Quaternary Science Reviews 49 (2012) 16–32

Contents lists available at SciVerse ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

History of late Pleistocene glaciations in the central Sayan-Tuva Upland (southern Siberia)

Sergei G. Arzhannikov [a,*], Regis Braucher [b], Marc Jolivet [c], Anastasia V. Arzhannikova [a], Riccardo Vassallo [d], Alain Chauvet [e], Didier Bourlès [b], Frédéric Chauvet [b]

[a] Institute of the Earth's Crust, Russian Academy of Sciences, Siberian Branch, Lermontova 128, 664033 Irkutsk, Russian Federation
[b] CEREGE, UMR7330, CNRS, Aix Marseille Univ., BP80, 13545 Aix en Provence, France
[c] Géosciences Rennes, UMR6118, CNRS – Université Rennes 1, Campus de Beaulieu, 35042 Rennes Cedex, France
[d] LGCA, Universite de Savoie, Le Bourget du Lac, France
[e] Laboratoire Geosciences Montpellier, CNRS-UMR5243, Universite Montpellier II, Montpellier, France

A R T I C L E I N F O

Article history:
Received 7 August 2011
Received in revised form
6 June 2012
Accepted 8 June 2012
Available online 16 July 2012

Keywords:
Late Pleistocene glaciations
Cosmogenic ^{10}Be
Southern Siberia
East Sayan Ridge
Moraines

A B S T R A C T

This work describes the history of late Pleistocene glaciations in the central Sayan-Tuva Upland (southern Siberia). Geological and geomorphological analysis as well as ^{10}Be surface-exposure dating revealed the glacier fluctuations in this continental area. The available published data show that the glaciers were formed in the MIS 6 and probably survived in the MIS 5. Data are also available concerning glacial advances in different periods of MIS 4, MIS 3 and MIS 2. ELAs were 2030–2230 m. Two distinct ^{10}Be exposure ages groups are highlighted reflecting the time of formation of glacial deposits in the MIS 2 associated to the Big Sayan Ridge outlet glaciers. The Sentsa – Sailag group (terminal moraine) has a mean exposure age of 16.44 ± 0.38 ka. The Jombolok (terminal moraine) – Jombolok (outwash plain) group has a mean exposure age of 22.80 ± 0.56 ka. The last glaciation that occurred at MIS 2 is characterized by the absence of ice cap on the Azas volcanic Plateau and of ice field in the Todza Basin. The thickness of the valley glacier was 300–400 m. At MIS 2, the terminal moraines were ~1300–1400 m a.s.l. in the Tissa, Sentsa, Jombolok and Sailag river valleys.

1. Introduction

This work presents a synthesis of the published literature on glaciations in the eastern part of the Sayan-Tuva Upland area (Big Sayan Ridge, Todza Basin, Oka Plateau and Azas volcanic Plateau) (Fig. 1). Newly acquired in situ produced cosmogenic ^{10}Be data associated to a detailed geomorphologic study have then been used to constrain the chronology of the late Pleistocene glaciations in this region.

The analysis of Quaternary glacial deposits in southern Siberia and northern Mongolia recently provided some answers to unsolved questions on glacial sedimentation in this region (Matsera, 1993; Nemchinov et al., 1999; Krivonogov et al., 2005; Gillespie et al., 2008; Krivonogov, 2010). The ages of the glacial and lacustrine deposits were estimated and glaciations-related structures were mapped (Matsera, 1993; Yarmolyuk et al., 2001; Sugorakova et al., 2003; Komatsu et al., 2007, 2009; Gillespie et al., 2008; Krivonogov, 2010).

Many geomorphological landforms resulting from late Pleistocene glaciers activity are preserved within the Sayan-Tuva Upland and make it possible to reconstruct the paleoenvironment using various independent approaches. For example, most of the Quaternary volcanoes in the Azas volcanic province were formed in a subglacial environment (Yarmolyuk et al., 2001; Sugorakova et al., 2003; Komatsu et al., 2007). Using the size, structure, morphology and age of the tuya-volcanoes it is possible to constrain the position and thickness of the overriding glaciers. Another example is the formation of the Darhad Lake and the geomorphic evolution of the Darhad Basin (Fig. 1). The outlet glaciers extending from the Big Sayan Ridge ice field toward the south formed a glacial dam in Shishid-Gol valley. Studying and dating the various lake deposits associated to this dam allowed reconstructing the advance of glaciers in the Darhad Basin (Krivonogov et al., 2005; Gillespie et al., 2008; Komatsu et al., 2009).

Considering the role of glaciation in the evolution of the relief of the Eastern Sayan, Matsera (1993) presents the data on glacial and alluvial deposits in nine cross-sections of the Todza Basin and Azas volcanic Plateau. According to TL age estimate for burnt sub-basalt deposits (160 ka), the glacial maximum was after the emplacement

* Corresponding author. Tel.: +7 3952 429534; fax: +7 3952 426900.
E-mail address: sarzhan@crust.irk.ru (S.G. Arzhannikov).

0277-3791/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.quascirev.2012.06.005

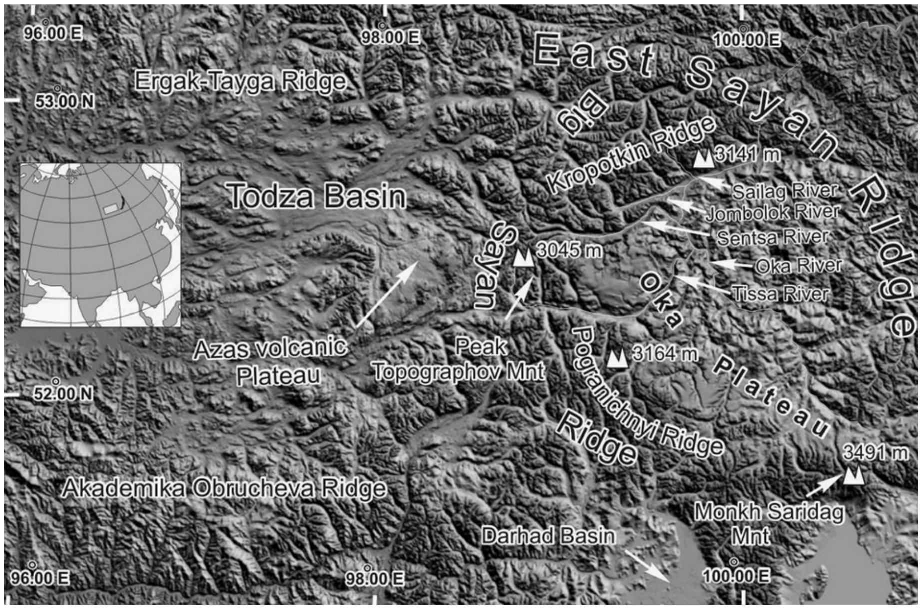

Fig. 1. Location map and topography of the investigated area with indications of the main orographic structures. (Topography from 90-m SRTM (Shuttle Radar Topography Mission)).

of the basaltic lava flow. No moraine deposits are found in pre-basalt sediments (Matsera, 1993).

This work intends to estimate the timing and extent of the late Pleistocene glaciations around the Big Sayan Ridge (Fig. 1). Different glacial features that developed during the various Quaternary glaciation stages were dated using in situ produced cosmogenic ^{10}Be. We especially focused on the marginal moraines in the Jombolok, Sentsa and Sailag river valleys. Investigations were conducted using cosmogenic isotopes geochronology (^{10}Be), radiocarbon dating (^{14}C), geomorphology, remote sensing data (90-m SRTM (Shuttle Radar Topography Mission)), 1:32,000 and 1:50,000 scale aerial photographs, Landsat images, 1:200,000 geological maps, 1:100,000 topographic maps, and field mapping.

2. Geographical setting and timing of glaciations: present knowledges

The central Sayan-Tuva Upland is a key area to understand the physical conditions and extent of glaciation in the eastern Siberian Mountains and to reconstruct the late Pleistocene paleogeography and climate of this area. In this region, the topography combines mountain ridges, elevated plateaus and deeply incised river valleys. Within the investigation area, the Todza Basin and the southern East Sayan Ridge are the major orographic structures. They include smaller-scale orographic objects such as the Big Sayan Ridge, the Oka Plateau and the Azas volcanic Plateau (Fig. 1).

The Big Sayan Ridge is located in the southern part of East Sayan Ridge, and forms the watershed between the basins of the Yenisei River and the Angara River. It consists of ridges and peaks (Fig. 1) with altitude varying between 2700 and 3491 m (the Kropotkin Ridge (3141 m), Peak Topographov (3044 m), the Pogranichnii Ridge (3164 m) and Monkh-Saridag Mountain (3491 m)).

The Oka Plateau, rising up to 1800–2500 m holds a central position therein. It is characterized by a well-preserved Cretaceous – Paleogene peneplanation surface forming the main part of the plateau (Arzhannikova et al., 2011; Jolivet et al., 2011). Owing to Neogene volcanism (Rasskazov et al., 2000), part of the plateau was covered by basalt and did not undergo intensive denudation since the Miocene (Jolivet et al., 2011). The major river systems draining the western Oka Plateau are the Jombolok, Sentsa, Tissa and Oka rivers showing measured incision depth of about 700–800 m. To the west, the Azas volcanic Plateau is covered by an accumulation of tertiary basalt sheets, Quaternary large tuya-volcanoes (with a relative height of about 500 m and an area of about 100 km^2), cone-shaped volcanoes and basalt lava flows. Farther west, the Todza Basin is the largest structure of the East Tuva region and is bounded by the Akademika Obrucheva Ridge to the south and by the Ergak Tayga Ridge to the north (Fig. 1).

Since the second half of the 19th century many Pleistocene glacial features have been described in the region, providing ideas of dimensional and characteristics of Pleistocene glaciers (e.g. Kropotkin, 1867; Chersky, 1881; Voieikov, 1881; De Henning-Michaelis, 1898; Peretolchin, 1908; Molchanov, 1934).

More recently, detailed glaciological studies were conducted using remote sensing and large-scale geological survey (Obruchev, 1953; Ravskii et al., 1964; Grosswald, 1965, 1987; Olyunin, 1965) which detailed the extent of piedmont glaciations in the Todza Basin as well as mountain and valley glaciations in the East Sayan ranges. The estimated ice thickness was ranging from several hundreds of meters (East Sayan) to 1 km (Todza Basin). Glaciations were concentrated on the axial part of the Big Sayan Ridge and on the Azas volcanic Plateau. The altitude of the terminal moraines was more than 930 m in the Todza Basin and more than 740 m in the East Sayan (Grosswald, 1965; Olyunin, 1965).

New data on glacial deposits in the East Sayan Ridge and northern Mongolia (^{14}C, OSL, IRSL, ^{10}Be, thermoluminescence (TL) and palynology) allowed recognition of late Pleistocene phases of glaciers extent corresponding to MIS 5d/5b, MIS 4, MIS 3 and MIS 2 (Matsera, 1993; Nemchinov et al., 1999; Krivonogov et al., 2005; Gillespie et al., 2008; Krivonogov, 2010).

The study of glacial and sub-basalt deposits in nine cross-sections of the Bii-Khem, Sorug and Azas river valleys (Fig. 2) provided important additional information on glacier dynamics for both late and middle Pleistocene (Matsera, 1993). In the Sorug valley the studies have been made into a series of cross-sections (A) and (B) (Fig. 2) whose bottom parts are composed of solid rocks, granites covered by bright-red sandy-loamy-grussy weathering crust (section A), and weathered reddish-yellow pebbles with