—A re-evaluation of MIS 3 glaciation using cosmogenic radionuclide and single grain luminescence ages, Kanas Valley, Chinese Altai

by Gribenski et al., 2017

Appendix S1: Re-evaluation of existing MIS 3 glacial chronologies in Central Asia: detailed analysis for each site

1. *Site details where a MIS 3 glacial advance has been proposed*

Range	Site No.	Site name	Moraine ID[1]	Location (°N/°E)	Extent	Moraine type sampled	Glaciation style/glacial deposit	Dating method	n	Original glacial timing	Author
Pamir-Alay	1	Great Bogchigir	BO1	37.74/72.84	beyond MIS 2	lateral moraine ridge	piedmont glaciation	^{10}Be	5	MIS5-4 (Model 1) or early MIS 3 (60-40 ka, Model 2)	Abramowski et al., 2006
	2	Orto Bogchigir A	M2	37.79/72.76	beyond MIS 2	hummocky lobe moraine	piedmont glaciation	^{10}Be	7	~47 ka	Zech et al., 2005
	3	Orto Bogchigir B	M3	37.77/72.76	beyond MIS 2	lateral moraine ridge	unclear due to fluvial erosion	^{10}Be	3[2]	~40 ka	Zech et al., 2005
	4	Koksu	KK	39.55/72.08	lLGM[3]	terminal moraine ridge	valley glaciation	^{10}Be	3	MIS4 or early MIS 3 (68-47 ka)	Abramowski et al., 2006
	5	Kokodak	m2G	38.59/75.00	lLGM[3]	morainic deposit	piedmont glaciation	^{10}Be	3	MIS 3 (29-57 ka)	Seong et al., 2009
	6	Kartamak	m2C	38.30/74.98	lLGM[3]	hummocky moraine	piedmont glaciation	^{10}Be	6	early MIS 3 or late MIS 2	Seong et al., 2009
	7	Yangbuk	m2B	38.34/75.02	lLGM[3]	subdued piedmont moraine ridge	piedmont glaciation	^{10}Be	8	MIS 3 and /or MIS4	Seong et al., 2009
Tian Shan	8	Ala Archa	MIII	42.63/74.61	lLGM[3]	large well-defined	n.s	^{10}Be	1	~50 ka	Koppes et al.,

						moraine					2008
	9	Terek Suu A	M2[a] or MIII[b]	41.05/75.75	No other MIS 2 identified	large well-defined lateral moraine	n.s	OSL[a]/^{10}Be[b]	1[a]+1[b]	Late MIS 3-MIS 2[a]/~32 ka[b]	Narama et al., 2009[a]/Koppes et al., 2008[b]
	10	Terek Suu B	MII	41.05/75.73	lLGM[3]	degraded piedmont complex	n.s	^{10}Be	1	~53 ka	Koppes et al., 2008
	11	Aksai	MIIIb	40.98/76.15	lLGM[3]	large well-defined lateral moraine	n.s	^{10}Be	1	MIS 3: 37-39 ka	Koppes et al., 2008
	12	Sary Tal	MII	41.20/76.30	no other MIS 2 identified	n.s	n.s	OSL	2	Late MIS 3-MIS 2	Narama et al., 2009
	13	Temir Kanat	MI	42.01/75.75	lLGM[3]	n.s	n.s	OSL	2	MIS4-early MIS 3	Narama et al., 2009
	14	Inylchek	terminal moraine	42.02/79.08	beyond MIS 2	moraine ridge	valley glaciation	^{10}Be (and ^{26}Al)	1	MIS 3 ~41ka	Lifton et al., 2014a
	15	Ateaoyinake	3rd set	41.70/80.90	slightly beyond MIS 2	terminal moraine	valley glaciation	ESR	4	MIS 3b (40-54 ka)	Zhao et al., 2009
	16	Muzart	5th set of Pochengzi moraines	41.49/80.9	beyond MIS 2	terminal moraine (arc aerial view)	valley glaciation	ESR	2	mid MIS 3 (39.5-40 ka)	Zhao et al., 2010
	17	Nalati Range, Takelete	TK4	42.99/83.59	no other MIS 2 identified	hummocky moraine	piedmont glaciation	^{10}Be	8	MIS 3 (55±3 to 34.9 ±2.1 ka)	Zhang et al., 2016
	18	Nalati Range, Sairenwuxunsala	SR4	43.12/98.57	no other MIS 2 identified	lateral moraine complex with hummocky topography	piedmont glaciation	^{10}Be	5	Late MIS 3/MIS 2 (31.6±1.7 to 13.8±0.8 ka)	Zhang et al., 2016
	19	Daxi	Shangwang-feng till[c,d] or UWF	43.12/86.92	no other MIS 2 identified[c]	till[c]/lateral terminal moraine[d]/subdued moraine ridges[e]	valley glaciation	ESR[c]/^{10}Be[d,e]	3[c]+3[d]+4[e]	MIS 3-2[c] /MIS 2[d,e]	Zhao et al., 2006 (including data from Yi et al., 2001)[c]

			moraine group[e]								/Kong et al., 2009[d]/Li et al., 2011[e]
	20	Ala A	M3	42.99/86.92	beyond MIS 2	terminal moraine ridge	valley glaciation	^{10}Be	7	Late MIS 3-MIS 2 (33-22 ka)	Li et al., 2014
	21	Ala B	M4	42.92/86.92	beyond MIS 2	lateral moraine (hummocky terminate)	valley glaciation	^{10}Be	7	MIS 3 (37 to 52 ka)	Li et al., 2014
	22	Turgan	M5	43.20/94.38	beyond MIS 2	hummocky moraine with supraglacial channel fill sediments	n.s.	OSL	5	MIS 3 (37.4 to 44.2 ka)	Chen et al., 2015
Altai and Khangai Mountains	23	Kanas A (Altai)*	sub complex 2 (or 1-2**)	48.70/87.02	beyond MIS 2	moraine ridges complex	valley glaciation	OSL	2[f]**+2[g]	mid MIS 3 (34-38 ka)[f]**/mid MIS 3 (38-52 ka)[g]	Xu et al., 2009[f]/Zhao et al., 2013[g]
	24	Kanas B (Altai)*	sub complex 3	48.70/87.02	beyond MIS 2	not well preserved terminal moraine (hummocky)	valley glaciation	OSL	1[h]+1[i]	MIS 3 (~50ka)[h]/MIS 4[i]	Xu et al., 2009[h]/ Zhao et al., 2013[i]
	25	Arshaan (Khangai)[4]	OT1 (Haryn saddle, Shuvuun hill)[4]	47.78/97.27	lLGM[3]	moraine ridges complex/ice overriden bedrock knob	valley glaciation	^{10}Be	6+3[4]	40-35 ka	Rother et al., 2014
	26	Hangai Dome (Khangai)	Khaak Nuur (KN)	47.46/98.57	lLGM[3]	large terminal moraine	valley glaciation	^{10}Be	3	MIS 3-MIS 2 (30.6±15.2 ka)	Smith et al., 2016
	27	Hoit Aguy (Darhaad Basin)	Right lateral moraine	51.55/98.71	lLGM[3]	Lateral moraine extending into terminal moraine	Valley glaciation	^{10}Be	2	MIS 3 (~35 ka)	Batbaatar and Gillespie, 2016
Kunlun Shan	28	Burhan Budai Shan-South side	M2	35.63/94.21	lLGM[3]	laterofrontal moraine	valley glaciation	^{10}Be	4	MIS 3	Owen et al., 2006

2. *Criteria summary for global chronological data analysis*

Criteria to evaluate the robustness of the published MIS 3 chronologies (cf. Table S2 for details of each sites) are based on the example of the Kanas Valley, and on other studies attempting to evaluate the reliability of cosmogenic, OSL or ESR glacial chronological data, in the light of recent advance and knowledge in geochronology (e.g. Heyman, 2014; Blomdin et al., 2016; Hughes et al., 2016; Small et al., 2017). Details of the chronological data robustness analysis for each site is provided further below. For all three dating methods, MIS 3 chronologies are discarded if they are based on only one sample collected.

Optically Stimulated Luminescence ages from glacial/glaciofluvial sediments must have undergone proper investigation of potential partial bleaching effect (e.g. small aliquot/single grain D_e distribution analysis, signal comparison for different aliquot size or wavelength stimulation), considering the commonness of incomplete resetting (bleaching) of the luminescence signal in glacial setting (Fuchs and Owen, 2008). Otherwise, the proposed MIS 3 chronology remains uncertain and and would need new supporting chronological evidence to be fully validated (Small et al., 2017).

Electron Spin Resonance signal in glacial sediments has been shown to be fully bleached only after extensive light exposure (several days), which is in general hardly achieved during glacial transport prior deposition (Yi et al., 2016), yielding to large age overestimates. To accept ESR ages as reliable we require data that with reasonable certainty indicate complete resetting of the ESR signal or can quantify the residual dose at the time of deposition. To date, there is an absence of techniques to evaluate the completeness of resetting or the residual dose at the deposition time, and hence, no existing ESR based MIS 3 chronology can be considered as reliable.

Cosmogenic nuclide exposure data sets obtained from glacial settings are often scattered beyond analytical uncertainties (Balco, 2011). This is also the case of the exposure data sets associated with the MIS 3 sites in Central Asia. Reliable glaciation timing may still be inferred from moderately clustered data set (Rinterknecht et al., 2006; Clark et al., 2009; Heyman, 2014; Shakun et al., 2015; Blomdin et al., 2016). We therefore accept exposure age based chronology fulfilling the following criteria:

- $n_{total} \geq 3$
- presence of a well-clustered ($\sigma/\mu \leq 15\%$; Blomdin et al., 2016) group or dominant sub-group ($n \geq 3$ after removal of the outliers)
- Removal of up to 1/3 of the original number of samples (Heyman, 2014) is allowed to test if the remaining samples can fulfil the $\sigma/\mu \leq 15\%$ criterion

Our statistical criteria for the ^{10}Be ages is somewhat arbitrary, with the minimum number of samples set to three and requiring the exposure age standard deviation to be less than 15% of the mean exposure age. However, it allows for an objective analysis with consistent criteria for multiple studies and without subjective decisions for each site.

MIS 3 glacial timing inference is accepted when the well clustered group/sub-group lies within MIS 3 (or most of it: ≥75% based on mean age and standard deviation). If the well-clustered group/sub group lies outside of the MIS 3 (or most of it), the ^{10}Be chronology reflects a well constrained glacial event, but more likely outside of the MIS 3 (or on the margin). Exposure age data sets for which no well-clustered group can be isolated following the criteria above are considered as unreliable. MIS 3 chronologies based on only two exposure ages agreeing within uncertainty remains uncertain and additional chronological data are necessary to confirm the proposed timing (Small et al., 2017).

3. Details of the chronological data robustness analysis for each site

Site 1: Great Bogchigir, BO1 moraine

Sample information:

Cosmogenic exposure dating

Author	ID	Lat (°N)	Long (°E)	Alt.(m a.s.l.)	Thick. (cm)	Density (g/cm^3)	Shield.	[Be] atoms/g	[Be] err atoms/g	Be standard.	year collected	Age (ka)	Ext. err.	Int. err.
Abramowski et al., 2006	BO11	37.735	72.838	4250	1.0	2.65	0.994	2698000	102000	S555	2002	34.5	2.3	1.3
	BO12	37.735	72.838	4225	3.0	2.65	0.994	2576000	116000	S555	2002	34.0	2.4	1.5
	BO13	37.735	72.838	4240	3.0	2.65	0.994	4253000	160000	S555	2002	53.7	3.5	2.0
	BO14	37.736	72.838	4240	2.0	2.65	0.996	5260000	197000	S555	2002	65.5	4.3	2.5
	BO17	37.736	72.838	4230	2.5	2.65	0.995	3958000	149000	S555	2002	49.6	3.3	1.9
In light grey: sample rejected for a minimum coefficient of variation, in the limit of 1/3 of samples allowed to be rejected to test if the remaining ages could fulfil the σ/μ<15% criterion											*Mean (μ)*	*43.0*		
											Std (σ)	*10.2*		
											χ^2_R	*39.7*		
											σ/μ	*0.24*		
											% MIS 3	*100*		

Data set analysis

Criteria	
n_{total}>1	yes
n≥3 after sample rejection	yes
Well-clustered remaining group: σ/μ<15%	no
>75% distribution within MIS 3	yes

Conclusion:

The data spread over several tens of ka, and no well-clustered dominant group (≥2/3 of n_{total}) could be isolated. Despite the majority of ages lie within the MIS 3 range, such dispersion reflects strong geomorphological processes effects. Due to the large age scatter and in the absence of additional supportive data, the MIS 3 inference therefore remains speculative.

Site 2: Orto Bogchigir A, M2 moraine

Sample information:

Cosmogenic exposure dating

Author	ID	Lat (°N)	Long (°E)	Alt.(m a.s.l.)	Thick. (cm)	Density (g/cm^3)	Shield.	[Be] atoms/g	[Be] err atoms/g	Be standard.	year collected	Age (ka)	Ext. err.	Int. err.
Zech et al., 2005	M2-1	37.791	72.763	3755	3	2.65	0.996	3765800	159300	S555	2003	62.6	4.3	2.7
	M2-2	37.790	72.762	3755	4	2.65	0.997	1253700	52200	S555	2003	23.1	1.6	1.0
	M2-3	37.789	72.761	3755	4	2.65	0.997	2094700	72300	S555	2003	36.0	2.3	1.3
	M2-4	37.787	72.761	3770	5	2.65	0.996	2681000	100300	S555	2003	44.5	2.9	1.7
	M2-5	37.787	72.761	3770	1	2.65	0.996	3941700	107200	S555	2003	63.9	3.9	1.8
	M2-6	37.775	72.766	3960	5	2.65	0.998	965100	59100	S555	2003	16.9	1.4	1.0
	M2-7	37.777	72.767	3945	5	2.65	0.999	1058300	48000	S555	2003	18.5	1.3	0.8
In light grey: samples rejected for a minimum coefficient of variation, in the limit of 1/3 of samples allowed to be rejected to test if the remaining ages could fulfil the σ/μ<15% criterion											*Mean (μ)*	*27.8*		
											Std (σ)	*12.0*		
											χ^2_R	*103.1*		
											σ/μ	*0.43*		
											% MIS 3	*55*		

Data set analysis

Criteria	
n_{total}>1	yes
n≥3 after sample rejection	yes
Well-clustered remaining group: σ/μ<15%	no
>75% distribution within MIS 3	no

Conclusion:

The data spread over several marine isotope stages, and no well-clustered dominant group (≥2/3 of n_{total}) could be isolated. Such dispersion reflects strong geomorphological processes effects, prohibiting the inference of a glacial timing due to the large age scatter. The MIS 3 inference is therefore considered unreliable.

Site 3: Orto Bogchigir B, M3 moraine

Sample information:

Cosmogenic exposure dating

Author	ID	Lat (°N)	Long (°E)	Alt.(m a.s.l.)	Thick. (cm)	Density (g/cm^3)	Shield.	[Be] atoms/g	[Be] err atoms/g	Be standard.	year collected	Age (ka)	Ext. err.	Int. err.
Zech et al., 2005	M3-1	37.771	72.764	4035	4	2.65	0.997	3924000	118100	S555	2003	55.9	3.4	1.7
	M3-2	37.771	72.764	4020	4	2.65	0.998	3518700	106200	S555	2003	50.2	3.1	1.5
	M3-3*	37.771	72.764	4005	4	2.65	0.998	2565900	95100	S555	2003	37.8	2.5	1.4
*Sample interpreted by the author as likely belonging to an individual subsequent advance based on geomorphological evidence documented in the field.											*Mean (μ)*	*48.0*		
											Std (σ)	*9.3*		
											χ^2_R	*38.4*		
											σ/μ	*0.19*		
											% MIS 3	*99*		

Data set analysis

Criteria	
$n_{total}>1$	yes
n≥3 after sample rejection	no
Well-clustered remaining group: σ/μ<15%	no
>75% distribution within MIS 3	yes

Comments and conclusion:

The data spread over several tens of ka, and no well-clustered dominant group (≥2/3 of n_{total}) could be isolated. Despite the majority of ages lie within the MIS 3 range, such dispersion reflects strong geomorphological processes effects. Due to the large age scatter and in the absence of additional supportive data, the MIS 3 inference therefore remains speculative.

The authors suggest the rejection of the youngest sample (M3-3) based on geomorphological evidence. If the rejection is taken into account, only two samples are left, close to the MIS 3/MIS 4 boundary, and are therefore also insufficient to provide robust evidence of MIS 3 advance, requiring additional chronological data.

Site 4: Koksu, KK moraine

Sample information:

Cosmogenic exposure dating

Author	ID	Lat (°N)	Long (°E)	Alt.(m a.s.l.)	Thick. (cm)	Density (g/cm^3)	Shield.	[Be] atoms/g	[Be] err atoms/g	Be standard.	year collected	Age (ka)	Ext. err.	Int. err.
Abramowski et al., 2006	KK1	39.550	72.08	2500	4	2.65	1	1850000	87000	S555	2002	66.0	4.7	3.2
	KK2	39.550	72.08	2500	4	2.65	1	2019000	94000	S555	2002	72.0	5.2	3.4
	KK3	39.550	72.08	2500	4	2.65	1	1727000	76000	S555	2002	61.8	4.3	2.8
											Mean (μ)	*67.6*		
											Std (σ)	*5.2*		
											χ^2_R	*2.8*		
											σ/μ	*0.08*		
											% MIS 3	*0*		

Data set analysis

Criteria	
n_{total}>1	yes
n≥3 after sample rejection*	yes
Well-clustered remaining group: σ/μ<15%	yes
>75% distribution within MIS 3	no

Conclusion:

The chronological data set allows reliable constraint of an MIS 4 glacial advance.

*no sample rejection allowed

Site 5: Kokodak, m2G moraine

Sample information:

Cosmogenic exposure dating

Author	ID	Lat (°N)	Long (°E)	Alt.(m a.s.l.)	Thick. (cm)	Density (g/cm^3)	Shield.	[Be] atoms/g	[Be] err atoms/g	Be standard.	year collected	Age (ka)	Ext. err.	Int. err.
Seong et al., 2009	KONG_29	38.593	75.01	3573	5	2.65	1	1566000	42000	KNSTD	2007	29.9	1.8	0.8
	KONG_30	38.595	75.003	3554	5	2.65	1	3023000	71000	KNSTD	2007	55.7	3.3	1.3
	KONG-P1	38.594	74.995	3541	5	2.65	0.99	2154000	54000	KNSTD	2007	40.5	2.4	1.0
											Mean (μ)	*42.0*		
											Std (σ)	*13.0*		
											χ^2_R	*171.6*		
											σ/μ	*0.31*		
											% MIS 3	*100*		

Data set analysis

Criteria	
n_{total}>1	yes
n≥3 after sample rejection*	yes
Well-clustered remaining group: σ/μ<15%	no
>75% distribution within MIS 3	yes

Comments and conclusion:

The data spread over several tens of ka, and no well-clustered dominant group (≥2/3 of n_{total}) could be isolated. Despite the majority of ages lie within the MIS 3 range, such dispersion reflects strong geomorphological processes effects. Due to the large age scatter and in the absence of additional supportive data, the MIS 3 inference therefore remains speculative.

*no sample rejection allowed

Site 6: Kartamak, m2C moraine

Sample information:

Cosmogenic exposure dating

Author	ID	Lat (°N)	Long (°E)	Alt.(m a.s.l.)	Thick. (cm)	Density (g/cm^3)	Shield.	[Be] atoms/g	[Be] err atoms/g	Be standard.	year collected	Age (ka)	Ext. err.	Int. err.
Seong et al., 2009	MUST-62	38.301	74.984	4005	5	2.65	1	1175000	46000	KNSTD	2007	19.0	1.3	0.7
	MUST-63	38.301	74.983	4001	5	2.65	1	1676000	45000	KNSTD	2007	25.7	1.5	0.7
	MUST-64	38.302	74.969	3987	5	2.65	1	1547000	37000	KNSTD	2007	24.1	1.4	0.6
	MUST-65	38.303	74.979	3979	5	2.65	1	4953000	93000	KNSTD	2007	71.1	4.0	1.4
	MUST-66	38.302	74.98	3995	5	2.65	1	3266000	56000	KNSTD	2007	46.1	2.6	0.8
	MUST-86	38.283	74.98	3988	5	2.65	1	1585000	38000	KNSTD	2007	24.6	1.4	0.6
In light grey: samples rejected for a minimum coefficient of variation, in the limit of 1/3 of samples allowed to be rejected to test if the remaining ages could fulfil the σ/μ<15% criterion											*Mean (μ)*	*23.4*		
											Std (σ)	*3.0*		
											χ^2_R	*18.6*		
											σ/μ	*0.13*		
											% MIS 3	*0*		

Data set analysis

Criteria	
n_{total}>1	yes
n≥3 after sample rejection	yes
Well-clustered remaining group: σ/μ<15%	yes
>75% distribution within MIS 3	no

Conclusion:

The chronological data set allows reliable constraint of an MIS 2 glacial advance.

Site 7: Yangbuk, m2B moraine

Sample information:

Cosmogenic exposure dating

Author	ID	Lat (°N)	Long (°E)	Alt.(m a.s.l.)	Thick. (cm)	Density (g/cm^3)	Shield.	[Be] atoms/g	[Be] err atoms/g	Be standard.	year collected	Age (ka)	Ext. err.	Int. err.
Seong et al., 2009	MUST-80	38.34	75.022	4181	5	2.65	1	2963000	79000	KNSTD	2007	38.5	2.3	1.0
	MUST-81	38.342	75.021	4181	5	2.65	1	1954000	46000	KNSTD	2007	26.8	1.6	0.6
	MUST-82	38.34	75.021	4168	5	2.65	1	5717000	69000	KNSTD	2007	73.6	4.1	0.9
	MUST-83	38.342	75.015	4123	5	2.65	1	1572000	47000	KNSTD	2007	22.8	1.4	0.7
	MUST-84	38.342	75.014	4113	5	2.65	1	4290000	75000	KNSTD	2007	57.2	3.2	1.0
	MUST-90	38.34	75.017	4126	5	2.65	1	7927000	117000	KNSTD	2007	104.5	5.9	1.6
	MUST-91	38.343	75.013	4117	5	2.65	1	1784000	44000	KNSTD	2007	25.5	1.5	0.6
	MUST-92	38.342	75.014	4117	5	2.65	1	4629000	158000	KNSTD	2007	61.5	3.9	2.1
In light grey: samples rejected for a minimum coefficient of variation, in the limit of 1/3 of samples allowed to be rejected to test if the remaining ages could fulfil the σ/μ<15% criterion											*Mean (μ)*	*38.7*		
											Std (σ)	*16.9*		
											χ^2_R	*317.2*		
											σ/μ	*0.44*		
											%MIS 3	*79*		

Data set analysis

Criteria	
n_{total}>1	yes
n≥3 after sample rejection	yes
Well-clustered remaining group: σ/μ<15%	no
>75% distribution within MIS 3	yes

Conclusion:

The data spread over several marine isotope stages, and no well-clustered dominant group (≥2/3 of n_{total}) could be isolated. Despite the majority of ages lie within the MIS 3 range, such dispersion reflects strong geomorphological processes effects. Due to the large age scatter and in the absence of additional supportive data, the MIS 3 inference therefore remains speculative.

Site 8: Ala Archa, MIII moraine

Sample information:

Cosmogenic exposure dating

Author	ID	Lat (°N)	Long (°E)	Alt.(m a.s.l.)	Thick. (cm)	Density (g/cm^3)	Shield.	[Be] atoms/g	[Be] err atoms/g	Be standard.	year collected	Age (ka)	Ext. err.	Int. err.
Koppes et al., 2008	KTS98-CS-104	42.63	74.61	2040	3	2.7	0.9966	1090000	39000	LLNL3000	1998	47.6	3.1	1.7

Data set analysis

Criteria	
$n_{total}>1$	no
n≥3 after sample rejection*	-
Well-clustered remaining group: σ/μ<15%	-
>75% distribution within MIS 3	-

Conclusion:

The number of samples collected is insufficient to establish a glacial chronology.

*no sample rejection allowed

Site 9: Terek Suu A, M2/MIII moraine

Sample information:

Cosmogenic exposure dating

Author	ID	Lat (°N)	Long (°E)	Alt.(m a.s.l.)	Thick. (cm)	Density (g/cm^3)	Shield.	[Be] atoms/g	[Be] err atoms/g	Be standard.	year collected	Age (ka)	Ext. err.	Int. err.
Koppes et al., 2008	KTS98-CS-81	41.05	75.73	2598	1	2.7	0.998	1032000	25000	LLNL3000	1998	31.6	1.9	0.7

OSL dating: Blue OSL signal from multi-grain aliquots of fine-grain quartz (4–11µm)

Author	ID	Lat (°N)	Long (°E)	Alt.(m a.s.l.)	Material	Water content (%)	U (ppm)	Th (ppm)	K (%)	Rb (ppm)	Dose rate (Gy/ka)	De (Gy)	Age (ka)	Err.
Narama et al., 2009	A-2	41.05*	75.75*	-	Supraglacial till	8	2.9±0.1	12.1±0.4	2.1±0.1	105.0±3.6	4.0±0.3	135.0±3.0	33.4	2.7

*rough geographic coordinates deduced from map published in the original paper, as no geographical coordinates were provided.

Data set analysis

Criteria	
$n_{total}>1$	yes
Partial bleaching investigated for OSL samples	no
n≥3 after sample rejection*	no
Well-clustered remaining group: σ/µ<15%	-
>75% distribution within MIS 3	-

*no sample rejection allowed

Conclusion:

Because of the absence of thorough partial bleaching investigation for the OSL sample, and the insufficient number of samples taken for cosmogenic dating, the inferred MIS 3 chronology remains uncertain despite the agreement between both chronologies, pending further chronological support.

Site 10: Terek Suu B, MII moraine

Sample information:

Cosmogenic exposure dating

Author	ID	Lat (°N)	Long (°E)	Alt.(m a.s.l.)	Thick. (cm)	Density (g/cm^3)	Shield.	[Be] atoms/g	[Be] err atoms/g	Be standard.	year collected	Age (ka)	Ext. err.	Int. err.
Koppes et al., 2008	KTS98-CS-83	41.05	75.73	2598	1	2.7	0.9981	1677000	42000	LLNL3000	1998	49.7	2.9	1.3

Data set analysis

Criteria	
$n_{total}>1$	no
n≥3 after sample rejection*	-
Well-clustered remaining group: σ/μ<15%	-
>75% distribution within MIS 3	-

Conclusion:

The number of samples collected is insufficient to establish a glacial chronology.

*no sample rejection allowed

Site 11: Aksai, MIIIb moraine

Sample information:

Cosmogenic exposure dating

Author	ID	Lat (°N)	Long (°E)	Alt.(m a.s.l.)	Thick. (cm)	Density (g/cm^3)	Shield.	[Be] atoms/g	[Be] err atoms/g	Be standard.	year collected	Age (ka)	Ext. err.	Int. err.
Koppes et al., 2008	KTS98-CS-66	40.98	76.15	3576	4	2.7	0.9964	2058000	35000	LLNL3000	1998	33.9	1.9	0.6

Data set analysis

Criteria	
$n_{total}>1$	no
n≥3 after sample rejection*	-
Well-clustered remaining group: σ/μ<15%	-
>75% distribution within MIS 3	-

Conclusion:

The number of samples collected is insufficient for establishing a reliable glacial chronology.

*no sample rejection allowed

Site 12: Sary Tal, MII moraine

Sample information:

OSL dating: Blue OSL signal from multi-grain aliquots of fine-grain quartz (4–11µm)

Author	ID	Lat (°N)	Long (°E)	Alt.(m a.s.l.)	Material	Water content (%)	U (ppm)	Th (ppm)	K (%)	Rb (ppm)	Dose rate (Gy/ka)	De (Gy)	Age (ka)	Err.
Narama et al., 2009	A-7	41.2*	76.3*	-	Supraglacial till	4	3.0±0.1	12.7±0.4	2.2±0.1	103.0±3.6	4.4±0.3	106.0±2.0	24.3	1.9
	A-8	41.2*	76.3*	-	Supraglacial till	8	2.8±0.1	12.7±0.4	2.3±0.1	110.0±3.9	4.3±0.3	134.0±5.0	31.5	2.7

*rough geographic coordinates deduced from map published in the original paper, as no geographical coordinates were provided.

Data set analysis

Criteria	
$n_{total}>1$	yes
Partial bleaching investigated for OSL samples	no
n≥3 after sample rejection	-
Well-clustered remaining group: σ/µ<15%	-
>75% distribution within MIS 3	-

Conclusion:

Because of the absence of thorough partial bleaching investigation for none of the OSL samples, the inferred MIS 3 chronology remains ambiguous and additional chronological data are necessary to confirm the proposed timing.

Site 13: Temir Kanat, MI moraine

Sample information:

OSL dating: Blue OSL signal from multi-grain aliquots of fine-grain quartz (4–11µm)

Author	ID	Lat (°N)	Long (°E)	Alt.(m a.s.l.)	Material	Water content (%)	U (ppm)	Th (ppm)	K (%)	Rb (ppm)	Dose rate (Gy/ka)	De (Gy)	Age (ka)	Err.
Narama et al., 2009	T-12	42.01*	76.95*	-	Supraglacial till	4	3	4.1±0.1	20.2±0.7	1.8±0.2	113.0±5.0	5.0±0.5	56.3	5.8
	T-13	42.01*	76.95*	-	Supraglacial till	8	3	3.8±0.1	18.6±0.6	2.4±0.1	108.0±3.6	5.3±0.4	71.3	5.6

*estimated geographic coordinates deduced from map published in the original paper, as no geographic coordinate information was provided by authors.

Data set analysis

Criteria	
$n_{total}>1$	yes
Partial bleaching investigated for OSL samples	no
n≥3 after sample rejection	-
Well-clustered remaining group: σ/µ<15%	-
>75% distribution within MIS 3	-

Conclusion:

Because of the absence of thorough partial bleaching investigation for all OSL samples, the inferred MIS 3 chronology remains ambiguous and additional chronological data are necessary to confirm the proposed timing.

Site 14: Inylchek, terminal moraine

Sample information:

Cosmogenic exposure dating

Author	ID	Lat (°N)	Long (°E)	Alt.(m a.s.l.)	Thick. (cm)	Density (g/cm^3)	Shield.	[Be] atoms/g	[Be] err atoms/g	Be standard.	[Al] at/gram	[Al] err.	Al standard.	year collected	Age (ka)	Ext. err.	Int. err.
Lifton et al., 2014	TS12-IN-12	42.019	79.079	2652	2	2.65	0.994	1177800	48600	07KNSTD	7120500	398400	KNSTD	2012	39.1	2.6	1.6

Data set analysis

Criteria	
$n_{total}>1$	no
n≥3 after sample rejection	-
Well-clustered remaining group: σ/μ<15%	-
>75% distribution within MIS 3	-

Conclusion:

The number of samples collected is insufficient to establish a glacial chronology.

Site 15: Ateaoyinake, 3rd moraine set

Sample information:

ESR dating

Author	ID	Lat (°N)	Long (°E)	Alt.(m a.s.l.)	Depth. (m)	Material	Water content (%)	U (ppm)	Th (ppm)	K_2O (%)	Cosmic ($mGy.a^{-1}$)	Total Dose (Gy)	Age (ka)	Err.
Zhao et al., 2009	Kqk-4	41.69	80.21	2983	25	Till	4.0	1.7	20.2	3.7	0.03	210.9	40.9	4
	18	41.69	80.2	3021	28	Till	7.1	1.5	16.4	3.5	0.03	207.5	46.2	4.2
	13	41.7	80.19	2995	26	Till	1.7	1.1	9.4	3.9	0.03	227.5	51	4.8
	16	41.71	80.22	3117	31	Till	1.0	1.9	11.7	3.5	0.03	246.1	54	5.2

Data set analysis

Criteria	
$n_{total}>1$	yes
Partial bleaching investigated for ESR samples	no
n≥3 after sample rejection	-
Well-clustered remaining group: σ/μ<15%	-
>75% distribution within MIS 3	-

Conclusion:

In the absence of techniques to evaluate the completeness of the ESR signal resetting or the residual dose at the deposition time, a MIS 3 chronology solely based on ESR dating cannot be considered reliable.

Site 16: Muzart, 5th set of Pochengzi moraine

Sample information:

ESR dating

Author	ID	Lat (°N)	Long (°E)	Alt.(m a.s.l.)	Depth. (m)	Material	Water content (%)	U (ppm)	Th (ppm)	K_2O (%)	Cosmic ($mGy.a^{-1}$)	Total Dose (Gy)	Age (ka)	Err.
Zhao et al., 2010	MZET-2-1	41.79	80.91	2001	2.9	Till	2.8	3.1	13.7	2.2	0.2	156.6	39.5	4.0
	MZET-2-2	41.79	80.9	1977	2.7	Till	3.0	3.6	12.5	2.4	0.2	169.4	40.4	4.0

Data set analysis

Criteria	
$n_{total}>1$	yes
Partial bleaching investigated for ESR samples	no
n≥3 after sample rejection	-
Well-clustered remaining group: σ/μ<15%	-
>75% distribution within MIS 3	-

Conclusion:

In the absence of techniques to evaluate the completeness of the ESR signal resetting or the residual dose at the deposition time, a MIS 3 chronology solely based on ESR dating cannot be considered reliable.

Site 17: Nalati Range, Takelete TK4

Sample information:

Cosmogenic exposure dating

Author	ID	Lat (°N)	Long (°E)	Alt.(m a.s.l.)	Thick. (cm)	Density (g/cm^3)	Shield.	[Be] atoms/g	[Be] err atoms/g	Be standard.	year collected	Age (ka)	Ext. err.	Int. err.
Zhang et al., 2016	BY-08-1	42.9917	83.5855	2871	2	2.65	0.999	2553300	42300	07KNSTD	2014	70.2	4.0	1.2
	BY-08-2	42.9916	83.586	2872	2	2.65	0.999	1182700	41200	07KNSTD	2014	33.1	2.1	1.2
	BY-08-3	42.9918	83.5858	2871	2	2.65	0.999	1828300	53800	07KNSTD	2014	50.1	3.1	1.5
	BY-08-6	42.9925	83.5962	2931	2	2.65	0.999	2405400	63200	07KNSTD	2014	63.5	3.8	1.7
	BY-08-7	42.9924	83.5961	2933	2	2.65	0.999	1495400	57200	07KNSTD	2014	39.6	2.6	1.5
	BY-08-8	42.9924	83.5961	2933	2	2.65	0.999	1962000	45600	07KNSTD	2014	51.6	3.0	1.2
	BY-08-11	43.003	83.5622	3060	2	2.65	0.999	2292100	64700	07KNSTD	2014	55.5	3.4	1.6
	BY-08-12	43.0033	83.5613	3068	2	2.65	0.999	1545000	34400	07KNSTD	2014	37.5	2.2	0.8
In light grey: samples rejected for a minimum coefficient of variation, in the limit of 1/3 of samples allowed to be rejected to test if the remaining ages could fulfil the σ/μ<15% criterion											*Mean (μ)*	*44.6*		
											Std (σ)	*9.0*		
											χ^2_R	*55.0*		
											σ/μ	*0.20*		
											% MIS 3	*100*		

Data set analysis

Criteria	
n_{total}>1	yes
n≥3 after sample rejection	yes
Well-clustered remaining group: σ/μ<15%	no
>75% distribution within MIS 3	yes

Conclusion:

The data spread over several tens of ka, and no well-clustered dominant group (≥2/3 of n_{total}) could be isolated. Despite the majority of ages lie within the MIS 3 range, such dispersion reflects strong geomorphological processes effects. Due to the large age scatter and in the absence of additional supportive data, the MIS 3 inference remains therefore speculative.

Site 18: Nalati Range, Sairenwuxunsala SR4

Sample information:

Cosmogenic exposure dating

Author	ID	Lat (°N)	Long (°E)	Alt.(m a.s.l.)	Thick. (cm)	Density (g/cm^3)	Shield.	[Be] atoms/g	[Be] err atoms/g	Be standard.	year collected	Age (ka)	Ext. err.	Int. err.
Zhang et al. (2016)	GNS-08-2	43.1178	85.7591	3167	2	2.65	0.998	1282200	30400	07KNSTD	2014	29.5	1.7	0.7
	GNS-08-3	43.1169	85.7596	3159	2	2.65	0.998	825600	27800	07KNSTD	2014	19.8	1.2	0.6
	GNS-08-4	43.1161	85.7587	3151	2	2.65	0.998	532600	19500	07KNSTD	2014	13.2	0.9	0.5
	GNS-08-5	43.1157	85.7598	3153	2	2.65	0.998	829700	15800	07KNSTD	2014	19.9	1.1	0.4
In light grey: sample rejected for a minimum coefficient of variation, in the limit of 1/3 of samples allowed to be rejected to test if the remaining ages could fulfil the σ/μ<15% criterion											*Mean (μ)*	*17.6*		
											Std (σ)	*3.8*		
											χ^2_R	*61.9*		
											σ/μ	*0.22*		
											% MIS 3	*0*		

Data set analysis

Criteria	
n_{total}>1	yes
n≥3 after sample rejection	yes
Well-clustered remaining group: σ/μ<15%	no
>75% distribution within MIS 3	no

Conclusion:

The data spread over several ka, and no well-clustered dominant group (≥2/3 of n_{total}) could be isolated. Such dispersion reflects strong geomorphological processes effects, prohibiting the inference of a glacial timing due to the large age scatter. The MIS 3 inference is therefore considered unreliable.

Site 19: Daxi, Shangwangfeng till/UWF moraine group

Sample information:

Cosmogenic exposure dating

Author	ID	Lat (°N)	Long (°E)	Alt.(m a.s.l.)	Thick. (cm)	Density (g/cm^3)	Shield.	[Be] atoms/g	[Be] err atoms/g	Be standard.	year collected	Age (ka)	Ext. err.	Int. err.
Kong et al., 2009	TD2	43.116	86.929	3164	3	2.65	0.98	987000	43000	NIST_30200	2007	22.1	1.5	1.0
	TD5	43.117	86.928	3170	3	2.65	0.98	757000	45000	NIST_30200	2007	17.3	1.4	1.0
	TD6	43.121	86.856	3449	3	2.65	0.99	887000	25000	NIST_30200	2007	16.8	1.0	0.5
Li et al., 2011	07_35	43.119	86.92	3192	2	2.65	0.939	660000	11000	07KNSTD	2007	16.7	0.9	0.3
	07_36	43.119	86.92	3186	2	2.65	0.939	739000	13000	07KNSTD	2007	18.6	1.0	0.3
	07_37	43.119	86.92	3183	3.5	2.65	0.927	701000	18000	07KNSTD	2007	18.1	1.1	0.5
	07_38	43.119	86.92	3179	3	2.65	0.931	637000	14000	07KNSTD	2007	16.5	0.9	0.4
											Mean (μ)	*18.0*		
											Std (σ)	*2.0*		
											χ^2_R	*10.1*		
											σ/μ	*0.11*		
											%MIS 3	*0 %*		

ESR dating

Author	ID	Lat (°N)	Long (°E)	Alt.(m a.s.l.)	Material	Water content (%)	U (ppm)	Th (ppm)	K_2O (%)	Total Dose (Gy)	Age (ka)	Err.
Zhao et al., 2006	MZET-2-1	43.12*	86.92*	no	Till	5.0	2.1	12.2	3.0	140.5	35.0	3.5
											27.6**	-
											37.4**	-

* rough geographic coordinates deduced from description in the original paper, as no geographical coordinates were provided.
**data reported in Zhao et al. (2006), from Yi et al. (2001, in Chinese)

Data set analysis

Criteria		Conclusion:
$n_{total}>1$	yes	In the absence of techniques to evaluate the completeness of the ESR signal resetting or the residual dose at the deposition time, ESR ages cannot be considered as reliable.
Partial bleaching investigated for ESR samples	no, all ESR samples rejected	
$n\geq3$ after sample rejection	yes	After rejection of the ESR chronological data, the remaining cosmogenic data set allows reliable constraint of an MIS 2 glacial advance.
Well-clustered remaining group: $\sigma/\mu<15\%$	yes	
>75% distribution within MIS 3	no	

Site 20: Ala A, M3 moraine

Sample information:

Cosmogenic exposure dating

Author	ID	Lat (°N)	Long (°E)	Alt.(m a.s.l.)	Thick. (cm)	Density (g/cm^3)	Shield.	[Be] atoms/g	[Be] err atoms/g	Be standard.	year collected	Age (ka)	Ext. err.	Int. err.
Li et al., 2014	AR-10-014	42.993	86.919	3489	5	2.7	0.9694	1041000	31000	07KNSTD	2010	21.2	1.3	0.6
	AR-10-015	42.993	86.919	3480	2	2.7	0.9694	1196000	30000	07KNSTD	2010	23.7	1.4	0.6
	AR-10-016	42.993	86.919	3489	5	2.7	0.9694	1283000	32000	07KNSTD	2010	25.7	1.5	0.6
	AR-10-017	42.993	86.918	3487	5	2.7	0.9694	1220000	28000	07KNSTD	2010	24.6	1.4	0.6
	AR-10-018	42.993	86.918	3479	3	2.7	0.9694	1969000	39000	07KNSTD	2010	37.9	2.1	0.8
	AR-10-019	42.993	86.918	3477	2	2.7	0.9694	1523000	29000	07KNSTD	2010	29.6	1.7	0.6
	AR-10-020	42.993	86.919	3487	3	2.7	0.9694	1559000	52000	07KNSTD	2010	30.3	1.9	1.0
In light grey: samples rejected for a minimum coefficient of variation, in the limit of 1/3 of samples allowed to be rejected to test if the remaining ages could fulfil the σ/μ<15% criterion											*Mean (μ)*	*25.9*		
											Std (σ)	*3.5*		
											χ^2_R	*28.5*		
											σ/μ	*0.14*		
											% MIS 3	*6 %*		

Data set analysis

Criteria	
n_{total}>1	yes
n≥3 after sample rejection	yes
Well-clustered remaining group: σ/μ<15%	yes
>75% distribution within MIS 3	no

Conclusion:

The chronological data allows reliable constraint of an MIS 2 glacial advance.

Site 21: Ala B, M4 moraine

Sample information:

Cosmogenic exposure dating

Author	ID	Lat (°N)	Long (°E)	Alt.(m a.s.l.)	Thick. (cm)	Density (g/cm^3)	Shield.	[Be] atoms/g	[Be] err atoms/g	Be standard.	year collected	Age (ka)	Ext. err.	Int. err.
Li et al., 2014	ARL-10-001	42.921	86.924	3283	3	2.7	0.9991	2307000	48000	07KNSTD	2010	48.3	2.8	1.0
	ARL-10-002	42.921	86.924	3278	3	2.7	0.9991	1981000	51000	07KNSTD	2010	41.7	2.5	1.1
	ARL-10-003	42.917	86.92	3272	3	2.7	0.9989	2086000	46000	07KNSTD	2010	44.0	2.5	0.9
	ARL-10-004	42.917	86.92	3274	3	2.7	0.9989	1718000	39000	07KNSTD	2010	36.7	2.1	0.8
	ARL-10-005	42.917	86.921	3275	4	2.7	0.9989	2116000	55000	07KNSTD	2010	44.8	2.7	1.2
	KXN-10-022	42.921	86.899	3256	1	2.7	0.9991	3648000	57000	07KNSTD	2010	76.9	4.3	1.2
	KXN-10-024	42.925	86.9	3271	3	2.7	0.9994	1595000	93000	07KNSTD	2010	34.3	2.7	2.0
In light grey: samples rejected for a minimum coefficient of variation, in the limit of 1/3 of samples allowed to be rejected to test if the remaining ages could fulfil the σ/μ<15% criterion											*Mean (μ)*	*41.6*		
											Std (σ)	*5.3*		
											χ^2_R	*22.0*		
											σ/μ	*0.13*		
											% MIS 3	*100 %*		

Data set analysis

Criteria	
n_{total}>1	yes
n≥3 after sample rejection	yes
Well-clustered remaining group: σ/μ<15%	yes
>75% distribution within MIS 3	yes

Conclusion:

The chronological data allows reliable constraint of an MIS 3 glacial advance.

Site 22: Turgan, M5 moraine

Sample information:

OSL dating: post-IR OSL signal from multi-grain aliquots (9.7 mm diameter) of fine-grain quartz (4–11μm)

Author	ID	Lat (°N)	Long (°E)	Alt.(m a.s.l.)	Depth. (m)	Material	Water content (%)	α counting rate (counts/ks)	K (%)	Total dose rate (Gy/ka)	De (Gy)	Age (ka)	Err.
Chen et al., 2015	YW-09-9-1	43.2043	94.3816	2660	1.9	supraglacial channel fills sediments within supraglacial till (profile 1)	23	7.55±0.18	2	3.4±0.2	148.7±14.2	44.2	4.3
	YW-09-9-2	43.2043	94.3816	2660	2.4		7	6.91±0.20	1.5	2.8±0.2	115.2±13.2	41.5	4.8
	YW-09-9-3	43.2043	94.3816	2660	2.8		8	8.95±0.23	1.8	3.4±0.2	148.1±10.3	43.4	3.1
	YW-09-9-7	43.2038	94.3816	2661	2.2	same as above (profile 2)	6	7.85±0.22	2.7	3.6±0.2	149.4±9.7	41.5	2.7
	YW-09-9-4	43.2038	94.3816	2661	2.7		17	8.41±0.23	1.9	3.7±0.2	135.7±14.3	37.4	4

Data set analysis

Criteria	
$n_{total}>1$	yes
Partial bleaching investigated for OSL samples	no
n≥3 after sample rejection	-
Well-clustered remaining group: σ/μ<15%	-
>75% distribution within MIS 3	-

Conclusion:

Because of the absence of thorough partial bleaching investigation for none of the OSL samples, the inferred MIS 3 chronology remains ambiguous and additional chronological data are necessary to confirm the proposed timing.

Site 23: Kanas A, sub-moraine complex 2 (or 1-2)

Sample information:

OSL dating: post-IR OSL signal from multi-grain aliquots (9.7 mm diameter) of fine-grain quartz (4–11 µm, Xu et al., 2009; 36–63 µm, Zhao et al., 2013)

Author	ID	lat. (°N)	long. (°E)	Alt. (m a.s.l)	Depth (m)	Material	Water content (%)	α counting rate (counts/ks)	U (ppm)	Th (ppm)	K (%)	Total dose rate (Gy/ka)	De (Gy)	Age (ka)	Err.
Xu et al., 2009	KNS07-67*	48.711	87.022	1391	-	glacial deposit	3	14.16±0.41	-	-	2.22	4.92±0.49	169.1±12.2	34.4	4.2
	KNS07-68*	48.711	87.022	1381	-	glacial deposit	5	14.68±0.25	-	-	2.25	5.18±0.52	197.3±12.6	38.1	4.5
Zhao et al., 2013	K3	48.697	87.020	1380	0.6	fluvioglacial deposits sandwiched between till units	2.8	-	3.1±0.2	15.1±0.4	1.7±0.1	3.5±0.2	164.5±24.1	43.6	6.7
	K5	48.702	87.036	1399	0.3		8.8	-	2.35±0.2	9.4±0.2	1.81±0.1	3.5±0.16	182.5±25.8	52.1	7.8

*The authors associate these samples to sub-moraine complex 2, however, based on the geographic coordinates and photos of the sampling sites provided in the original paper, these samples are located in the inner part of the Kanas complex, and so in the sub-moraine complex 1 (based on the subdivision of the Kanas complex into three sub-complexes proposed by the authors)

Data set analysis

Criteria	
$n_{total}>1$	yes
Partial bleaching investigated for OSL samples	no
n≥3 after sample rejection	-
Well-clustered remaining group: σ/µ<15%	-
>75% distribution within MIS 3	-

Conclusion and comments:

Inferred MIS 3 glacial event is disregarded as for none of the OSL samples, thorough partial bleaching investigations have been carried out. Furthermore, geomorphological investigation of the Kanas complex, cosmogenic exposure ages and single grain IRSL ages presented in this study do not support the differentiation of the Kanas complex into three sub-complexes reflecting three distinct glacial events (including a MIS 3 event). The presented data instead indicate that the entire Kanas complex was formed during a single MIS 2 glaciation.

Site 24: Kanas B, sub-moraine complex 3

Sample information:

OSL dating: post-IR OSL signal from multi-grain aliquots (9.7 mm diameter) of fine-grain quartz (4–11 µm, Xu et al., 2009; 36–63 µm, Zhao et al., 2013)

Author	ID	lat. (°N)	long. (°E)	Alt. (m a.s.l)	Depth (m)	Material	Water content (%)	α counting rate (counts/ks)	U (ppm)	Th (ppm)	K (%)	Total dose rate (Gy/ka)	De (Gy)	Age (ka)	Err.
Xu et al., 2009	KNS07-57	48.695	87.023	1366	-	glacial deposit	21	13.56±0.3			2.9	4.50±0.45	224.4±9.1	49.9	5.4
Zhao et al., 2013	K4	48.692	87.015	1378	0.4	fluvioglacial deposits sandwiched between till units	2.4	-	2.04±0.17	10.05±0.25	1.84±0.07	3.47±0.16	253.4±19.7	73.1	6.6

Data set analysis

Criteria	
$n_{total}>1$	yes
Partial bleaching investigated for OSL samples	No, all samples rejected
n≥3 after sample rejection	-
Well-clustered remaining group: σ/µ<15%	-
>75% distribution within MIS 3	-

Conclusion and comments:

Inferred MIS 3 glacial event is disregarded as for none of the OSL samples, thorough partial bleaching investigations have been carried out. Furthermore, geomorphological investigation of the Kanas complex, cosmogenic exposure ages and single grain IRSL ages presented in this study do not support the differentiation of the Kanas complex into three sub-complexes reflecting three distinct glacial events (including a MIS 3 event). The presented data instead indicate that the entire Kanas complex was formed during a single MIS 2 glaciation.

Site 25: Arshaan, OT1 (Haryn saddle, Shuvuun hill)

Sample information:

Cosmogenic exposure dating

Author	ID*	Lat (°N)	Long (°E)	Alt.(m a.s.l.)	Thick. (cm)	Density (g/cm^3)	Shield.	[Be] atoms/g	[Be] err atoms/g	Be standard.	year collected	Age (ka)	Ext. err.	Int. err.
Rother et al., 2014	MON-E-I-I	47.850	97.333	2568	4	2.6	1	1285000	32000	NIST_27900	2012	40.1	2.4	1.0
	MON-E-I-II	47.860	97.333	2563	4	2.6	1	1768000	43000	NIST_27900	2012	55.5	3.3	1.4
	MON-E-I-III	47.860	97.334	2560	4	2.6	1	953000	48000	NIST_27900	2012	30.2	2.2	1.5
	MON-E-II-I	47.860	97.316	2580	4	2.6	1	1908000	54000	NIST_27900	2012	59.2	3.6	1.7
	MON-E-II-II	47.859	97.320	2596	4	2.6	0.998	723000	19000	NIST_27900	2012	22.6	1.3	0.6
	MON-E-II-III	47.858	97.322	2600	4	2.6	0.998	1224000	31000	NIST_27900	2012	37.5	2.2	0.9
	MON-D-I-I	47.684	97.210	2140	5	2.6	1	995000	24000	NIST_27900	2012	43.1	2.5	1.1
	MON-D-I-II	47.684	97.210	2133	4	2.6	1	498000	12000	NIST_27900	2012	21.9	1.3	0.5
	MON-D-I-III	47.684	97.210	2137	4	2.6	1	931000	23000	NIST_27900	2012	40.2	2.4	1.0
*samples "MON-E" were taken from the Haryn saddle and samples "MON-D" were taken from the Shuvuun hill. The two sites are associated with the same glacial extent. In light grey: samples rejected for a minimum coefficient of variation, in the limit of 1/3 of samples allowed to be rejected to test if the remaining ages could fulfil the σ/μ<15% criterion.											*Mean (μ)*	*41.1*		
											Std (σ)	*8.31*		
											χ^2_R	*36.4*		
											σ/μ	*0.20*		
											%MIS 3	*100%*		

Data set analysis

Criteria	
n_{total}>1	yes
n≥3 after sample rejection	yes
Well-clustered remaining group: σ/μ<15%	no
>75% distribution within MIS 3	yes

Comments and conclusion:

The data spread over several tens of ka, and no well-clustered dominant group (≥2/3 of n_{total}) could be isolated. Despite the majority of ages lie within the MIS 3 range, such dispersion reflects strong geomorphological processes effects. Due to the large age scatter and in the absence of additional supportive data, the MIS 3 inference therefore remains speculative.

Site 26: Hangai Dome (Khangai), Khaak Nuur

Sample information:

Cosmogenic exposure dating

Author	ID	Lat (°N)	Long (°E)	Alt.(m a.s.l.)	Thick. (cm)	Density (g/cm^3)	Shield.	[Be] atoms/g	[Be] err atoms/g	Be standard.	year collected	Age (ka)	Ext. err.	Int. err.
Smith et al., 2016	MN0711-15A	47.4621	98.56841	2676	3	2.65	1	1252000	34100	KNSTD	2011	36.2	2.2	0.9
	MN0711-15B	47.4626	98.56909	2677	3	2.65	1	1605000	43600	KNSTD	2011	46.0	2.8	1.3
	MN0711-15C	47.4631	98.56913	2676	3	2.65	1	501000	13700	KNSTD	2011	15.0	0.9	0.4
											Mean (μ)	*32.4*		
											Std (σ)	*15.8*		
											χ^2_R	*1009.8*		
											σ/μ	*0.49*		
											% MIS 3	*61*		

Data set analysis

Criteria	
n_{total}>1	yes
n≥3 after sample rejection*	yes
Well-clustered remaining group: σ/μ<15%	no
>75% distribution within MIS 3	no

Conclusion:

The data spread over several marine isotope stages, and no well-clustered dominant group (≥2/3 of n_{total}) could be isolated. Such dispersion reflects strong geomorphological processes effects, prohibiting the inference of a glacial timing due to the too large uncertainty. The MIS 3 inference is therefore considered unreliable.

*no sample rejection allowed

Site 27: Hoit Aguy (Darhaad Basin), right lateral moraine

Sample information:

Cosmogenic exposure dating

Author	ID	Lat (°N)	Long (°E)	Alt.(m a.s.l.)	Thick. (cm)	Density (g/cm^3)	Shield.	[Be] atoms/g	[Be] err atoms/g	Be standard.	year collected	Age (ka)	Ext. err.	Int. err.
Batbaatar and Gillespie, 2016	080709-HA-JB-02	51.552	98.715	2332	2.5	2.65	1	979900	29000	07KNSTD	2009	34.3	2.1	1.0
	080709-HA-JB-03	51.552	98.715	2335	2.5	2.65	1	926600	44700	07KNSTD	2009	32.4	2.3	1.6
											Mean (μ)	*33.4*		
											Std (σ)	*1.3*		
											χ^2_R	*1.3*		
											σ/μ	*0.04*		
											% MIS 3	*100*		

Data set analysis

Criteria	
n_{total}>1	yes
n≥3 after sample rejection*	yes
Well-clustered remaining group: σ/μ<15%	no
>75% distribution within MIS 3	no

Conclusion:

Although these samples agree within analytical uncertainty, the number of samples collected (n=2) is insufficient to establish a reliable glacial chronology. The inferred MIS 3 chronology remains uncertain and additional chronological data are necessary to confirm the proposed timing.

*no sample rejection allowed

Site 28: Burhan Budai Shan-South side, M2 moraine

Sample information:

Cosmogenic exposure dating

Author	ID*	Lat (°N)	Long (°E)	Alt.(m a.s.l.)	Thick. (cm)	Density (g/cm^3)	Shield.	[Be] atoms/g	[Be] err atoms/g	Be standard.	year collected	Age (ka)	Ext. err.	Int. err.
Owen et al., 2006	PR22	35.630	94.211	5098	5	2.65	0.97	4643060	88351	LLNL3000	2004	39.6	2.2	0.7
	PR23	35.630	94.211	5104	5	2.65	0.97	2941252	53712	LLNL3000	2004	26.9	1.5	0.5
	PR24	35.630	94.213	5113	5	2.65	0.97	1874692	39306	LLNL3000	2004	18.6	1.1	0.4
	PR25	35.630	94.213	5113	5	2.65	0.97	1292592	28475	LLNL3000	2004	13.4	0.8	0.3
In light grey: sample rejected for a minimum coefficient of variation, in the limit of 1/3 of samples allowed to be rejected to test if the remaining ages could fulfil the σ/μ<15% criterion											*Mean (μ)*	*19.6*		
											Std (σ)	*6.8*		
											χ^2_R	*42.5*		
											σ/μ	*0.35*		
											%MIS 3	*0 %*		

Data set analysis

Criteria	
n_{total}>1	yes
n≥3 after sample rejection	yes
Well-clustered remaining group: σ/μ<15%	no
>75% distribution within MIS 3	no

Conclusion:

The data spread several tens of ka and no well-clustered dominant group (≥2/3 of n_{total}) could be isolated. Such dispersion reflects strong geomorphological processes effects, prohibiting the inference of a glacial timing due to the large age scatter. The MIS 3 inference is therefore considered unreliable.

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A re-evaluation of MIS 3 glaciation using cosmogenic radionuclide and single grain luminescence ages, Kanas Valley, Chinese Altai

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Supplementary figures and tables

Figure S1. Boulders sampled in the Kanas Valley for cosmogenic nuclide exposure dating.

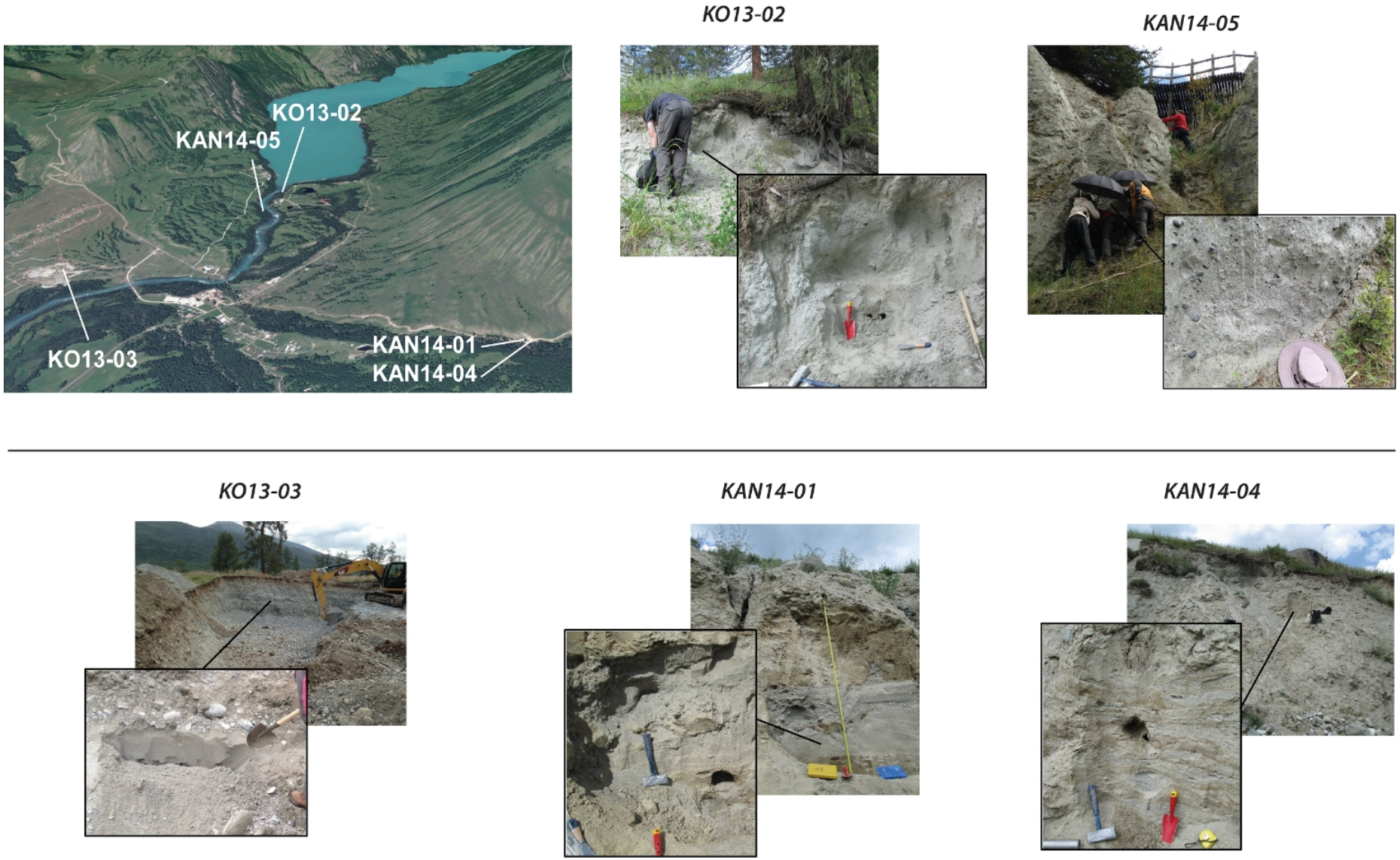

Figure S2. Location and picture of the sedimentary sections sampled for luminescence dating in the Kanas Valley.

Table S1. Sedimentological description of luminescence samples.

Sample	Morphological unit	Location (°N/°E)	Altitude (m a.s.l.)	Sedimentological description	Depositional environment
KO13-02	Kanas moraine complex	48.7114/87.0220	1383	Massive deposit, chaotic (with rare flipped layered patches). Matrix supported (fine sand to silt), with ~15% coarser components (gravel to cobbles). Sub-angular to sub-rounded clasts, several lithologies. Slightly consolidated.	Till deposit including proglacial lake deposit (very proximal) reworked during glacial standstill and re-advance episode.
KAN14-05		48.7068/87.0213	1382	As above.	As above.
KO13-03	Kanas outwash	48.6911/87.0116	1373	Very well-sorted medium sand dominated unit from a larger deposit composed of sorted to well-sorted, sand to rounded pebble-cobble dominated layers. Imbrication of clasts in coarse component dominated layers. Two main lithologies: granite and schists.	Glaciofluvial deposit.
KAN14-01	Outer lateral moraine ridge	48.6920/87.0567	1627	Well-sorted silt-fine sand layered unit from a larger deposit with well-sorted silty to coarse sandy layers (and few gravel dominated layers) capped by diamicton.	Glaciofluvial deposit, consistent with a proximal ice position, to supraglacial environment.
KAN14-04		48.6922/87.0613	1616	Alternation of thin, undulated and slightly dipped layers of fine to medium sand and silt. Unit from a larger deposit with well-sorted silty to sandy layers capped by diamicton.	As above.

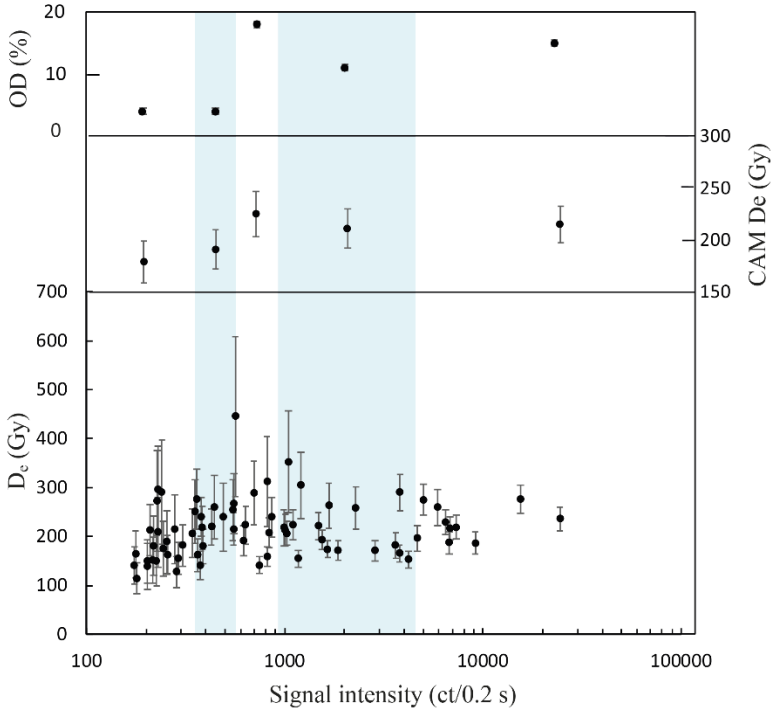

Figure S3. Single grain IRSL D_e values plotted against the signal intensity in response to a ~15 Gy test dose (lower graph) for the sample KAN14-04. The data set was separated into five bins accounting for 20% of the population (blue shaded and unshaded areas), for which the associated CAM D_e value (middle graph) and the over-dispersion (OD, upper graph) were calculated.

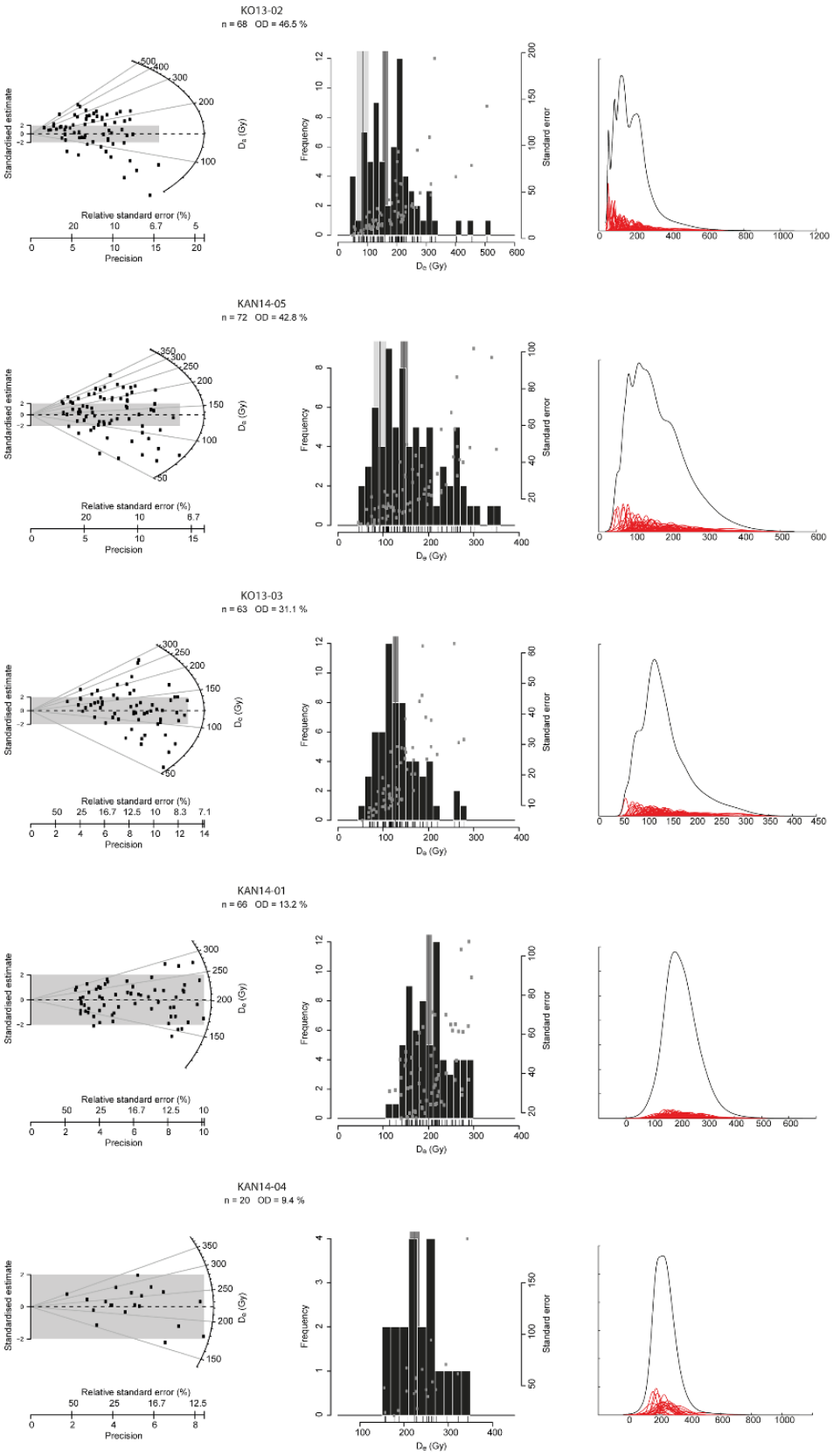

Figure S4. Radial plots (left) and histograms (right) representing the IRSL single grain De distribution associated with the samples collected in the Kanas Valley. On the histograms, dark grey vertical bars represent the final mean De with error obtained using the CAM, and the light grey bars (for KO13-02 and KAN14-05) represent the final De with error obtained using the MAM.