Sr and Nd isotope ratios and REE abundances of moraines in the mountain areas surrounding the Taklimakan Desert, NW China

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The first systematic data of Sr and Nd isotopic ratios, REE abundances, major element and mineral compositions are reported for the Chinese moraines from the western Kunlun Mts. and southern and northern flanks of the Tianshan Mts. and soils from the Tibet Plateau. This study was conducted in order to characterize the isotopic and geochemical features of these moraines and soils, which are considered as possible sources of the Taklimakan Desert sands. The moraines and the desert sands consist of quartz and feldspar as dominant minerals, but the former have higher clay and mica and lower carbonate mineral abundances than the latter. In spite of the wide variation, average values of most major elements of the moraines are generally similar to those of the Taklimakan Desert sands, except for CaO depletion and K₂O enrichment in the moraines. Sr and Nd isotopic ratios are also highly variable for moraines, particularly from the Tianshan northern flank, while those for the desert sands show restricted values. In the Sr-Nd isotopic diagram, the Taklimakan Desert sands are plotted in the narrow field overlapped by both the moraine matrices from the western Kunlun Mts. and from the Tianshan southern flank. In addition, it is noted that average value of Nd isotopic ratios for the moraines is clearly higher than those for the desert sands. Two Tibetan soils of this study show wide variation in mineral composition and major element compositions (SiO₂ = 75% and CaO = 1.5% for one sample and SiO₂ = 44% and CaO = 31.8% for the other). However, Sr isotopic ratios of both soils are similar to those of the desert sands and their Nd isotopic data are slightly smaller than the desert sands. These results suggest moraine matrices from both the western Kunlun Mts. and the Tianshan southern flank and the Tibetan soils as possible sources for the Taklimakan Desert sands.

INTRODUCTION

Glacial moraines in the surrounding mountain areas of the Taklimakan Desert are expected to bear important information on source material composition and formation mechanism of the desert sand. Glacial grinding has been proposed to be a main mechanism responsible for the formation of fine particles in huge amounts and large distribution scale (Smalley, 1966; Smalley and Vita-Finzi, 1968). Recent study on geochemical,

mineralogical and sedimentological features of the Taklimakan Desert sands confirmed the importance of glacial activity besides aeolian activity in the homogenization of the Taklimakan Desert sands (Honda and Shimizu, 1998). However, direct investigation on the moraine deposits surrounding the Taklimakan Desert has been very scarce.

The Taklimakan Desert, located in the central of Tarim Basin in northwest China, is the largest sand desert in China, with a total area about

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Fig. 1. Location of the Taklimakan Desert, Tianshan Mountains and Kunlun Mountains, with sampling sites.

337,000 km². Unlike other sand deserts in the world, it is enclosed by high mountains, i.e., the Tianshan Mts. in the north and the Kunlun and Altun Mts. in the south and southeast (Fig. 1). In these mountains, the glaciation was inferred to be extensive and much larger in the late Pliocene and Pleistocene than present (Zheng *et al.*, 1990; Xinjiang Institute of Geography, 1986). Larger glaciers including big ice cap occupying the main Kunlun Mts. formed during Middle Pleistocene (Zheng *et al.*, 1990; Derbyshire, 1996). The existence of Late Pleistocene glacial deposits of approximately 60 m in thickness, on the southern flank of the Tianshan Mts., was reported by the Xinjiang Institute of Geography (1986). It is also reported that multiple glaciations had occurred during the Pleistocene in Kunlun Mts. with glacier extent changing from restricted valleys as mountain glaciation to large areas as ice sheet glaciation (Derbyshire, 1996). The widespread glaciation in these mountain areas as well as the close location and large altitude gap between the desert

and the mountain areas further enhances the probability that a huge quantity of sand grains was principally derived from detrital sediments produced by glacial grinding in the surrounding mountain areas.

Sr and Nd isotopic compositions of sediments may provide useful information about their source materials. Liu *et al.* (1994) measured the Rb-Sr, Sm-Nd and La-Ce isotopic compositions for the loess, loess-like, desert sand and river deposits collected from the southwest Taklimakan Desert. They showed that the desert sands of the Taklimakan Desert and loess of the Loess Plateau are indistinguishable in Nd isotopic and chemical compositions, and suggested a desert origin for the Chinese loess and the Taklimakan Desert as the source area. Isotopic study on moraine matrix, representing average components of glacial grinding products, is expected to shed insight into the source and formation and homogenous mechanism of desert sands and loesses. Limited investigations on the moraine deposits of these areas had

been done thus far. Ishii *et al.* (1995) studied the distribution, petrologic features and oxygen isotope composition of moraine deposits surrounding the Taklimakan Desert. Matsuhisa *et al.* (1996) compared the $\delta^{18}\text{O}$ values of quartz in loess, moraine and basement rock of Tarim Basin, and proposed a descriptive model concerning derivation of sand grains, i.e., fine particles could be formed initially by glacial erosion then deposited as moraine matrix and finally transported to the desert.

Until the present, systematic geochemical and Sr-Nd isotopic study has not been carried out for the Chinese moraines. Knowledge on source materials of the Taklimakan Desert sands is still very poor. In this paper, we presented new results of Sr and Nd isotopic compositions, REE abundances, major element and mineral compositions for moraines in surrounding mountain areas of the Taklimakan Desert as well as for the Taklimakan Desert sands. Surface soil samples from the northwest Tibet Plateau were also analyzed. Accumulation of these geochemical and isotopic data will give information on the relative contribution of the moraines against other possible sources to the Taklimakan Desert sands, even though some uncertainties of the extent of the Pleistocene glaciation in the Kunlun and Tianshan Mts. are present.

SAMPLES AND ANALYTICAL METHODS

The moraine matrix in the surrounding mountain areas of Taklimakan Desert is mainly the mixture of basement rock detritus derived from glacial grinding and sedimentation. It represents an average composition of sedimentary rocks (chiefly sandstone, shale and limestone) from Precambrian to Quaternary ages and granitic rocks from the Proterozoic to Cretaceous (Bureau of Geology and Mineral Resources of Xinjiang Uygur Autonomous Region, 1993). The moraine samples of this study were collected from Gez and Karakuri Lake areas in west Kunlun Mountains, and Bosten and No. 1 Glacier areas in the south and north flanks of Tianshan Mountains (Fig. 1 and Table 1). Surface soil samples from northwest Tibet Plateau were collected at Duoma and Daxiong. In addi-

tion, three desert sand and two river sand samples from the northern part of the Taklimakan Desert were examined to complement the limited existing reference data for the Taklimakan Desert sand (Liu *et al.*, 1994; Tanaka *et al.*, 1990). The possible size effects on isotopic ratio and REE concentration are examined in this study for size fractions relatively coarser (from $>500\text{ }\mu\text{m}$ to $32\text{--}20\text{ }\mu\text{m}$) than those in previous studies (e.g., Basile *et al.*, 1997 and Asahara *et al.*, 1999 for Sr isotope; Goldstein *et al.*, 1984 and Grousset *et al.*, 1992 for Nd isotope).

Major element abundance was determined using X-ray fluorescence spectrometer (XRF, Shimadzu VF-320A) by the method given by Honda and Shimizu (1998). Repeated analyses of standard rocks showed the precision to be better than 1% for SiO_2 and 3–5% for other major elements. Mineralogical composition of powdered sample was determined by X-ray diffraction (XRD, Mac Science M18XHF-SRA 1180) and checked by microscopic examination for coarser grains. Mineral abundance was estimated from the best fitting of major elements composition with the XRD identification.

Concentrations of REE, Rb and Sr were determined by inductively coupled plasma mass spectrometer (ICP-MS, VG PQ3), and Sr and Nd isotopic ratios were measured by thermal ionization mass spectrometer (TIMS, VG Sector-54) with three Faraday collectors at the Institute of Physical and Chemical Research. The analytical methods were given in Shimizu *et al.* (2000). Analytical uncertainties are 3% for Rb and Sr concentrations and 5% for most REE. Blanks on REE determination were less than 0.1% of measured values of all REE. The measured isotopic ratios were normalized to $^{86}\text{Sr}/^{88}\text{Sr} = 0.1194$ and $^{146}\text{Nd}/^{144}\text{Nd} = 0.7219$. The average for the NBS987 strontium standard was 0.71024 ± 0.00002 (2σ , $n = 18$), and for JNdi-1 neodymium standard of Geology Survey of Japan (Tanaka *et al.*, 1996) was 0.51210 ± 0.00001 (2σ , $n = 15$) during the measurement. The $^{143}\text{Nd}/^{144}\text{Nd}$ ratios for the JNdi-1 standard and La Jolla standard have been reported to be 0.512106 ± 0.000003 (2σ) and $0.511851 \pm$

Table 1. Sample descriptions

Sample No.	Location	Location No.	Brief description
Moraines of north Tianshan Mts.			
9301	end position of No. 1 glacier	92	fine fraction
9302	end position of No. 1 glacier	93	fine fraction
9304	lower reach of No. 1 glacier	94	matrix
9305	left bank of Urumqi River	95	fine fraction
Moraines of south Tianshan Mts.			
9315-2M	north of Bosten	105	matrix
9315-G	north of Bosten	105	gravel
Moraines of west Kunlun Mts.			
9404-2	Subashi Pass	125	matrix, 80–380 cm in depth
9403-3	Karakuri Lake	124	grey silt, 40–70 cm in depth
9405	Karakuri Lake	126	ancient moraine matrix, 60 cm
9407-2	Karakuri Lake	128	grey, matrix, 33 cm in depth
9408-2	Gez	129	grey, M3 moraine matrix, 1 m + thickness
9408-3	Gez	129	outwash of M3 moraine, silt
9409	Gez	130	matrix of M1 moraine
9410-2	Gez	131	grey, matrix
9412-1	Oytag	133	black, matrix
Sands of north Taklimakan Desert			
9206	Luntai	79	barchan sand
A92501-A	Aral	64	dune sand
9213	Shaya	86	barchan sand
A92802	Yakrik	70	river sand (Muzat River)
9208	Luntai	81	river sand (Tarim River)
Northwest Tibet soils			
TLR-25A	Duoma, Tibet		surface soil
TLC-35A	Daxiong, Tibet		surface soil

0.000006 (2σ) by Miyazaki and Shuto (1998), and 0.512115 ± 0.000016 (2σ) and 0.511857 ± 0.000018 (2σ) by Dragusanu and Tanaka (1999). The procedure blank of chemical separation is estimated less than 1–2 ng for Sr and 0.2 ng for Nd. The blank values of Sr and Nd are both about 0.05% of the total and considered to be negligible in all isotopic measurements.

RESULTS AND DISCUSSION

Mineralogical compositions

Mineralogical compositions are presented in Table 2 and Fig. 2. Quartz and feldspars are the dominant minerals in moraine matrix, varying in 30–50% and 18–45%, respectively. Calcite is iden-

tified in varying abundance but generally <5%; two highest abundances about 15% are found in moraine from south flank of Tianshan Mts. (9315-2M) and west Kunlun Mts. (9412-1). Mica and kaolinite are also essential constituents of the moraines and their XRD peak ratios against quartz vary from 0.1 to 0.3 and from 0.02 to 0.3, respectively. Some moraine samples contain gypsum and its content reaches to 15% in a Kunlun Mts. moraine sample of 9408-2. Tibet soils are quite variable in mineral composition; one shows high quartz content (*ca.* 55%) and the other shows high calcite content (*ca.* 43%) besides quartz (*ca.* 26%).

The moraines and desert sands are similar in feldspar content. Quartz and calcite are generally more abundant in desert sands than in moraines

Table 2. Mineral composition (%) and XRD peak ratios against quartz for the Kunlun and Tianshan Mts. moraines, the Taklimakan Desert sands and Tibet soils

Sample No.	Abundance (%) ^(a)					Quartz relative XRD peak ratio ^(c)						
	Quartz	Feldspar	Calcite	Gypsum	Others ^(b)	Pl/Q	Kf/Q	Cal/Q	Gy/Q	Dol/Q	Mi/Q	Ka/Q
Moraines of north Tianshan Mts.												
9301	32	24	2	0	43	0.26	0.09	0.03	0	0	0.24	0.17
9302	41	23	0	0	36	0.28	0.24	0.01	0	0	0.20	0.09
9304	30	33	0	0	37	0.92	0.49	0	0	0	0.07	0.12
9305	42	22	6	0	31	0.10	0	0.09	0	0	0.10	0.27
Moraines of south Tianshan Mts.												
9315-2M	37	24	13	3	23	0.43	0.24	0.27	0.13	0.08	0.11	0.09
9315-G	27	45	5	0	23	1.36	1.63	0.10	0	0	0.13	0.06
Moraines of west Kunlun Mts.												
9404-2	36	36	4	<1	23	1.42	0.55	0.20	0	0	0.08	0.12
9403-3	43	23	2	<1	31	0.92	0.74	0.02	0.01	0	0.29	0.03
9405	38	19	5	0	38	0.49	0.20	0.11	0.03	0.03	0.32	0.07
9407-2	39	21	4	2	34	0.36	0.23	0.07	0.05	0	0.27	0.10
9408-2	43	22	0	15	20	0.80	0.44	0	0.99	0.11	0.23	0.05
9408-3	38	27	5	<1	31	0.58	0.42	0.08	0	0.04	0.15	0.08
9409	37	27	0	9	27	0.57	0.48	0	0.27	0	0.26	0.03
9410-2	49	22	0	<1	29	0.32	0.53	0	0	0	0.14	0.02
9412-1	39	18	13	1	29	0.10	0	0.52	0	0.17	0.18	0.20
Sands of north Taklimakan Desert												
9206	49 (48)	25 (32)	6 (7)	<1	19	1.00	0.29	0.17	0	0.05	0.04	0.03
A92501-A	45 (47)	24 (17)	7 (10)	<1	24	0.42	0.19	0.22	0	0.07	0.07	0.04
9213	(29)	(24)	(33)	—	(14)	0.18	0.10	1.04	0	0.19	0.07	0.04
A92802	38 (41)	18 (20)	29 (18)	0	15	0.17	0.10	0.83	0	0.32	0.10	0.04
9208	48 (44)	20 (12)	11 (10)	<1	20	0.27	0.21	0.45	0	0.17	0.07	0.05
Northwest Tibet soils												
TLR-25A	53	19	0	1	26	0.27	0.16	0.01	0	0.04	0.05	0.05
TLC-35A	26	9	43	0	22	0.04	0	1.56	0	1.47	0.11	0.08

^(a)Numbers in brackets are point-counting results.

^(b)Others include dolomite (mainly in the desert sands), kaolinite, mica, chlorite, hematite, epidote and amphibole minerals.

^(c)Q = quartz, Pl = plagioclase, Kf = K-feldspar, Cal = calcite, Gy = gypsum, Dol = dolomite, Mi = mica, Ka = kaolinite.

(Fig. 3), whereas mica and kaolinite are less abundant in desert sands (Table 2). Higher calcite contents in the desert sands than in moraines suggest an addition of secondary calcite to the desert sands. It is also found that dolomite occurs more commonly in the desert sand than in moraine. Hot and dry desert environments may favor the formation of dolomite from the evaporation of Mg rich saline solution (Deer *et al.*, 1992). Low content of mica and kaolinite in the desert sands relative to moraines is likely to be the result of particle sorting.

Mg-Fe chlorite, amphibolite, epidote and opaque minerals such as hematite are also ob-

served in the moraine samples by microscopy observation and EPMA determination. They are rarely observed in the desert sands.

In the Taklimakan Desert sands of this study, quartz, feldspars and calcite are the main constituent commonly associated with mica and kaolinite. Quartz, feldspars and calcite contents are 40–50%, 15–25% and 5–30%, respectively. These mineral compositions for the sands from north side of the Taklimakan Desert are similar to those from south and central parts of the Taklimakan Desert (Honda and Shimizu, 1998), showing homogeneity in mineral compositions in the Taklimakan Desert.

Fig. 2. Mineral compositions of the moraines, the desert sands and northwest Tibet soils.

Fig. 3. (a) Quartz versus feldspar, and (b) quartz versus calcite abundance diagrams for the moraines and the desert sands. Data of southwest Taklimakan Desert sands are from Honda and Shimizu (1998).

Major element compositions

Major element data are given in Table 3 and average upper continental crust (UCC; Taylor and McLennan, 1985) normalized values are shown in Fig. 4. The sands from northern part of the Taklimakan Desert have very similar major element compositions to those from the south and

central parts of the desert; all showing higher CaO content and lower Na_2O and K_2O content against UCC.

Compared with the Taklimakan Desert sands (this study; Honda and Shimizu, 1998), the moraine samples are more heterogeneous (Fig. 4). The UCC-normalized values for the moraine

Table 3. Major element compositions (%) of the moraines, Taklimakan Desert sands and Tibet soils

Sample No.	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃ ^(a)	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	Total	LOI ^(b)	CIA ^(c)	K ₂ O/Na ₂ O	SiO ₂ /Al ₂ O ₃
Moraines of north Tianshan Mts.															
9301	63.1	0.87	16.2	7.95	0.14	3.04	1.31	1.69	3.55	0.19	98.0	8.0	65.4	2.10	3.89
9302	70.6	0.53	15.2	3.85	0.05	1.58	0.70	1.96	4.60	0.07	99.1	1.8	59.2	2.34	4.64
9304	64.4	0.90	14.3	5.76	0.11	2.57	2.51	3.36	3.31	0.15	97.4	2.8	52.4	0.99	4.50
9305	65.2	1.03	12.1	8.79	0.21	4.90	4.11	1.48	1.69	0.14	99.6	4.2	66.9	1.14	5.39
Moraines of south Tianshan Mts.															
9315-2M	60.6	0.47	12.0	3.67	0.07	2.12	13.2	2.57	2.42	0.12	97.2	10.7	55.0	0.94	5.05
9315-G	66.7	0.22	15.8	2.36	0.10	0.40	3.54	4.10	5.53	0.07	98.8	1.9	47.5	1.35	4.22
Moraines of west Kunlun Mts.															
9404-2	69.5	0.35	14.0	3.71	0.09	1.08	4.15	3.65	3.05	0.10	99.8	3.3	51.0	0.84	4.95
9403-3	72.6	0.26	13.5	2.78	0.06	0.79	1.82	3.08	4.43	0.07	99.5	1.1	50.2	1.44	5.37
9405	64.4	0.74	14.3	6.11	0.18	2.62	5.83	1.95	2.86	0.16	99.1	6.1	62.5	1.46	4.51
9407-2	65.5	0.53	15.6	5.00	0.09	2.19	3.46	2.45	3.95	0.11	98.8	5.0	58.4	1.61	4.20
9408-2	64.8	0.26	11.6	2.58	0.05	0.80	9.89	2.60	3.41	0.07	96.0	2.7	51.4	1.32	5.59
9408-3	68.4	0.50	14.3	4.21	0.09	1.86	4.14	2.41	3.74	0.14	99.8	4.2	57.0	1.55	4.80
9409	66.2	0.28	13.6	3.14	0.07	0.63	5.54	3.38	3.79	0.07	96.7	2.0	50.0	1.12	4.88
9410-2	74.3	0.27	13.5	2.43	0.06	0.54	1.88	2.80	4.61	0.08	100.5	1.1	51.4	1.65	5.49
9412-1	59.4	0.52	13.7	5.17	0.10	2.77	14.4	1.04	2.52	0.16	99.8	13.5	70.8	2.41	4.35
Sands of north Taklimakan Desert															
9206	72.0	0.28	10.8	2.20	0.04	1.51	6.92	2.57	2.64	0.07	99.0	5.8	51.8	1.03	6.65
A92501-A	69.8	0.39	11.6	2.89	0.05	1.86	7.08	2.63	2.67	0.09	99.0	6.4	53.1	1.01	6.03
9213	50.5	0.32	7.81	2.23	0.06	3.32	32.3	1.42	2.06	0.09	100.0	16.1	55.7	1.45	6.46
A92802	56.3	0.35	8.83	2.47	0.07	3.70	24.9	1.74	2.34	0.09	100.8	17.6	54.4	1.34	6.38
9208	68.2	0.50	10.4	2.99	0.06	2.40	11.2	2.28	2.23	0.14	100.4	9.1	54.3	0.98	6.55
Northwestern Tibet soils															
TLR-25A	75.4	0.60	11.8	4.26	0.05	1.72	1.45	1.75	2.53	0.14	99.7	3.73	60.7	1.45	6.39
TLC-35A	43.6	0.37	10.4	2.97	0.03	7.40	31.8	0.38	2.01	0.11	99.0	25.3	76.2	5.29	4.21

^(a)Fe₂O₃ as total iron.^(b)LOI = loss on ignition at 980°C for 2 hours. Total is calculated on a LOI-free basis.^(c)CIA: chemical index of alteration, [CIA = Al₂O₃/(Al₂O₃ + CaO* + Na₂O + K₂O), Nesbitt and Young, 1982].

Fig. 4. UCC-normalized major element composition for the moraines, desert sands and loesses. The data of southwestern and central Taklimakan Desert sands are from Honda and Shimizu (1998) and the Luochuan loess are from Gallet *et al.* (1996). Average UCC values are from Taylor and McLennan (1985).

samples are 0.9–1.1 for SiO_2 , 0.2–3.5 for CaO , 0.7–1.1 for Al_2O_3 , 0.4–2.3 for TiO_2 , MgO and total iron as Fe_2O_3 , 0.3–1.0 for Na_2O and 0.5–1.6 for K_2O . In accordance with the mineral composition difference between the moraines and desert sands, average CaO content are higher in the desert sands, and K_2O , Al_2O_3 and Fe_2O_3 are higher in the moraines (Fig. 5(a)). In spite of these differences and great heterogeneity, the average values of most major elements for 15 moraine samples show a general resemblance with the desert sands (Fig. 5(a)). This suggests that fine-grained subglacial deposits could be the source for the Taklimakan Desert sands. Regional variation of the major element compositions seems unclear between the Tianshan and Kunlun Mts. (Fig. 5(b)).

The correlation between Fe_2O_3 and MgO was clearly different for the moraines and desert sands (Fig. 6). Moraines show significant positive correlation between the two elements; the desert sands

show relatively higher MgO in respect to Fe_2O_3 and poor correlation between them, indicating that Fe and Mg are hosted in different minerals in these two sediments. Mineral composition data have suggested abundant chlorite and amphibole minerals in moraines and higher dolomite content in the sands. Relatively low Fe_2O_3 of desert sands than the moraines and loess (Figs. 6 and 4) may imply the preferential distribution of chlorite during wind sorting of fine grains. However, further study on detailed mineral composition data of Chinese loess is needed to support such explanation.

Moraines differ from the desert sands in ratios of $\text{SiO}_2/\text{Al}_2\text{O}_3$ and $\text{K}_2\text{O}/\text{Na}_2\text{O}$ as shown in Fig. 7. $\text{K}_2\text{O}/\text{Na}_2\text{O}$ ratios are generally greater than 1.0 in the moraines, but less than 1.0 for the desert sands. This difference may be due to higher mica contents in the moraines than in the desert sands. $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratios of moraines vary from 3.8 to 5.6,

Fig. 5. Comparisons of average major element compositions (a) between the moraines and the Taklimakan Desert sands (this study and Honda and Shimizu, 1998), and (b) between moraines from the Kunlun and Tianshan Mts. Error bars correspond to 1σ level.

Fig. 6. MgO vs. total iron diagram for the moraines and the Taklimakan Desert sands, showing that MgO and Fe_2O_3 are associated in different minerals in the moraine and the desert sand.

being slightly higher than that of UCC but clearly lower than those of the Taklimakan Desert sands. Higher kaolinite content in the moraines than in the desert sands is consistent with lower $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratios in the former than in the latter. XRD peak ratios of kaolinite/quartz in the moraines positively correlate with CIA (chemical index of alteration; Nesbitt and Young, 1982) values, as

shown in Fig. 8. CIA was calculated as $\text{CIA} = [\text{Al}_2\text{O}_3/(\text{Al}_2\text{O}_3 + \text{CaO}^* + \text{Na}_2\text{O} + \text{K}_2\text{O})] \times 100$, in molecular proportion, where CaO^* is the amount of CaO in silicate. CaO^* was calculated after Honda and Shimizu (1998), assuming the Ca:Na ratio in plagioclase to be 1:3. CIA values of moraines vary from 47 to 71 (Table 3), which are consistent with typical values of Pleistocene till

Fig. 7. Plot of $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratio against $\text{K}_2\text{O}/\text{Na}_2\text{O}$ ratio for the Kunlun and Tianshan Mts. moraines and the Taklimakan Desert sands (this study and Honda and Shimizu, 1998).

Fig. 8. Kaolinite/quartz XRD peak intensity ratios against CIA value for the Kunlun and Tianshan Mts. moraines.

matrix and glacial clays (Nesbitt and Young, 1982). This range partly overlaps that of the Taklimakan Desert sands (e.g., 52–56 in this study and the values reported by Honda and Shimizu, 1998) and on average, is slightly lower than that of loess of the Loess Plateau (Gallet *et al.*, 1996).

CIA value originally indicates the degree of alteration of feldspars to clay minerals. However, moraines generally suffer from little chemical weathering, and kaolinite in the moraines is thought to be derived from sedimentary rocks before glacial moraine deposition. Therefore, large variations of CIA value and kaolinite content in the moraines reflect poor homogenization of glacial grinding process.

Rare earth element (REE) abundances

REE abundance data are given in Table 4 and chondrite-normalized patterns are shown in Fig. 9. All samples including the moraines, desert sands and soils show light REE enriched patterns with negative Eu anomalies, which are similar to that of UCC (Taylor and McLennan, 1985). Moraine samples show wide variations in $(\text{La}/\text{Yb})_{\text{N}}$ and Eu/Eu^* ratios with lower values in contrast to restricted and higher values for the Taklimakan Desert sand and Tarim loess (Liu *et al.*, 1993) (Fig. 10(a)). Moreover, moraines from the north flank of the Tianshan Mts. tend to have smaller $(\text{La}/\text{Yb})_{\text{N}}$ ratios than those from the western Kunlun Mts. and southern flank of the Tianshan Mts. The

Table 4. REE abundances (ppm) of the Kunlun and Tianshan Mts. moraines, Taklimakan Desert sands and Tibet soils

Sample No.	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	ΣREE	Eu/Eu*	(La/Yb) _N
Moraines of north Tianshan Mts.																		
9301	29.1	40.8	86.4	9.50	36.3	6.90	1.35	5.91	1.01	5.43	1.11	3.13	0.454	2.99	0.455	202	0.65	9.0
9302	24.6	26.6	60.0	6.63	25.1	5.25	0.668	4.64	0.804	4.57	0.910	2.75	0.402	2.66	0.402	141	0.42	6.6
9304	43.2	24.2	64.1	6.78	25.7	6.29	0.992	6.54	1.22	8.16	1.64	4.94	0.771	5.05	0.737	157	0.48	3.2
9305	24.7	19.7	41.2	5.05	20.3	4.55	0.961	4.54	0.791	4.57	0.958	2.63	0.384	2.45	0.349	108	0.65	5.3
Moraines of south Tianshan Mts.																		
9315-2M	23.8	34.9	69.2	7.63	28.1	5.64	0.944	4.73	0.818	4.74	0.906	2.44	0.369	2.46	0.337	163	0.56	9.3
9315-G	24.6	36.1	77.6	8.71	32.3	6.50	0.882	5.12	0.876	4.77	0.937	2.69	0.400	2.59	0.377	180	0.47	9.2
Moraines of west Kunlun Mts.																		
9404-2	20.8	24.1	51.6	5.85	22.0	4.35	0.765	3.67	0.658	3.68	0.794	2.33	0.338	2.29	0.331	123	0.59	6.9
9403-3	35.0	42.7	89.5	10.2	36.8	7.90	0.627	6.83	1.17	6.55	1.32	3.88	0.546	3.51	0.503	212	0.26	8.0
9405	22.6	33.7	80.8	7.94	29.6	5.86	1.15	4.93	0.850	4.55	0.880	2.53	0.354	2.30	0.328	176	0.66	9.7
9407-2	23.6	22.7	51.9	5.63	20.6	4.50	0.703	4.74	0.733	4.42	0.896	2.69	0.418	2.79	0.384	123	0.47	5.4
9408-2	19.6	32.8	67.4	7.59	26.9	5.24	0.763	4.47	0.724	3.80	0.741	2.17	0.320	2.04	0.299	155	0.49	10.6
9408-3	29.7	54.5	110.8	12.1	44.5	7.90	1.06	6.26	1.03	5.36	1.08	3.17	0.442	2.96	0.409	252	0.47	12.1
9409	19.9	26.3	53.6	6.21	22.4	4.45	0.837	3.82	0.637	3.49	0.721	2.21	0.339	2.20	0.342	127	0.63	7.9
9410-2	19.3	36.9	78.7	8.61	28.3	5.16	0.685	3.92	0.688	4.00	0.791	2.37	0.338	2.25	0.321	173	0.47	10.8
9412-1	12.1	21.4	44.4	5.39	19.8	3.96	0.671	3.26	0.514	2.87	0.560	1.64	0.242	1.46	0.203	106	0.58	9.7
Sands of north Taklimakan Desert																		
9206	15.1	19.5	37.0	4.21	15.7	3.00	0.692	2.73	0.423	2.17	0.430	1.29	0.162	1.29	0.166	88.7	0.75	9.9
A92501-A	13.0	26.9	52.2	5.89	21.0	3.96	0.823	3.36	0.538	2.98	0.547	1.64	0.218	1.38	0.200	122	0.70	12.8
9213	26.9	22.1	41.5	4.70	17.1	3.13	0.609	2.78	0.436	2.41	0.456	1.28	0.181	1.15	0.158	97.9	0.64	12.6
A92802	16.4	32.8	63.6	7.25	27.5	5.05	0.726	3.82	0.668	3.58	0.717	2.16	0.307	2.01	0.268	150	0.51	10.8
9208	22.9	32.8	67.3	7.89	29.2	5.63	0.962	4.60	0.703	3.99	0.780	2.21	0.315	2.09	0.302	159	0.58	10.3
Northwest Tibet soils																		
TLR-25A	14.9	28.7	57.6	6.16	23.1	4.12	0.801	3.25	0.535	2.81	0.548	1.61	0.227	1.57	0.228	131	0.68	12.0
TLC-35A	12.2	20.7	38.1	4.20	15.6	2.87	0.547	2.59	0.419	2.30	0.487	1.41	0.208	1.37	0.205	91.0	0.62	10.0

Fig. 9. Chondrite-normalized REE patterns of the Kunlun and Tianshan Mts. moraines, the Taklimakan Desert sands and Tibet soils. REE abundances in the Leedey chondrite (Masuda *et al.*, 1973; Masuda, 1975) are used for normalization. For comparison the average REE composition of UCC (Taylor and McLennan, 1985) is shown as dashed line.

loesses of the Loess Plateau (Gallet *et al.*, 1996, 1998) show slightly lower $(La/Yb)_N$ ratio but similar Eu/Eu^* value to the Taklimakan Desert sands and Tarim loess. The Tibet soils are similar to the Taklimakan Desert sands and the Tarim loess in the $(La/Yb)_N$ and Eu/Eu^* ratios. The $(La/Yb)_N$ ratio difference among the moraines, desert sands and loesses might be due to the grain-size difference and associated mineral sorting among these samples, as discussed below.

REE abundance variation with grain size fractions for the Kunlun moraine 9412-1 is given in Table 5 and the variation of $(La/Yb)_N$ ratio and Nd abundance with grain size is traced in Fig. 10(b). From the fraction $>500 \mu m$ to the $20-32 \mu m$ fraction, $(La/Yb)_N$ ratios and Nd abundances increase by a factor of 1.9 and 2.4, respectively. $(La/Yb)_N$ ratios and Nd abundances are 8.5 and 17 ppm for the former fraction and 16 and 41 ppm for the latter fraction, while the 9412-1 whole rock

Fig. 10. Plots of $(La/Yb)_N$ - Eu/Eu^* and $(La/Yb)_N$ -Nd abundances for the Kunlun and Tianshan Mts. moraines and the Taklimakan Desert sands. Data of Loess Plateau are from Gallet et al. (1996); Tarim Basin loess and south-western Taklimakan Desert sand from Liu et al. (1993).

Fig. 11. $\epsilon_{Nd}(0)$ - $^{87}Sr/^{86}Sr$ plot for the Kunlun and Tianshan Mts. moraines, the Taklimakan Desert sands and Tibet soils. The data of desert sands from the southwestern Taklimakan Desert (Liu et al., 1994) and those of Luochuan loesses (Gallet et al., 1996) are also plotted.

Table 5. REE abundances (ppm) of different grain size fractions of the west Kunlun Mts. moraine sample 9412-1

Size fraction	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Σ REE	Eu/Eu*	(La/Yb) _N
moraine sample: 9412-1																		
20–32 μm	22.5	49.7	100.0	11.2	41.0	7.44	1.32	6.95	0.993	4.42	0.812	2.41	0.319	2.03	0.290	229	0.57	16.2
32–45 μm	21.5	39.2	79.9	8.89	32.0	6.03	1.02	5.67	0.794	3.69	0.690	2.11	0.289	1.84	0.257	182	0.54	14.0
45–63 μm	16.3	38.4	78.4	8.94	32.9	6.10	1.03	5.56	0.767	3.61	0.647	1.95	0.270	1.69	0.242	181	0.54	14.9
63–90 μm	19.4	34.2	70.4	7.92	28.9	5.36	1.01	5.16	0.713	3.62	0.709	2.03	0.286	1.91	0.268	162	0.60	11.8
90–125 μm	19.5	35.8	75.4	8.36	30.4	5.61	1.02	4.97	0.725	3.61	0.697	1.96	0.284	1.83	0.265	171	0.59	12.9
125–180 μm	19.8	39.0	81.6	9.29	34.2	6.31	1.16	5.57	0.750	3.58	0.685	1.97	0.282	1.91	0.269	187	0.60	13.5
180–250 μm	20.4	30.2	62.5	6.90	25.3	4.74	0.935	4.52	0.672	3.48	0.692	2.02	0.293	1.92	0.271	144	0.62	10.4
250–355 μm	16.7	28.3	58.2	6.54	24.3	4.60	0.932	4.21	0.608	3.00	0.565	1.58	0.224	1.49	0.198	135	0.65	12.5
355–500 μm	16.7	24.4	49.2	5.48	20.2	3.90	0.838	3.92	0.559	2.87	0.560	1.63	0.228	1.60	0.224	116	0.66	10.0
>500 μm	15.5	18.4	34.1	4.42	16.8	3.59	0.759	3.50	0.504	2.83	0.550	1.54	0.228	1.43	0.203	88.9	0.66	8.5
whole rock	12.1	21.4	44.4	5.39	19.8	3.96	0.671	3.26	0.514	2.87	0.560	1.64	0.242	1.46	0.203	106	0.58	9.7

sample has (La/Yb)_N ratio of 9.7 and Nd abundance of 20 ppm. Grain sizes of the Taklimakan Desert sands and the Loess Plateau loesses are chiefly 60–250 μm and 10–40 μm (e.g., Honda and Shimizu, 1998). Our result suggests some modifications in REE features by grain size sorting, which might take place during formation of the desert sand and loess from moraine. The modification in mineral composition during grain size sorting might responsible for the REE features differences among these deposits. It is noted that the variations of (La/Yb)_N ratios and Nd abundances with grain size are comparable to those observed for the moraines and desert sands. Therefore, if the modification in REE feature with grain size sorting is considered, estimation of source for the desert sand and loess by direct comparison of (La/Yb)_N ratio and REE abundance is difficult.

Nd and Sr isotopic compositions

Nd and Sr isotopic data are given in Table 6. For convenience in comparison, $^{143}\text{Nd}/^{144}\text{Nd}$ ratios are reported as ϵ_{Nd} notation (DePaolo and Wasserburg, 1976). The present-day $\epsilon_{\text{Nd}}(0)$ values are calculated by using the CHUR $^{143}\text{Nd}/^{144}\text{Nd} = 0.512638$ (Jacobsen and Wasserburg, 1980).

Moraine deposits are highly variable in both Sr and Nd isotopic compositions, compared with the desert sands (Fig. 11). In particular, moraines from the northern flank of Tianshan Mts. show extremely wide variations in $^{87}\text{Sr}/^{86}\text{Sr}$ ratio from 0.717 to 0.801 and $\epsilon_{\text{Nd}}(0)$ value from –1.9 to –11.0. Moraines from the western Kunlun Mts. are relatively less variation in $^{87}\text{Sr}/^{86}\text{Sr}$ ratios and $\epsilon_{\text{Nd}}(0)$ values, with $^{87}\text{Sr}/^{86}\text{Sr}$ ratios varying from 0.710 to 0.727 and $\epsilon_{\text{Nd}}(0)$ values from –6.6 to –11.0, plotted in the lower $^{87}\text{Sr}/^{86}\text{Sr}$ ratio field than the moraines from the Tianshan north flank. Two moraine samples from south slope of the Tianshan Mts., matrix and gravel samples (9315-2M and 9315-G), show different $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of 0.714 and 0.728 with similar $\epsilon_{\text{Nd}}(0)$ values of –9.2 and –10.6. In the $\epsilon_{\text{Nd}}(0)$ – $^{87}\text{Sr}/^{86}\text{Sr}$ diagram, the moraine matrix sample (9315-2M) from south flank of the Tianshan Mts. is plotted in the field of moraines from the western Kunlun Mts., while the moraine

Table 6. Sr and Nd isotopic compositions of the Kunlun and Tianshan Mts. moraines, Taklimakan Desert sands and Tibet soils

Sample No.	Sm (ppm)	Nd (ppm)	Sm/Nd	$^{147}\text{Sm}/^{144}\text{Nd}$	$^{143}\text{Nd}/^{144}\text{Nd}$	$\epsilon_{\text{Nd}}(0)$	Rb (ppm)	Sr (ppm)	$^{87}\text{Rb}/^{86}\text{Sr}$	$^{87}\text{Sr}/^{86}\text{Sr}$
Moraines of north Tianshan Mts.										
9301	6.90	36.3	0.19	0.115	0.512079 ± 7	-10.9	156	114	3.97	0.732220 ± 29
9302	5.25	25.1	0.21	0.127	0.512073 ± 7	-11.0	229	55.0	12.2	0.800929 ± 22
9304	6.29	25.7	0.24	0.148	0.512542 ± 6	-1.9	237	177	3.88	0.717288 ± 22
9305	4.55	20.3	0.22	0.135	0.512354 ± 14	-5.5	79.2	102	2.24	0.721583 ± 20
Moraines of south Tianshan Mts.										
9315-2M	5.64	28.1	0.20	0.121	0.512096 ± 8	-10.6	126	331	1.11	0.714474 ± 21
9315-G	6.50	32.3	0.20	0.122	0.512165 ± 6	-9.2	215	153	4.07	0.728077 ± 23
Moraines of west Kunlun Mts.										
9404-2	4.35	22.0	0.20	0.120	0.512298 ± 7	-6.6	117	303	1.12	0.711648 ± 23
9403-3	7.90	36.8	0.21	0.130	0.512275 ± 7	-7.1	227	118	5.55	0.727085 ± 22
9405	5.86	29.6	0.20	0.120	0.512114 ± 7	-10.2	127	243	1.52	0.716220 ± 20
9407-2	4.50	20.6	0.22	0.132	0.512222 ± 7	-8.1	270	236	3.32	0.717154 ± 22
9408-2	5.24	26.9	0.20	0.118	0.512238 ± 8	-7.8	138	736	0.542	0.711796 ± 20
9408-3	7.90	44.5	0.18	0.107	0.512154 ± 9	-9.4	159	180	2.57	0.718253 ± 23
9409	4.45	22.4	0.20	0.120	0.512287 ± 7	-6.9	160	522	0.884	0.712315 ± 23
9410-2	5.16	28.3	0.18	0.110	0.512209 ± 8	-8.4	252	161	4.55	0.722497 ± 23
9412-1	3.96	19.8	0.20	0.121	0.512072 ± 7	-11.0	174	621	0.813	0.710178 ± 23
Sands of north Taklimakan Desert										
9206	3.00	15.7	0.19	0.115	0.512109 ± 8	-10.3	92.5	277	0.967	0.715209 ± 19
A92501-A	3.96	21.0	0.19	0.114	0.512111 ± 8	-10.3	98.1	259	1.10	0.716582 ± 21
9213	3.13	17.1	0.18	0.111	0.512091 ± 7	-10.7	78.8	239	0.953	0.713540 ± 23
A92802	5.05	27.5	0.18	0.111	0.512092 ± 8	-10.6	71.7	261	0.796	0.713230 ± 23
9208	5.63	29.2	0.19	0.116	0.512108 ± 7	-10.3	74.9	266	0.815	0.713861 ± 21
Northwest Tibet soils										
TLR-25A	4.12	23.1	0.18	0.108	0.512079 ± 7	-10.9	98.0	139	2.04	0.716402 ± 21
TLC-35A	2.87	15.6	0.18	0.111	0.512012 ± 8	-12.2	80.5	103	2.26	0.714245 ± 18

Errors of isotopic ratios are $2\sigma_m$ and correspond to the last significant figures.

gravel sample (9315-G) from the Tianshan south slope is in the moraines from Tianshan north flank. Two Tibet soils have $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of 0.716 and 0.714 and $\epsilon_{\text{Nd}}(0)$ values of -10.9 and -12.1, plotted in the lower $\epsilon_{\text{Nd}}(0)$ field than the western Kunlun moraines and the Taklimakan Desert sands (Fig. 11).

The Taklimakan Desert sands are restrictive in Sr and Nd isotopic compositions, with $^{87}\text{Sr}/^{86}\text{Sr}$ ratios between 0.713 and 0.716 and $\epsilon_{\text{Nd}}(0)$ values around -10.4. These isotopic data are essentially the same with those reported for the sand from southwestern Taklimakan Desert (Liu *et al.*, 1994), suggesting isotopic homogeneous feature for all Taklimakan Desert sands.

Sr isotopic ratios in the moraine and desert sand samples seem to depend on CaO content and Sr abundance as shown in $^{87}\text{Sr}/^{86}\text{Sr}$ -1/Ca and $^{87}\text{Sr}/^{86}\text{Sr}$ -1/Sr diagrams (Figs. 12(a) and (b)). The data suggest a component having high Ca and Sr contents with low $^{87}\text{Sr}/^{86}\text{Sr}$ ratio around 0.710. In addition, it is noted that Sr abundance in the desert sand samples have small range between 240 and 275 ppm irrespective of the large variation of CaO content (6–30%, Fig. 12(c)). This observation implies low Sr contents in the secondary carbonates added to the desert sands.

Sr and Nd isotopic ratios of different grain size fractions of the moraine 9412-1 are given in Table 7 and in Fig. 13, where $^{87}\text{Sr}/^{86}\text{Sr}$ ratios decrease

from 0.7111 in 125–180 μm fraction to 0.7106 in 20–32 μm fraction with constant $\epsilon_{\text{Nd}}(0)$ values between -10.5 and -11.0 . As shown in the $\epsilon_{\text{Nd}}(0)$ - $^{87}\text{Sr}/^{86}\text{Sr}$ diagram (Fig. 11), however, the Sr and Nd isotopic ratio variation with grain sizes is small, compared with the wide variations of these ratios among moraine samples. Therefore, the

variation of isotopic ratio with grain size is negligible in discussing the source materials for the Taklimakan Desert sands.

In the $\epsilon_{\text{Nd}}(0)$ - $^{87}\text{Sr}/^{86}\text{Sr}$ diagram (Fig. 11), the Taklimakan Desert sands are included in the field overlapped by both the moraines from western Kunlun Mts. and the Tianshan southern flank, but

Fig. 12. (a) $^{87}\text{Sr}/^{86}\text{Sr}$ vs. $1/\text{Ca}$, (b) $^{87}\text{Sr}/^{86}\text{Sr}$ vs. $1/\text{Sr}$, and (c) CaO vs. Sr diagrams for the Kunlun and Tianshan Mts. moraines and the Taklimakan Desert sand of this study.

Fig. 13. Variation of $^{87}Sr/^{86}Sr$ ratios and $\epsilon_{Nd}(0)$ values with change of grain sizes (in μm) of the Kunlun moraine sample 9412-1. Error bars are measurement errors in 2σ .

separated from that of the Tianshan northern flank moraines. In addition, it is noted that the average $^{87}Sr/^{86}Sr$ ratios for the moraines from western Kunlun Mts. and from the Tianshan south flank are similar to that of the Taklimakan Desert sands, but the corresponding $\epsilon_{Nd}(0)$ values for the moraines are about 2ϵ unit higher than for the sands (Fig. 14). The $\epsilon_{Nd}(0)$ value discrepancy between the moraines and the desert sands suggests a contribution from other sources for the Taklimakan Desert sands. One possibility is the contribution from the Tibet soils, which have smaller $\epsilon_{Nd}(0)$ value but similar $^{87}Sr/^{86}Sr$ ratio to the Taklimakan Desert sands. The mixture between the Tibet soils and the moraines from the western Kunlun Mts. and the Tianshan south flank will yield the $^{87}Sr/^{86}Sr$ ratio similar to those of the end-members and $\epsilon_{Nd}(0)$ value between them (Fig. 14). Mixing calculation (Langmuir *et al.*, 1978) using the average values of Sr and Nd isotopic and abundance data of the Kunlun moraines and Tibet soils shows that the Sr and Nd isotopic ratios for the *ca.* 2:3 mixture of the moraines and the Tibet soils generally agree with those for the desert sands. However, the Sr abundances calculated from the mixing model are lower in 30% than the observed values for the desert sands. Particle sorting and the addition of secondary calcite into the sands could explain the Sr abundance discrepancy. As

Table 7. Sr and Nd isotopic data of different grain size fractions of the Kunlun Mts. moraine sample 9412-1

Size fraction	Weight percent	Sm (ppm)	Nd (ppm)	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	ϵ_{Nd}	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
20–32 μm	1.6	7.44	41.0	0.110	0.512070 ± 7	-11.1	94.7	440	0.623	0.710610 ± 26
32–45 μm	1.9	6.03	32.0	0.114	0.512082 ± 6	-10.8	115	443	0.753	0.710763 ± 23
45–63 μm	1.7	6.10	32.9	0.112	0.512089 ± 8	-10.7	126	470	0.774	0.710831 ± 28
63–90 μm	1.4	5.36	28.9	0.112	0.512075 ± 10	-11.0	125	480	0.755	0.710975 ± 20
90–125 μm	1.0	5.61	30.4	0.112	0.512082 ± 8	-10.8	138	463	0.862	0.710992 ± 21
125–180 μm	1.2	6.31	34.2	0.111	0.512076 ± 7	-11.0	132	435	0.881	0.711068 ± 21
180–250 μm	1.1	4.74	25.3	0.113	0.512098 ± 7	-10.5	128	432	0.856	0.710975 ± 21
250–355 μm	0.8	4.60	24.3	0.115	0.512100 ± 7	-10.5	125	444	0.812	0.710936 ± 23
355–500 μm	1.4	3.90	20.2	0.117	0.512086 ± 30	-10.8	115	472	0.704	0.710937 ± 23
>500 μm	88	3.59	16.8				57.4	877	0.189	0.709443 ± 23
whole rock		3.96	19.8	0.121	0.512072 ± 7	-11.0	174	621	0.813	0.710178 ± 23
<5 μm fraction (leached with 1N acetic acid)										0.711101 ± 11

Errors are $2\sigma_m$ and correspond to the last significant figures.

Fig. 14. Histograms of $^{87}\text{Sr}/^{86}\text{Sr}$ ratios and $\epsilon_{\text{Nd}}(0)$ values for the moraines, desert sands and Tibet soils.

Fig. 15. Map showing Nd and Sr isotopic compositions of the moraines and Taklimakan Desert sands. Numbers are location number and those in boxes are the values of $\epsilon_{\text{Nd}}(0)$ and $^{87}\text{Sr}/^{86}\text{Sr}$. Data of desert sand of southwestern Taklimakan are from Liu *et al.* (1994).

shown in Table 7, particle sorting has greater effect on Sr and Nd abundances than on the isotopic compositions. Although a statistical significance of the average isotopic values of the moraines is unclear because of wide variation of individual data, and the number of Tibet sample is limited, the mixing calculation suggests one of the possible models. In conclusion, these results imply that Kunlun Mts. and southern flank of Tianshan Mts. probably serve as source region for the desert sand, and that the Tibet Plateau also has made a considerable contribution to the Taklimakan Desert. It seems quite natural from the geographical viewpoint that the Nd and Sr isotopic data for the Taklimakan Desert sands fall not in the field for those from the northern flank of the Tianshan Mts., but in the field for the moraine matrix from the western Kunlun Mts. and southern flank of the Tianshan Mts. (Figs. 11 and 15).

SUMMARY

This paper reported the first systematic data of Sr and Nd isotopic compositions, REE and major element abundances and mineral composi-

tion for the Chinese moraines from the western Kunlun Mts. and the Tianshan Mts., which are possible sources for the Taklimakan Desert sand and Chinese loess. The data were also reported for the soils from the northwest Tibet and the desert sands and river sands from the north side of the Taklimakan Desert. The results are summarized in Table 8. The following conclusions can be drawn from the present results.

1. Quartz and feldspars are the main constituent minerals both in the desert sands and in moraine deposits, although the desert sands show slightly higher quartz content than the moraines (40–50% for the desert sands and 30–50% for the moraines). Higher calcite contents in the desert sands (>5%) than in the moraines (<5%) are observed, suggesting an addition of secondary calcite to the desert sands. Mica and clay mineral contents are higher in the moraines.

2. Major element compositions of the moraines show wider variations than those of the desert sands. The average values of most major elements show general agreement between the moraines and desert sands, although CaO enrichment and K₂O depletion are observed in the desert

Table 8. Summary of mineralogical and geochemical features for the moraines, Taklimakan Desert sands and northwestern Tibet soils

	Moraines			Taklimakan Desert sands		Northwestern Tibet soils
	NTM	STM	WKM	NTD	CSWTD ^(a)	
Quartz (%)	32–41 (36)	27–37 (32)	36–49 (40)	29–49 (42)	31–53 (48)	26–53 (40)
Feldspar (%)	22–33 (26)	24–45 (34)	18–36 (24)	12–32 (22)	27–31 (30)	9–19 (14)
Calcite (%)	0–6 (<2)	5–13 (9)	0–13 (3)	6–33 (17)	8–13 (11)	0–43 (21)
SiO ₂ /Al ₂ O ₃	3.9–5.4 (4.6)	4.2–5.0 (4.6)	4.2–5.6 (4.9)	6.0–6.6 (6.4)	5.4–8.3 (6.3)	4.2–6.4 (5.3)
K ₂ O/Na ₂ O	1.0–2.3 (1.6)	0.9–1.35 (1.2)	0.8–2.4 (1.5)	1.0–1.4 (1.2)	0.65–0.94 (0.9)	1.5–5.3 (3.4)
CaO (%)	0.7–4.1 (2.2)	3.5–13.2 (8.4)	1.8–14.4 (5.7)	6.9–32.3 (16.5)	4.3–9.7 (7.5)	1.5–31.8 (16.6)
(La/Yb) _N	3.2–9.0 (6.0)	9.2–9.3 (9.2)	5.4–12.1 (9.0)	9.9–12.8 (11.3)	11.9	10.0–12.0 (11.0)
Eu/Eu*	0.42–0.65 (0.55)	0.47–0.56 (0.52)	0.26–0.66 (0.51)	0.51–0.75 (0.63)	0.64	0.62–0.68 (0.65)
Nd (ppm)	20.3–36.3 (26.8)	28.1–32.3 (30.2)	19.8–44.5 (27.9)	15.7–29.2 (22.1)	18.8	15.6–23.1 (19.4)
⁸⁷ Sr/ ⁸⁶ Sr	0.7173–0.8009 (0.7430)	0.7145–0.7281 (0.7213)	0.7102–0.7271 (0.7163)	0.7132–0.7166 (0.7145)	0.7144	0.7142–0.7164 (0.7153)
ε _{Nd} (0)	–1.9 ~ –11.0 (–7.3)	–9.2 ~ –10.6 (–9.9)	–6.6 ~ –11.0 (–8.4)	–10.3 ~ –10.7 (–10.4)	–10.5	–10.9 ~ –12.1 (–11.6)

NTM = northern Tianshan Mts., STM = southern Tianshan Mts., WKM = western Kunlun Mts., NTD = northern Taklimakan Desert, CSWTD = central and southwestern Taklimakan Desert. Number in bracket is average value.

^(a)Data for central and southwest Taklimakan Desert are from Honda and Shimizu (1998), Liu et al. (1993, 1994).

sands, compared with the moraines. Moraines show lower $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratio than the desert sands. These minor differences in major element compositions might be explained by the minor difference in mineral compositions between the moraines and desert sands; higher mica and kaolinite contents and lower calcite contents in the former than in the latter.

3. Moraines show REE features similar to those of desert sand and loess, with some difference in inclination of REE patterns. For the moraine sample, however, finer grain size fractions tend to have larger inclination in REE patterns and higher REE abundances than the coarser fractions by a factor around 2, suggesting minor modifications in REE features by grain size sorting. This result implies that estimation of sources for the desert sands and loesses is hard by simple comparison of inclination in REE patterns and REE abundance.

4. Moraine deposits are highly variable in both Sr and Nd isotopic compositions, compared with the Taklimakan Desert sands. $^{87}\text{Sr}/^{86}\text{Sr}$ and $\epsilon_{\text{Nd}}(0)$ vary from 0.717 to 0.801 and from -1.9 to 11.0 for the Tianshan north flank moraines, from 0.714 to 0.728 and from -9.2 to -10.6 for the Tianshan south flank moraines and from 0.710 to 0.727 and from -6.6 to -11.0 for the Kunlun moraines. The Taklimakan Desert sands show narrow ranges of $^{87}\text{Sr}/^{86}\text{Sr}$ ratios between 0.713 and 0.716 and $\epsilon_{\text{Nd}}(0)$ values around -10.4, plotted near the moraine matrix sample from the Tianshan south flank and in the lower $\epsilon_{\text{Nd}}(0)$ region of the western Kunlun moraines in the $^{87}\text{Sr}/^{86}\text{Sr}$ - $\epsilon_{\text{Nd}}(0)$ diagram. The Nd isotopic data of the Taklimakan Desert sands are slightly higher than those of the Tibet soils. These isotopic data imply that the Taklimakan Desert sands were derived not from the Tianshan north flank moraines, but from the Tianshan south flank moraines, the Kunlun moraines and the Tibet soils.

5. Our mineralogical and isotopic data as well as chemical data for the desert sands from the north side of the Taklimakan Desert are essentially identical to those for the desert sands from the south and central parts of the Taklimakan Desert, show-

ing specifically the homogeneity of the Taklimakan Desert sands.

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