Evidence in favor of that over the Pleistocene cryodiversity in Northwestern Siberia developed as interaction of permafrost and mountain glaciers but not of ice sheets

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ABSTRACT
During the Quaternary, permafrost in Northwestern Siberia fluctuated in size but always occupied a vast space. Nevertheless, some researchers suppose ice sheets covering that terrain, though to explain their combined development with permafrost is impossible. They must transform their frozen bed, whereas the latter occur in the fair preservation. The point is that study of glaciation in Siberia began to carry out on the base of the Alpine model suitable to explain forming the sheets in Europe moistened from the Atlantic; however it is not suitable in Siberia where cold and dry environments prevailed over the Quaternary. It made conditional on the particular glaciers interacted with permafrost. They become a new element of cryodiversity (a set of objects and phenomena produced by cold), and differ from those considered as of the Alpine glaciation model, and obtain properties which are more characteristic for permafrost objects, than for the Alpine-type glaciers.

RÉSUMÉ
Au cours du Quaternaire, la répartition spatiale du pergélisol au nord de la Sibérie occidentale a maintes fois varié, tout en occupant un vaste territoire. Néanmoins, certains chercheurs évoquent l'hypothèse qu'au cours de cette période, d'immenses calottes glaciaires auraient recouvert cette région limitant le développement du pergélisol. La présence des glaciers aurait dû mettre en place des formes de terrain, mais la surface du sol est restée intacte. Cette particularité s'explique par l'utilisation de modèles de glaciation en Sibérie initialement basés sur un modèle de glaciation alpin. Celui-ci explique adéquatement la formation des calottes glaciaires en Europe alors que le climat était beaucoup plus humide, mais ce modèle n'est pas adapté aux environnements climatiques froids et secs, tel que prévalut en Sibérie durant le Quaternaire. Cette dynamique est responsable de l'interaction entre les glaciers et le pergélisol. Cette dynamique glaciaire devient donc un nouvel élément de cryodiversité (l'ensemble d'objets et de phénomènes produits par le froid) et se différencie des modèles de glaciation alpine par des propriétés semblables aux caractéristiques des formes périglaciaires plutôt qu'aux glaciers alpins.

1 INTRODUCTION

The today's systematic knowledge of the cold world opens new avenues in cryological research, which requires synthesizing the available data into a framework of views covering all cold effects. All these effects can be considered as elements of cryodiversity (a set of objects and phenomena produced by cold), within the single context of studying Earth's cryosphere.

In the beginning, we note that the terms '*cold'* and '*warm'* refer to human perception rather than to physical properties. The concepts of '*cold'* and '*warm'* characterize the thermal state of objects as people feel it, while physics deals with the parameter of '*heat'* and its amount corresponding to the energy transferred from one body to another during heating or cooling.

However, the concept of '*cold'* is a key one in permafrost science and refers to a medium at negative temperatures (below 0°C), as well as other terms derived from the Greek word '*χρνος'* (*cryos*) meaning '*cold*, *frost'*, and also '*ice'*. The Greek, which together with the Latin makes basis for the scientific terminology, is used broadly in the Mediterranean where the concepts related to cold and frost have been always associated with the ice, or the cold effect.

So, the terms derived from '*cryos'* are especially important elements of the basic permafrost terminology to name the effects of cold. The widespread term '*cryogenesis'* covering various processes that develop below freezing and produce frozen bodies literally means *'born by cold'*. Nevertheless, the concept of '*cold'* referring to a medium at negative temperatures in permafrost sciences becomes ambiguous when applied to glaciers: it appears strange to attribute glaciers to cryogenesis, even in the permafrost zone. The reason is that historically the studies began with glaciers which occurred outside the permafrost zone and before the permafrost science developed. However, glaciers derived from snow, which is a result of atmospheric cryogenesis, may form either outside or within the permafrost area. In the latter case, this is cryogenesis in a complex and dynamic geological system consisting of snow and snow-derived ice upon frozen rocks.

There is also another form of surface glaciation: icing (naled) caused by freezing of water-bearing taliks (thawed ground) and thus classified among permafrost phenomena. Unlike the glacier ice produced by deposition and metamorphism of snow, icing forms by congelation, or rather re-congelation. So that the non-frozen and deeply frozen glaciers, icing, and other related phenomena are different components of the Earth's cryosphere, as well as permafrost. They can be systematized using a concise concept of *cryodiversity* – diversity of phenomena yielded by cold.

In Siberia all glaciers occur within the permafrost (*Sheinkman, 2011*) and are related to cryogenic processes both in atmosphere and lithosphere. Thus glaciation becomes in focus of both glaciology and permafrost sciences, and has to be studied in terms of Earth's cryology considering ice of all types as elements of cryodiversity and components of cryogenic geological systems (*Sheinkman, Melnikov, 2014*).

As to nival-glacial systems proper, in Siberia they include glaciers and snow, which form geological bodies within the permafrost area and are thus permafrost (cryolithogenic) systems. To describe these systems more precisely but with the common terms, we suggest adding the clarifying attributes '*nival'* or '*glacial'* to the name of the systems. Thus, the cryogenic geological systems can be then either '*nival-permafrost' (nival-cryolithogenic)* or '*glacial-permafrost' (glacial-cryolithogenic)* ones. They are currently available all over Siberia at present and during the Quaternary. So, we synthesize data on such systems and explain, on the base of studying the glaciation and permafrost in Northwestern Siberia, and their interrelation.

2 STUDY AREA AND SCIENTIFIC BACKGROUND

Different points of view are an attribute of the considered field of knowledge. Not infrequently they oppose to each other fundamentally. The reason behind the differing views has to do with the fact that, from the beginning, the views of Siberia's glaciation relied on a traditional Alpine model. This is on its basis that the first glaciation patterns in Western Siberia and, subsequently, in other parts of Siberia were constructed. However, significant experience and numerous data demonstrate that development of glaciers in Siberia acquires specific features differing from the parameters of the Alpine model fundamentally (*Sheinkman, 2011, 2012; Sheinkman, Melnikov, 2014*). To understand this fact required some time; the results came to be recognized during the last several decades only.

Today, the use of paleoreconstructions in developing models of predictive nature must, among other things, give the answer to a central, acute question: what is the character of glaciation and its relation with permafrost to form the basis for the constructions undertaken? One is forced to accept the fact that, unfortunately, opinions on this matter are not only different but they are in complete contrast to one another (*Arkhipov, 1997; Astakhov, 1998; Grosswald, Hughes, 2002; Kuzin, 2005; Svendsen et all., 2004*). Some researchers apply, as the basis of glaciation models for Northwestern Siberia, the inland ice sheet pattern encompassing the entire north of the West Siberian Plane. Although others reject such a model, and think that their opponents have erroneously taken as traces of glaciers the features produced by other processes so that the size of former glaciation is sharply reduced. And also others negate the occurrence of ancient glaciers in Siberia entirely. As a result, it would seem that the firmly established concepts are, from time to time, subjected to revision, and the trends of environment under the influence of glaciation are re-evaluated. The reason is that different factors, at the background of the permafrost development, influence the area of Northwestern Siberia, and they impose on one another (Fig. 1).

Figure 1. Study area and factors influencing on it

So, the goal of our research was to look into the existing situation, carry out a comparative analysis of the glaciation and relation with permafrost in Northwestern Siberia, and suggest the model for the development of nature incorporating the present views. At that, when glaciation has been considered, we have to take in account that it develops as interacted with permafrost, and, thus, we are to study glacial-permafrost systems, but not only glaciation.

Anyway we had to cope in Northwestern Siberia with an intricate dilemma. On the one hand, the region under consideration is one of the best studied areas in Siberia. The models for its development are based on an objective research framework – in respect to the determined by the time of its creation, of course. On the other hand, there is a need to work out the unifying approaches, but to accomplish this requires compelling evidence which would satisfy the disputing parties.

To our opinion, the cause for the disagreements, both previous and still emerging, with respect to the glaciation of Northwestern Siberia is largely due to the fact that researchers adhere to definite certain stereotypes yielded by the traditional Alpine approach, and do not want to dismiss them. An equally important role is also played by an inadequate account of the glaciation characteristics, especially in Siberia, where, throughout the Quaternary, glaciers were evolving under conditions of cryoaridization (increase in climatic continentality at a background of lowering air temperature), and in the region where preexisting permafrost developed.

So, first and foremost, we had to gain an understanding of the existing situation and unravel the specific character of the glaciation in Northwestern Siberia through identification of ancient glaciers developed under conditions of cryoaridization and their location in the permafrost area. Since Alpine concepts have for long been used in Siberia, no special attention was paid to the parameters of glaciation evolution in the region of permafrost zone, and it was to fill in the gap with the results of our research.

3 REGULARITIES IN DEVELOPMENT OF GLACIATION IN NORTHWESTERN SIBERIA

Experience in doing research in different glacial regions of Siberia, and results from analyzing the relevant findings, which show activity of the modern and ancient glaciers, demonstrate the glaciers have been located only in the mountains within the permafrost area, under conditions of developed cryoaridization, and Northwestern Siberia is no exception in this regard (*Sheinkman, 2011, 2012; Sheinkman, Melnikov, 2014*). The fact that the glaciers are located in a setting with clearly expressed permafrost implies their development under a continental climate with long cold winters and short, yet warm and frequently hot, summers providing active ablation.

On the one hand, all of these have determined a significant ablation on the glaciers even during the Quaternary Cryochrones, whereas, on the other hand, a special pathway to compensate the ablation takes place. In such a situation, the ablation has been compensated not by abundant snow supply, as it is adopted in the traditional Alpine model of glaciation, but by alimentation from the congelation component that has received the name ‘icy alimentation’. Under conditions of low moistening, it comes about through the formation of superimposed ice (infiltration-congelation and repeatedly-congelation ice) where the cold stored during the long wintertime has been realized in the warm season of the year as the process of freezing snowy-water and icy-water layers on the base of cold ice. (Glaciers are significantly cooled below 0°C in Siberia everywhere).

As to the ice sheets in the Insular Arctic, they are in the very high latitudes and their equilibrium line runs nearby the sea level so that they reach the developmental stage of ice sheets, whereas the glaciers in Siberia have been located in the high mountains only, and, being controlled by active summer ablation (an attribute of continental climate), are characterized by a high altitude of the equilibrium line. Today, at regularly zonal glaciers, the lowest position of this line is at an altitude of about 2000 m a.s.l. – in the near-polar area of the mountain ridges of Northeastern Siberia. In the South of Eastern Siberia, the equilibrium line lies on the glaciers at a height of about 2500 m a.s.l., and higher than 3000 m a.s.l. in the mountains in the South of Western Siberia.

If it is even assumed that during the Quaternary Cryochrones the equilibrium line on the glaciers lowered by 500–600 m, sometimes – up to 1000 m (such estimates are recognized by most authors), it will nevertheless lie much above the sea level. It is in general agreement with that the maximal fall of temperatures even during the strongest Quaternary Cryochrones has been estimated in the north of Siberia by 10-12°C. The more lowering of the equilibrium line has to be accompanied, accordingly, by the more significant fall in temperature, but such a fall is impossible by its nature.

An exception is, to some extent, provided by small azonal glaciers produced by wind-blown snow and located in not so high mountains oriented along the meridians. At present local firn line runs here more than one kilometer below the level of the climatic snow line (as it is the case of the mountain ridges spanning the study area both in the East and West – see Fig. 1), while during the Quaternary Cryochrones this difference between the local and climatic snow lines was decreasing due to a depression of the latter. In any case the two snow limits were much above the sea level and lying high up in the mountains.

When responding to the rhythmic in the Cryochrone −Thermochrone format, the high-latitude Arctic glaciers determined by the low location of their equilibrium line, varied in their sizes, but the ice flows forming them were usually represented by ice sheets. However, Siberia’s glaciers occurring high in the mountains were increasing in size many times during the Quaternary Cryochrones, but could be almost disappeared during the Thermochrones.

It may be recalled that the traditional Alpine model assumes active evaporation of moisture from the ocean, its transport to the continent over which it travels a relatively short distance, and conservation by the glaciers, which mostly lie not on a frozen bed, and the main factor of glaciation is represented by an intense metamorphism of snow when it is abundant. Ice melt is balanced by an intense input to the ablation zone of new portions of ice mass, and heat arriving at the glaciers largely goes into overcoming the melt threshold with high heat of fusion of ice which is predominantly in an isothermal state at a temperature of 0 ºC. In such a case, the glaciers, even at middle altitudes and under a geologically rapid change of Thermochrones for Cryochrones (it is an attribute of the Quaternary climatic rhythmic with such main interval as 20 000 yrs.) were able to reach during glacial times a final stage of development, the ice sheet, as was the case in Europe. It should be also pointed out that a change of Thermochrones for Cryochrones is accompanied then by clearly pronounced humid phases of glaciation: warm first and cold then (*Velichko et al., 2011*). With a still abundant snow supply persisting during the early phase of cooling, a decrease in the ablation time will lead to a rapid lowering of the snow line, entailing an active growth of the glaciers. After that, the cold humid phase of glaciation will change for a cold dry phase with a deceleration of glacier growth; nevertheless, the mass of ice sufficient for the formation of the ice sheet will be able to accumulate.

Although the Alpine model is commonly used in different regions, it is unacceptable under continental climate conditions of Siberia, including Northwestern Siberia, because permafrost and the setting under conditions of cryoaridization here remain constant throughout the entire Quaternary. Moisture arrives in Siberia mainly together with the westerly air masses, passing large distances and much of it is expended *en route*; during the Quaternary Cryochrones, a larger part of it is intercepted by the ice sheet in North Europe. Hence, the overall volume of moisture transferred to Siberia can never be large either today or in the past, especially during the Quaternary Cryochrones.

It is also necessary to take into consideration that a significant portion of moisture in Siberia is conserved not by glaciers. Ground ice and icings in the permafrost area participate in such a process as well.

During the Quaternary Cryochrones the Siberia's glaciers respond differently to climate change also, if to compare them with those that conform to the regularities of the Alpine model. The amount of atmospheric precipitation is small in Siberia; in the process of climatic cooling and, hence, cryoaridization, the precipitation amount is becoming still smaller, and increasingly more moisture in the periglacial zone will be conserved by icings and ground ice. Consequently, the glaciers will be growing slowly. During short-lasting Quaternary Cryochrones they are only able to reach the stage of valley forms even eventually, and the format 'Cryochrone–Thermochrone' in Siberia is not always identical with the format 'Ice age–Interglacial' (*Sheinkman, 2011, 2012*).

In Siberia, unlike Europe under the influence of the Atlantic, climate cooling was able to cause primarily an enhancement in cryogenesis, and an expansion of the permafrost area, and only when under conditions of cryoaridization the mountains penetrated deep into the chionosphere, it ensures input of a sufficient amount of initial material of glaciers, i.e. snow, and there occurred a growth of glaciers which remained mountain glaciers. So, glaciers in Northwestern Siberia could advance during the Quaternary Cryochrones from the only glacial centers in the mountains surrounding the West-Siberian plain towards their foothills (see Fig. 1).

In order to reveal the nature of the glaciation in details, let us now examine that issue which is one of the most disputable questions in the context of the problem under discussion. At that we will rely on facts and data obtained during our recent investigation carried out in Northwestern Siberia.

The modern glaciers in Northwestern Siberia (in the northern spurs of Urals, as is the case with the similar glaciers in the mountains of Taimyr and Putorana – see Fig. 1) are located about one kilometer below the climatic snow limit and fed by the wind-blown snow from the neighboring slopes predominately. Only rarely and slightly do the highest peaks in the surrounding mountains of Northwestern Siberia exceed a height of 1500 m a.s.l. Further south, on Urals and within the basin of the Lower Tunguska River, the mountains are substantially lower, and they have neither modern glaciers nor evidence of reworking of the mountains by ancient ice flows.

The modern glaciers, indeed, advance enough lowly and reach an altitude of about 700 m a.s.l. (Fig. 2). It will be, however, recalled that these glaciers represent an exception as they are small azonal ice flows.

Figure 2. Romantics' Glacier, Polar Urals

If it is assumed in this case that the depression of the snow limit at the time of climate cooling compensated the aforementioned difference between the climatic snow line and the local (on the glaciers) firn line, the region of ice catchment could encompass only the highest (limited in area) part of the mountains, and the amount of the advanced ice mass could not be larger as this amount would suffice for mountain glaciation.

Furthermore, currently there are no so called warm glaciers in Siberia, and the surface cold layers on its largest glaciers move very slowly. In Northeastern Siberia where the length of some modern glaciers reaches nearly 10 km, the velocity of their surface layers is less than 10 m per year; the velocity is slightly higher for Siberia's largest Altai glaciers, around 15–20 m per year. All-in-all, we can only rely on such data to extrapolate them in the Pleistocene past.

It should be also noted that the mountain glaciers move more slowly in the case of a more intense cooling which occurs during the Quaternary Cryochrones. So, let us assume that the glaciers in Northwestern Siberia in the period of climate cooling during the Pleistocene Cryochrones were steadily increasing in length at the rate of 15–20 m per year, without a deceleration at the bed, with their temporal part not melting even partly (although such a situation is impossible in respect to Siberia by its nature). In this case, too, even very simple calculations show that the advance of the glaciers will be only about 15-20 km per 1000 years.

In other words, even with such assumptions, at the period of the 20 thousand-year-long climatic cycle for the basic time of a Cryochrone (a portion of the cycle corresponds also to the Thermochrone), the glaciers from Urals could, at best, only come closer to the Ob' River Valley, and only at the maximum of their development when they could pass a distance of about 150-200 km. Similar processes occurred in the surrounding mountains in the East of the West-Siberian Plain represented in the highest part by the Putorana and Byrranga mountains, although they are, relative to Urals, under conditions of a substantially larger cryoaridization. The slowly flowing cold ice from there could not advance for the geologically short Quaternary Cryochrones beyond the foothills of Byrranga and Putorana (see Fig. 1).

The question was raised, however, in respect to stony debris (middle-sized boulders, pebbles) occurred from time to time in the area of the Yenisei-Ob' interfluve north of the Middle Ob' River. Some researchers consider the debris as a moraine remained by a giant ancient glacier covering all area of Northwestern Siberia (*Arkhipov, 1997; Astakhov, 1998; Grosswald, Hughes, 2002*). However, it is unlikely that the glaciers were able to advance from the Putorana Plateau even to the valley of the Lower Tunguska River, whereas ice-floe drifts can be the process capable to spread the stony material.

To appreciate the significance of this statement, we can give a simple example. At present not so powerful river as Tom', a right-hand tributary of the Ob' River, is able to transport, by dint of ice-floe drift, the boulders from the mountains of Kuznetskii Alatau (Sayan system) to the suburbs of Tomsk, i.e. at a distance of several hundred kilometers. So, the scatter of stony material in our case is realistic. Consequently, it can result from the ice-floe spread of the material from the glaciers which reached the foothills of the surrounding mountains in Northwestern Siberia. It is realistic only during some ingression of the sea on the side of the Arctic Ocean when the level of its water surface rose to inundate the river valleys, or during high river floods which are usual for rivers in Siberia even at present (*Yamskikh et al., 1999*).

As to the widespread sea transgressions on the side of the Arctic Ocean (it is also a known fact occurred in past), it must be emphasized that at least in the Late Pleistocene, and so far, the Arctic coastal area has been everywhere dissected by the unaffected repeated ice wedges yielded by conditions of low-temperature permafrost. This means the wedges did not thawed, as the thawing ought to be occurred under subaquatic conditions.

In any case there are different ways for the rivers to overfill their stream canals in order to spill over low water-divides within the West Siberian Plane and transport the stony material to the area of the Ob'-Yenisei interfluve. However it can be a result of river specific development but not of giant glaciers moving from the North.

4 RELICS OF ANCIENT GLACIERS AND OTHER PROCESSES INFLUENCING ON THE STUDY AREA IN PAST

If to look at the Pleistocene troughs in the mountains surrounding the study area, these are well expressed valleys reworked by ancient mountain glaciers developed in the permafrost area. Sediments in their bottoms are frozen and include ground ice, whereas many sites in the bottoms have been influenced by icings (Fig. 3).

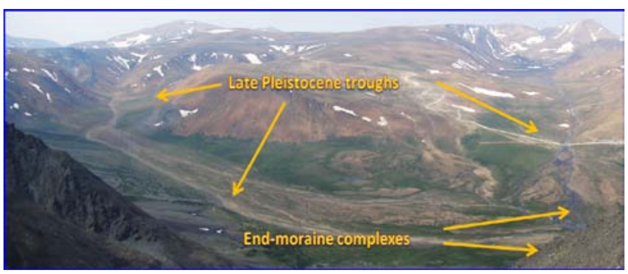

Figure 3. Valleys reworked by ancient glaciers, Polar Urals

The stony moraine material, however, has been distributed within the troughs and in the debouchments of the troughs only, and no relics of the glaciers advanced beyond them have been revealed in the area all over the foothills. There are results of ^{10}Be absolute dating obtained by J. Mangerud's scientific group (*Mangerud et al., 2008*) from boulders of terminal moraines lying in the vicinity of the modern glaciers of Polar Urals. As is apparent from these data, the MIS2 moraines lie immediately close to the modern glaciers, while the older MIS4 moraines are located in the foothill areas. Along with these data, the results obtained previously in the mountains in the South of Western Siberia (*Sheinkman, 2002, 2011*) also agree with such drawn conclusions. It was found then that the ancient glaciers advanced even from high mountains only to the boundaries of the middle mountains; they had a mountain-valley appearance and stopped at the edges of the intermountain depressions. The phase of their maximum occurrence corresponded to the beginning of the Late Pleistocene, and, thus, the general picture of development of the Pleistocene glaciation in Western Siberia has been integral.

The very intrigued phenomenon in such a case, and, at that time, the most interesting and very disputed formation reflecting the events from the Pleistocene in Northwestern Siberia, is so called Siberian Uval (in Russian – *Sibirskie Uvali*). This is a morphologically low upland (less than 300 m a. s. l.) at the right-hand bank of the Middle Ob' River. It has been stretched along the sub-latitudinal direction from Urals to the Yenisei River (Fig. 1). It was long thought to provide the basis for the conclusions that the Uval is a moraine delineating the boundaries of the former ice sheet occupying the entire north of the West-Siberian Plain (*Arkhipov, 1997; Astakhov, 1998, Grosswald, Hughes, 2002*). The reason is that the Uval, when to look at the map (see Fig. 1), is in the form of a ridge like to a moraine ridge; however, it is only in the form.

Another intrigued phenomenon in such a case is presence of erratic boulders and pebbles included in the deposits making up the upland of the Uval. Nevertheless, the structure of sedimentary material making up the Siberian Uval is everywhere of one type. It is composed of fluvial, mostly sandy, deposits. Indeed, their characteristic feature is availability of some stony erratic material, but it is much dispersed debris embedded in sandy deposits close the surface (Fig. 4-I, II). Moreover, a series of paleosols which have been first revealed during our research, are included in the body of the Uval (Fig. 4-III).

The stony material is represented by slightly rounded debris differing in composition and size. As usual these are middle-sized boulders and pebbles, and gravel in places.

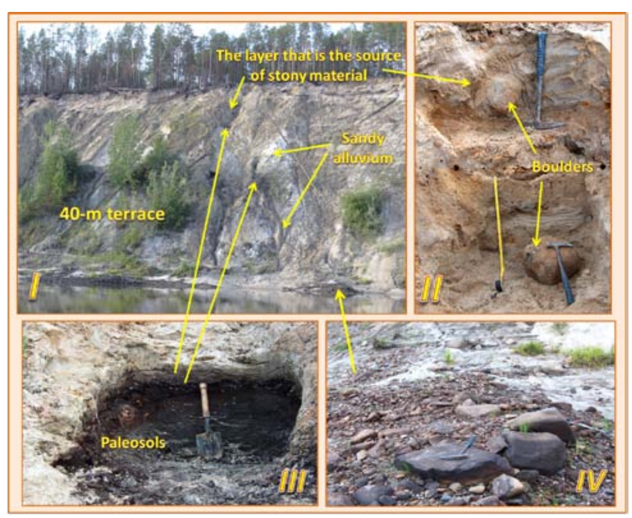

Figure 4.40-m section showing composition and structure of the Siberian Uval in its eastern part

Overall, the Siberian Uval represents a system typical of river terraces which have alternating extensive planate areas with a different degree of dissection. Not unfrequently the debris has been washed away from the terrace body, transported to the base of the terrace and accumulated at the river banks (Fig. 4-IV).

As indicated above, it may be safely suggested that such stony material is a result of river ice-floe drift, though initially it formed as a moraine at the foothills of the mountains surrounding the West Siberian Plain. All-in-all, the surface of the upland forming the Siberian Uval, in the area located along the latitudinal part of the Middle Ob' River at its right-hand bank (see Fig. 1), is a plane lying at an altitudes of 110–120 m a.s.l., increasing to 130–140 m a.s.l. in places. In separate blocks of sedimentary rocks, the absolute altitude of the surface is twice as large and has a maximum of 285 m a.s.l.; these blocks in the composition of the Siberian Uval are adjacent to Urals and to the Yenisei Valley only.

To our mind, the evolution of the considered upland is connected indirectly with the activity of the ancient glaciers yielding only the sediments which are a result of river ice-floe drift. Our findings showed that the Siberian Uval is not a moraine but constitutes a complicated system of the Ob' River terraces. In our opinion, it is a block of sedimentary rocks elevated by tectonic processes along ancient (but renewing during the Quaternary) faults. This block includes different sediments which are regular for reflecting the river activity but not for any glacial geological work.

It is appropriate to mark out three parts of the considered upland which differ by the certain characteristics. In the middle and eastern parts of the Siberian Uval, stony material embedded in the body of the terraces is not distinguished by a large size as a rule (Fig. 4). It is usually represented by pebbles and middle-sized boulders, the largest of which do not exceed half a meter across. However there are rare findings, here, of boulders at the rate of about 1m and even more across. All the stones are composed of rocks predominantly of the basaltic series. Usually, they include dolerites brought in from the Central Siberian Plateau, from the mountains of Putorana first of all (see Fig. 1).

It is intriguing that, characteristically, stony erratic material has obviously an initial glacial origin. The reason is that not unfrequently the boulders are represented by slightly rounded fragments of rocks brought in from far away, exhibiting so called glacial scars, scratches and grooves (Fig. 5-I).

Figure 5. Boulders washed away from the body of the Siberian Uval in its eastern part

However, the outward appearance of the boulders shows that the stony material was reworked intensely and resided in the aqueous environment for a long time. Fresh shears of the pebbles and boulders clearly show that the 1–2-millimeter surface layer is comprised of transformed (experiencing long-lasting water corrosion) light-color material (see Fig. 5-II). It confirms that such sediments can be a result of river ice-floe drift.

The relative height of the terraces produced by the tectonic elevation of the main block of sedimentary rocks between the valley of the Ob' River and the upper reaches of the Taz River is about of 30-40 m. Their surface lies at a height of about 120 m a.s.l., and they are generally uniform in their structure but differ in the outer appearance. In the eastern sector of the Siberian Uval, the terraces show abrupt bluffs formed by a deep incision of the upper reaches of the Vakh River (a right-hand tributary of the Ob' River) into the upland.

A characteristic feature is that stony material, when removed from the body of the terraces, accumulates at their foot to form separate areas with an almost continuous cover of natural bars by it, whereas in the middle part of the Siberian Uval, there are no deeply cutting valleys of the river network with a clearly visible structure of material in the bluffs. The absolute altitude of the terrace surface somewhat lowers here; it is at a height of about 110 m a.s.l., and its features are smooth.

In general, in this part of the Siberian Uval, the surface is weakly dissected. Nevertheless, we found by means of a series of digging pits in different areas of the terrace surface that its structure and the character of deposits remain the same as in the eastern part of the Siberian Uval.

In all these places the terraces continue to be composed largely of sandy deposits, and their composition includes from time to time embedded, weakly rounded coarse-debris stony material. There occur, among other things, middle-sized boulders composed of rocks predominantly of the basaltic series that have been brought in from the Central Siberian Plateau, as in the eastern part of the Siberian Uval. Once, nevertheless, in an excavation place, the boulders more than 1m across were revealed here. Usually, they are dolerites of the same composition as in the eastern part of the Siberian Uval, and on shears they clearly show a 1–2-millimeter corrosion crust, sharply contrasting with dark-color material beneath it.

All-in-all, it is possible to consider the central and eastern parts of the Siberian Uval as a uniform upland with the same composition of sediments. Nevertheless, the situation dramatically alters in the western part of the Siberian Uval.

In the western part of the Siberian Uval the upland is cut through by the valley of the Ob' River. Sandy cliffs of the 30-40-m terrace are also seen here, but, however, the boulder material on the banks becomes other than in the previous case (Fig. 6). The stony material now represents a cover stretching along the river banks over several kilometers, and the boulders have quite a different composition. They become rather large and often reach 2–3 m across. On the left-hand as well as the right-hand banks of the Ob' River, the boulders are represented largely by intrusive rocks (granites prevail among them) which was brought in from the northern spurs of Urals.

Figure 6. Boulders washed away from the body of the Siberian Uval in its western part

Nevertheless, the boulders, as before, are only embedded in the sandy bodies of the river terraces. The debris also gives evidence that the stony material underwent, for a long time, influence of the aqueous environment, as the stones are covered by a clearly seen thin corrosion crust on fresh shears but darker in color than material beneath it (see Fig. 6). In comparison with the eastern part of the Siberian Uval, the difference in the larger size and in the more quantity of the stony material in the western part of the Siberian Uval has been determined by more powerful activity of such stream as the main Ob' channel here.

It was important that we have revealed a series of paleosols included in the body of the considered terraces. In the meantime it occurred in the eastern part of the Siberian Uval, in the upper reaches of the Vakh River. According to analysis carried out by Prof. Sergey Sedov from the University of Mexoco, the paleosols refer to the type of cold hydromorphic soils which are quite well dated by the radiocarbon method. When the recent soil on the surface is a well-developed Podzol formed on the well-expressed sandy alluvial sediments, the burial paleosols in the body of the terraces are quite different.

The first buried paleosol level was encountered at a depth of a few meters on the parent substrate of a half-meter thickness with alternating clayey, loamy and sandy-loamy layers. One conventional radiocarbon date has been obtained from the total organic carbon of the first paleosol humus horizon. The measured radiocarbon age is 22100 $\pm$ 325 ^{14}C yr. BP (SOAN-7550), which after calibration produced the date 25693 – 27748 Cal BP, and it confirms the Last Karga Interglacial Time (MIS3) of the soil formation.

The paleosol underlays the sandy layer with the boulders and pebbles which occur at the top of the terrace (see Fig. 4). The stony material had thus to be washed up and distributed in the area of the Ob'-Yenisei interfluve during the Cryochrone MIS2. The samples from the second paleosol have been while processed, whereas the paleosols revealed upstream at the base of the terrace gave us out-of-limit ^{14}C ages – more than 40 000 yrs. (SOAN–7551, and SOAN–7552).

The finding of the paleosol, together with absence of unquestionable glacial sediments as between this paleosol and modern soil, so also between the upper and lower paleosols, and between them and the sandy base of the terrace, prove that the studied area was not covered by an ice sheet. Ancient glaciers developed in the mountain surrounding of Northwestern Siberia only, and then the stony moraine material could spread by river ice-floe drift during river floods, and also as a result of sea-water ingressions along the rivers on the side of the Arctic Ocean.

It is alluringly to explain appearance of the stony debris in the north of the West Siberian Plame as a result from an iceberg spread under the influence of wide sea transgressions on the side of the Arctic Ocean, but not only of local sea-water ingressions under that influence. However, widespread development of the repeated ice wedges everywhere in the north of the West Siberian Plane (*Streletskaia et al., 2011*) confirms that this area during the Quaternary Cryochrones (at least – during the Late Pleistocene Cryochrone) was a subaerial, but not subaquatic area.

So that the Siberian Uval as such constitute a complex system of river terraces in the form of an upland stretching along the latitude produced by a tectonic elevation of a large block of the Earth's crust along the right-hand bank of the Middle Ob' River on the system of ancient (but renewing during the Quaternary) faults, all the more so that the faults are often recorded by special-purpose investigations (*Kuzin, 2005*).

Anyway, the Arctic Ocean is a young, opening ocean, which is emphasized by the fact that it is traversed by the middle-oceanic ridges. It seems plausible that it is within the Arctic Ocean that the tectonic processes could trigger an inclination of the northern part of the West-Siberian plate from south to north, leading to the fact that its northern part was inundated periodically by the sea on the side of the Arctic Ocean, and a block of the Earth's crust on the right bank of the Middle Ob' River was elevated. That is why the well-expressed river terraces appear here.

CONCLUSIONS

North-West Siberia is a specific region because the first schemes of environmental development during the Quaternary have been appeared just here to be used then all over Siberia. At present there are different opinions in currently available models which differ widely on the glaciation pattern in Siberia in the past. To bridge the gap between different views we have to consider glaciation as an element of cryodiversity and take in account that in Siberia it inseparably linked with development of permafrost.

The past is not unfrequently used as the starting point for paleogeographical reconstructions. In the present state of affairs some models are based on the land ice-sheet pattern, whereas others entirely rule out the possibility that glaciers are indeed evolving, because formations produced by other processes are taken erroneously as their traces. However, the settings in which glaciers reside constitute a sensible indicator of heat and moisture balance, and an understanding of their dynamics is of significant importance because results obtained determine the reliability of analysis of the current climate warming trends, a critical factor of environmental changes. So, many researchers try to solve this problem and find acceptable solution.

It can be said with confidence that, in Siberia, it is appropriate to carry out a modeling of the foregoing processes by only taking into consideration the fact that the glaciation here was always evolving under permafrost conditions, in a setting of a developed cryoaridization. Therefore, it acquired a specific character to be taken thoroughly into account. Analysis of the material obtained from such a perspective demonstrates there were not the inland ice sheets in Siberia throughout the entire Quaternary. Even in the period of the most widespread occurrence of the Quaternary glaciation, it tended to occur in local centers in the mountains, and ice fields of the foot glaciers formed only in the debouchments of the troughs.

As a result of the research done in Northwestern Siberia, which has long been regarded as a classical region covered by the continental ice sheet, it may be safely suggested that in this case, too, there occurred only mountain glaciers. They developed in close interaction with permafrost and advanced to the plain from the surrounding mountains and stopped in the foothill areas.

In respect to the Siberian Uval, which was often taken previously as a moraine of the continental ice sheet covering the north of Western Siberia, a detailed study clearly demonstrated that it is a complex system of the Ob' River terraces. The greater part of them was produced as a result of the sub-latitudinal tectonic uplift of a block of the Earth's crust along the right bank of the Middle Ob' River at the end of the Late Pleistocene. This property is readily apparent from the age diagnostic of the near-surface sediments in the body of the Siberian Uval, as well as from availability of a series of paleosols included in these sediments.

All-in-all cryodiversity appear in Siberia (Northwestern Siberia is no exception) both at present and during the Quaternary as interaction and interrelation of mountain glaciers and permafrost phenomena. Researchers have to take into account such a fact to avoid distortions in their models showing development of the modern and ancient glaciation.

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