CHRONOLOGY AND EVOLUTION OF GLACIO-NIVAL SYSTEMS OF MONGUN-TAIGA MOUNTAIN MASSIF IN LATE PLEISTOCENE AND HOLOCENE.

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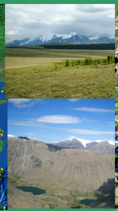
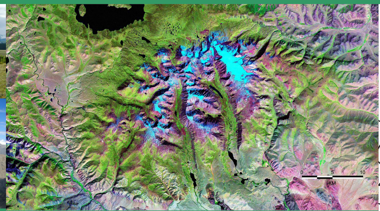
The main glacial complex of western Tuva - Mongun-Taiga mountain massif (3970 m, 50°16'N.L. 90°8' E.L.) i s situated in the intersection of Russian Altai, Mongolian Altai and Sayan mountain ridges. The massif is located to the south of the watershed of the Arctic Ocean and the inland drainage basin, in particular, the Great Lakes basin. Since 1988, the present and past landscapes of the massif have been studied by the scientists of St. Petersburg State University. The study of the glaciers includes in situ monitoring of their current state, meteorological and balance observations. Paleogeographic studies are based mostly on geomorphologic methods, radiocarbon and dendrological dating and mathematical modeling. Despite rarity of organic material we have a collection of about 50 …. Of buried soils, peat and wood from Mongun-Taiga massif and surrounding territories. Some of them were included into this article.

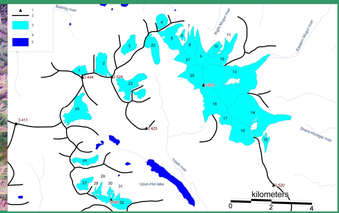
General location of the area of research.



Mongun-Taiga massif from space.



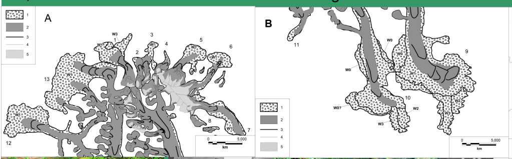
Modern glaciation of the massif. 1 - peaks, 2 - ridges, 3 - rivers, 4 - lakes, 5 - glaciers



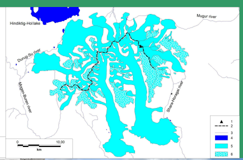
Modern glaciation of the massif is represented mostly by small forms, its total area is 20 km². Average annual temperature at the foot of the massif is -2.6℃, annual precipitation is 145 mm (about 300 mm in the glacial area, about 35-50% in the summer). Glaciers exist due to low temperatures and high concentration of snow on the leeward north-eastern slopes. There are 2 glacial complexes: around the main peak and on the plateau with the highest point of 3,681 m. Both complexes are formed by dome-shaped ice fields in their central parts that make united accumulation zones for the glaciers that radiate from them. The ELA average altitude is 3380 m.

There are 4 groups of old moraine complexes in the massif. The first group are remains of glaciation that covered high plateaus and flat summits–fragments of basal moraine with erratic blocks jn the watershed areas in the periphery of the massif. Probable age of glaciation is mid-Pleistocene though there are no isotopic data on it and very little information on its extent. Moraines of the next group extend from cirques at the level of about 3100 m on troughs shoulders to the flat piedmonts forming lobes reaching the level of 1830 m in the south of the massif and 2200 м in the north. Numerous old thermokarst forms and lakes on their surface are the result of fast transformation of the lobes of the glaciers into the massifs of dead ice.

Late Pleistocene Moraines of the north (A) and south (B) of the massif. 1- Early Stage of the LG, 2- Maximum of the Late Stage of the LG, 3- Postmaximal advances of the Late Stage of the LG

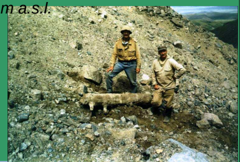


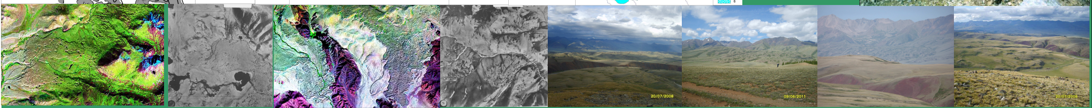
Reconstruction of the glaciers of the massif in the maximum of the Early Stage of the LG



1- main mountain peak of the massif, 2- main watershed, 3- modern rivers, 4- modern lakes, 5- valley and piedmont glaciers, 6- snowfields of flat summits and plateaus

Wood with radiocarbon age 58-43 t.e. BP melting out from moraine at altitude about 3000 m a.s.l.



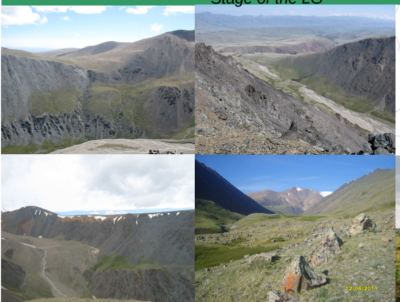


There are traces of 4 glacial advances, during the maximal (W1) the area of glaciation reached 513 km² with 800 m of depression of firn line. Moraines of later advances W2 and W3 inside the troughs have lower level and their lobes have less area. At the same time in some places at the piedmont of the massif they overlap the maximal moraine, reaching the lowest points of glacial extent in the late Pleistocene.

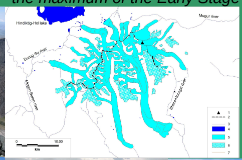
Moraine complexes of this group are typical for south-eastern Altai and northern Mongolia, maximal advance is TL-dated 58±6,7 ka BP (Borisov B.A, Minina E.A., 1989) the corresponding with the glaciation pluvials - 76±9 ka BP and 63±8 ka BP (Devyatkin E.V., 1981). We consider these glacial advances as the Early Stage of the Last Glaciation (MIS 4) Though we have no isotopic data of glacial advances of this period in the massif, the warm period after them is indentified by numerous carbon data in the interval 58-39 ka BP and 27-25 ka BP of buried wood found 600 m and 900 m higher than present upper forest line. This proves that during MIS-3 the glaciers of the massif were less, than now. This wood was buried by moraines of the next group that correspond with glacial advances of the Late Stage of the LG.

Trough shoulders

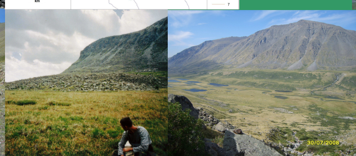
Moraines of the Late Stage of the LG



Reconstruction of the glaciers of the massif in the maximum of the Early Stage of the LG



1- main mountain peak of the massif, 2- main watershed, 3- modern rivers, 4- modern lakes, 5- valley glaciers, 6- snowfields of flat summits and plateaus



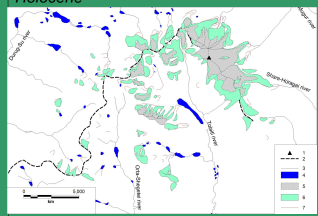
Moraines of the Late Stage of the LG

Moraines of the Late Stage of the LG glaciers extend from cirques at the level 2600-2700 m. Flank moraines on trough shoulders are situated 200-500 m lower, than those of the Early Stage. Terminal moraines reach the minimal level of 2200 m in the south and 2400 m in the north. The area of glaciation in the maximum was about 320 km², firn line depression about 690 m. There are 4 moraine complexes of postmaximal advances, many of them, especially moraines of the the last of them are (presumably Younger Dryas with firn line depression about 500 m) are marked by series of moraine-dammed lakes.

In the Early Holocene glaciers reduced rapidly, evidence of this reduction are samples of wood with age 9120±110 cal. B.P. that were found about 350 m over the present forest line. Geomorphologic evidence of this period – erosion trench cutting through the moraines of the Late Stage of the LG to the level of 3000-3100 m. In the Atlantic period glaciers of the massif didn't exceed their present size and mostly were less than now. It is proved by numerous samples of buried wood, soils and peat taken between the LIA moraines and the present forest line with radiocarbon age in the interval about 6000-3600 years B.P .

Late Holocene moraines are complexes of 2-4 terminal moraines adjacent or thrust one another. They are thick, poorly covered with vegetatio or bare, have steep foreslopes and often contain buried ice. The glacial advance of the historical (subatlantic) stage took part between 3600 and 1200 years B.P., reconstructed depression of firn line is 155 m, probable cooling was 1.5 ℃ relative to pre sent. Climatic conditions of the interstadial 1200-1130 years B.P. were not colder than present. Glacial advance of the LIA probably had 2 phases, the culmination of the last of them took place in the middle of the XIX century (dendrological reconstruction). Reconstructed depression of firn line is 120 m, cooling 0.9 ℃ relative to present

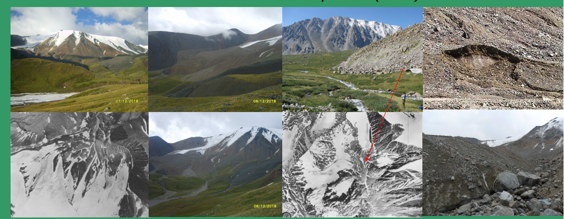
Glaciation of Mongun-Taiga massif in Late Holocene



1- main mountain peak of the massif, 2- main watershed, 3- modern rivers, 4- modern lakes, 5- modern glaciers, 6- glaciers of the massif in the middle of the XIX century (2 phase of LIA) 7- other moraines of Late Holocene

Moraines of Late Holocene and their aerial photos (1965)

Ice core of LIA moraines



Reconstruction of climatic conditions of the glacial stages was found through the values of firn line depression for the appropriate period. Calculations were based on model of G.E. Glazyrin (1985), according to which mass balance (*M*)on some level *Z* close to the firn line level *Zf* is the following: : *M(Z)=M(Zf)+E(Z-Zf) (1),* where *E-* energy of glacierization (activity index)

In case of changes of precipitation and temperature mass balance on this level can be calculated as: *M(Z)=P·c(Zf)-a(T(Zf)+ΔT)+E(Z-Zf) (2)* , where: *c(Zf)-* present accumulation on firn line; *P-* ratio of past precipitation to present; *a(T(Zf)+ΔT)-* ablation at present firn line level in case of change of temperature ΔT; *E-* energy of glacierization (activity index) in new climatic conditions.

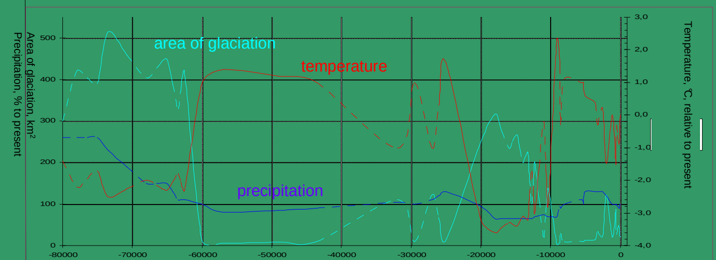
The level where in new climatic conditions annual mass balance is 0 is the *new level of firn line (Zfn): P·c(Zf)-a(T(Zf)+ΔT)+E(Zfn-Zf)=0 (3),* in this way *Zfn=Zf-(P·c(Zf)-a(T(Zf)+ΔT))/E (4). Firn line depression* ***(ΔZf)*** *can be found by formula:* ***ΔZf=P·c(Zf)-a(T(Zf)+ΔT)/E. (5)***

energy of glacierization (activity index) can be calculated by formula: *E=P·K·(Δp/ΔZ)+ Δa/Z (6)*, where: *K-* coefficient of concentration of snow, *Δp/ΔZ-* gradient of precipitation, *Δa/ΔZ-* gradient of ablation.

If we find *ΔZf* for the reconstructed glaciers we can use formula *(5)* to find *P (if we know ΔT)* or *ΔT (if we know P).* One of the solutions is to calculate different climatic scenarios when one of the unknown parameters is preassigned. Choice of the most probable scenarios can be done on basis on regional paleoclimatic reconstructions of other scientists and on regional dependences. The first one is dependence of summer precipitation from average summer temperatures on meteostations of Altai (for the scenarios of humifying and cooling). The second one is dependence of precipitation from temperature in the closest to Mongun-Taiga massif meteostation Mugur-Aksy (for the scenarios of aridization and cooling).

For the warm periods (MIS-3, Early Holocene, Atlantic period) we know the difference between the present tree upper limit and its level in the past, so *ΔT* is easy calculated on the basis of regional altitudinal gradient of summer temperature (0.69℃/100 m). Then we have to solve inverse problem: *ΔT* is the known parameter, *P* and *ΔZf* are the unknown. The choice of the most probable scenarios was made in the same way as for the glacial stages It is necessary to put some corrections into the climatic scenarios. On base of geomorphologic evidence we presume 400 m tectonic uplift of the central part of the massif from the ending of the Early Stage of the LG. This means 400 m corrections into *ΔZf* for the Early Stage of the LG and the beginning of MIS-3 warming, about 125 m- for the Late Stage of the LG in case of steadiness of the uplift.. For the Holocene the corrections are insufficient

Reconstruction of glaciation and climate of Mongun-Taiga massif in Late Pleistocne and Holocene. Main dating used: 1- 76±9 ka BP . [Devyatkin E.V., 1981]; 2- 63±8 ka BP [Devyatkin E.V., 1981], 3. 58±6,7 ka BP [Borisov B.A., Minina E.A., 1989; Svitoch A.A., Faustov S.S., 1978], 4-9- ¹⁴C dating of buried wood, Mongun-Taiga massif, in the interval 58-43 ka BP ., 10- 26±3 ka BP [Devyatkin E.V., 1981]; 11- 25±0,2 ka BP [Revushkin A.S., 1979], 12- 11,5±1,18 ka BP[Sevastyanov D.V. et. al., 1994], 13- 9,12±0,11 ka BP[ЛУ-6949];14- 5,25±0,16 ka BP(ЛУ-5830;) 15- 3,61±0,09 ka BP(ЛУ-6452); 16- 1,2±0,09 ka BP(ЛУ-6818). .



Some of the most probable climatic scenarios

Period	ΔT°	P%
Early Stage of LG	-2,5	230
MIS-3	1,4	80
Late Stage of LG	-3.6	65
Younger Dryas	-2.8	70
Early Holocene	1.5	70
LIA (2nd phase)	-0.9	90