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QR Forum

Luminescence sensitivities of quartz grains from eolian deposits in northern China and their implications for provenance

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ABSTRACT

The thermoluminescence (TL) and optically stimulated luminescence (OSL) sensitivities of quartz grains from deserts and loess–red clay sequences are used to trace eolian provenances in northern China. Our results indicate that the 110°C TL peak and OSL sensitivities of quartz grains show differences among Chinese deserts, which can be subdivided into four groups according to the spatial variations of luminescence sensitivities. Such differences are related mostly to the regional difference in rock types of mountains surrounding or adjacent to the deserts. We also examine the possible provenance changes between the Quaternary loess and the Tertiary eolian red clay, and the results indicate that the luminescence sensitivity of Tertiary red clay is higher than that of Quaternary loess (L1, L15, and L33), implying source materials of the eolian deposits changed relative to those of the Quaternary.

Introduction

China has the largest mid-latitude arid and semi-arid regions in the world, characterized by the zonal distributions of gobi (stony desert), desert, and loess deposits. In the past decades, the paleoclimatic record of the Chinese loess has been intensively studied by using various climatic proxies (e.g., Liu, 1985; An et al., 1991; Ding et al., 1999a). However, compared with the paleoclimatic studies, there have been only limited studies concerning the provenance of desert sediments and/or loess (e.g., Derbyshire et al., 1998; Ono et al., 1998; Sun et al., 2001; Sun, 2002a,b; Xie and Ding, 2007; Sun et al., 2008; Stevens et al., 2010). In this paper, we will focus on investigating the provenance of sand deserts in China.

Different opinions about the source materials of deserts in China have been expressed. Zhu et al. (1980) proposed that the sand sources of deserts are of local origin, mainly on the basis of heavy-mineral analysis. Yang et al. (2008) examined oxygen isotopic compositions of quartz grains a suggesting regional differences among deserts. In recent years, the U–Pb ages of zircon grains separating from deserts have been also used to constrain sand provenance (Xie et al., 2007; Stevens et al., 2010).

Different from the above methods, we use the luminescence sensitivities of quartz grains to study the provenance of deserts. Optical stimulated luminescence dating (OSL) has been successfully used in dating loess and dune sands (e.g. Wintle, 1987, 1990; Stokes, 1992; Aitken, 1998; Murray and Olley, 2002; Sun et al., 2006; Wang et al., 2006; Lai et al., 2007; Li et al., 2007; Stevens et al., 2007; Buylaert et al., 2008; Jacobs, 2008; Roberts, 2008; Lai et al., 2009; Stevens and Lu, 2009; Lai et al., 2010). In recent years, the luminescence sensitivity of quartz grains has been suggested to be related to dust/sand source (e.g., Lai and Wintle, 2006; Li et al., 2007; Tsukamoto et al., 2011). Lai and Wintle (2006) found an increase in OSL sensitivity for the loess deposits above the Pleistocene/Holocene boundary in the northwestern Chinese Loess Plateau, and they suggested that this change could be related to a change in dust source. Li et al. (2007) proved that the sensitivities of quartz from four deserts in northern China can be subdivided into two groups in accordance with geographical proximity. Zheng et al. (2009) investigated the luminescence sensitivity of coarse quartz extracted from desert sands in northern China, and they found that two groups (western and eastern deserts) can be: samples from the western deserts are less sensitive than those from the eastern deserts. OSL components of quartz from Japan Sea sediments are also used to examine provenance (Tsukamoto et al., 2011). Electron Spin Resonance (ESR) sensitivity has also been used in tracing provenance of Japanese and Chinese loess/dust (e.g., Ono et al., 1998; Sun et al., 2008).

This paper discusses the following questions: (1) examining the provenance of desert sediments based on luminescence sensitivities of quartz grains from different deserts; and (2) exploring the possible provenance differences between the Quaternary loess and the Tertiary eolian red clay.

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Material and methods

Geological setting and sampling

The gobi and sand deserts occupy 13.6% area of China (Zhu et al., 1980). In this study, nine modern dune sand samples were collected from different deserts (Figure 1). Moreover, we also collected three Quaternary loess samples (L1, L15, and L33) and one Tertiary red clay sample from the Jingbian section (Figure 2), which is located in the northern Loess Plateau (see Figure 1 for location), in order to examine the temporal provenance changes.

Quartz purification

Bulk samples were treated with 10% HCl and 10% H_2O_2 to remove carbonates and organic materials. For desert samples, fractions of 64–90, 90–125, and 125–150 µm were selected for density extraction. However, for the loess and the red clay samples, only the fine sand fraction of 64 to 90 µm was used due to the low content of coarse sand-size particles. Quartz grains were separated by using sodium polytungstate heavy liquid of densities between 2.62 and 2.75 g/cm^3. After that the grains were treated with 40% hydrofluoric acid to remove feldspar. The time of etching was variable depending on the grain size and the amount of separated grains, but was generally 90 min. Separated quartz grains were mounted on 10-mm-diameter aluminum discs with Silkospay silicon oil. The quartz grains on each disc were examined under microscope to ensure a mono-layer of quartz grains. Subsequently, each disc was weighed by using a high-precision (with readability of 0.01 mg) analytical electronic balance in order to evaluate weight-normalized luminescence signals. The purity of quartz grains was tested by monitoring for the presence of feldspar by measuring the infrared-stimulated luminescence (IRSL).

TL and OSL measurements were performed in the Luminescence Dating Laboratory in the Institute of Geology and Geophysics, Chinese Academy of Sciences, using an automated RisϕTL/OSL reader (TL/OSL-DA-15) (Markey et al., 1997).

The RisϕTL/OSL reader is equipped with a high-power blue LED array light source, an infrared solid state laser and a 0.09 Gy/s $^{90}Sr/^{90}Y$ β-ray source (Bøtter-Jensen et al., 2000). Blue-light stimulation for OSL was achieved using LEDs (470 ± 30 nm) delivering up to 45 mW/cm^2 at the sample position. The detection optics included a U-340 filter that was used for all luminescence measurements.

Measurement procedure

The luminescence sensitivities were obtained using the procedures as shown in Table 1. During our measurements, four regeneration doses (10, 15, 20, 0 Gy) were applied. The reason for choosing the above doses was based on the luminescence growth curves which indicate a linear growth below 20 Gy (Figure 3). The zero dose was used in order to check the recuperation. The 110°C TL peak areas (obtained before each OSL measurement, and integrated from 100°C to 120°C with dark count rate subtracted) and OSL observed in the first 0.7 s of stimulation with background (based on the average OSL observed in the last few seconds of stimulation) subtracted were gained. After the TL and OSL signals were normalized to the weight of quartz grains on each disc, the growth curves of 110°C TL peak and the OSL signal to regenerative dose were constructed respectively. The normalized TL and OSL signals of quartz grains of the Hunshandake and Hulun Buir deserts were plotted versus regenerative doses (Figure 4) as examples, indicating a linear growth curve within the dose range of 0 to 20 Gy. The linear gradient value was used to represent luminescence sensitivity (Aitken, 1985). Such properties are also found for the other samples of different deserts. For each sample, at least fifteen aliquots were used for growth-curve construction.

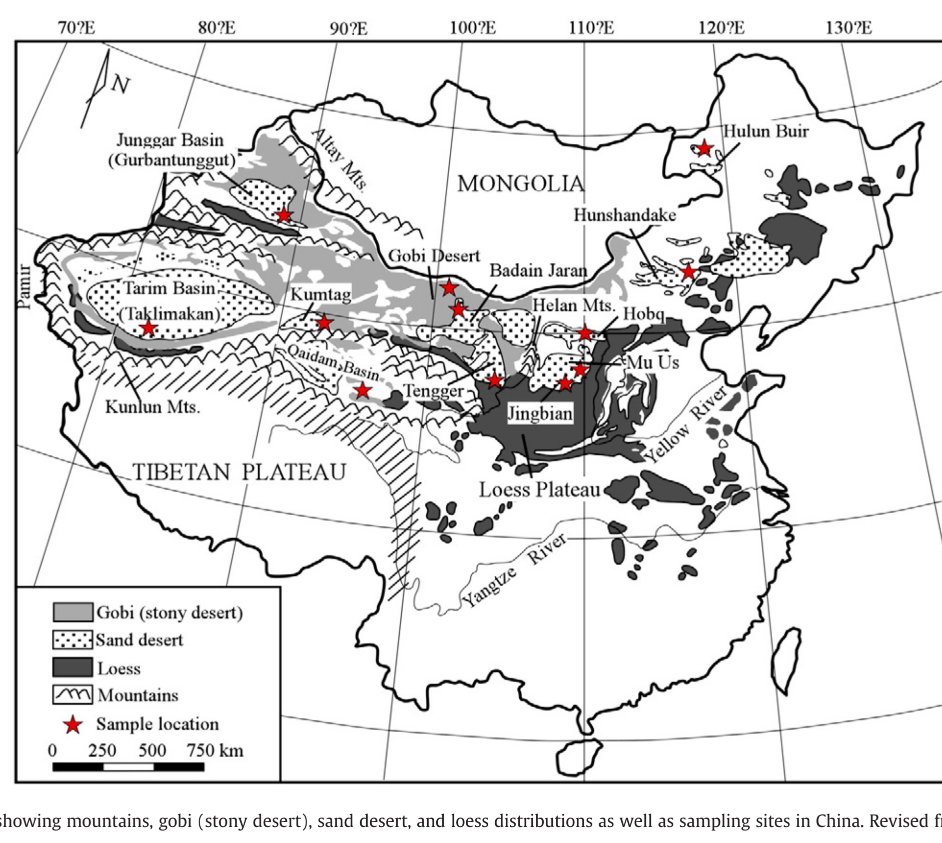

Figure 1. Map showing mountains, gobi (stony desert), sand desert, and loess distributions as well as sampling sites in China. Revised from Sun and Zhu, 2010.

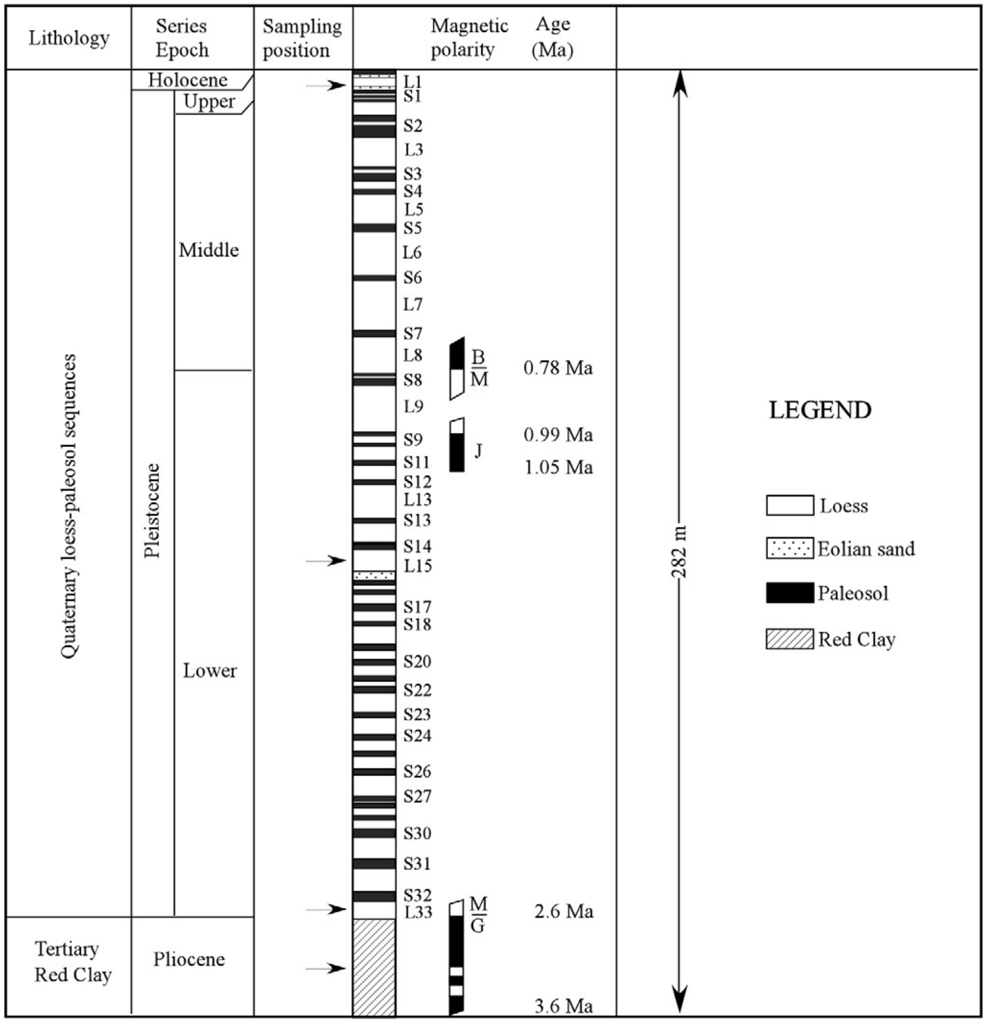

Figure 2. The lithology and magnetostratigraphy of the Jingbian section. The arrows show our sampling positions. The magnetic Brunhes–Matuyama (B/M) boundary and the Jaramillo (J) subchron are from Guo et al. (2002); the Tertiary magnetostratigraphy is from Ding et al. (1999b).

Results

Size-dependent luminescence sensitivities of quartz grains in Chinese eolian deposits

Dune sands usually have a large range of size fractions, ranging from fine to coarse particles. Moreover, particle sizes change from desert to desert. Therefore, in order to trace sand provenance more effectively, it is important to verify size-dependent properties of luminescence sensitivity. Figure 5 shows the luminescence sensitivities of quartz grains among different fractions (64–90 μm, 90–125 μm, and 125–150 μm). It indicates that there exists a general increasing trend of TL and OSL sensitivity signals toward finer grain size. Several factors can account for this change. Firstly, the grain-size of sediment reflects the degree of wind sorting, and finer particles are derived from distal sources and better mixing during transportation compared with the proximal coarser particles. Secondly, because the finer particles can be transported for longer distance, quartz particles acquire more opportunities for irradiation and illumination, which can result in increasing sensitivity. Pietsch et al. (2008) proved this assumption by observing that sensitivity increased downwind. Finally, the luminescence sensitivities of quartz measured for different grain sizes may also be partially dependent on the surface area of the grains on each disc facing the photomultiplier on each disc. Because the sensitivity has been normalized by the mass of grains on each aliquot, the finer grains may have larger total surface area, leading to higher sensitivity.

In this study, we use the same fraction of 90–125 μm of the desert samples to trace provenance changes. However, the Quaternary loess and Tertiary red clay typically lack sand particles larger than 90 μm, and for these samples we chose the fine sand fraction of 64–90 μm.

Table 1
Experimental sequences for luminescence sensitivity measurement.

Step	Treatment	Observation and objective
1	Stimulate for 40 s	Optically bleaching the natural OSL signals
2	Give dose[a]	–
3	Heat to 260°C	TL measurement and to remove the shallow traps
4	Stimulate for 40 s at 125°C	OSL measurement
5	Go to step 2	–

[a] Four regeneration doses (10, 15, 20, 0 Gy) were applied.

Spatial variations of luminescence sensitivity of quartz grains among deserts

The luminescence sensitivity of the 110°C TL peak of quartz grains (90–125 μm) is plotted against the OSL sensitivity in Figure 6. It shows that the samples can be generally subdivided into four groups according to their luminescence sensitivities (Figure 6): (1) samples from the Hulun Buir and Hunshandake deserts are characterized by the strongest TL and OSL sensitivities compared with the other deserts; (2) the second group includes samples from the Badain Jaran, Gobi Desert, Tengger,

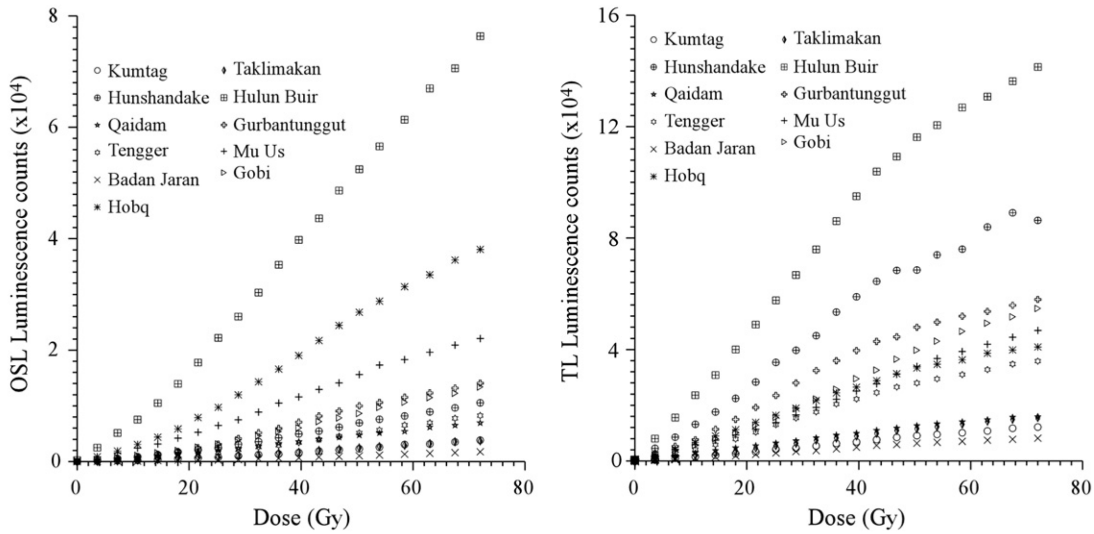

Figure 3. Growth curves of OSL and TL signals of quartz grains (90–125 µm) from Chinese deserts.

Hobq and Mu Us deserts, and most of their TL and OSL sensitivities are among the intermediate values compared with the other deserts (Figure 6); (3) samples from the Gurbantonggut desert differ from that of the other deserts, falling into a distinct field; and (4) the fourth group includes three deserts (Taklimakan, Qaidam, and Kumtag deserts) marked by the lowest sensitivities of both the 110°C TL peak and OSL.

Temporal variations of 110°C TL peak and OSL sensitivities of quartz grains in the Jingbian section

Quartz grains of the fine sand (64–90 µm) fraction from the Quaternary loess beds (L1, L15, and L33) and the Tertiary eolian red clay at Jingbian (see Figure 1 for site location) were measured by using the same procedure (Figure 7). In the plots of the sensitivities of the

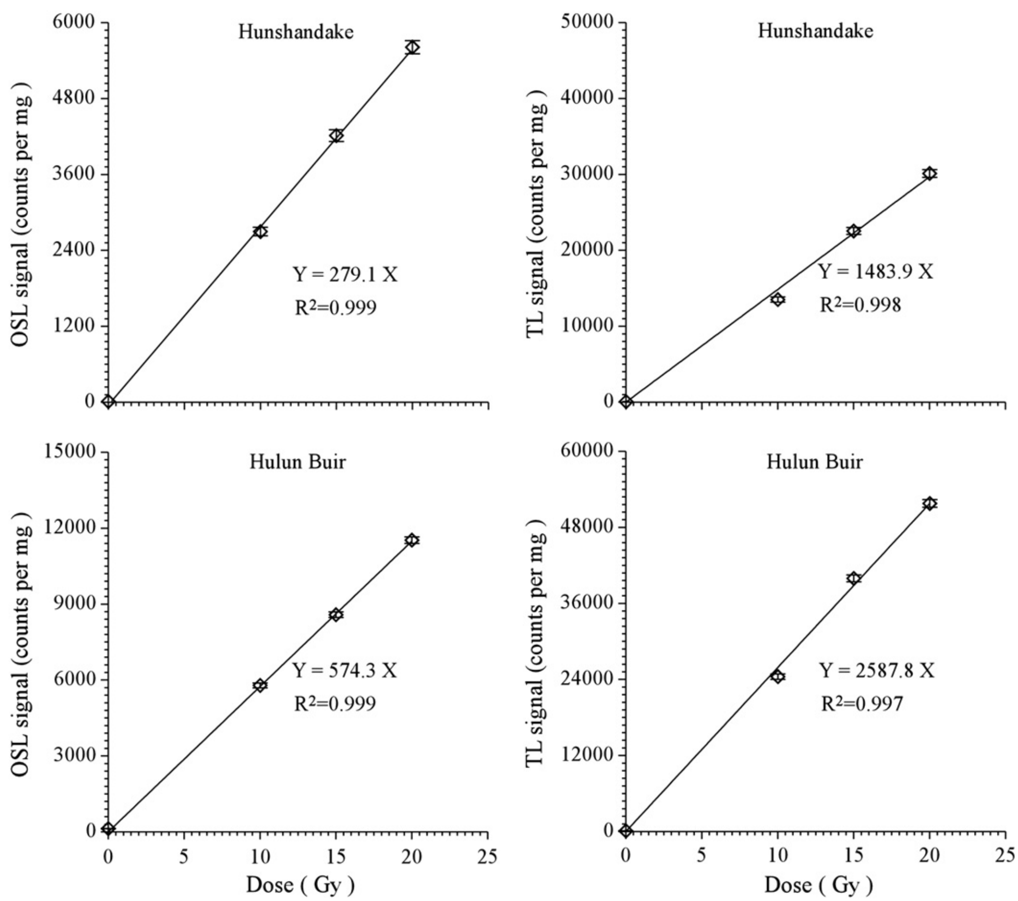

Figure 4. The response of 110°C TL peak and the OSL signal to regenerative dose (0, 10, 15, and 20 Gy). All the TL and OSL signals are normalized to the weights of quartz grains on each disc. The curves can be well fitted by a linear equation in which the line gradient was used to represent luminescence sensitivity. A zero regenerative dose was measured to check the degree of recuperation. The first circle point represents the luminescence signal of the zero dose. This value is small, showing that the influence of recuperation is negligible.

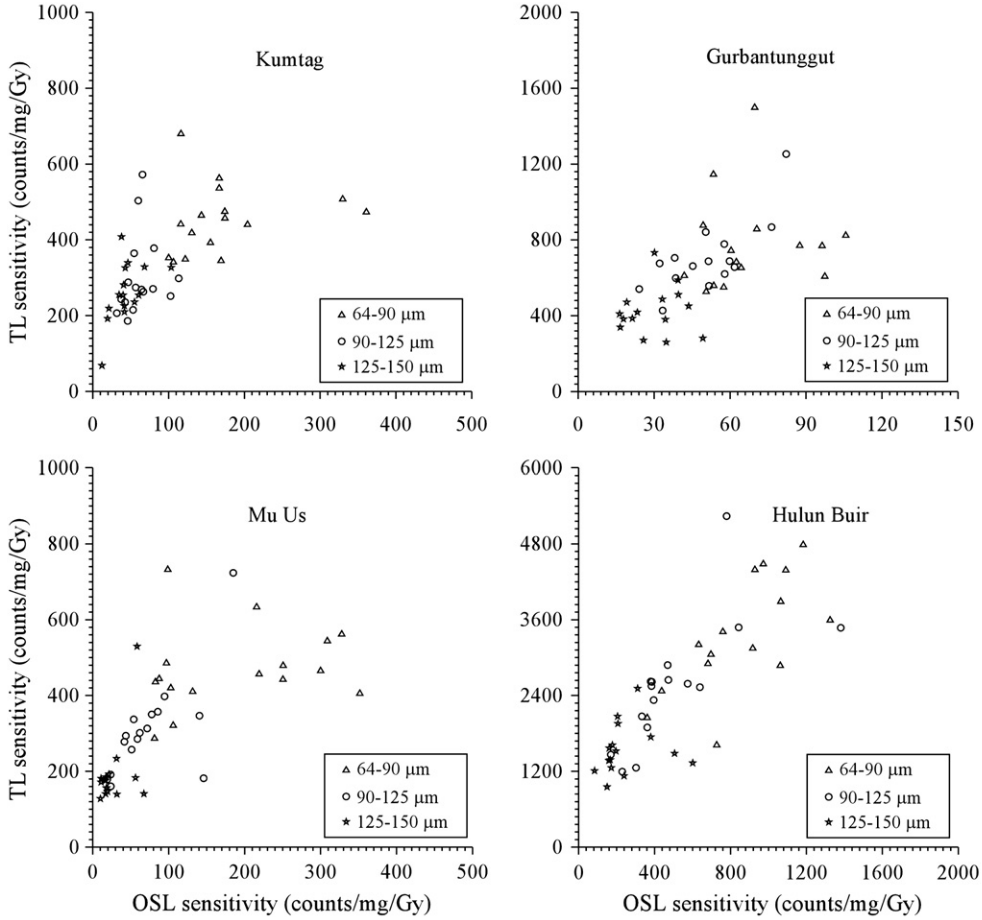

Figure 5. The luminescence sensitivities in 110°C TL peak versus the OSL sensitivities of quartz particles among different size fractions. Note the generally trend of increasing sensitivities toward finer particle size.

110°C TL peak versus OSL, the Quaternary loess samples and the Tertiary red clay samples fall into two distinct fields implying different provenances (Figure 7).

Discussion

Factors influencing luminescence sensitivities of quartz grains

The mechanism of luminescence sensitivity has been studied by different authors (e.g., Zimmerman, 1971; Aitken, 1985; Bøtter-Jensen et al., 1995; Li, 1995; Wintle and Murray, 1999; Li, 2002; Li et al., 2002, 2008, 2010). Zimmerman (1971) proposed a model to explain TL sensitivity, and she argued that luminescence centers are a particular type of defect usually due to impurities dependent on the structure of ionic crystal. Another model was proposed by Li (1995) to emphasize the competitions between the "easy to bleach" and "hard to bleach" traps. Except for the laboratory conditions as discussed in the previous section, there are other factors accounting for the sensitivity variations of quartz grains including different provenances, buried history, and the variable geological processes which provide opportunities for repeated irradiation, heating and illumination (Li, 1995; Wintle and Murray, 1999, 2000; Roberts and Wintle, 2003; Pietsch et al., 2008). The factors accounting for luminescence sensitivity variations make them to be used as tracers.

Source materials of Chinese deserts based on luminescence sensitivities of quartz grains

Based on the spatial variations of luminescence sensitivities of the 90–125 μm fraction, four regional groups are recognized including the eastern (Hulun Buir and Hunshandake), central (Gobi Desert, Badain Jaran, Tengger, Hobq, and Mu Us), western (Taklimakan, Qaidam, and Kumtag), and the northwestern (Gurbantonggut) deserts (Figure 8).

The strongest luminescence sensitivities of quartz grains concentrate in the deserts of eastern China, being broadly consistent with the previous results (Li, 2002; Li et al., 2007; Zheng et al., 2009). Such features cannot be explained by the result of feldspar contamination because all of the discs have been IRSL-screened. It has been reported that the 110°C TL and OSL sensitivities are strongly dependent on the source of the quartz grains (Han et al., 1997; Li et al., 2002; Zheng et al., 2009) and their thermal history (Chen et al., 2001). Therefore, the most sensitive of quartz grains in the Hunshandake and Hulun Buir deserts should be related to the host rocks (Krbetschek, et al., 1997). According to previous studies, Mesozoic (mainly Jurassic and Cretaceous) and Paleozoic volcanic rocks (Figure 9) are widespread in the eastern desert regions of China (Ma, 2002). Moreover, the longest mountain range of the Da Hinggan (see Figure 8 for location) mainly consists of volcanic rocks, which is adjacent to the east deserts. These volcanic rocks are potential source materials for these deserts. Yang et al. (2008) proved that the sands of the Hunshandake and Hulun Buir deserts are mainly of lava rocks. Additionally, the luminescence sensitivities of quartz will increase when heating to high temperature (Aitken, 1985; Yin and Li, 2000; Lai et al., 2008). Therefore, the widespread volcanic rocks in the northeastern China can account for the strongest sensitivities of quartz grains from the Hunshandake and Hulun Buir deserts.

The central deserts, including the Gobi Desert, Badain Jaran, Tengger, Hobq, and Mu Us deserts, have multiple sand sources. The clastic materials derived from the adjacent mountains of Qilian, Helan, Gobi Altay, Hangayn, Yinshan, and Helan ranges are transported to piedmonts by floods and rivers forming large-scale fluvial fans, and

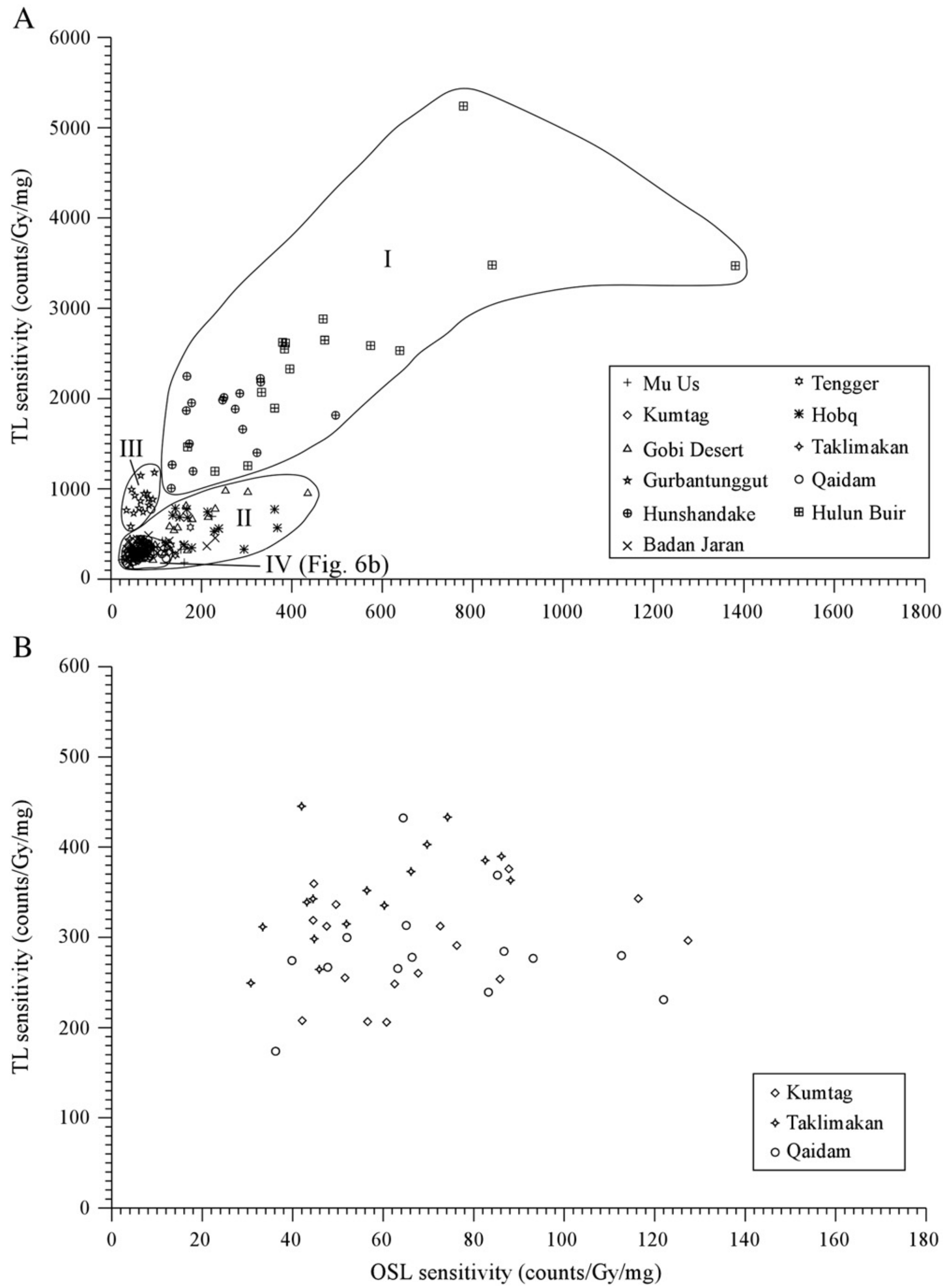

Figure 6. (A) TL and OSL luminescence sensitivities of quartz particles (90–125 μm fraction) from deserts in northern China, noting the samples fall into four groups (I to IV). (B) Enlarged diagram of group IV in order to show the details of the luminescence sensitivities of the corresponding deserts.

winding sorting by the northwesterly winter monsoon leads to the zonal distributions of gobi, sand desert, and loess (Loess Plateau) in central North China (Figure 8). Additionally, physical erosion of the widespread Cretaceous sandstone underlying the Hobq and Mu Us deserts may be another sand source (e.g., Zhu et al., 1980). Moreover, the fluvial deposits of the Yellow River can also be potential sources of the Hobq and Mu Us deserts. Therefore, the potential source rocks for the central deserts include metamorphic rocks, igneous rocks, sedimentary rocks, and fluvial sediments. The multiple sand sources of the central deserts can account for the relatively large variable range of the luminescence sensitivities compared with that from the inland basins in the Junggar Basin (Gurbantunggut Desert), the Tarim (Taklimakan Desert) and the Qaidam Basin (Figures 6A and 8). The main rock types in the Gobi Altay, Hangayn, and Yinshan mountains are metamorphic rocks and igneous rocks such as granites (Ma, 2002). The existence of igneous rocks may partially contribute to the relatively higher luminescence sensitivities of quartz grains compared with the deserts in western China (Figure 6A).

The sensitivities of quartz grains from the Taklimakan, Qaidam, and Kumtag deserts are the lowest compared with the other deserts. Among them, the Taklimakan Desert, the largest sand sea in China, is located in the Tarim Basin surrounded by the Tianshan mountains to the north, and the Kunlun mountains to the south, whereas the sand dunes in the Qaidam Basin are restricted by the Kunlun, Altyn and Qilian mountains. The Kumtag Desert is located to the north of the Altyn Mountains (Figure 8). Such mountains provide important source materials to the

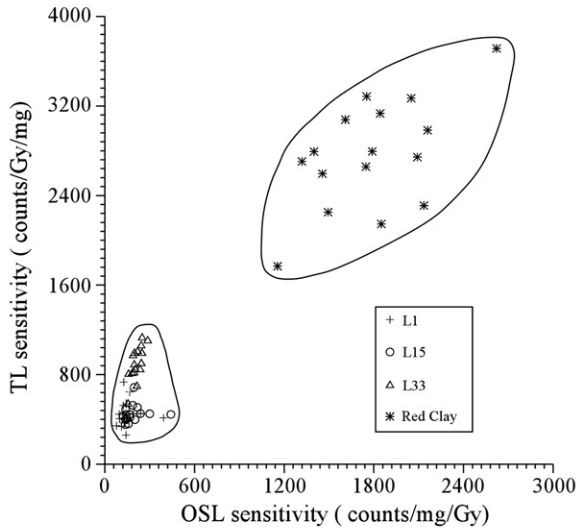

Figure 7. The luminescence sensitivities in 110°CTL peak versus the OSL sensitivities of quartz particles of the 64–90 μm fraction of the Tertiary red clay and the Quaternary loess (L1, L15, and L33) at Jingbian. Note that they fall into two distinct fields.

above deserts. All these mountains mainly consist of Paleozoic metamorphic rocks (Ma, 2002). The metamorphic rock is subjected to heat and pressure (temperatures greater than 150 to 200°C and pressures of 1500 bars) causing profound physical and/or chemical change (Blatt and Tracy, 1996). Generally, due to the recrystallization during metamorphism, the degree of crystallization of metamorphic rocks is higher than that of the original rocks (including sedimentary, igneous, or another metamorphic rock) (Lu and Sang, 2002). Therefore the source materials generated from these mountains have fewer crystal defects (Lu and Sang, 2002), leading to low luminescence sensitivities of quartz grains.

The luminescence sensitivities of quartz particles from the Gurbantonggut Desert are unique compared with the other deserts. The signals of OSL sensitivities are similar with those of the western deserts, however, the TL sensitivities have a large and variable range (Figure 6A). This implies that the provenance of Gurbantonggut Desert is different from the other deserts. This desert is restricted by the Altay mountains to the north, and the Tianshan mountains to the south. However, there are several mountain gaps (open areas) in the western edge (Figure 8). Although rock types of the Tianshan and Altay mountains are mainly Paleozoic metamorphic rocks, source materials derived from the Central Asia can also be transported to this desert by westerly wind (Sun et al., 2010). This could account for the specific luminescence sensitivities of quartz grains in this desert.

Evidence for temporal provenance change of Chinese eolian deposits since the beginning of the Quaternary

The luminescence sensitivities between the Quaternary loess and the Tertiary red clay are quite different, marked by the higher sensitivities in the red clay (Figure 7). We have the following explanations for this change. Firstly, the most significant climate change in the late Cenozoic is the formation of the large-scale ice sheet in the northern Hemisphere since the beginning of the Quaternary (Shackleton et al., 1984). The glacial climate initiated 2.6 Ma ago is favorable for glacial grinding and/or frost weathering in high mountains in the north and northwestern China. In this sense, more materials derived from high peaks of mountains became important sources of the Quaternary deserts, leading to the changing provenance between the Quaternary loess and the Tertiary red clay (e.g., Sun, 2005; Sun and Zhu, 2010). Secondly, the increased size of the ice sheet in the northern Hemisphere intensified cold-air outbreaks and

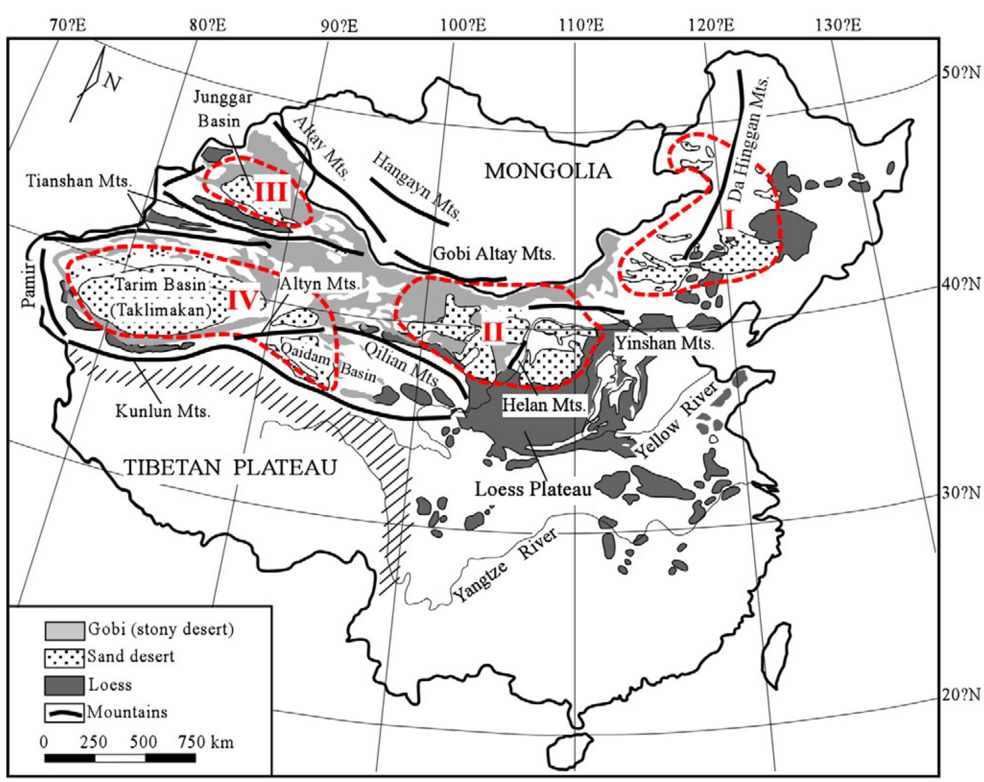

Figure 8. Map showing the corresponding geographic locations of the four groups of deserts (I to IV) according to their spatial luminescence sensitivities. The sand sources of deserts are related to the mountains surrounding or adjacent to the deserts in northern China.

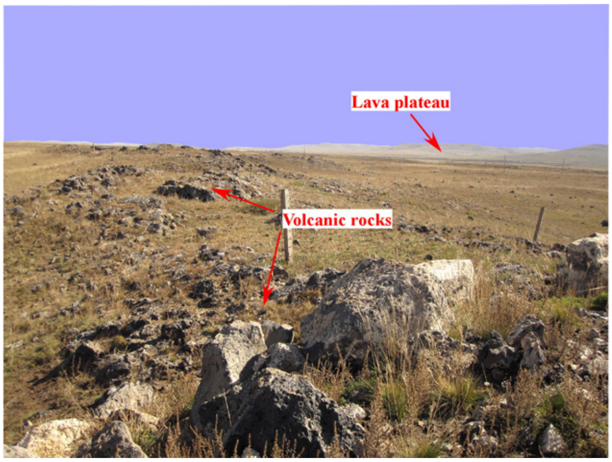

Figure 9. Photo shows the commonly distributed Mesozoic volcanic rocks and lava platforms within the northeastern desert regions of China.

then the enhanced Siberian High, resulting in much strengthened northwest winter monsoon. The increased wind speeds, together with the enlarged source materials, led to the expansion of the deserts during the Quaternary (Sun et al., 1998, 1999). Therefore, compared with the Quaternary loess, the Tertiary red clay was derived from more distal source regions. The longer distance transport of the Tertiary red clay meant that the sediments underwent more irradiation, heating and illumination. Moreover, during the Tertiary, the lower wind speeds ensure sorting of sediment to finer particle sizes. All these processes can partially account for the much enhanced luminescence sensitivities of the Tertiary red clay. Finally, because there is also evidence that sensitivity may change during burial in loess (e.g., Wintle and Murray, 1999; Stevens et al., 2007), the burial in the profile may also alter the temporal variations of sensitivity.

Conclusions

Variations of luminescence sensitivities are dependent on grain size. Generally, the finer particles have stronger signals, mostly related to source areas, wind sorting and transport distances from source areas.

Based on the luminescence sensitivity variations of quartz grains from Chinese deserts, four regional groups of deserts can be distinguished including the eastern (Hulun Buir and Hunshandake), central (Gobi Desert, Badain Jaran, Tengger, Hobq, and Mu Us), western (Taklimakan, Qaidam, and Kumtag), and northwestern (Gurbantonggut) deserts. The different luminescence sensitivity signals are dominantly related to the rock types of mountains surrounding or adjacent to the deserts.

The luminescence sensitivity of Tertiary red clay is higher than that of Quaternary loess (L1, L15, and L33) mostly implies that the provenance of the Chinese eolian deposits changed since the beginning of the Quaternary.

Acknowledgments

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