Electronic Appendix 1: Materials and methods

1.1 Sampling, petrology and mineral chemistry

The studied magmatic complex was described in the eastern Khantaishir Mountain Range (NE of Biger, southern–central Mongolia, Fig. 1b) during the Czech Geological Survey (CGS) expedition in 2012. Twenty-four samples of the major igneous rock types selected for petrological study are listed in Table 1, and their locations are shown in Fig. 1b.

Electron-microprobe analyses (EMPA) were performed using the Cameca SX-100 instrument at the Joint Laboratory of Electron Microscopy and Microanalysis of Masaryk University and the Czech Geological Survey (Brno, Czech Republic). The measurements were carried out in wave-dispersion mode under the following conditions: accelerating voltage of 15 kV, beam current of 10 nA and beam diameter of 5 μm. Natural and synthetic standards were used (Si, Al – sanidine, Mg – olivine, Fe – almandine, Ca – andradite, Mn – rhodonite, Ti – Ti-hornblende, Cr – chromite, Na – albite, K – orthoclase, P – apatite, F – topaz, Cl, V – vanadinite, Zn – gahnite, Cu – metallic Cu, Y – YAG). The raw concentrations were corrected using the method of Pouchou and Pichoir (1985).

1.2 Whole-rock geochemistry

In total, 19 whole-rock samples, each 5–10 kg in weight, were obtained in the field (see Fig. 1b for locations). After conventional crushing and homogenization, the powders produced using an agate mill were analyzed at ActLabs (Vancouver, Canada), using the 4Lithoresearch procedure (http://www.actlabs.com). Major-element concentrations were obtained by Inductively-Coupled Plasma Optical Emission Spectrometry (ICP-OES) and trace-element concentrations by Inductively-Coupled Plasma Mass Spectrometry (ICP-MS), following lithium metaborate/tetraborate fusion and weak nitric acid dissolution. Such a procedure
ensures that the entire sample is digested, including refractory phases such as zircon and sphene.

1.3 Whole-rock Sr–Nd isotopic compositions

For radiogenic isotope determinations, samples were dissolved using a combined HF–HCl–HNO₃ digestion. Strontium and REE were isolated from the bulk matrix by a column chromatography technique using TRU and Sr resins by Triskem Intl. (Pin et al., 1994). Nd was further separated from the REE fraction using a Ln resin (Pin and Zalduegui, 1997). Further analytical details were reported by Miková and Denková (2007). Isotopic analyses of Sr and Nd were performed on a Finnigan MAT 262 thermal ionization mass spectrometer housed at CGS, using dynamic mode and a single Ta filament for Sr and in static mode using a double Re filament assembly for Nd. The \(^{143}\text{Nd}/^{144}\text{Nd}\) ratios were corrected for mass fractionation to \(^{146}\text{Nd}/^{144}\text{Nd} = 0.7219\) (Wasserburg et al., 1981), and \(^{87}\text{Sr}/^{86}\text{Sr}\) ratios assuming \(^{86}\text{Sr}/^{88}\text{Sr} = 0.1194\). External reproducibility is estimated from repeated analyses of the JNd1 standard (Tanaka et al., 2000) (\(^{143}\text{Nd}/^{144}\text{Nd} = 0.512107 \pm 28\) (2\(\sigma\), \(n = 10\)) and standard NBS 987 (\(^{87}\text{Sr}/^{86}\text{Sr} = 0.710239 \pm 26\) (2\(\sigma\), \(n = 17\)). The decay constants applied to age-correct the isotopic ratios are from Steiger and Jäger (1977 – Sr) and Lugmair and Marti (1978 – Nd). The \(\varepsilon_{\text{Nd}}\) values were obtained using Bulk Earth parameters of Jacobsen and Wasserburg (1980). In order to compensate for the effects of crystal accumulation upon the \(^{147}\text{Sm}/^{144}\text{Nd}\) ratios, we calculated not only single-stage but also two-stage Depleted Mantle Nd model ages \((T^{\text{Nd}}_{\text{DM}})\), using the parameters and the approach of Liew and Hofmann (1988).

1.4 U–Pb geochronology

Zircons were separated using heavy liquids and magnetic techniques and then purified by handpicking under a binocular microscope. Zircon grains >50 μm in size were selected,
mounted in epoxy resin and then polished. Cathodoluminescence (CL) imaging was performed on a CAMECA SX-100 electron microprobe equipped with a Mono CL3 detector at the Institute of Petrology and Structural Geology, Charles University, Prague.

Except for samples M310 and M311, zircon dating used an ArF excimer 193 nm laser ablation system (Resolution M-50), coupled with a Nu Plasma HR MC-ICP-MS at the Department of Earth Sciences, University of Hong Kong, following the analytical procedure of Xia et al. (2011). Most analyses were carried out with a beam diameter of 40 µm, 5 Hz repetition rate and energy of ~5 J/cm² per pulse. Zircon standard 91500 was used for calibration. The mass fractionation correction and isotopic results were calculated by ICPMSDataCal (version 7.0, Liu et al., 2008). The age calculations and concordia plots were performed using ISOPLOT (version 3.0, Ludwig, 2003). Individual analyses are presented with 1σ error in the concordia diagrams, and uncertainties in mean age calculations are quoted at the 95% level (2σ).

For measurement of U/Pb and Pb/Pb isotopic ratios in zircons from samples M310 and M311, a Thermo-Finnigan Element 2 sector field ICP-MS, coupled to a 193 ArF Excimer laser (Resonetics RESOlution M50-LR) at Bergen University, Norway was used following the technique described by Košler et al. (2002). The sample introduction system was modified to enable simultaneous nebulization of a tracer solution and laser ablation of the solid sample (Horn et al., 2000). Natural Tl (205Tl/203Tl = 2.3871; Dunstan et al., 1980), 209Bi and enriched 233U and 237Np (> 99 %) were used in the tracer solution, which was aspirated to the plasma in an argon–helium carrier gas mixture through an Apex desolvation nebulizer (Elemental Scientific) and a T-piece tube attached to the back end of the plasma torch. A helium gas line carrying the sample from the laser cell to the plasma was also attached to the T-piece tube. The laser was set up to produce an energy density of c. 7 J/cm² at a repetition rate of 5 Hz. The laser beam was imaged on the surface of the sample placed in
a two-volume ablation cell, which was mounted on a computer-driven motorized stage of a microscope. During ablation the stage was moved beneath the stationary laser beam (19–26 μm in diameter) to produce a linear raster on the sample. Typical acquisitions consisted of a 35 s measurement of analytes in the gas blank and aspirated solution, particularly $^{203}\text{Tl}–^{205}\text{Tl}–^{209}\text{Bi}–^{233}\text{U}–^{237}\text{Np}$, followed by the measurement of U and Pb signals from zircon, along with the continuous signal from the aspirated solution, for another 120 s. The data were acquired in a time resolved – peak jumping – pulse counting mode with 1 point measured per peak for masses 202 (flyback), 203 and 205 (Tl), 206 and 207 (Pb), 209 (Bi), 233 (U), 237 (Np), 238 (U), 249 ($^{233}\text{U}$ oxide), 253 ($^{237}\text{Np}$ oxide) and 254 ($^{238}\text{U}$ oxide). Raw data were corrected for dead time of the electron multiplier and processed off line in the spreadsheet-based program Lamdate (Košler et al., 2002) and plotted on concordia diagrams using Isoplot 4.15 (Ludwig, 2012). Data reduction included correction for gas blank, laser-induced elemental fractionation of Pb and U and instrumental mass bias. Minor formation of oxides of U and Np was corrected for by adding signal intensities at masses 249, 253 and 254 to the intensities at masses 233, 237 and 238, respectively. No common Pb correction was applied to the data. Details of data reduction and corrections are described in Košler et al. (2002) and Košler and Sylvester (2003). Zircon reference materials GJ-1 (609 Ma – Jackson et al., 2004) and Plešovice (337 Ma – Sláma et al., 2008) were periodically analyzed during this study and yielded pooled concordia ages of 600 ± 4 and 340 ± 3 Ma, respectively.

1.5 Zircon Lu–Hf isotope analyses

In situ zircon Lu–Hf isotopic analyses were carried out on a Neptune Plus multi-collector ICP-MS equipped with a Resolution M-50-LR laser-ablation system at the Guangzhou Institute of Geochemistry, Chinese Academy of Sciences. The measurements were conducted on selected large, previously dated zircon grains with a beam diameter of 45 μm and a laser
repetition rate of 8 Hz at 80 mJ. Helium was used as carrier gas, and some nitrogen was
added to the gas line to enhance the sample signal. The signal collection mode was one block
with 200 cycles for each analysis, which consisted of 30 s gas blank collection and 30 s laser
ablation. The measured isotopic ratios of $^{176}\text{Hf} / ^{177}\text{Hf}$ were normalized to $^{176}\text{Hf} / ^{177}\text{Hf} = 0.7325$, using an exponential correction for mass bias. Isobaric interference of $^{176}\text{Lu}$ on $^{176}\text{Hf}$
was corrected by using a recommended $^{176}\text{Lu} / ^{175}\text{Lu}$ ratio of 0.02655 (Machado and
Simonetti, 2001)). Interference of $^{176}\text{Yb}$ on $^{176}\text{Hf}$ was corrected by using mass bias obtained
on line and assuming $^{176}\text{Yb} / ^{171}\text{Yb} = 0.90184$ (Wu et al., 2006). A Penglai zircon was used as
the reference standard (Li et al., 2010). Detailed instrumental settings and analytical
procedures were described by Zhang et al. (2015).

All Hf-in-zircon isotopic data were calculated with the decay constant of $1.867 \times 10^{-11}$
year$^{-1}$ (Söderlund et al., 2004). The chondritic values of $^{176}\text{Hf} / ^{177}\text{Hf} = 0.282772$
and $^{176}\text{Lu} / ^{177}\text{Hf} = 0.0332$ reported by Blichert-Toft and Albarède (1997) were employed for
the calculation of $\varepsilon_{\text{Hf}}$ values. The depleted-mantle evolution line is defined by present-day
$^{176}\text{Hf} / ^{177}\text{Hf}$ of 0.28325 and $^{176}\text{Lu} / ^{177}\text{Hf}$ of 0.0384 (Griffin et al., 2000). A “crustal” Hf model
age ($T_{\text{DM}}^{\text{DM}}$) is considered to be more meaningful for the studied rocks than a depleted mantle
model age. This model age ($T_{\text{DM}}^{\text{DM}}$) was calculated separately for each zircon grain, assuming
a mean basaltic $^{176}\text{Lu} / ^{177}\text{Hf}$ ratio of 0.022 for the 2$^{nd}$ stage of the model (Lancaster et al.,
2011). In the calculation, $^{206}\text{Pb} / ^{238}\text{U}$ ages were used for analyses younger than 1.0 Ga, and
$^{207}\text{Pb} / ^{206}\text{Pb}$ ages for older grains.

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