Supplementary material 1

Analytical methods

Samples

The aim of the sampling was to identify formation ages and geochemical characteristics of magmatic rocks of the Togtokhinshil Complex. For whole-rock geochemistry, 3–7 kg and for zircon dating, 10–15 kg of fresh rock per sample were taken directly from the outcrops or from in-situ blocks. The rock crushing and homogenization as well as the zircon separation were made in Central Geological Laboratory and in laboratory of the Geological Investigation Center in Ulaanbaatar, Mongolia. The rock powders were produced under acetone in agate mill. Localization and brief petrographical description of samples are given in Tab. 1 (see Fig. 2 for sample locations).

Mineral chemistry

Chemical composition of minerals has been analysed using the Cameca SX100 electron microprobe in the Joint Laboratory of the Masaryk University and the Czech Geological Survey (Brno, Czech Republic). The measurements were carried out using a wave-dispersion mode with an accelerating voltage of 15 kV, beam current of 10 nA and beam diameter of 5 μm. Natural minerals and well-defined synthetic phases were used as standards. The raw concentration data were corrected using the method of Pouchou and Pichoir (1985). The abbreviations of mineral names are after Kretz (1983). Representative analyses are listed in supplementary material 2.

Whole-rock geochemistry

Major- and trace-element analyses were carried out in the Activation Laboratories Ltd. (Ulaanbaatar, Mongolia) using the procedure 4Lithoresearch (*http://www.actlabs.com*).

Major-element oxide concentrations were obtained by inductively coupled plasma optical emission spectrometry (ICP-OES), trace-element concentrations by inductively-coupled plasma mass spectrometry (ICP-MS). The dissolution of the rock powders in both cases followed fusion with a $LiBO_2/Li_2B_4O_7$ flux. Data management, recalculation, and plotting of the whole-rock geochemical data were facilitated using *GCDkit* (Janoušek et al. 2006). Whole-rock major- and trace-element analyses are listed in electronic supplements 3 and 4.

Zircon U–Pb dating

Zircon grains were separated from the fresh rock sample using conventional techniques: crushing, Wilfley concentration table, and finally, magnetic and heavy liquid separations. Handpicked zircon grains were mounted in one-inch epoxy-filled blocks and polished. Internal zircon structure, zoning patterns and possible presence of older inherited components in individual grains was checked by cathodoluminescence (CL) imaging using scanning electron microscope at the Czech Geological Survey in Prague.

An Element 2 high-resolution sector field mass spectrometer (Thermo Scientific) coupled with a 213-nm NdYAG UP-213 laser ablation system (New Wave Research) at the Institute of Geology of the CAS in Prague was used to acquire the Pb/U isotopic ratios. Samples were ablated in an in-house small volume ablation cell, construction inspired by a conception of Koojiman et al. (2012). The laser was fired at a repetition rate of 5 Hz, using a spot size of 30 μm and a fluence of *c.* 4–5 J/cm^2. Acquisitions for all measured samples consisted of a 35 s measurement of blank followed by U and Pb signals from zircons for another 50 s. Data were collected for masses 204, 206, 207, 208, 232 and 238 using both analogue and ion counting modes of the SEM detector, one point per mass peak and relevant dwell times per mass of 10, 15, 30, 10, 10 and 15 ms. The sample introduction system was modified using Y-piece tube attached to the back end of the plasma torch and connected to the helium gas line carrying the sample from the laser cell. The Hg impurity in the carrier He gas, which can cause isobaric interference of ^{204}Hg on ^{204}Pb and the relative contribution of common Pb to total Pb, were reduced by using in-house made gold-coated sand trap. The relative contribution of common Pb to total Pb was less than 0.1 % and, therefore, no common Pb correction was applied to the data. Elemental fractionation and instrumental mass bias were corrected by normalization of internal U–Pb calibration zircon standard 91500 (1065 Ma, Wiedenbeck et al. 1995) and reference natural zircon standard GJ-1 (609 Ma, Jackson et al. 2004; 603 Ma, Kylander-Clark et al. 2013) periodically analyzed during the measurement for quality control purposes. Raw data reduction and age calculations, including corrections for baseline, instrumental drift, mass bias and down-hole fractionation, were carried out using the computer program Iolite (v. 3.0; Paton et al. 2011). The U–Th–Pb isotopic data listed in the electronic supplement 5 and zircon ages shown in concordia diagrams have been generated with Iolite program (Paton et al. 2010, 2011). For the data presented here, blank intensities and instrumental bias were interpolated using an automatic spline function while down-hole inter-element fractionation was corrected using an exponential function.

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