



# Holocene glacier fluctuations and climate changes in the southeastern part of the Russian Altai (South Siberia) based on a radiocarbon chronology

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## Abstract

This study investigates glacier dynamic and climatic variations in the southeastern part of the Russian Altai (SE Altai) during the last 7000 years. Recent glacier retreats and ice melting in moraines has led to exhumation of organic material allowing the possibility of radiocarbon dating. We report here 57 new radiocarbon dates from wood remains buried by moraines and from proglacial forefields, from peat layers and lacustrine sediments that cover moraines, from dead trees at the upper tree limit, and from rock glaciers on trough slopes from six glacial valleys in the North Chuya Range, SE Altai. Such a numerous dataset for the vast but unified in neotectonic and climatic conditions area is presented for the first time the history of research in the Altai.

Together with 62 previously published radiocarbon ages, mainly of fossil soils and peat layers in the foot of the ranges in SE Altai, they form the basis for understanding the relative magnitudes and timing of the most important glacial and climatic events of SE Altai. New data refute the traditional concept of the Russian Altai Holocene glaciations as a consecutive retreat of the late Würm glaciers and argue their complete degradation at the head of trough valleys at least 7000 cal. years BP. Moraine complexes of three Holocene glacial stages are morphologically expressed in trough valleys of the North Chuya range. They correlate with three identified periods of glacial advances: from 4900 to 4200 cal. years BP (Akkem stage), from 2300 to 1700 cal. years BP (Historical stage) and in the 13th–19th centuries (Little Ice Age (LIA) or Aktru stage). The coincident extremes of lowering temperature and increasing precipitation during the Akkem stage led to abrupt glacier advances and forming of the most remote moraine complexes downstream in the valleys. Following glacier advances had distinctly smaller magnitudes. In addition to the radiocarbon data, the time limits of the Historical stage were defined more precisely using dendrochronological and archaeological data from Scythian burials of Pazyryk culture in SE Altai. Repeated forest regrowth in the presently glaciatiated area indicates significant retreat or even complete glacier degradation during interstage warming. The decreases of glacier length in the following stages argues for intensification of aridity in the

SE Altai during the second half of the Holocene. The thermal minimum in the middle of 19th century, the greatest in the last millennium, did not positively influence the mass balance of glaciers, which also supports this conclusion.

## Highlights

► The Holocene glacier dynamics of the Russian Altai (South Siberia) is investigated. ► 57 new radiocarbon dates from various environments is presented. ► Three morphologically expressed moraine complexes have been dated.

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## Introduction

In contrast to a hypothesis of a stable Holocene climate, as indicated by oxygen isotope records from the Greenland Ice core (Johnsen et al., 1997), a growing number of studies (e.g. Mayewski et al., 2004 and references therein) have demonstrated that distinct periods of climate change occurred repeatedly throughout the Holocene. Mountain glaciers are potentially good climatic indicators, but most of the information on the dynamic responses of mountain glaciers to past climate changes comes from European glaciers which only form 3% of the world's glaciated area (Dyrgerov and Meier, 1997). Knowledge of the Holocene glacier behaviour of remote and inaccessible mountain regions, often characterized by a high degree of glaciation, is rather limited. For better understanding of the global spatial-temporal climate variability throughout the Holocene, it is very important to study worldwide glacier dynamics, including the mountains of inner Asia. This paper seeks to expand the current Holocene climatic records worldwide by presenting and analyzing data gathered from six trough valleys of the North Chuya range, SE Altai, Russia (Fig.1).

The Altai Mountains are part of the Central Asia collision belt. They stretch northwest more than 1500km across the borders of Mongolia, China, Kazakhstan and Russia, and form a wedge shape narrowest in the southeast and widest in the northwest. Modern climate of Altai Mountains is determined by its intracontinental position, with main moisture transfer from the west (Atlantic Ocean), and to a lesser degree from the north (Arctic), and a dominant influence of the Mongolian anticyclone, giving rise to increasing aridity eastwards and complicated latitude-longitude orographic climatic zoning.

The high-mountain southeastern part of the Russian Altai (SE Altai) which is examined in this paper is characterized by an arid climate - the mean annual precipitation is <200mm in the floor of Kurai and Chuya intermountain depressions (Rusanov, 1961). Nevertheless, the SE Altai is the centre of modern Altai glaciation; about 75% of the modern glaciated area in the Russian Altai, with a total surface 910km<sup>2</sup>, is concentrated here (Revjakin et al., 1979). In spite of the arid climate, the high altitudes of the ridges (up to 4500ma.s.l. – the largest for Asian part of Russia) are favourable to glacier formation. The mean annual precipitation near the snow line decreases along the W-E axis from 2000mm to less than 500mm (Naroznyi and Osipov, 1999), and as a result, the altitude of the snow line rises from 2400ma.s.l. in the western part of Katun ridge to 3350ma.s.l. on the Mongolian border. The upper forest line (2350–2450ma.s.l.) is slightly above or equal to the altitudes of glacier terminus positions (2200–2500ma.s.l.), and the upper tree limit has absolute altitude about 2500ma.s.l. In the eastern part of the studied area the forest has an insular distribution. Under conditions of moisture deficit, the main factors controlling glacier cover are: absolute altitudes, slope insolation (which is particularly important in the case of the sub-latitudinal trending of the most mountain ranges within SE Altai), asymmetric structure of mountain ranges (gentle northern slopes are much longer than steep southern ones which cause a larger surface for the glacier basins with northern exposure), and the concentration of solid precipitation on northern leeward slopes. Thus, the overwhelming majority of the glaciers are located on the northern slopes of the highest ranges of SE Altai: Katun, South

Chuya and North Chuya. The total ice volume on the northern slopes of the North Chuya range is twice as much as on the southern ones, and within the South Chuya range located to the east this ratio is about 7:1 (Nikitin et al., 2000). The similar distribution of modern, Holocene, and late Pleistocene glaciers argue for the same oroclimatic zoning and moisture deficit in this area from the beginning of the late Pleistocene (Agatova, 2005).

During the last decade a unique opportunity for investigation of the Holocene glacial history occurred. Ongoing glacier retreats and ice melting in moraines led to the exhumation of organic material allowing the possibility of radiocarbon dating. This study reports 57 radiocarbon dates from wood remains buried by moraines and from proglacial forefields, from peat layers and lacustrine sediments that cover moraines, from dead trees at the upper tree limit, and from rock glaciers on trough slopes within six glacial valleys of the North Chuya Range, SE Altai (Russia).

We have also analyzed all previous 62 radiocarbon dates obtained by prior studies in the SE Altai (Table 1). Only 18 of these, and all our samples, were collected in the heads of trough valleys. The remaining 44 samples are from fossil soils and peat layers from sediments within the Kurai and Chuya intermountain depressions and from the bases of framing ridges, therefore, they cannot answer questions about the magnitudes of glacier retreats and upper tree limit rising in crest areas of the ridges. Instead, we use these data for the basis of the timing of interstage warm periods during the Holocene.

The new data refute the traditional concept of the SE Altai Holocene glaciations as a consecutive retreat of the late Würm glaciers, and allow the timing of the most important glacial and climatic events in the area during the second half of the Holocene to be determined. This study bases the chronology of the last three stages of glacier advances on their expression in the topography: Akkem, Historical and Aktru (LIA) stages.

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## Section snippets

### History of investigations into the Russian Altai Holocene glaciations

Holocene glacier variations in the Russian Altai have been investigated and debated by many researchers (Mjagkov, 1936; Tjumencev, 1936; Vardanyants, 1938; Dushkin, 1965; Ivanovsky, 1967, Ivanovsky, 1993; Ivanovsky and Panychev, 1978; Ivanovsky et al., 1982; Okishev, 1982; Butvilovsky, 1993; Solomina, 1999; Galahov et al., 2005, Galahov et al., 2008). The Holocene glacial stages in the Russian Altai are traditionally marked out according to the scheme of Würm glacier degradation, suggested by ...

### Methods

Geomorphological methods were used for reconstruction of glacier advances for different stages. The distribution of moraines and proglacial landforms in the North Chuya range was investigated based on interpretation of aerial photographs, topographic maps at a scale of 1:25,000, and field investigations which included mapping and sedimentological analysis of terminal and flank moraines in different states of preservation and vegetation cover. Moraines in each glacial valley were initially...

### Stage moraine complexes in glacier valleys of the North Chuya range

Typical altitudes of the North Chuya range, one of the centres of modern Altai glaciation, are about 3000–3100 m a.s.l., and in the central part, the Bish-Iirdu massif, up to 3500–3700 m a.s.l. The highest peaks are Maashey (4177 m a.s.l.) and Aktru (4056 m a.s.l.). The ridge crest areas are characterized by alpine topography.

Valleys represent embedded troughs where the upper part is occupied by glaciers. The glaciers have retreated steadily since the beginning of the 20th century (average...

## Glaciological interpretation of dated samples

Dating of glacially-generated landforms requires corresponding attention to the processes leading to the formation or deposition of the dated features. The interpretation of data derived from collected samples depends on their history. Sources of uncertainty include different initial locations of wood, transportation, and the position of the wood at collection sites. Therefore, it is important to specify the history of the samples in order to enable a conclusive interpretation.

Our...

## Results

Our investigations of glacier dynamics and climatic variations in the southeastern part of the Russian Altai allowed us to gather a collection of organic material from within six glaciated valleys of the North Chuya range which characterize the time period from 7000 to 400 cal. years BP. All the radiocarbon dates obtained are presented in Table 3 and Fig. 9. The locations of all the study sites are shown in Fig. 10. The samples can be divided into five groups on the basis of their location,...

### 7.1.1. 10,000–7000 cal. years BP (degradation of Late Würm (Sartan) glaciation)

Radiocarbon ages of plant remains in lacustrine sediments from a small Dzhangyskol lake of glacial origin and from pingos in Eshtykkel stow (1750 ma.s.l.; Fig. 10I) confirm deglaciation of the foot of the north slope of the North Chuya range had occurred by 15,000 cal. years BP (12,600±1371 (SOAN 1665), 12,837±107 (SOAN 236), 15,473±475 Utc 8470) (Butvilovsky, 1993; Blyakharchuk et al., 2008).

By the early Holocene a more humid and warm climate in comparison with the modern one, dominated ...

## Conclusion

Research in glacially-generated landforms in the heads of six glacial valleys in the North Chuya Range, SE Altai, Russia, has identified organic material of different types. The radiocarbon ages of dated samples are used to establish the time periods favourable for forest growth in modern glaciated areas and to identify the upper tree limit position associated with prolonged and steady climatic improvements. The extended dataset of such favourable periods limits the times of climate...

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