bound up with the development of pasture ecosystems. Having ousted forests in the latest ice age, pastures occupied them most of the earth's land surface. Their soils in the form of a thick permafrost sheet even now cover North Siberian plains. It serves as the world's largest stock of organic carbon. What is to become with the world climate if permafrost starts thawing? Can pasture ecosystems stem the process?

Plains of northern Siberia are covered by multi-meter-thick mammoth tundra and steppe soils. In many places these layers are over 50-meter thick. As a result of soil erosion these fertile soils are overgrown with grasses as early as the next year.

Yakut horses do not need any additional fodder in tundra meadows (north of the Kolyma Lowland).



Mosses and lichen have been trampled down at the reindeer breeders' camp site, and the tundra has been transformed into a highly productive meadow.

FROM PLEISTOCENE TO HOLOCENE

By advancing and retreating, the giant ice sheets have been plowing the north of Europe and America* in the past million years. However, the situation in North Siberia was relatively calm in geological terms in the Pleistocene** epoch: erosion prevailed in the mountains and silt and dust were accumulated in the vast plains and valleys. Life did not come to a standstill even in the highest latitudes. Mammoths, woolly rhinoceroses, bisons, horses, reindeer***, musk oxen, ancestors of red deer, elks, saigas and yaks then grazed on grassy pastures. Beasts of prey–tigers, lions and wolves–never went hungry. In winter ground cracked at low freezing temperatures, with water collected in deep cracks. As it froze, thin ice veins were formed. The process went on for thousands of years and, as a result, a many-meter-thick sheet of silty loam pierced by crisscrossed ice veins covered northern plains. In fact, it is nothing but permafrost soils of the prehistoric period's largest ecosystem of mammoth tundra steppes. And the thick layer filled with grass roots, live microorganisms and animal bones is a detailed record of the ecosystem's development.

At the peak of the ice age it encompassed the territory from what is now France to Canada, from the Arctic Islands to Northern China. But at the start of the Holocene period* that ecosystem was nowhere to be found. In the North of Siberia it had been ousted by moss tundra and forest tundra. Then the big question is: why did it happen that, having survived in the most austere glacial period, mammoths and other wildlife species vanished in the peri-

* *See*: Yu. Malinovsky, "Self-Regulation of Biosphere and Great Glaciations", *Science in Russia*, No. 6, 2006.–*Ed.*

** Pleistocene (1.8 mln-11.5 thous. years ago)–the earlier subdivision of the Quaternary period, characterized by general climate cooling on Earth and periodical origin of large continental glaciations in medium latitudes.–*Ed.*

*** *See*: Ye. Syroyechkovsky, "The Reindeer Problem", *Science in Russia*, No. 2, 1990.–*Ed.*

* Holocene (the post-glacial epoch) is the later part of the current Quaternary period, which started approximately 9,600 years B.C.–*Ed.*

In places of intensive grazing of the Pleistocene Park animals eat up in the winter whatever has grown there in the summer.

Meadows account for a third of the Pleistocene Park territory.

ods of interglacial climate warming*? The simple explanation seems to be only too obvious: the fact is that the glacial climate was arid (dry), and in Holocene it was replaced by humid climate. So the grassy pastures were transformed into tundra and swamps. Horses with their narrow hooves and heavy mammoths, used as they were to solid steppe ground, got stuck in that quagmire in summer, and in the snow–in winter. The long wool of mammoths, musk oxen and bisons was soaked with moisture and no longer protected them at freezing temperatures.

The theory seems to be logical enough: steppe animals thrived in polar latitudes owing to steppe climate there, while Holocene proved a catastrophe to them. However, information of radiocarbon dating accumulated in the past few decades testifies that musk oxen still existed in the north of Siberia some 2,700 years ago. Moreover, they have survived even in our times on the driest islands of the Canadian Arctic with their extremely severe climate. Not that the climate is very auspicious for them there, but man's absence is of crucial importance. In the 20th century musk oxen were successfully reintroduced in Alaska, Chukotka, Taimyr, Yakutia and even in super-humid Norway. Alaska, including its Arctic coast, was the habitat of bisons throughout the Holocene epoch, and they were finally exterminated only 160 years ago. They have been brought there again and currently proliferate successfully.

Moreover, it has been proved that even mammoths existed in the Holocene epoch–on small islands of the Chukchi and Bering seas–of all places–that are hardly suitable for those large animals. And they became extinct there when there were no climate changes. Horses had survived in the north of Siberia until the historic times. They roam Yakutia even now and manage to survive without additional feed even on the Pole of Cold in Oimyakon and Verkhoyansk, with freezing temperatures dropping sometimes down to –72°C there. In wintertime their hooves become as small as cups as a result of

* *See*: Yu. Burlakov, A. Smirnov, "Polar Region of Russia: Fossil Ivory", *Science in Russia*, No. 6, 2006.–*Ed.*

With the passage of time, as the density of the herbivorous populations grows, grasses in the Pleistocene Park will no longer be so high but their protein content will grow.

raking snow, while in summertime the hooves grow and look more like plates.

So, the conclusion is that climate warming was not actually the reason behind the disappearance of wildlife of the mammoth ecosystem.

Incidentally, the north of Siberia is far from the only place on Earth without large mammals roaming it in our days. The appearance of man in the areas of their habitat with his new hunting technologies was the reason for their undoing. For instance, 70 percent of large animal species became extinct after people had settled in America, and 23 of the largest animal species became extinct in Australia for the same reason. Aurochs, bisons and steppe bisons, Asiatic wild asses, wild horses and saigas, among other, have been almost completely exterminated in steppes and prairies even in historical times.

Consequently, we may well assume that many of the wildlife species were exterminated in the north of Siberia also by man. But why was it that the former grass pastures had been transformed into moss tundra? Was it because arid climate had been transformed into humid? Why then did not cardinal changes in landscapes take place in the previous interglacial periods? At the peak of the last glacial period, when the mammoth steppe in Europe predominated on its territory, the annual indicator for precipitation at that time was 200-250 mm, i.e., twice or thrice less than today, according to the results of research. And freezing temperatures in January dropped down to –25- –35°C. However, climate in the north of Siberia is exactly the same even today, but there are no steppes. What conditions are required for grasses to dominate again in that region?

The aridity degree is estimated on the basis of the radiation aridity ratio offered by a Russian geophysicist, Academician Mikhail Budyko (1920-2001), i.e., the ratio of the energy received by the earth's surface (annual radiation balance) to the energy required for the evaporation of the total annual precipitation. The ratio from 1 to 2 corresponds to the climate of steppes, that from 2 to 3 is typical of semi-deserts. And what kind of climate has the Siberian Polar Region today? A total of 11 radiation balance-measuring stations are currently located in the region east of Taimyr. According to their data, the average aridity ratio is 2! Consequently, this shows that steppe climate prevails here even today. But why do we find swamps here?

Plants are largely responsible for moisture evaporation from landscapes. For the green leaf to catch one molecule of carbon dioxide via its minute open stomata, it will inevitably lose several hundred water molecules. That is why the plants' productivity is inseparably bound up with evaporation.

Southern steppes have warm soils, and the cyclical process may be supported for a long time owing to the decomposition of organic substances in the soil and on its surface. The picture is different in the north, for soils are cool there. Grass communities may be stable there solely owing to herbivorous animals, with organic substances decomposed in their stomachs. So, in the mammoth ecosystem millions of animals that consumed summer grass in wintertime contributed to biological turnover. They fertilized the soil, trampled down mosses and bushes, thus keeping their pastures in proper condition. That is why the ecosystem hardly depended on climate.

Holocene climate warming with its more generous precipitation contributed to the expansion of forests in Europe, but under the extremely cold and arid conditions of Siberia's north that could not destroy the mammoth ecosystem. True, trees and bushes could make their appearance largely on sandy and stony ground, with an increase in the elk population as a result. However, the aggregate productivity of pastures and the population of herbivorous animals would have only increased. And this is confirmed by the fact: according to the glacial record data, some 14,700 years ago a sharp pre-Holocene climate warming and humidification took place in

Animals in the Pleistocene Park will have no fear of man.

the north. Immediately the mammoth population considerably increased.

In our days, the climatic peak of the mammoth ecosystem is most probably observed in Northwestern Siberia. Pasture productivity drops in areas of cooler and more arid conditions, and in those with a warmer and more humid climate it is more difficult for the animals to obtain feed under the snow and oppose the expansion of trees and bushes. That is why Holocene climate warming, I repeat, could not have destroyed mammoth steppes in the region. But the dwindling herds of herbivores had proved sufficient for cardinal changes in the local landscapes.

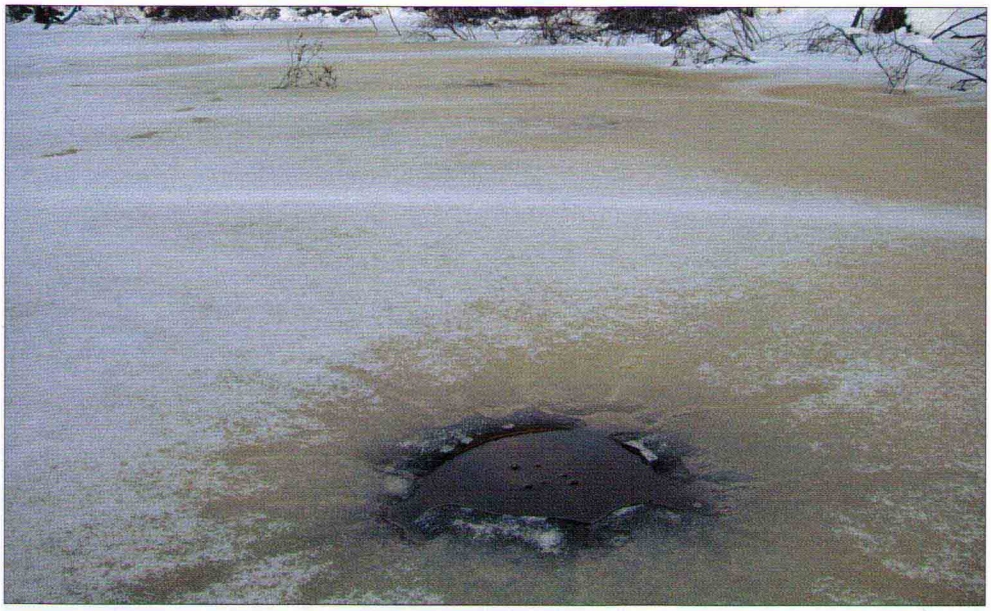
PASTURE ECOSYSTEMS

Grasses and herbivores are very young, i.e., they are "only" approximately 20 million years old, and the bioturnover of their ecosystems is the most rapid. To compare: photosynthesis has a relatively low intensity in evergreen plants that they have a longer evolutionary history. Their leaves (needles) live for years. They have to defend themselves not to be eaten up. Having withered away, the bitter (toxin-saturated) leaves and tissues decompose also for many years on end. Practically no animals eat them. Rapidly growing grasses are an entirely different thing. Their goal is to win the place under the sun as soon as possible and utilize the resources of moisture by grabbing it from their slower competitors. But herbivores aim to eat and trample down whatever has grown in the course of the summer (in the season of rains) and rapidly return the chemical elements to the soil. The predators' task is to destroy sick animals (mass-scale epizootic diseases are highly probable due to great density) and distribute evenly herbivores by territories for the latter to graze where it is safer, not tastier.

Pasture ecosystems use their advantages to the utmost on loamy ground (powerful photosynthesis requires an abundant supply of mineral nutrients) and in dynamic external conditions–frequent droughts, floods, erosion, fires. These communities are change-prone, for the biomass of plants and the composition of varieties undergo rapid changes in them, with great changes in the population of animals, even large ones (by an order). It will take many years for forests or moss tundra to be restored after fire, while the pasture ecosystem will need just a few weeks for it.

By ousting forests, as I have already said, tundra-steppes, steppes and savannas have occupied a large part of the world in the past million years owing to the changing Pleistocene climate. The animal biomass by far exceeds that in forests. It was precisely in such ecosystems with an abundant stock of food that man first appeared and later settled throughout the planet. However, with civilization, the animals' defense strategies could not catch up with man's hunting tools and technologies. And vast mammoth steppes were the first to fall victim. Animal populations dwindled there, and grasses in the north were ousted by moss forests and tundra. Wild pasture ecosystems had to retreat under the onslaught of land cultivation and stock breeding when man set about creating its multi-rotation pasture ecosystems. They were primitive ecology-wise, had a limited quantity of varieties and no biological competition to speak of. However, their aggressive nature was superb. Wild nature resisted them to the best of its ability. Hordes of weeds attacked cultivated fields, livestock fell victim to predators and infectious diseases, eagles and polecats preyed on poultry, wild stallions lured mares away from herds, wild oxen broke fences and trampled down crops; birds, rodents and insects ate up the harvest. Nevertheless, in our days almost all meadows, steppes and prairies have been plowed or transformed into pastures and hayfields. Animals could survive provided they were clever enough to find refuge in forests or arid deserts.

In our days you will find large quantities of wild animals solely in African reserves. And it seems incredible that no less number of them once inhabited territories in medium lati-



In places of intensive bank erosion bubble methane is released from the bottom of thermokarst lakes at a rate of 200 l/sq m per annum.

tudes and in the north. The prominent 19th century Russian traveler Nikolai Przhevalsky was among the last lucky ones to observe such a picture: "Unless you have seen it with your own eyes it would seem incredible that such a large quantity of animals, sometimes gathered in innumerable herds, could exist in those localities, certainly not rich in gifts of nature. It is only by roaming across the country that those herds are able to find sufficient feed on the meager pastures of the desert. On the other hand, these animals know nothing about man, their chief enemy, and their existence is free and unrestricted, far removed as they are from their blood-thirsty pursuers." This is how Przhevalsky described the deserts of Northern Tibet! And you can imagine the density of animal populations in other, more favorable regions before man had made his appearance there!

Civilization has been waging its warfare against pasture ecosystems for thousands of years. Just a century ago hunters who had killed thousands of animals in Africa on their pleasure trips were given a red-carpet reception in Europe like Olympic champions. In our days, however, people are prepared to protect nature. Although not much of it has been left without man's interference. More often than not those are some plant communities where large animals and birds are either absent or their populations are too insignificant to have any effect on the landscape. Today you will find many wild animal species solely in the zoos or on the farms. However, in those cases ostriches, bisons, deer, and so on, have been domesticated and only look like their wild counterparts. They are certainly not the species whose individual members can migrate across hundreds of kilometers, offer resistance to predators and rivals and are resistant to parasites and natural toxins and infections. Animal species should be preserved in ecosystems, although, first, the latter should be restored.

The most important domestic plants and animals (and actually man in the past) served as components of wild pasture ecosystems. They stood at the genetic source of civilization. Is it possible to recreate highly organized self-regulating pasture ecosystems in medium latitudes? Yes, it is, in technical terms. The region with a suitable climate should be proclaimed a reserve for as many animals as possible whose habitat in the past had similar conditions, and they will occupy their own vacant niches in line with their ecological functions. And the animals should not be necessarily brought from the same region. The same species may originate, for instance, from Mongolia, Yakutia and Canada. The fact is that most of the animal populations in wild ecosystems were migrants in the past: horses had been brought to Asia from America, and bisons—the other way round. And they should not be necessarily thoroughbred. Crossbreeds and feral domestic animals will do as well. For instance, wild horses were exterminated in America some 10,000 years ago and mustangs had occupied their niche.

Will it be possible for the pasture ecosystem (and it tends to be stable solely on large areas) to offer economic competition to agriculture in the fight for its territory? In Africa each lion earns up to $1 mln annually for its park by attracting tourists. Nevertheless, farmers and poachers are winning land from nature. In Russia the situation is different: competition on the market of agricultural products and fuel prices are growing, the population is dwindling and millions of hectares of land have been withdrawn from agricultural turnover. Maybe there is no reason to sound alarm, for uncultivated soil will accumulate humus. However, uncultivated fields tend to be overgrown with bushes and low forest. Why should we lose land in this way? It would be expedient to create pasture ecosystems precisely there.

There are prospects for their regeneration, say, in the south of the Far East. If actual reserves were to be set up there, the currently uncultivated fields, surrounded by oak woods and the taiga, could become the habitat of roe deer, sika deer,

A decade ago on the slopes of this hill in the Pleistocene Park grasses stopped the permafrost erosion process provoked by fire. However, due to the low population of herbivorous animals the meadow is degenerating.

Manchurian deer, wild boars and, next, wolves, bears, tigers and leopards. Horses and bisons may well be also brought there, for the area was their habitat in Pleistocene, so the tigers' memory may be revived in retrospect of the way they had hunted those animals.

However, we would need ... strong fences for a conflict-free coexistence of civilization and wild nature.

PLEISTOCENE PARK

The vast plains of Siberia's north are fenced off by snow-capped mountain ranges from cultivated southern fields and livestock pastures. Northern Siberia is currently the habitat (although of rather small populations) of such herbivorous as reindeer, elks, Yakut horses, musk oxen, hares, marmots, gophers and of such carnivorous as wolves, bears, trots, wolverines, foxes and polar foxes. Several Canadian bisons have been brought to Yakutia. Its climate is optimal for pasture ecosystems, so attempts may be made to restore them here. With this aim in view we launched the Pleistocene Park experiment over a decade ago in northeastern Yakutia, in the lower reaches of the Kolyma River, at a distance of 100 km from its mouth. Meadows, willow coppices and larch forests with swamps and lakes occupy the park's territory in equal shares. Average temperature in January over many years is approximately –33°C in January, in July +12°C, annual precipitation–200-250 mm.

Our task is to settle on this territory the surviving animals of the mammoth ecosystem (first, without large predators), and ensure a high degree of their density within the limits of the multi-kilometer fence for them to have a powerful effect on plants and soils. Our initial experiments were staged in a 50-ha corral (enclosure). The construction of another corral with an area of 1,900 ha has been completed recently. We observed an increased protein content in winter feeds in intensive grazing places. The animals dig the snow with the greatest care here. Horses, elks, reindeer, a bear family, trots and wolverines represent large animals in the park. We are planning to increase their populations, bring to the park musk oxen, Canadian bisons and Manchurian deer and expand the park's territory. As soon as the total population of animals has approached thousand, we will try to acclimatize Amur tigers in order to control the wolf population. Incidentally, it is not climate but poaching and the low density of hoofed animals that are the factors limiting the tigers' survival (tigers were observed in Yakutia earlier).

If the animals keep in proper condition and expand their pastures, the experiment will prove a success. What is to be done next? Shall we further "cultivate" the ecosystem or let it take care of itself? Will that pose a threat to animals, people and–in the long perspective–probably to climate as well?

A total of 7 bln tons of carbon is ejected annually into the air as a result of oil and gas fueled by us, with the concentration of hothouse gases steadily growing in the atmosphere*. According to the latest forecasts of the Intergovernmental Panel on Climate Change (IPCC), as early as in the current century air temperature at the earth's surface will rise on average by 1.8-3.4°C, and in the north by 4-7°C. What will happen then to the northern plains? The content of ice veins accounts for 50 percent of their loamy soils. If an intensive thawing process sets in there, the present-day relief, vegetation, settlements and infrastructure will be destroyed. Colossal mud torrents will flow to rivers and, next, to the ocean.

Soils of the mammoth steppes (termed *yedoma* locally) are among the planet's largest carbon reservoirs with their stocks of about 500 bln tons of organic carbon, i.e., 150 percent more than all the world's rain forests, although its content is the same as in other soils–2.5 percent. However, in the planet's other regions the carbon-rich layer is usually less than

* *See*: Yu. Israel, "Threat of Climatic Catastrophe?", *Science in Russia*, No. 4, 2004.–*Ed.*

The fire that broke out on the slanting slope triggered permafrost thawing with thousands of cubic meters of forest soils washed down into the river system. The Gornaya Filippovka River was transformed into a mud current. However, next year grasses stopped the erosion process.

0.5-meter-thick, while in the north of Siberia this layer is often dozens of meters-thick.

If mammoth steppe soils thaw under excessively humid conditions (without oxygen's access), microorganisms transform organic substances into methane. Mammoth steppe soils thaw under thermokarst lakes, slowly migrating across the plains, with methane bubbles rising from the bottom in all seasons. In wintertime ice is not formed on the spots of their intensive escape even at the lowest freezing temperatures, and gas escapes into the atmosphere via these openings. In our days such plots account for less than 1 percent of the territory of the northern plains. But their area may grow out of proportion in the event of intensive climate warming. Methane absorbs long-wave radiation emitted from the Earth's surface to outer space 20 times more intensively than carbon dioxide. That is why its contribution to global warming from the mammoth steppe soil may be even more significant than the flow of CO_2 released from the same soils.*

How long the process of permafrost thawing will take depends on climate changes. According to certain forecasts, the whole of mammoth steppe soil will thaw as early as in the 21st century. Is that a realistic forecast? Global climate warming has been insignificant so far, i.e., less than 1°C, but it is gaining momentum. The ice cover of the Arctic is shrinking now, and there is less snow on the continents**–the planet grows darker and, consequently, it will be heated more intensively. Hothouse gases in the atmosphere obstruct, in their turn, the outflow of heat into outer space. That is why intensive heating and permafrost thawing are highly probable, which should add to the hothouse effect.

Will permafrost resist intensive climate warming? Today its temperature even in the Extreme North, for instance, in the region of the Pleistocene Park, is only –2-3°C. Consequently, as soon as the temperature rises by 3°C, permafrost will thaw. That will trigger the process of surface erosion, with the ground above ice veins caving in. And as soon as the fertile mammoth soils have thawed, the surface will be overgrown with thick grasses. True, they will hamper the process of erosion but not of permafrost thawing. However, if a pasture ecosystem densely populated by herbivorous is located nearby, they will immediately come here. The permafrost temperature strongly depends on snow height and density. By digging snow in search of food the animals effectively trample it down. At the peak of wintertime the freezing temperature of the ground surface in Pleistocene Park pastures drops 20°C below that in similar places without pastures. It should be stressed that pasture ecosystems is probably the only method to cool and save permafrost without large outlays. As soon as permafrost starts thawing in a certain area, the grasses and herbivorous will arrive on their own and hamper that process.

As the proverb goes, "forests are the planet's lungs". However, in the period of the latest glacial period the taiga was almost completely destroyed and rain forests dwindled significantly, although the content of CO_2 was then 50 percent less in the atmosphere than today. It was pasture ecosystems that managed to play the role of the Earth's lungs then. Once regenerated, they may prove an effective remedy for global warming today by contributing to global cooling. As distinct from dark forests, they reflect well solar energy both in winter and summer, can remove more carbon from the atmosphere than forests and hide it reliably from fires in the ground. Pasture systems should be restored to Nature.

Illustrations supplied by the author

* *See*: G. Golitsyn, "Methane... and Hothouse Effect", *Science in Russia*, No. 6, 2002.–*Ed.*

** *See*: V. Kotlyakov, "Environment, Its Past and Future: Glaciology Bears Witness", *Science in Russia*, No. 1, 2001.–*Ed.*