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Research paper

OSL dating of glacial deposits during the Last Glacial in the Terskey-Alatoo Range, Kyrgyz Republic

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Abstract

Optically stimulated luminescence (OSL) dating was applied to glacial and loess deposits in the north flank of the Terskey-Alatoo Range, Kyrgyz Republic, to elucidate the glacier chronology of the central Asian mountains during the Last Glacial. Moraines in five parts of study area were classified into four stages (Terskey Stages I–IV) based on their geographical position and elevation, and their moraine rock weathering. According to this classification, the oldest moraines (Terskey Stage I) were at 2100–2250 m a.s.l. and the second-oldest moraines (Terskey Stage II) were at 2400–2700 m a.s.l. Quartz samples from moraines of these two stages were used for OSL dating. The OSL ages of the quartz samples indicate that glacier expansion in the Terskey Stage II occurred between 21 and 29 ka BP.

Keywords: OSL dating; Last Glacial; Glacier chronology; Kyrgyz Republic

1. Introduction

Due to local climate variability, mountain glaciers of the world responded differently to the climate of the Last Glacial (Derbyshire et al., 1991; Gillespie and Molnar, 1995). The glacier history of the central Asian mountains is known mainly through relative dating methods including soil development (Bäumler et al., 1999; Zech et al., 2000) and moraine elevations (Grosswald et al., 1994; Meiners, 1997; Heuberger and Sgibnev, 1998). Recently, the glacier chronology has been studied using ^{14}C ages of soil layers in lateral moraines in the Pamir-Alay (Zech et al., 2000; Narama and Okuno, in press) and using the cosmogenic ^{10}Be surface exposure ages in the central Pamirs (Zech et al., 2005). Absolute dating is a critical component of glacier chronologies, particularly in mountains with a complex climate environment such as the central Asian mountains. Thus absolute method should also be applied to the glacial chronology studies in this region. Optically stimulated luminescence (OSL) dating has also been applied to glacial deposits in the high mountains of the Himalayas and Karakoram (Richards et al., 2000; Owen et al., 2002; Tsukamoto et al., 2002). This paper reports OSL age estimates from loess and glacial deposits located on the northern flank of the Terskey-Alatoo Range, Kyrgyz Republic, with the purpose of elucidating the times of glacier expansion and retreat in the area.

2. Research area

The Terskey-Alatoo Range is located along the south shore of Lake Issyk-Kul in the northeastern part of the Kyrgyz Republic (Fig. 1A, B). Our research was done in five areas (Turasu, Alabash, Dengtala, Kek-Say, and Temir-Kanat) on the northern flank of the western part of the Terskey-Alatoo Range (Fig. 1C). Most glaciers in

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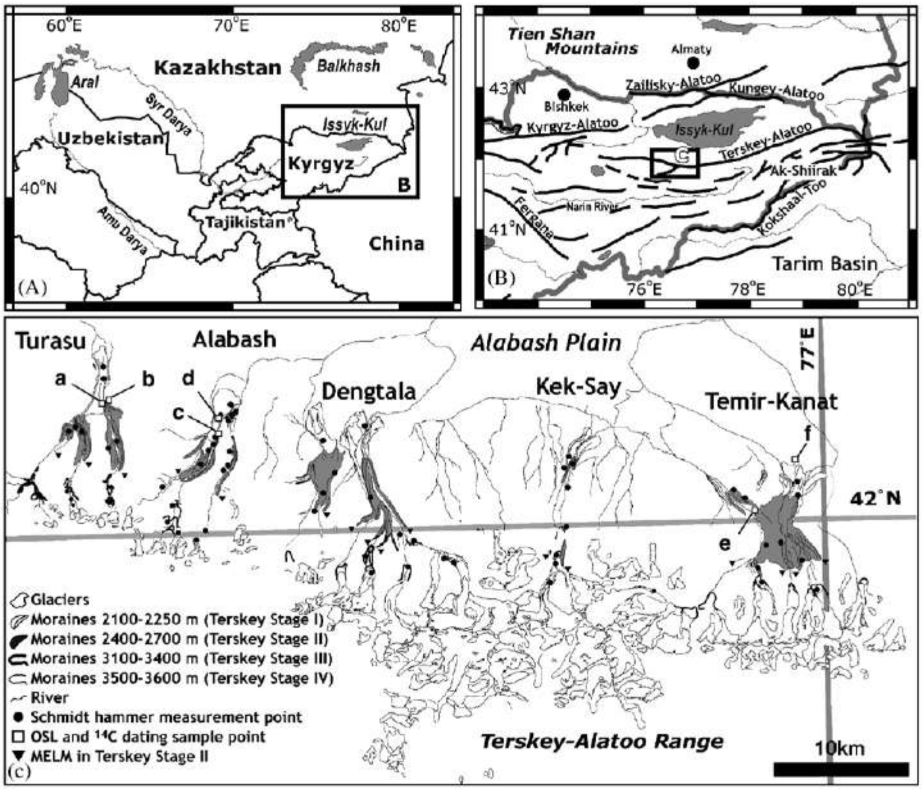

Fig. 1. Study area of the western part of the Terskey-Alatoo Range and the northeastern Kyrgyz Republic in central Asia (A,B). Research was done in five on the north flank of the Terskey-Alatoo Range: Turasu, Alabash, Dengtala, Kek-Say, and Temir-Kanat (C). (a)–(f) show locations of sampling for OSL dating.

this region have an areal extent of less than 5 km^2 (Narama et al., in press). Glacier termini in the Terskey-Alatoo Range are between 3400 and 3800 m above sea level (a.s.l.). In this mountain range, glaciers accumulate mass mainly in spring from westerly systems (Aizen et al., 1995).

3. Methods

3.1. *Classification of glacier advance stages*

Field observations were used to map the moraines in the study area to topographic maps at a scale of 1:25,000. Moraines in each area were initially classified using elevation, geographical position, and the degree of weathering of moraine rocks (following Matthews and Shakesby, 1984). The *R*-values of moraine clasts by Schmidt hammer were determined from the average of the middle three values from five measurements. The average *R*-values of 30 granite boulders with long axes over 30 cm were used as a measure of weathering degree for each site. Using these indices, we classified the moraines into several stages and named them with local geographic names.

3.2. *Sample preparation and dose estimation method of OSL dating*

Nine samples for OSL dating were collected from exposed moraines in three areas: Turasu (T-1, -2, -3), Alabash (T-4, -5, -6, -7), and Temir-Kanat (T-8, -9). Coarse-grained samples were sieved and separated using a heavy liquid to obtain the 180–250 μm fraction. The fraction was treated with 10% hydrogen peroxide (H_2O_2) for 1 h, and 10% hydrochloric acid (HCl) for 1 h. It was then etched with 10% hydrofluoric acid (HF) for 30 min and 46% HF for 1 h to obtain quartz grains. Fine-grained samples (4–11 μm) were obtained using the Stokes law, and the fractions were treated with 10% H_2O_2 and 10% HCl as above, and then etched with 40% fluosilisic acid (H_2SiF_6) twice, for 4 days each time.

OSL measurements were performed on an automated Risø reader at the Tokyo Metropolitan University. The emissions were filtered with a 7.5-mm HOYA U-340. The single-aliquot regenerative-dose (SAR) protocol (Murray and Wintle, 2000) was used to determine the equivalent dose (D_e) for the samples and 5–18 disks were measured for each sample. Large aliquots (8 mm) were used for quartz samples, because the quartz appeared to be very dim. The SAR protocol is shown in Table 1. The purity of quartz extracts was checked using IR stimulation. In no quartz sample was the initial IR–OSL intensity greater than 10% of the initial OSL signal, however, IR bleach was inserted prior to each OSL measurement in the SAR protocol to reduce any possible feldspar contribution to the OSL signals. A preheat plateau test was conducted at the preheat temperatures at 200, 220, 240, 260 and 280 °C using T-6. The D_e values show no significant variation over the

Table 1
The SAR protocol used in this study

1	Give dose, D_x
2	Preheat (240 °C, 10 s)
3	IR bleach for 100 s
4	OSL at 125 °C for 100 s, L_x
5	Give test dose, D_t
7	IR bleach for 100 s
8	Test dose OSL at 125 °C for 100 s, T_x
9	Return to 1

entire temperature range, and a preheat at 240 °C for 10 s was used for all the samples.

A dose recovery test (Murray and Wintle, 2003) was performed using T-5. The aliquots were bleached at room temperature using blue LEDs for 200 s, stored at room temperature for 10,000 s, bleached again for 200 s, and finally given a beta dose of 128 Gy. The ratio of measured dose to given dose was close to unity (0.98 ± 0.02).

Dose rate of the samples was estimated using U, Th, K, and Rb concentrations determined by Neutron Activation Analyses at the Becquerel Laboratory in Mississauga, Ontario, Canada. Gamma dose from adjacent tills were taken into account to calculate the dose rate for loess samples, because loess samples were collected from near the border of glacial and loess deposits. Water content was estimated by averaging the measured water content in 2003 and 2004 and ±5% error was taken into account. An *a*-value is 0.04 ± 0.02 (Rees-Jones, 1995) was used for the calculation of alpha dose rate for fine grains.

3.3. ^{14}C dating

To evaluate the accuracy of the OSL age estimates, we applied ^{14}C dating to organic material, such as soil buried in the moraine. The ^{14}C dating measurements were done at the AMS Laboratory of Paleo-Labo Co. in Gunma, Japan. These ^{14}C ages were tentatively calibrated to calendar years based on the calibration of Oxcal 3.10 (INTCAL04, Bronk Ramsey, 2001).

4. Results

4.1. Glacier advance stages based on relative dating

The moraines were located at altitudes between 2100 and 3600 m a.s.l. in five areas: Turasu, Alabash, Dengtala, Kek-Say, and Temir-Kanat (Fig. 1C). The largest moraines were at 2100–2250 m and extended onto the Alabash Plain. Extensive moraines were also at 2400–2700 m. Moraines in these two elevation ranges, which were present in all five areas, are classified as large-scale moraines because they were about 100 m in elevation above the riverbed. In contrast, small-scale moraines with a relative elevation of 30 m above the riverbed existed at 3100–3400 and 3500–3600 m a.s.l. Moraines at 3100–3400 m were covered with grass and had indistinct ridges. In contrast, moraines at 3500–3600 m were closest to the present-day glacier fronts and, were not vegetated, consisting instead of recently deposited boulders. *R*-values of moraine boulders at 53 sites (Fig. 1C) were determined using a Schmidt hammer (Fig. 2). Boulders from the lowest moraines (2100–2250 m) had the lowest *R*-values in the study area. *R*-values for moraines at similar elevations always exhibited a consistent range of values.

As the result of the consistent dating estimates, we classified the moraines into four groups, hereafter Terskey Stages I to IV. Terskey Stage I consisted of large moraines that extend to the Alabash Plain at the lowest elevations (2100–2250 m). Terskey Stage II was composed of a well preserved, large moraine at 2400–2700 m. Terskey Stage III encompassed moraines at 3100–3400 m that had indistinct ridges and were grass-covered. Terskey Stage IV was comprised unvegetated moraines at 3500–3600 m adjacent to glacier termini. Samples for OSL dating were collected from moraine exposures belonging to Terskey Stages I and II in three areas: Turasu, Alabash, and Temir-Kanat.

4.2. OSL dating of sediment from moraine exposures

4.2.1. Turasu area

Three Terskey Stage II moraines exist in the Turasu area (Fig. 1C). Samples were obtained from exposures on both ridges of lateral moraines along the Bulak River. Material on the left bank of the river consisted of resedimented glacial deposits and loess (Fig. 3a). The resedimented deposits consisted of angular-subrounded boulders with clast-supported deposits, including fluvial deposits. The facies was massive and had no bedding. Samples were obtained from the bottom of a 40-cm-thick loess layer (T-1) and from the resedimented deposits (T-2). The OSL age of the loess deposits was 9 ka BP (T-1; fine-grained quartz; Table S1) and that of the resedimented deposits was 44 ka BP (T-2; coarse-grained quartz). The upper part of

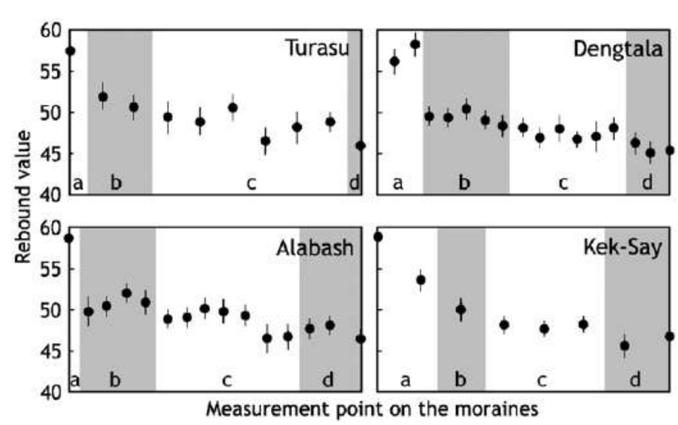

Fig. 2. *R*-values of Schmidt hammer for over 30 granite stones on the moraines. Vertical bars represent 95% confidence intervals. (a) moraines at 3500–3600 m, (b) moraines at 3100–3400 m, (c) moraines at 2400–2700 m, (d) moraines at 2100–2250 m.

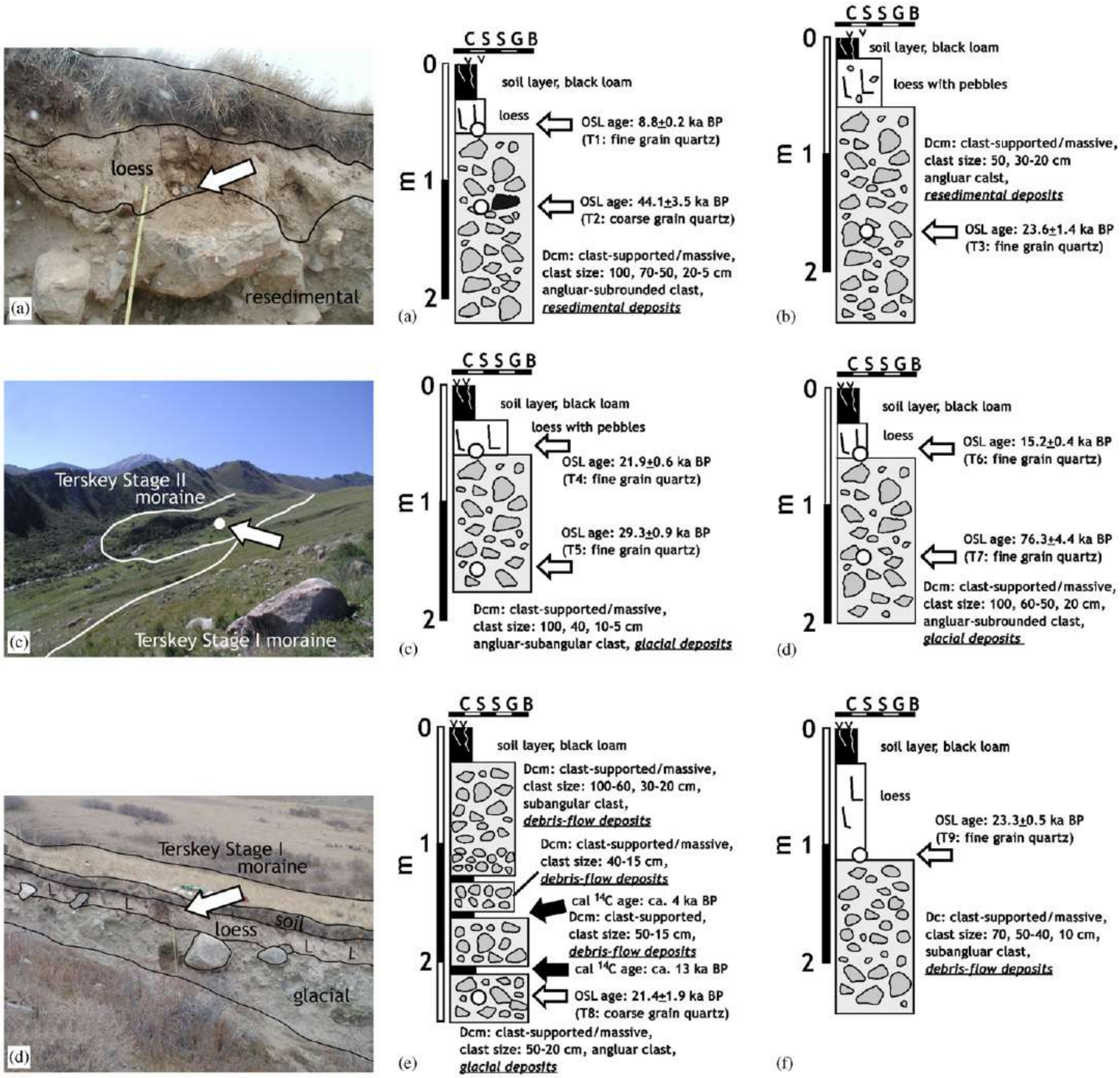

Fig. 3. Profiles ((a–b) Turasu; (c–d) Alabash; (e–f) Termir-Kanat) of sediments at exposures correlated with the Terskey Stage I and II moraines. Photos show outline of profile ((a) Turasu; (d) Alabash), and Terskey Stage II moraines in Alabash area (c). Locations of profiles (a–f) are shown in Fig. 1C. Particle size of the profiles is C = Clay, S = Silt, S = Sand, G = Gravel, B = Boulder. Sedimentary facies codes are those of Eyles et al. (1983).

the moraine on the right bank consisted of the same type of deposits as on the left bank, and was dated 24 ka BP (T-3; fine-grained quartz; Fig. 3b).

D_e values of T-2 had greater scatter than the other samples, presumably owing to some degree of insufficient bleaching before burial. The standard deviation of the data was largest ($\sigma = 29\%$) in samples of the study area. Therefore, its age may be regarded as a maximum age, indicating that the Terskey Stage II moraines here formed between 9 and 24 ka BP.

4.2.2. Alabash area

Two moraines are present in each of Terskey Stages I and II (Fig. 1C). The exposure at the top of the lateral moraine on the left bank of the Sary-Tor River consisted of unbedded, angular-subangular boulders with clast-supported deposits and loess (Fig. 3c). The OSL age estimate for the loess overlying the glacial deposits was 22 ka BP (T-4; fine-grained quartz; Table S1). The OSL age estimate obtained for the glacial deposits was 29 ka BP (T-5; fine-grained quartz).

Samples were also collected from an exposure of a Terskey Stage I moraine (Fig. 3d). The exposure consisted of massive, unbedded, subangular-subrounded boulders in clast-supported deposits. The OSL age estimate of the thick loess covering the glacial deposits was 15 ka BP (T-6; fine-grained quartz). The OSL age of glacial deposits (T-7) was 76 ka, indicating that Terskey Stage I was correlated with the first half of the Last Glacial (Marine Isotope Stage [MIS] 4).

4.2.3. Temir-Kanat area

Terskey Stage II hummocky moraines and Terskey Stage I moraines exist in this area (Fig. 1C). Samples were obtained from exposures at two sites: a Terskey Stage II moraine along the Djeruy River and a ridge of a Terskey Stage I moraine farther downstream. The Terskey Stage II lateral moraine consisted of glacial deposits, soil layers, debris-flow deposits, and discontinuous loess deposits (Fig. 3e). The ^{14}C ages of the buried soil layers that were intercalated with debris-flow deposits on the glacial deposits were 13,630–13,830 calendar years BP (11,870 ± 90 yr BP; PLD-4125) and 4475–4525 calendar years BP (3970 ± 25 yr BP; PLD-4288). The OSL age estimate of the glacial deposits was 21 ka BP (T-8; coarse-grained quartz; Table S1). The relationship between the OSL age and ^{14}C ages concurred with the stratigraphic sequence. A small ridge on a Terskey Stage I moraine further downstream contained a 90-cm-thick loess layer overlying deposits, and was estimated at 23 ka BP (T-9; fine-grained quartz; Fig. 3f).

5. Discussion

5.1. Glacier advance stages using OSL dating

Periods of glacier advance during Terskey Stages I and II were clarified using OSL dating. Most of the samples used for OSL dating were obtained from the Terskey Stage II moraines. The OSL age estimates of loess deposits were 9–22 ka BP, whereas those of the underlying glacial deposits were 21–29 ka BP, indicating that a glacier advance occurred during MIS2. Quartz sample from Terskey Stage I moraines in the Alabash area was 76 ka BP, suggesting that this stage of the glacier advance probably occurred in the first half of the Last Glacial, that is, during MIS4. Glacier advance during MIS2 occurred in the Pamir-Alay region (Zech et al., 2000, 2005; Narama and Okuno, in press). However, large glacier expansions in MIS3 have not been confirmed in the westerlies region of these central Asian mountains.

5.2. Decline in equilibrium line altitude s (ELAs) during MIS2

Fig. 4 shows the maximum elevation of lateral moraine (MELM) in the study area. MELM reflects the position of the corresponding equilibrium line altitude (ELA). This is because lateral moraines are deposited only in the ablation zone below the ELA (Nesje and Dahl, 2000). MELMs of the well preserved Terskey Stage II moraines exist at 3000–3300 m a.s.l. Given that some of the moraines are eroded, the highest elevation of the MELM in each area was adopted as the past ELA for the Terskey Stage II moraines. In each area, the highest elevations are about 3200–3300 m. The present ELA is 3900–3950 m a.s.l., which implies that the ELA was 600–700 m lower during MIS2 than it is the present. However, Grosswald et al. (1994) postulated that the glaciers in the Terskey-Alatoo Range expanded to Lake Issyk-Kul at an elevation of 1607 m during the Last Glacial, and the corresponding ELA was estimated to decline to 1200 m.

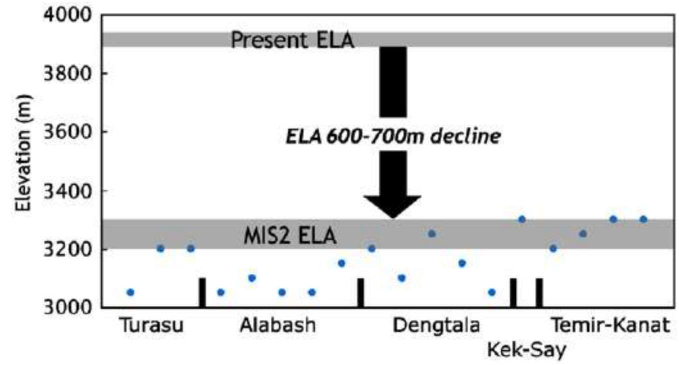

Fig. 4. The maximum elevation of lateral moraine (MELM) in the Terskye Stage II. The present ELA is 3900–3950 m a.s.l., which implies that the ELA was 600–700 m lower during MIS2 of the Last Glacial.

The difference in the terminal moraine elevations between Terskey Stages I and II is about 350 m. The amount of glacier expansion was different in each stage. It is plausible that the paleoclimate in Terskey Stage I (MIS4) was colder or more humid that of Terskey Stage II (MIS2).

6. Conclusions

OSL dating was performed on fine- and coarse-grained quartz collected from loess and glacial deposits in the Terskey-Alatoo Range, Kyrgyz Republic. ^{14}C ages were used to check the result. The OSL age estimates indicated that glaciers in the Terskey-Alatoo Range expanded between 21 and 29 ka BP, resulting in deposition of Terskey Stage II moraines now evident at elevations between 2400 and 2700 m. The ELA was about 600–700 m lower during MIS2 than it is at present. Maximum glacier expansion occurred at about 76 ka BP, during the MIS4 cold interval, which corresponds to Terskey Stage I. The difference in terminal moraine elevations of Terskey Stages I and II was about 350 m. This suggests that the amount of glacier expansion differed during the two stages of the Last Glacial. Hence, it is likely that the Terskey Stage I moraines record a colder or more humid paleoclimate that those of Terskey Stage II.

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Appendix A. Supplemental data

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.quageo.2006.06.007.

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