Supporting Information

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SI Materials and Methods

We have conducted 33 $\delta^{11}B$, ~2,000 $\delta^{18}O$, $\delta^{13}C$ and $CaCO_3$, and ~1,000 TOC analyses from the 1,050-m-long sediment core, in addition to ostracod and grain size analyses on selected samples. High-resolution (2–4 ky) measurements for $\delta^{18}O$, $CaCO_3$, and TOC were performed from the core depth of 300–1,050 m to resolve detailed features at orbital timescales.

Boron Isotope Analysis. Each of ~5 g clay sediments was dissolved with 35 mL 1.0 mol/L high-purity HCl. Sample solutions were heated for 8 h at 60 °C, and then shaken for 12 h on the oscillator. The clear liquid solution and undissolved sediments were separated with centrifugation, and the insoluble was discarded. The pH of clear liquid solution was adjusted to 8 with subboiling ammonia water, and then the solution was centrifuged again. The clear liquid solution was then passed through the Amberlite IRA 743 borate-specific chelating resin column. The remaining hydroxide precipitate was redissolved with 1.0 mol/L high-purity HCl. The pH of solution was adjusted again with $NH_3 \bullet H_2O$ till around 8. This treatment process was repeated five times, and the clear liquid solution was passed through the same Amberlite IRA 743 resin column.

The adsorbed boron on the resin column was eluted at 75 °C with 10 mL 0.1 mol/L high-purity HCl. To reduce the amount of mixed resin, the eluted solution was blown down in a superclean evaporator at 60 °C. Then the concentrated solution was loaded onto a column filled with mixed resin of cation-exchange resin (H^+ form) and anion-exchange resin (ion-exchange II, HCO_3^- form). The boron was eluted by 10 mL of boron-free water. After adding the mannitol with equal molar mass boron, the eluted solution was concentrated again at 60 °C to be about 1 μg B/μL for isotopic measurement.

The isotope composition of boron was measured using a positive thermal ionization mass spectrometry (P-TIMS) at the Institute of Qinghai Salt Lake, Chinese Academy of Sciences (CAS), based on the measurement of $Cs_2BO_2^+$ with graphite. Using a special 308/309 static dual-receiving Faraday Cup system to measure I309 ($^{133}Cs_2{}^{11}B^{16}O_2^+$) and I308 ($^{133}Cs_2{}^{10}B^{16}O_2^+$), the value of R(309/308) was obtained. The isotopic ratios were corrected for the contribution of ^{17}O to mass 309 by the following: $^{11}B/^{10}B = R(309/308) - 2(^{17}O/^{16}O) = R(309/308) - 0.00075$.

The boron isotopic composition is reported using the delta (δ) notation relative to the standard NIST SRM951. Replicate analyses of the $^{11}B/^{10}B$ ratio in the standard NIST SRM951 were 4.0493‰ ± 0.0006 (2σ, $n = 10$), very close to the certified value of 4.0469‰ ± 0.0002. Typical analytical error is within 0.15‰. The procedural blank measured by isotope dilution using a spike of NIST SRM952 ^{10}B-enriched boric acid standard was less than 82 ng boron.

Carbonate Oxygen and Carbon Isotope Analysis. Before isotope analysis, ~1 g sediment samples were grounded in an agate mortar and sieved through a 100-mesh (150-μm) screen. Analyses of carbonate samples were performed using an isotope ratio mass spectrometer [MAT-252 (Finnigan)] with an automated carbonate preparation device (Kiel II) at the Institute of Earth Environment, CAS. Oxygen and carbon isotope composition is expressed in the delta (δ) notation relative to the V-PDB standard. Repeated analyses of laboratory carbonate standards with known $\delta^{18}O$ and $\delta^{13}C$ values were performed daily to ensure instrumental accuracy. Typical SD for the repeated analyses of these laboratory standards is smaller than ±0.1‰.

TOC Analysis. The sediment samples were air-dried, grounded in an agate mortar, passed through a 100-mesh sieve, and then analyzed for organic carbon content. TOC content was determined by wet oxidation under heating. In the procedure, 5 mL 0.8 M potassium dichromate ($K_2Cr_2O_7$) and 5 mL sulphuric acid (H_2SO_4) were added into the weighed samples and then boiled at 170–180 °C for 5 min. After oxidation, excess potassium dichromate was determined by titration with 0.2 mol/L ferrous sulfate ($FeSO_4$) solution. Typical analytical error for TOC is about ±1%.

$CaCO_3$ Analysis. The carbonate content was determined by using the neutralization-titration method (1). Each of ~0.3 g material was decarbonated with 30 mL of HC1 solution (~0.2 mol/L) for 24 h. After centrifugation at 2,500 rpm on an 80-2 low-speed bench top centrifuge [Shanghai Medical Instruments (Group)], 10 mL of supernatant was titrated with NaOH solution (~0.1 mol/L) with two drops of phenolphthalein solution as the indicator. A blank experiment was also conducted in parallel. The content of carbonate can be calculated as follows:

$$CaCO_3\% = [150 \times C_1 - 15 \times (V_1 - V_2) \times C_2]/M,$$

where M is the amount of sediment material; C_1 is the concentration of the HCl solution; C_2 is the concentration of the NaOH solution; and V_1 and V_2 are the volumes of the NaOH solution used for titration of the sample and the blank, respectively. Typical analytical error is about ±0.5%.

Ostracod Analysis. Wet samples of ~15–20 g were soaked in deionized water for about 48 h and then rotated for ~6 h with a gentle speed of 1 rps. The well-dispersed samples were sieved through a 250-mesh sieve. The residues were dried under room temperature. Ostracod valves were picked out from the dried residues with a fine paint brush under a binocular microscope and were identified and counted for statistics.

Grain Size Analysis. All samples were pretreated by 10% H_2O_2 and 10% HCl to remove organic matter and carbonates. Then samples were filled with distilled water and kept overnight in beakers. Before grain size measurements, water was siphoned off and samples were dispersed by ultrasonification in 10 mL 10% $(NaPO_3)_6$ solution for 10 min. Grain size distributions were finally determined using a Malvern 2000 laser instrument.

1. Hesse PR (1971) *A Textbook of Soil Chemical Analysis* (Chemical Publishing Co. Inc., New York), pp 1–520.

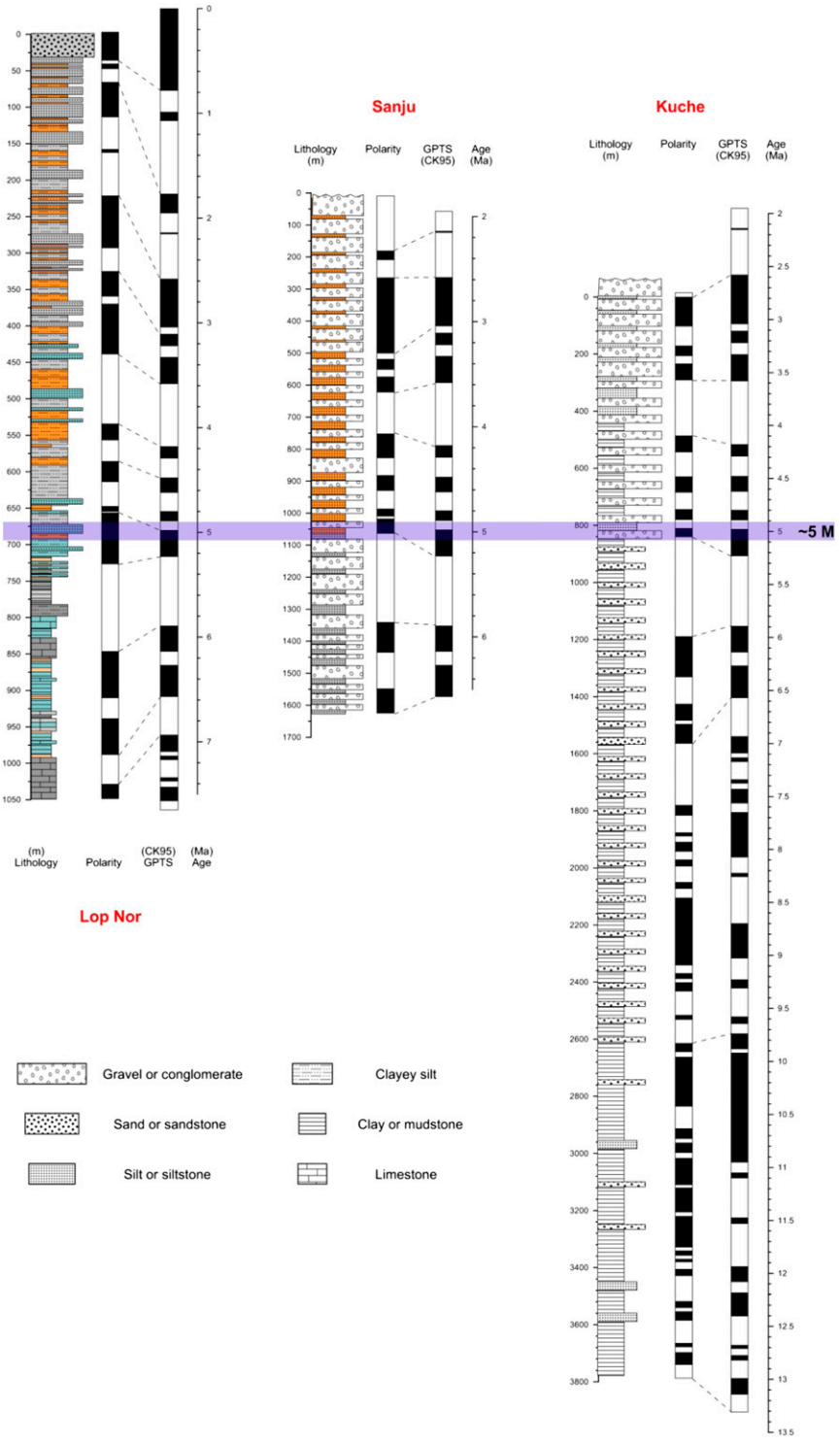

Fig. S1. Lithological features in the studied sediment columns or strata from various parts of the Tarim Basin, Lop Nor (1), Sanju (2), and Kuche (3). Locations of these sections can be found in Fig. 1. Magnetostratigraphic correlations with the CK95 timescale for each location are also indicated with dashed lines. Mudstones or siltstones, likely deposited in lacustrine settings, were present in all sections during the Late Miocene and were replaced by fluvial-eolian sand deposits or conglomerates later. The transition to prevailing desert environments occurred at ~5 Ma.

1. Chang H, et al. (2012) Magnetostratigraphic and paleoenvironmental records for a Late Cenozoic sedimentary sequence drilled from Lop Nor in the eastern Tarim Basin. *Global Planet Change* 80-81:113–122.
2. Sun J, Liu T (2006) The age of the Taklimakan Desert. *Science* 312(5780):1621.
3. Zhang ZQ, Sun JM (2011) Palynological evidence for Neogene environmental change in the foreland basin of the southern Tianshan range, northwestern China. *Global Planet Change* 75(1-2):56–66.

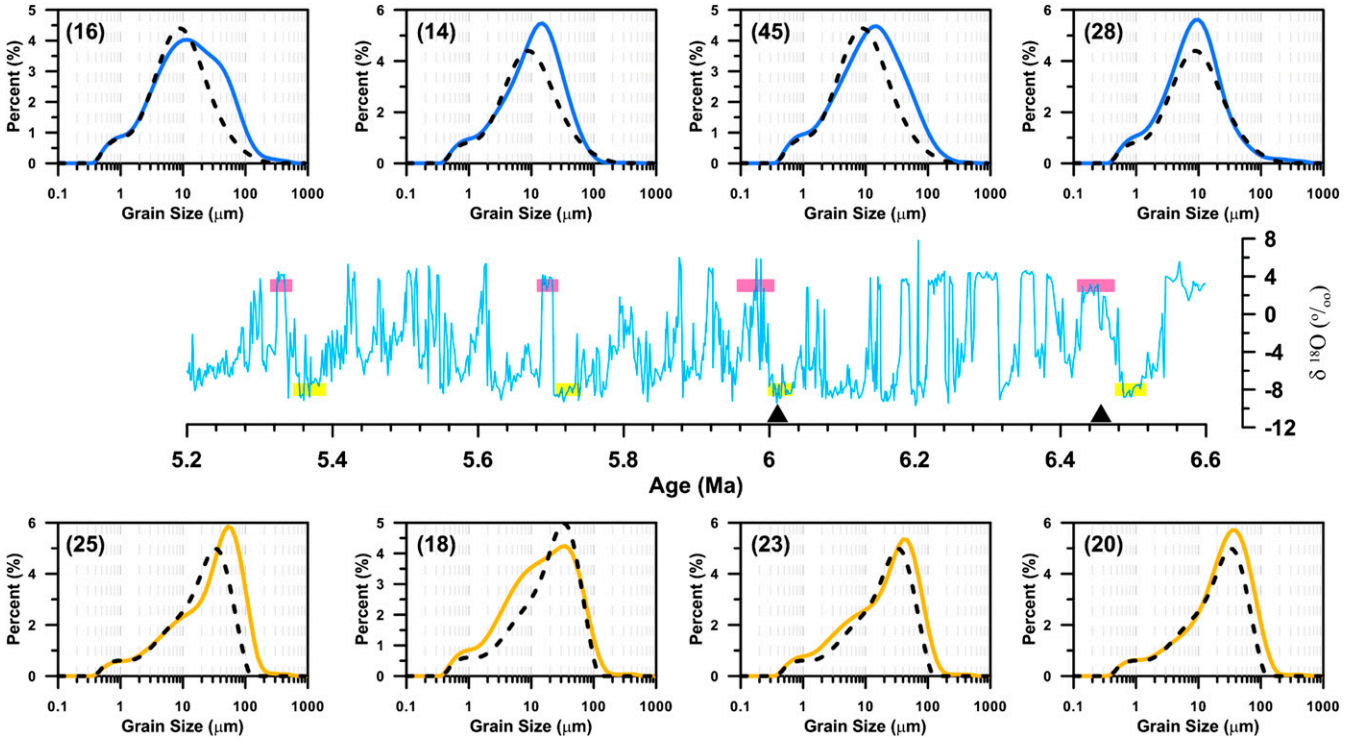

Fig. S2. Mean grain size changes during typical lacustrine vs. nonlacustrine phases. Number in parentheses indicates the number of samples averaged over the specified interval. Smaller grain size occurred at typical lacustrine phases (high $\delta^{18}O$ values), where its frequency distribution (*Top*) is similar to the surface sediments from Lake Qinghai. Greater grain size occurred within the periods of low $\delta^{18}O$ values, where its frequency distribution (*Bottom*) is similar to the eolian loess on Chinese Loess Plateau. The grain size distribution pattern during the transition of $\delta^{18}O$ changes is rather complex, which we suspect reflects fluvial/playa-like environments, and is not shown here. The two triangles indicate intervals where photomicrographs of sediments were examined (Fig. S3), one with typical low $\delta^{18}O$ value at ~6.011 Ma and the other with high $\delta^{18}O$ value at ~6.456 Ma.

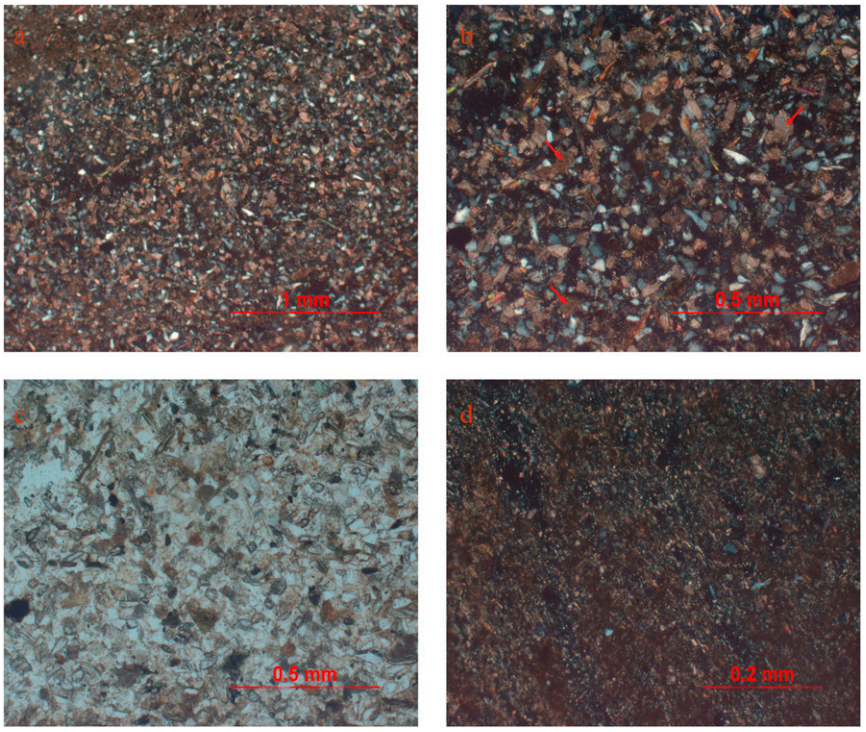

Fig. S3. Photomicrographs of two representative samples, Ls2-521-17725 under crossed polars (*A* and *B*) and plane polars (*C*) and Ls2-575-19568 under crossed polars (*D*). Sample Ls2-521-17725 is identified as siltstone with typical silt texture under crossed polars. It contains >70 vol % angular or subangular silts with diameters of 0.07–0.01 mm. The detrital silts consist of 30–40 vol % quartz and feldspar, 5–10 vol % mica, and 30–40 vol % micritic limestone. Detrital limestone is composed of aggregates of micrites (<0.005 mm in diameter). As indicated by its typical silt texture and negative $\delta^{18}O$ value, the detrital micritic limestone is likely derived from marine carbonates. Sample Ls2-575-19568 is identified as marlite with marl texture under crossed polars. It mainly consists of microcrystalline calcites and clay minerals, with <10 vol % detrital silts. Calcites are generally <0.03 mm in diameter and show microcrystalline texture. They are often intercalated with clay minerals. The texture and mineral composition of marlite, together with its positive $\delta^{18}O$ value, indicate its lacustrine origin. The detrital carbonate grains in sample Ls2-521-17725 are indicated by arrows in *B*.

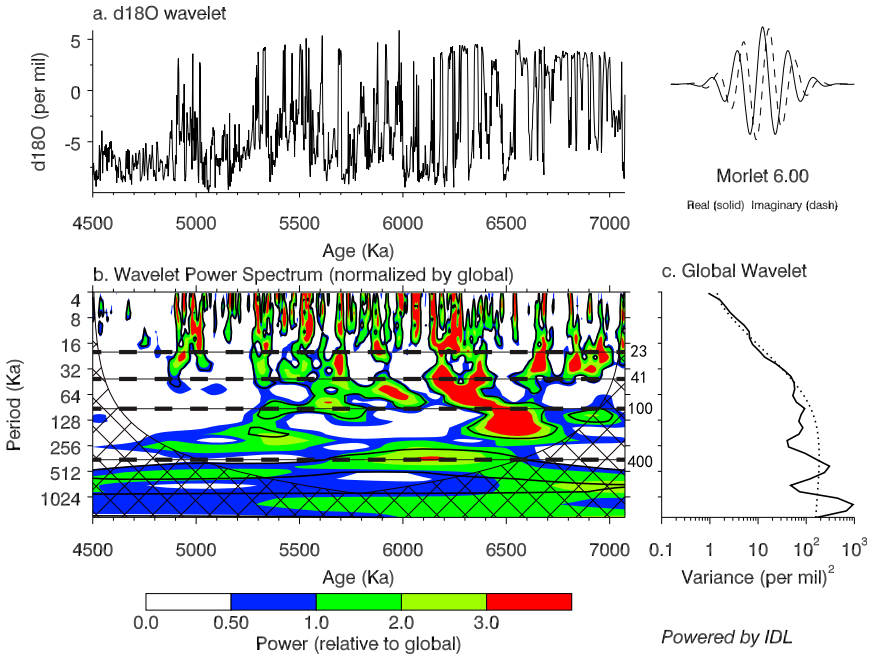

Fig. S4. (*A*) Carbonate $\delta^{18}O$ time series over the interval 4.5–7.1 Ma. (*B*) The wavelet power spectrum. The power has been scaled by the global wavelet spectrum (at right). Black contour is the 50% significance level, using a red noise (autoregressive lag1) background spectrum. Dashed lines highlight orbital periods at ~400, 100, 41, and 23 ky. (*C*) The global wavelet power spectrum. The interactive wavelet program (1) can be found at paos.colorado.edu/research/wavelets/.

1. Torrence C, Compo GP (1998) A practical guide to wavelet analysis. *Bull Am Meteorol Soc* 79(1):61–78.

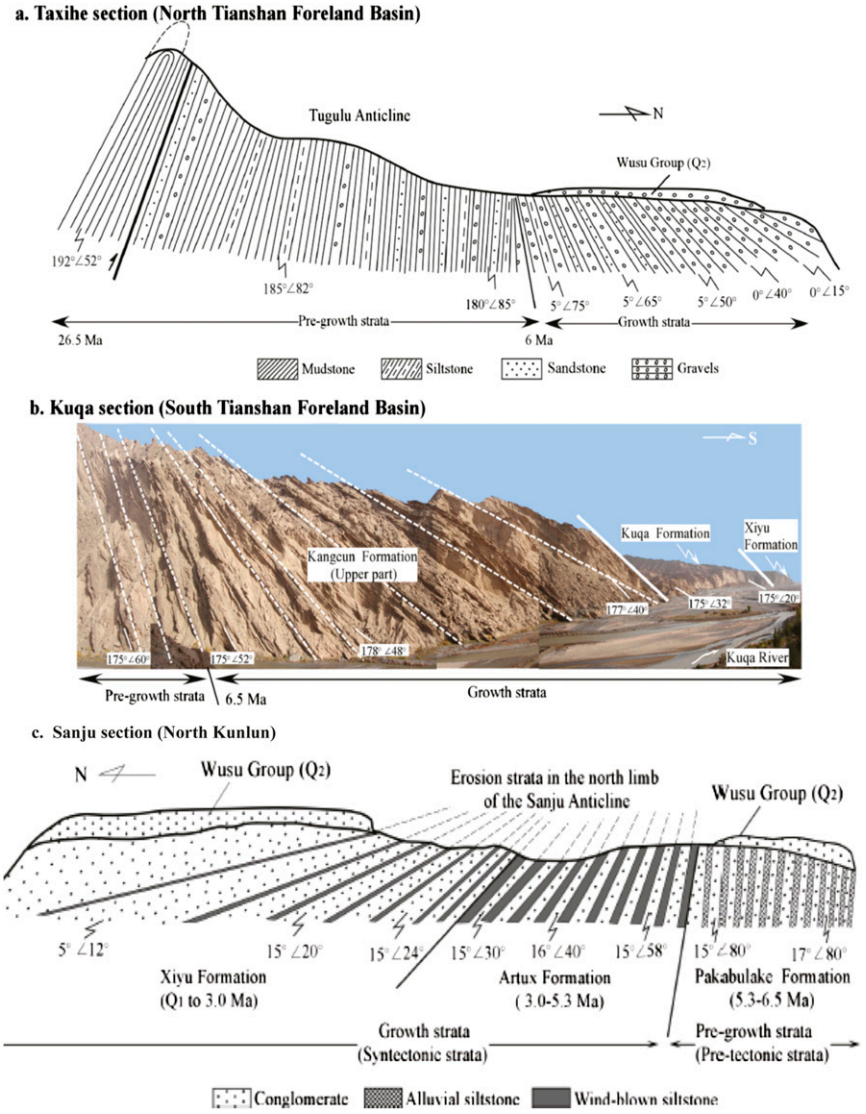

Fig. S5. Syntectonic growth strata from the foreland basins of (*A*) North Tianshan (1), (*B*) South Tianshan (2), and (*C*) North Kunlun (3) show strong crust shortening and potential mountain uplift initiated at ~6.5–5 Ma.

1. Sun JM, Zhang ZQ (2008) Palynological evidence for the Mid-Miocene Climatic Optimum recorded in Cenozoic sediments of the Tian Shan Range, northwestern China. *Global Planet Change* 64(1-2):53–68.
2. Sun JM, Li Y, Zhang ZQ, Fu BH (2009) Magneostratigraphic data on the Neogene growth folding in the foreland basin of the southern Tianshan Mountains. *Geology* 37(11):1051–1054.
3. Sun JM, Zhang LY, Deng CL, Zhu RX (2008) Evidence for enhanced aridity in the Tarim Basin of China since 5.3 Ma. *Quat Sci Rev* 27(9-10):1012–1023.

Dataset S1. Data of B, C, and O isotopic values and TOC and $CaCO_3$ contents, together with corresponding sample IDs, depths, and ages

Dataset S1